Advances in Intelligent Systems and Computing 473

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Rafael Corchuelo · Philippe Mathieu
Zita Vale · Andrew T. Campbell
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Trends in Practical Applications of Scalable Multi-Agent Systems, the PAAMS Collection

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Preface

PAAMS'16 Special Sessions are a very useful tool in order to complement the regular program with new or emerging topics of particular interest to the participating community. Special Sessions that emphasized on multi-disciplinary and transversal aspects, as well as cutting-edge topics were especially encouraged and welcome.

PAAMS, the International Conference on Practical Applications of Agents and Multi-Agent Systems is an evolution of the International Workshop on Practical Applications of Agents and Multi-Agent Systems. PAAMS is an international yearly tribune to present, to discuss, and to disseminate the latest developments and the most important outcomes related to real-world applications. It provides a unique opportunity to bring multi-disciplinary experts, academics and practitioners together to exchange their experience in the development of Agents and Multi-Agent Systems.

This volume presents the papers that have been accepted for the 2016 special sessions: Agents Behaviours and Artificial Markets (ABAM); Advances on Demand Response and Renewable Energy Sources in Agent Based Smart Grids (ADRESS); Agents and Mobile Devices (AM); Agent Methodologies for Intelligent Robotics Applications (AMIRA); Learning, Agents and Formal Languages (LAFLang); Multi-Agent Systems and Ambient Intelligence (MASMAI); Web Mining and Recommender systems (WebMiRes). The volume also includes the paper accepted for the Doctoral Consortium in PAAMS 2016 and Collocated Events.

We would like to thank all the contributing authors, the members of the Program Committee and the Organizing Committee for their hard and highly valuable work. Their work has helped to contribute to the success of the PAAMS'16 event. Thanks for your help − PAAMS'16 would not exist without your contribution.

June 2016

Fernando De la Prieta
María José Escalona

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Special Sessions

SS1 - Agents Behaviours and Artificial Markets (ABAM)
SS2 - Advances on Demand Response and Renewable Energy Sources in Agent Based Smart Grids (ADRESS)
SS3 - Agents and Mobile Devices (AM)
SS4 - Agent Methodologies for Intelligent Robotics Applications (AMIRA)
SS5 - Learning, Agents and Formal Languages (LAFLang)
SS6 - Multi-Agent Systems and Ambient Intelligence (MASMAI)
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Part I
Special Session on Agents Behaviours and Artificial Markets (ABAM)

An Agent-Based Model to Study the Impact of Convex Incentives on Financial Markets

Annalisa Fabretti, Tommy Gärling, Stefano Herzel and Martin Holmen

Abstract We investigate by means of agent-based simulations the influence of convex incentives, e.g. option-like compensation, on financial markets. We propose an agent based model already developed in Fabretti et al (2015), where the model was build with the aim of studying convex contract effect using the results of a laboratory experiment performed by Holmen et al. (2014) as benchmark. Here we replicate their results studying prices dynamics, volatility, volumes and risk preference effect. We show that convex incentives produces higher prices, lower liquidity and higher volatility when agents are risk averse, while, differently from Fabretti et al (2015), their effect is less evident if agents are risk lovers. This appears related to the fact that prices in the long run converge more likely to the equilibrium when agents are risk averse.

JEL Classification G10, D40, D53

Keywords Incentives · Market instability · Agent-Based simulations

1 Introduction

The compensation structures of financial market participants became an issue highly discussed after the unfolding of the financial crisis in 2007-2009 (see e.g. Bebchuk

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et al., 2010, Dewatripont et al., 2010, French et al., 2010, Gennaioli et al., 2010). Rajan (2006) suggests that convex incentives structures can be considered among the causes of instability in highly developed financial markets.

Convex incentive structures are largely used since they reduce moral hazard concerns aligning the interests of the portfolio manager (agent) and the investor (principal) (see e.g. Allen, 2001; Kritzman, 1987; Goetzmann et al., 2003; Cuoco and Kaniel, 2011). Under convex incentives the portfolio manager does not share the losses with the investor but receives a proportion of the profits. In Allen and Gorton's (1993) model rational bubbles appear as the portfolio manager's convex incentives and limited downside risk make it rational for her to trade at prices above fundamental value.

This paper proposes an agent based model to assess the impact of convex incentives on the market. This paper is related to Fabretti et al (2015). In Fabretti et al (2015) the focus is on the comparison of the agent based model simulations with results found in Holmen et al (2014) obtained with laboratory experiment with humans. Instead in the present paper the agent based model is presented in a more general framework. Differently from Fabretti et al (2015), here the convex contract effects are studied varying the number of agents in a longer time period. Having a larger time window allows us to see the effect on the long run, which confirms some results of Fabretti et al (2015) but it provides also a different insight on the effect of risk preference.

Linear incentives resemble the incentives structure if the trader invests her own money, while convex incentives resemble the incentive structure if the trader invests other people's money and receives part of the profits but does not share the losses, i.e. an option-like compensation. In line with previously proposed theoretical models, e.g. Allen and Gorton (1993), Malamud and Petrov (2014), and Sotes-Paladino and Zapatero (2014), our model predicts that convex incentives are associated with higher prices. More importantly, our model implies that a bang-bang strategy may be optimal, i.e., at a certain price the traders switch from a positive demand for the asset to a negative demand (supply).The bang-bang strategy is more likely to be optimal and stronger in the presence of convex incentives. In contrast for risk-averse traders with linear incentives, the demand functions do not have the bang-bang features. Agent based methodology allows to replicate artificially the market under many different conditions, hence we can investigate among many issues how risk preferences, agents heterogeneity, contract parameters, dividend distribution can affect prices and market volatility.

We report that, as argued by Rajan (2006), convex incentives lead to an increase of prices and volatility, we observe an evident effect when agents are all risk averse, while the same effect cannot be claimed in the case of all risk lovers agents. Differently from Fabretti et al (2015) on the long run the convex contract strong effect almost vanishes when agents are all risk lovers. Indeed we still observe higher prices but the increment is so slight that a real difference cannot be claimed. We also report, when agents are risk averse, that convex incentives lead to a decrease of liquidity, that is, lower volumes and higher spreads. Under convex contracts, risk aversion affects neither agent behavior nor market behavior. Thus, convex incentive structures eliminate the influence of differences in risk aversion. By another hand we observe qualitatively a likely convergence to the equilibrium price when agents are risk averse (both with linear and convex contract), but this conjecture deserves more investigations. We provide also a quantitative study measuring the impacts of the variables of interest on the quantities under our analysis. We believe that some of our observations may turn out to be useful both to build new models and to devise new experimental markets. For instance, the insignificance of agents risk aversions may be relevant when constructing a theoretical model of financial decisions under convex incentives, while our finding that the effects of increasing the number of convex contracts are analogous to increasing the number of agents with a lower initial endowment provides a motivation to experimentally investigate differences in endowments which few previous studies have explicitly done (Noussair and Tucker 2013; Palan 2013).

The evidence presented here may have also implications for the debate about policy regulations of investment managers' incentive schemes (see e.g. Turner, 2009; Walker, 2009). Yet, additional research is needed before any firm policy recommendations can be made. We have demonstrated the potential usefulness of using agent-based simulations in studying financial markets and in particular in this case to study the effect of the manager's compensation structure, which is an issue largely debated.

The paper is organized as follows, in Section 2 we illustrate the model including a theoretical analysis. In Section 3 we propose the results and the discussion of many simulations. Section 4 concludes.

2 The Agent Based Model

We implement a double auction market in which artificial intelligent agents trade a single security that pays at a future time T, a dividend X that is a binomial random variable assuming non negative value X_1 with probability p and X_2 with probability $1 - p$. Shorting assets and borrowing money are not allowed. Trading takes place in a double auction market with open order books. Each trading period consists of T intervals in which each trader in a randomly selected order can submit an order (market or limit order).

There are N agents trading the asset, each of them is provided, at the initial time 0, with an amount of cash $m_i(0)$ and $\omega_i(0)$ shares of the asset, for $i = 1, .., N$. Agents can be noise traders or rational, in the neoclassical sense, i.e. they maximize their expected utility. Noise traders are zero intelligence traders acting in a random way just taking care of their budget constraints; while rational agents act in order to achieve the maximum expected utility. We endow all rational agents with a CRRA (Constant Relative Risk Aversion) utility, $u(x) = \frac{x^{1-\gamma}}{1-\gamma}$. Rational traders differ for the risk preference, the compensation scheme. The final value of the portfolio of agent i is

$$W_i(\theta_i, P) = m_i(0) + (\omega_i(0) + \theta_i)X - \theta_i P, \quad i = 1, \ldots, N \tag{1}$$

where θ_i is the total number of shares exchanged by agent i and P is the price per share.

Each rational agent is endowed with a compensation scheme representing the payoff to be received at time T, after the dividends have been paid. A *linear contract* lets agent i keep all the final portfolio value W_i, a *convex contract* provides the agent with a fixed amount plus an extra to be paid if the final value W_i is greater than a given threshold. The formal specifications of the contract functions are

$$f_i(W_i(\theta_i, P)) = \begin{cases} W_i(\theta_i, P) & \text{linear contract} \\ \phi + \delta \max(W_i(\theta_i, P) - K, 0) & \text{convex contract} \end{cases} \tag{2}$$

where ϕ, δ and K are constants.

The utility function u_i is an increasing function of the payoff of the contract function and it may be concave or convex depending on the risk-preferences of the agent. At round t, the trader i with a current position consisting of $m_i(t)$ amount of cash and $\omega_i(t)$ shares of the asset, determines the optimal amount of units θ_i^* to be exchanged at a price P by maximizing expected utility subject to the budget constraints (no short-selling and no money-borrowing),

$$\max_{\theta_i} E[u_i\ (f_i\ (W_i(\theta_i, P))))] \tag{3}$$
$$m_i(t) - \theta_i P \geq 0$$
$$\omega_i(t) + \theta_i \geq 0$$

2.1 Trading Mechanism

The trading mechanism is a double auction, where agents can submit either market or limit order. At each interval each trader enters the market and observes the book. If the trader is rational, she checks the best quotes available in the market and then decides whether (seeking for higher utility) to place a market order in buy or sell side, or a limit book order, that is an offer that improves the current trading book with a lower bid or a higher ask price. If the agent is zero intelligence she acts randomly.

The mechanism proceeds by following these steps:

1. Trader i is randomly selected among those who have not yet traded in the present round.
2. Any previous book order by trader i, if still present in the book, is canceled.
3. The trader decides whether to submit a sell order, a buy order, or a limit order. She acts accordingly to their type, rational or zero intelligence.
4. If there are still agents who have not traded yet in this round, go to step 1, otherwise go to the next round.

Rational Agents. The rational trader decides whether to submit a sell order, a buy order, or a limit order by comparing the expected utilities of a) selling the maximal feasible units of the asset at the current bid price, b) buying the maximal feasible units of the asset at the current ask price, c) holding the current portfolio. If the agent i's choice is a sell (resp. buy) order, the trader solves Problem (3) with $P = P^b(t)$ the current bid price (resp. $P^a(t)$ the current ask price) . If the optimal solution θ_i^* is a negative value (resp. positive) then the agent places the sell order (resp. the buy order). If the quantity posted in the book is greater (in absolute value) than θ_i^*, the quantity θ_i^* is exchanged, otherwise the agent's demand is only partially satisfied and the next bid (resp. ask) in the order book is attended. If the agent's best choice is a limit order, trader decides a reservation price $\tilde{P}$ between the current bid and ask prices. The agent solves problem (3) with $P = \tilde{P}$ and, if the optimal quantity θ^* is not zero, posts a book order, buy or sell according to the sign of θ^*. We remark that all agents have access to the same set of information.

Noise Traders. The zero intelligence trader selects randomly whether a) selling at the current bid price, b) buying at the current ask price, c) submit a limit order with a random quantity at a random price between the bid and the ask prices. Whatever her choice is, she selects randomly the quantity to trade and the submitted price if required (last case). The only constraint is the budget one.

2.2 Theoretical Analysis

In this section we analyze the optimization problem of the rational agent's. Then we study the equilibrium price aggregating the agents' optimal demand.

Demands with a Linear Contract Function. Solving the agent's optimization problem (3), when the agent has a CRRA utility with γ positive, the optimal demand is the continuous function

$$\theta^*(P) = \begin{cases} \frac{W_0}{P} & \text{if} \quad P \leq P^d \\ \theta_z(P) & \text{if } P \in (P^d, P^u) \\ -\omega & \text{if} \quad P \geq P^u \end{cases} \tag{4}$$

where $\theta_z(P)$ is the internal solution satisfying the first order condition and $P^u = E[X]$ and $P^d = \frac{E[X^{1-\gamma}]}{E[X^{-\gamma}]}$.

When the agent is not risk averse, γ is negative, her optimal demand is discontinuous taking the form

$$\theta_i^*(P) = \frac{W_0}{P}\mathbf{1}_{P<\bar{P}_i} - \omega\mathbf{1}_{P>\bar{P}_i} \quad , i = 1, \ldots, N \tag{5}$$

where $\mathbf{1}_A$ is the indicator function of the set A and the switching price $\bar{P}_i$ satisfies

$$E\left[u\left(\left(\omega + \frac{W_0}{P}\right)X\right)\right] - u(W_0 + \omega P) = 0. \tag{6}$$

If the agent is risk-neutral, i.e. $\gamma = 0$, we get $\bar{P}_i = E[X]$. Note that in the case $P = \bar{P}_i$, the agent is indifferent between buying as much as she can or selling all her assets.

Demands with a Convex Contract Function. When the contract function is convex and the agent is risk-averse, the expected utility in Problem (3) is *piece-wise* concave as a function of θ. The reason of the piece-wise concavity stems from the fact the contract function in this case is piece-wise linear. Since the asset X assumes only two values, the expected utility has two nodes, corresponding to the values of θ satisfying

$$W_0 + (\omega + \theta)X_i - \theta P = K, \quad i = 1, 2$$

In this case the optimal demand $\theta^*(P)$ may coincide with the boundaries of the feasibility interval. When the incentive is convex, the optimal demand function is always discontinuous, independently of the risk preferences and takes a form as in Equation (5) with a $\bar{P}$ which equals the expected utility of selling all with the expected utility of buying as much as possible.

2.3 *The Equilibrium Price*

We can consider theoretical the equilibrium price only when all the traders are rational. The equilibrium price is the price which clears the market, that is the value P that solves the equation

$$\sum_{i=1}^{N} \theta_i^*(P) = 0, \tag{7}$$

where $\theta_i^*(P)$ is the optimal demand for agent i at price P. The aggregate demand function is a decreasing function of P, with a number of points of discontinuity that is less than or equal to the total number of agents. Since the aggregate demand is discontinuous, Equation (7) may not have a solution, and hence an equilibrium price may not exist. However, we can always identify the value $\tilde{P}$ where the aggregated demand changes its sign. The price $\tilde{P}$ represents the price that maximizes the volume of exchanges between the agents. We call it the "quasi-equilibrium" price. Of course, any equilibrium price is also a quasi-equilibrium price.

For the existence of an equilibrium price there must be a sufficient degree of heterogeneity among agents, otherwise they will make the same choices and obviously no price can clear the market (however, also in this case, there would exist a quasi-equilibrium price). Except some special cases which can be considered theoretical (see Fabretti et al (2015)) in a general setting, the equilibrium, or the quasi-equilibrium price, have to be determined through a numerical procedure.

3 Simulations and Results

In Fabretti et al (2015), we performed a first set of simulations in order to compare our model with data collected in a laboratory experiment performed by Holmen et al (2014). In this laboratory experiment humans have been involved to act as asset managers. We set parameters as in the laboratory experiments. In such experiments the number of individuals in each market replication was $N = 10$, endowed (for all $i = 1, .., N$) with $\omega_i(0) = 40$ assets and $m_i(0) = 2000$ units of the experimental currency Taler (with an exchange rate of 200 Talers for 1 Euro). The terminal dividends of the risky asset are either $X_1 = 15$ Taler or $X_2 = 65$ Taler with probability $p = 0.8$. Thus, the expected dividend is $E[X] = 25$ Taler. By the estimation of risk parameters[1] we found that five of ten agents are risk neutral, with $\gamma_i = 0$, two of ten are risk averse, with $\gamma_i = 0.208$ and three of ten are risk lover with $\gamma_i = -1.409$ and $\gamma_i = -0.286$. These estimated coefficients of risk-aversion are used throughout the first set of simulations. Each experiment consisted of twelve rounds of trading. Individuals are endowed with a linear or a convex contract. The contract parameters ϕ, δ and K, have been set so that the expected earnings for the hold strategy are equal for the two contracts. This ensures to make linear and convex incentives comparable.Values in the laboratory experiments are $\phi = 1600$, $\delta = 4.375$ and $K = 3000$.

We observe that convex incentives increase prices and the demands of the risky asset. Our prices are close to those observed in the laboratory experiments, however the volumes of exchanges and the bid-ask spreads recorded in the lab experiment are, respectively, higher and lower than the corresponding values of the simulations. Since higher volumes and lower spreads are an indication of greater liquidity, we may summarize this observation by saying that the experimental market is more liquid than the simulated one. While our agents trade only when they can improve their expected utility, human subjects trade more often and thus presumably for other reasons. However phenomena of overtrading are not rare in laboratory experiment, see Huber et al (2014), Haruvy, Lahav and Noussair 2007, Loomes, Starmer and Sugden, 2003. A possible explanation of overtrading in the experiment is that human participants need some initial learning before being able to make decisions that maximize expected utility.

We can conclude that qualitatively the model enough describes human dynamics, indeed the simulations as the laboratory experiments suggest that the introduction of convex incentives increases prices; while differences are imputable to the fact that probably human subjects have a tendency to trade more often than what expected utility maximization requires.

[1] Details can be found in Fabretti et al. (2015).

In a second set of simulations we run the model with 100 agents considering both noise and rational traders with linear or convex contract and varying the risk preference parameters with the aim to infer the effect of risk preference and contract type on prices. In Figure 1 prices, prices distribution, volumes and volatility are shown for a simulation done with 20% of noise traders and 80% rational risk averse traders endowed with linear contract (the panel of four plots on the left) and convex contract (the panel of four plots on the right). In Figure 2 prices, prices distribution, volumes and volatility are shown for a simulation done with 20% of noise traders and 80% rational risk lover traders endowed with linear contract (panel on the left) and convex contract (panel on the right). By comparison we observe that convex contracts enhance both the market prices, the equilibrium prices and volatility, while decrease volumes. The effect of convex contract is more evident when agents are all risk averse than when agents are all risk lovers, in the latter case we have still higher prices but the difference is less remarkable. Risk preference matters, indeed the higher the percentage of risk lovers the higher the number of trades and prices. When agents are risk averse and have linear contract, prices are below the dividend expected value 25, price distribution is asymmetric, volumes decrease over time. When agents are risk averse with convex contract, prices and volatility are higher, while volumes are lower, see Figure 1 on the right. When traders are all risk averse and all have a linear contract prices seem to converge to the equilibrium, in contrast when agents are risk lovers prices oscillates around the equilibrium and convergence is doubtful. Also when all agents are risk averse with convex contract prices seem to converge to the equilibrium, this suggests that the risk aversion can play an important role in having market in equilibrium. For this reason the effect of convex contract when agents are all risk lovers is less evident since market is less stable around equilibrium.

In conclusion we can observe from this preliminary qualitative analysis that both risk preference and convex contract presence affect prices and volatility magnitude.

Table 1 Regressions with Price, Percentage Volume, Relative Spread, and Volatility as dependent variable. The regressors are the percentages of agents with convex contracts, of Highly Risk Averse agents (HRA), of Higher Initial Endowment (HIE) agents and of Noise agents. The total number of assets assigned to HIE agents is used as a control variable. The last column contains the R-square statistics. Data have been produced by one thousand simulations with one hundred agents. A star denotes significance at the 95% level.

	α	β_1	β_2	β_3	β_4	R^2
Price	11.2784*	0.1950*	0.1354	-0.0318*	0.3063*	0.8166
Volume (%)	15.4420*	-0.0830*	0.2478	0.0176*	0.1137*	0.7335
Spread (%)	10.0215*	0.5680*	0.5435	-0.1135*	0.2383*	0.5813
Volatility (%)	1.2113*	0.2993*	0.3222	-0.0519*	0.2117*	0.8145

Moreover we can conjecture that risk aversion plays an interesting role to make prices converging to the equilibrium.

After this qualitative analysis a new set of simulations has been done to analyze quantitatively the impact of the percentage of convex contracts, the level of risk aversion (we focus on $\gamma > 0$), the initial endowment of assets. The test consists of one thousand simulations of a market where one hundred rational agents trade for twelve rounds. For each simulation we randomly set the number of convex contracts $\mathcal{C}_i$, the level of risk aversion $\mathcal{R}_i$, the initial endowments of assets u_i assigned to the agents and the number of noise traders $\mathcal{N}_i$. We estimate the model

$$y_i = \alpha + \beta_1 \mathcal{C}_i + \beta_2 \mathcal{R}_i + \beta_3 u_i \times 100 + \beta_4 \mathcal{N}_i + \beta_5 x_i^H + \epsilon_i, \quad i = 1, \ldots, 1000$$

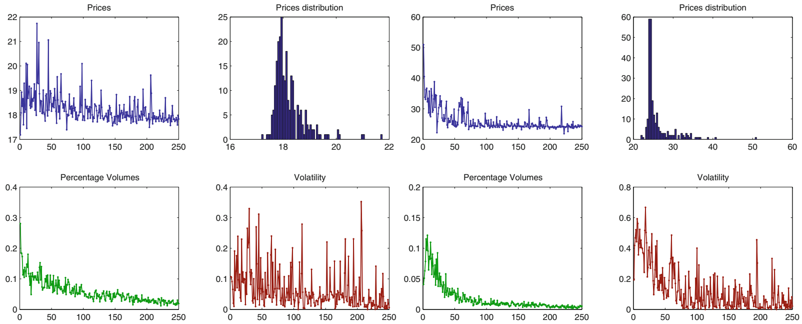

Fig. 1 The panel of four plots on the left refers to linear case with all risk averse agents. The panel of plots on the right refers to a simulation with all risk averse agents all endowed with convex contract. Each panel presents from the left up corner in a clockwise order prices, their distribution, volatility and percentage of volumes. Both the simulation are done with 100 agents, whose 20% are noise traders, the risk preference parameters are randomly selected between 0 and 10.

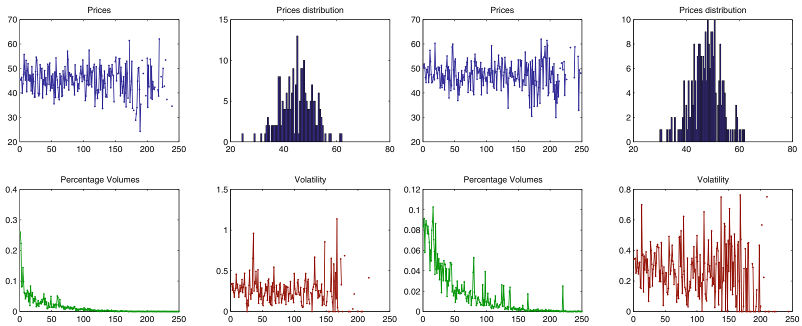

Fig. 2 The panel of four plots on the left refers to linear case with all risk lover agents. The panel of plots on the right refers to a simulation with all risk lover agents all endowed with convex contract. Each panel presents from the left up corner in a clockwise order prices, their distribution, volatility and percentage of volumes. Both the simulation are done with 100 agents, whose 20% are noise traders, the risk preference parameters are randomly selected between −10 and 0.

where ϵ_i are i.i.d. error terms and y_i is a place holder for the price, Percentage Volume, the Relative Spread and the Volatility. The results of the regressions are presented in Table 1. First, the effect of agents' risk aversion is reduced in presence of convex contracts; second, increasing the number of convex contracts increases the level of prices and their volatility, while it decreases the liquidity, measured by relative spreads and volumes; third, the effect of increasing the inequality among agents' endowments is similar to that of increasing the number of convex contracts.

4 Conclusion

We propose an approach based on agent-based simulations to investigate how convex incentives to asset market participants affect the behavior of the markets. The model was originally proposed in Fabretti et al (2015) with the aim to replicate results obtained in experiment done with humans, see Holmen et al (2014). Despite some differences the model can successfully replicate human behavior, hence we can extend our analysis to issues which cannot be explored by laboratory experiments, as for example risk preference effect or initial endowment heterogeneity. We report that convex incentives lead to an increase of prices and volatility and to a decrease of liquidity, that is, lower volumes and higher spreads. The level of risk aversion affects the behavior of agents with linear contracts. However, with convex contracts, risk aversion affects neither agent behavior nor market behavior. We observe also that when agents are all risk averse prices approach on the long run the equilibrium price. We deem that some of our observations may help to build new models and to devise new experimental markets. Moreover the evidence presented here may have also implications for the debate about policy regulations of investment managers' incentive schemes. We believe and tried to demonstrate that agent-based approach can help in studying financial markets and in particular in this case to study the effect of the manager's compensation structure, which is an issue largely debated.

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A Reexamination of High Frequency Trading Regulation Effectiveness in an Artificial Market Framework

Iryna Veryzhenko, Lise Arena, Etienne Harb and Nathalie Oriol

Abstract In this paper we analyze the impact of the French cancel order tax on market quality measured by market liquidity and volatility. Additionally, this paper raises the question whether this tax leads to reduction of high-frequency trading (HFT) activities and a declining in trading volume. Moreover, we test market rules that have not been yet introduced using artificial market framework.

Keywords High frequency trading market regulation · Market liquidity and volatility · Agent-based modeling

1 Introduction

The historical evolution of information systems on financial markets has shown their increasing role in traders' activities. They are responsible as well for the emergence of new forms of volatility. Financial markets have became increasingly swift and reactive, yet increasingly sensitive, leading to the amplification of a global instable climate. Accordingly, there is a growing body of literature on the rise of algorithmic trading and high frequency traders' influence on market quality. Empirical evidence [4, 30] shows positive correlation between HFT and increasing volatility which gives rise to the hypothesis that HFT activities are purely speculative and destabilize

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trading strategies. Yet, others also argue that most HFT trading volume contributes to liquidity provision or at least, that there is no evidence of increasing volatility [17, 20]. Quantitative trading strategies, supporting high frequency trading, increases the number of smaller orders and enables more efficient allocation, price discovery and market liquidity [1, 5, 10].

To identify the responsibilities for (in)stability and market (in)efficiencies is difficult due to the limited ability of regulators and researchers to establish the "real drivers" of assets price dynamics. First, because of the "3V" characteristics of financial big data (Volume, Velocity and Variety), as well as the dark and shadow trading flows that escape from regulatory monitoring. The evolving nature of financial markets also makes the study complicated. According to Cliff and Northrop [12], financial markets have became "ultra large scale complex socio technical systems". Thus, their analysis as purely technical systems (computer science literature) or purely agent system (financial literature) is reductionist. Order flows and price discovery process are the result of trader-to-machine, machine-to-machine, and trader-to-trader non-trivial interactions. Investors are not external users of the systems [8], they are vital components within the system, even if today, they can be outside of the running process. Hence, their IT-centric behavior, as much as their social coordination are keys to understand macroscopic events such as a new type of market instability.

The introduction of a "good" HFT regulation is not a simple task, since HFTs are heterogeneous and have heterogeneous impacts on market quality. Then, a "good" regulation should be the most predictable and adaptive one. Predictable because its positive and negative potential effects should be well-understood ex ante. And adaptive, because regulators must have appropriate tools to evaluate the impact of new rules ex post for readjustments.

In this paper we estimate the effect of HFTs on market quality and trading activity and address the question of a "good" HFT regulation in the artificial financial market. This computational-experimental approach enables us to perform several tests, to validate some hypotheses and, eventually, to make preliminary suggestions to regulators about setting some rules in order to stabilize the market and limit speculation. The use of a simulation platform allows us to shed some new light on the non-linear relationship between local behavior based on traders' strategies and global behavior of that system characterized by its unstable nature. To this extent, the use of a simulation platform is in line with Simon's *"Science of the Artificial"* [29] that claims that computational intelligence (seen as intelligent devices in the artificial intelligence field) is needed to understand complex systems. Agent-based artificial markets allow us to reproduce main features of real trading on the fine grain and to test trading rules not applied by regulator in the real market. Here, we use ArTifcial Open Market (ATOM) [6] as a software-defined intelligent device which is a highly flexible simulations platform and allows different parameterization of microstructure and traders' behavior for different scenarios. To the best of our knowledge, this paper is the first attempt to examine the effect of french HFT cancel order tax implemented on August 1st, 2012 on trading activities and market quality in the artificial market framework. Based on the first results, the government estimated that the tax on HFT generated no revenue in 2012. This paper seeks to shed some new light on this phenomenon. Especially, we try to figure out whether this regulatory policy has reduced high-frequency activities, discouraged speculative transactions, and, as a result, we identify the effect on market quality. We settle two scenarios. The first one is without any taxes. This case is considered as a benchmark and a control group for statistical test. The second scenario proposes a market under tax regulations. We compute a wide range of measures of liquidity and volatility to account for different dimensions of market quality. To estimate the impact of this new regulation on the market quality measure, we use a difference-in-difference technique (DiD).

2 The Model

2.1 Traders Strategies

Trading process is a trade-off between execution cost and benefits generated by transaction (decreased risk exposure, increased return, etc). So trading is determined not only by the global strategy (for instance, utility maximization), but also by "technical" details, like order timing, order volume, type of order, etc. Johnson [22] presents factors that motivate an agent to be more aggressive or more patient in his order submission, they can be classified based on liquidity, price and time relevance.

To keep our model as simple as possible for tractability reasons, we focus only on three groups of traders: slow fundamentalists, high-frequency "contrarians" and high-frequency directional traders.

Fundamentalists are driven by the true (fundamental) asset's value. The fundamental value of each stock evolves according to a jump process $V_t = V_{t-1} + \delta_t$, where $\delta_t \sim N(0, \sigma)$. As the agents are bounded rational (or noisily informed), the fundamental value is biased by ϵ_i, which determines the accuracy of the agent i to interpret the fundamental information $W_t = V_t + \epsilon_i$, $\epsilon_i \sim N(0, \sigma_W)$. Agents are heterogeneous with respect to their parameter ϵ_i. To make a buy/sell decision an agent compares the stock's current price P_t with fundamental value W_t. The price fixing mechanism is inspired from the paper of Chan *et al.* [9] and summarized in Table 1. The fundamentalists submit their orders according to procedure described in Table 1. To summarize, agents buy undervalued stocks and sell overvalued stocks according to their beliefs. They stop trading when they are out of cash or stocks.

High Frequency Traders
High frequency trading refer to strategies relying on fast algorithm for order generation using very fast access to trading platforms and market information. HFTs have short holding periods and trade frequently. They take long and short position of the market and trade near the best-ask and best-bid.

The high frequency traders adopt directional strategies [23]. They try to get benefit from anticipation of price variations $|\frac{P_t - P_{t-n}}{P_{t-n}}| > \Delta_i$. The agents are heterogeneous with respect to the parameter Δ_i of minimal price variation and its? interpretation.

Table 1 The order-submission procedure. P_{ask} denotes a best ask price, P_{bid} best bid price, α_t ask tick size, β_t bid tick size, Q_t is a volume of the order issued at the moment t, N_{t-1} is a number of stocks hold by an agent at moment $t-1$, C_{t-1} is available cash hold by an agent at moment $t-1$, $U(x_1, x_2)$ the uniform distribution in the interval $[x_1, x_2]$

Conditions	Order type
Existing bid, existing ask	
$W_t > P_{ask}$	bid market order
$W_t < P_{bid}$	ask market order
$P_{bid} < W_t < P_{ask}$	bid/ask order with probability 50%/50% at price $\sim U(P_{bid}, P_{ask})$
Order book is empty	
with probability 1/2	limit ask order at $W_t + \alpha_t$, $Q_t \sim U(1, N_t - 1)$
with probability 1/2	limit bid order at $W_t - \beta_t$, $Q_t \sim U(1, C_t/(W_t - \beta_t))$
Empty bid side, existing ask	
$W_t > P_{ask}$	bid market order, $Q_t \sim U(1, C_t/P_{ask})$
$W_t \leq P_{ask}$	limit bid order at $W_t - \beta_t$, $Q_t \sim U(1, C_t/(W_t - \beta_t))$
Existing bid side, empty ask side	
$W_t < P_{bid}$	ask market order, $Q_t \sim U(1, N_t - 1)$
$W_t \geq P_{bid}$	limit ask order at $W_t + \alpha_t$, $Q_t \sim U(1, N_t - 1)$

According to Brogaard *et al.* [7] some part of HFTs act as liquidity providers meaning that they buy (sell) stocks whose prices have been declining (increasing) in the last 10 to 100 seconds. We will call this group of traders *contrarians*. The other group called *?trend followers?* buys (sells) when stock value has been increasing (declining) over last n time stamps. As we observe on average 4000 trades per day, it represents about 0.13 trades per trading round, thus the parameter n is settled in the limit [2; 15]. They have also different trading frequencies, how often they update their positions: cancel pending order and submit a new one. The high-frequency traders do such revision more often than fundamentalists.

The volume of bid order is determined as follow $Q_t \sim U(1, \triangle \times \lfloor \frac{C_{t-1}}{P_t} \rfloor)$, where $U(x_1, x_2)$ uniform distribution in the limit $[x1, x2]$, C_{t-1} is allowed cash, P_{t-1} is observed market price, and $\triangle$ is borrowing rate. $\triangle > 1$ if borrowing is allowed. The volume of ask order is determined as $Q_t \sim U(1, \triangle \times S_{t-1})$, where S_{t-1} is a number of held stocks, $\triangle$ is a short selling rate. $\triangle > 1$ if short selling is allowed. According to Boehmer *et al.*[5] HFT increase a number of smaller order, thus in current simulations HFTs are attributed initially less equities than fundamentalists. However, we recognize the importance of quantity as a choice variable and that our volume submission is a simplification of a real one, which depends on risk aversion. We believe results are not too sensitive to this aspect.

Tax is not directly implemented into the agents decision making as they are taxed at the end of the trading day and only operations exceeding 80% of the total threshold are taxed. Specifically, traders can cancel and modify up to 80% of their orders free of charge. Moreover, in the real market a trader prefers to cancel an unprofitable operation, to accept potential losses and to conclude a new more profitable transaction. HFTs stop trading when they are out of cash or stocks, in such a way we test how the tax on canceling makes high frequency activities unprofitable.

Each limit order is submitted as a Good-Till-Cancelled (GTC). Agents can have only one pending order in the order book, so they have a possibility to cancel their unexecuted order and resubmit at different limit prices. All parameters are detailed in Table 2.

2.2 Timing

We use a simulated time approach meaning that the platform attributes a time stamp to each event. So time is considered to be discrete with millisecond granularity, 30 600 000 milliseconds that represents a trading round of 8.5 hours [24]. At each millisecond, one of the traders is uniformly picked to make a trading decision. The simulator always start by the group of HFT in such a way this group of agents has faster access to an order book, then the group of fundamentalists is activated. Each agent has a choice to do nothing, to cancel a pending non-executed or partially executed order and to send a market or limit order. The traders are heterogeneous with respect to their trading frequency.

3 Econometric Analysis

HFT Activity Proxies. In this paper we estimate the HFT activities as a special group of traders. First, we focus on evolution of Order-to-Trade Ratio (*OTR*) with introduction of the cancel order tax. Order-to-Trade ratio is calculated for all HFT agents, and not for each member separately, over all orders they submit and the trades that result. The numerator includes all types of orders. The denominator includes all trades with HFT agent as a counterpart.

To address the HFT activity, as a subclass of algorithmic trading, we also use a measure proposed by Hendershott *et al.* [19]: $alg - trad = -\frac{\text{Dollar Volume}}{\text{Message Traffic}}$, where Message traffic is the sum of the number of trades, and the number of quote revisions and cancellations, calculated based on the intraday trades and entire order book. Later in this paper this measure will be called Algorithmic Trading (AT) ratio.

Market Liquidity. Measuring liquidity by volume is the most intuitive way, as by definition, liquidity is the ability to trade large volume order without affecting a price in a significant manner. First, we compute *log dollar volume*, as follow $ln\,(Q_t \times P_t)$ where P_t is the transaction price at the moment t, and Q_t is traded volume at the moment t. This measure captures the facility to turn around a position [11].

We include also *depth* into our study, that is measured as the average number of shares that can be traded at the best bid and ask quotes [18]. *Euro depth* is calculated as the average of the sum of the number of shares quoted at the ask price plus the number of shares quoted at the bid price, times their respective quoted prices [18].

Table 2 Parameters and their initialization used in simulations

Parameter	Value	Description
N_{fund}	1000	Number of fundamentalists
N_{HFT}	500	Number of HF traders
$C_{0,i}$	[1 000 000; 2 000 000]	Initial cash attributed at moment 0 to the agent i
$S_{0,i}^{fund}$	[100; 1000]	Number of stocks attributed at moment 0 to the fundamentalist i
$S_{0,i}^{HFT}$	[10; 200]	Number of stocks attributed at moment 0 to the HFT i
tax_C	{0%, 0.01%, ...0.1%}	the tax on orders canceled under a determined time span
tax_A	0.2%	the tax on acquisition of securities
N_{rounds}	30 600 000	Number of rounds per day
N_{days}	60	Number of days

Another widely used measure of liquidity is bid-ask spread. The spread is defined based on the lowest price at which someone is willing to sell (best ask) and the higher price at which someone is willing to buy (best bid). We focus on different dimensions of this measure: *effective spread, realized spread, and quoted spread.* The smaller the spreads are, the more liquid the market is.

Volatility. We proxy volatility by the squared return R^2 and absolute return $|R|$.

Market Efficiency. We measure informational efficiency by the absolute deviation between the price $P_{t,k}$ and fundamental value $F_{t,k}$, $\frac{100}{T}\sum_{t=1}^{T}|\frac{P_{t,k}-F_{t,k}}{F_{t,k}}|$.

4 Simulations and Discussions

We run several computational experiments. In the first experiment set, later called *different tax regimes*, for each run, all parameters are fixed, with the exception of cancel order tax, which varies from 0% to 1% with 0.01% step. These settings allow us to study the tax impact on HFT activities. For each settled tax the simulations are repeated 100 times in order to get more representative results. The parameters used in the simulations are listed in Table 2. The estimation of these parameters is inspired by the papers of [24, 26, 27].

In other series of experiments, all parameters are fixed, with the exception of tax that switches from 0.0% to 0.01% in the middle of trading period (60 days). This later is used to analyze the impact of the new regulation on the market using difference in difference technique.

Using real order book data we cannot directly observe whether a particular order is generated by an algorithm. For this reason, the rate of electronic message traffic is used as a proxy for the amount of AT. The advantage of agent-based simulations is that we can easily identify a sender for each order and estimate the activity level of HFT, that is not an easy task with real market data. As in these simulations HF traders are event driven agents, we first estimate how many orders they send to the market and how many of them are canceled under different tax regimes. We also use AT proxies widely applied in the literature to study real market order book.

Table 3 Activity measures of high-frequency traders under different tax regimes. This table reports different proxies for HFT activity. *OTR* – Order-to-Trade Ratio. *alg trad* a proxy for algorithmic trading, which is defined as the negative of trading volume divided by the number of messages. Each metric is an average of 100 simulations. Linear regression coefficients are computed based on the total sample. Signif. codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', 0.1 ' ', 1.

Tax	*OTR*	*alg trad*
0.00%	173.04563	-1603
0.01%	78.35619	-4753
0.02%	67.74425	-6964
0.03%	74.08699	-7720
0.04%	71.93468	-8197
0.05%	82.19863	-8765
0.06%	75.01937	-8878
0.07%	69.69344	-7333
0.08%	76.05431	-8046
0.09%	65.04254	-9896
0.10%	69.41141	-11184
coef.	−502.00	−65118.2
p-value	0.0833 .	0.001234**
R^2	0.2183	0.6716

From Table 3 we can report a dramatic decrease in Order-to-Trade ratio with tax introduction, but our findings don't provide the undisputed evidence of clear linear relationship between the tax and Order-to-Trade ratio. The Order-to-Trade ratio is about 173:1 in untaxed market, and about 72:1 (average value for market with cancel order tax). Table 3 reports the slope coefficients for linear regression, when the dependent variable is OTR or $alg - trad$. The coefficient of -502.00 implies that increased cancel transaction tax decreases Order to Trade ratio by 5.020.

For untaxed market, there is about \$1, 603 of trading volume per electronic message, and it increases dramatically with tax increase to \$11, 184 per electronic message for 0.1% of tax. Table 3 shows that there is a significant negative relationship between the the tax and our measure of AT, *alg-trad*, which is the negative of dollar volume per electronic message. Higher tax removes faster HFTs who are characterized by high number of small volume orders. Thus, it is clear that higher tax leads to less of HFT activities.

4.1 Difference-in-Difference

To understand the impact of tax on market quality metrics, we run extensive simulations of 30 days before and after the introduction of 0.01% tax on cancel and update orders. Each of such simulations results on average by 250000 intraday trades and millions of messages. These data are analyzed with *difference in difference* technique.

Table 4 The impact of the tax introduction on stock market liquidity and volatility. Difference in difference analysis. ln(Volume) = ln(Number of traded shares × Price). *% Bid-Ask spread* = $\frac{1}{2} \times \left(\frac{Ask_{it} - Bid_{it}}{M_{it}}\right) \times 100$, $M_{it} = \frac{Ask_{it} + Bid_{it}}{2}$, where Ask_{it} and Bid_{it} are the posted ask price and bid price. Depth = $\frac{Q_t^{bid} + Q_t^{ask}}{2}$ where Q_t^{bid} is the best bid size, Q_t^{ask} is the best ask size. Euro depth = $\frac{Q_t^{bid} \times Bid_{it} + Q_t^{ask} \times Ask_{it}}{2}$. $R_t = log(P_t/P_{t-1})$ is the log return. R_t^2 and $|R_t|$ are respectively squared and absolute returns. Signif. codes: 0 '***', 0.001 '**', 0.01 '*', 0.05 '.', 0.1 ' ', 1

Volume			
Tax	(s.e.)	adj. R^2	p-value
0.02721	1.112	0.002651	0.38663
half Bid/ask spread			
Tax	(s.e.)	adj. R^2	p-value
0.116941	0.4288	0.01605	$< 2e-16$***
% Bid/ask spread			
Tax	(s.e.)	adj. R^2	p-value
2.739e-05	0.0001123	0.01402	$< 2e-16$***
Depth			
Tax	(s.e.)	adj. R^2	p-value
-21.5402	33.04	0.06075	$< 2e-16$***
Euro depth			
Tax	(s.e.)	adj. R^2	p-value
-57671	99950	0.05916	$< 2e-16$***
Effective spread			
Tax	(s.e.)	adj. R^2	p-value
0.114501	0.44	0.01319	$< 2e-16$***
Squared return			
Tax	(s.e.)	adj. R^2	p-value
0.05286	16.51	0.0001181	0.910
Absolute return			
Tax	(s.e.)	adj. R^2	p-value
0.045090	0.8858	0.0001501	0.000105***
% Deviation from fundamental			
Tax	(s.e.)	adj. R^2	p-value
1.835e-04	6.748	0.001329	0.00422**

A difference-in-difference [2] is a widely used technique to estimate the impact of a policy change or some other shock on population. We consider two groups and two periods case. One population is exposed to cancel order tax.

$$Y_i = \beta_0 + \beta_1 \cdot D^{treated} + \beta_2 \cdot D^{tax} + \tau \cdot \overbrace{D^{treated} \cdot D^{tax}}^{treated \times tax} + \epsilon_i \tag{1}$$

We regress liquidity and volatility metrics Y_i on a set of treatment indicators that include a dummy variable picking out the treated group $D^{treated} \in \{0, 1\}$, a dummy indicating an after tax period $D^{tax} \in \{0, 1\}$ and the interaction of those two dummies $treated \times tax$. τ is a parameter of interest. If the tax has an significant effect on dependent variables it will appear as a significant coefficient on the $treated \times tax$.

Based on the figures presented in Table 4, we can report a reduction of market liquidity after introduction of HFT tax. The bid/ask spread increases by 2.739e-05%, and effective spread increase by 0.114501. The wider spread measures, the less liquid is the stock. Our results confirm that the tax introduction alters the market liquidity as stated by of Haferkorn [16] and Meyer [25] who investigated the impact of the French FTT on market liquidity. It also converges with the results of [3], [28] who find a negative relationship between transaction tax and market liquidity and recently with the results of Friederich [14] who studies the impact of the implemented penalty on OTR in Italian stock market. At the same time we report the depth and euro depth declines and increased volatility. The impact we find of HFT tax on volatility meets the results of [15, 21, 28]. Additionally, the introduction of the tax increases the deviation from the fundamental by 1.835e-04 percents, that demonstrate a deterioration of market efficiency.

Our results show that financial transaction taxes on canceled orders decrease liquidity, significantly increase volatility, deteriorate market efficiency.

5 Conclusions

Modern financial markets can be considered as adaptive complex socio-technological "system of systems". They are based on softwares which evolve and learn from experience (machine learning). They are also complex, as they allow emergent practices and behaviors that cannot totally be planned ex-ante. In such a manner, SMA and the difference-in-difference methodology are a consistent approach to back-test new rules and delimit their different impacts [12].

As an illustration, we run two experiments in the agent-based artificial market: i) different tax regimes ii) tax introduced in the middle of trading period. Based on our findings, we report that introduction of cancel order tax reduces only slightly HFT activities, but it significantly affects market liquidity, increases market volatility and deteriorates the market efficiency. We conclude, that it is difficult to dissuade investors from entering into unproductive trades and eliminate negative outputs of HFT (such as price manipulations) through tax without altering the benefits of HFT like liquidity provision and efficient price discovery.

Thus, one would agree with [25] and [13] that an FTT is sensitive to many aspects as the composition of the trading floor population, the characteristics of the asset treated and the market microstructure. Policy makers and regulators need to separate the FTTs objectives (collect revenues for financing the burdens of the financial crisis, curb speculative trading, etc.) in order to design an appropriate tax with a clearer view of its costs and benefits.

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Optimization of Electricity Markets Participation with Simulated Annealing

Ricardo Faia, Tiago Pinto and Zita Vale

Abstract The electricity markets environment has changed completely with the introduction of renewable energy sources in the energy distribution systems. With such alterations, preventing the system from collapsing required the development of tools to avoid system failure. In this new market environment competitiveness increases, new and different power producers have emerged, each of them with different characteristics, although some are shared for all of them, such as the unpredictability. In order to battle the unpredictability, the power supplies of this nature are supported by techniques of artificial intelligence that enables them crucial information for participation in the energy markets. In electricity markets any player aims to get the best profit, but is necessary have knowledge of the future with a degree of confidence leading to possible build successful actions. With optimization techniques based on artificial intelligence it is possible to achieve results in considerable time so that producers are able to optimize their profits from the sale of Electricity. Nowadays, there are many optimization problems where there are no that cannot be solved with exact methods, or where deterministic methods are computationally too complex to implement. Heuristic optimization methods have, thus, become a promising solution. In this paper, a simulated annealing based approach is used to solve the portfolio optimization problem for multiple electricity markets participation. A case study based on real electricity markets data is presented, and the results using the proposed approach are compared to those achieved by a previous implementation using particle swarm optimization.

Keywords Artificial intelligence · Electricity markets · Portfolio optimization · Simulated annealing

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1 Introduction

The electric sector has undergone several changes, which caused an increase in competitiveness. These changes are due to the new imposed rules and to the physical limitations, which led to emergence of financial issues [1], [2]. Electricity market participants, mainly sellers and buyers have the need for effective methods that support their actions; the system itself also requires methods to assure the functioning of markets [3].One of the main causes for the changes in electricity markets is the massive integration of renewable energy sources, which has very particular characteristics: intermittence in the production and distributed nature. In this context we can highlight mainly wind power and solar energy. These hold a great influence on how the management of the electricity network is made and but also in how electricity is traded.

One of the most accepted solutions to deal with the introduction of distributed renewable energy sources is the emergence of the concept of Smart Grid [4], which in recent times has evolved from a concept to a visible reality. Smart Grid are small sub-systems capable of maintaining operating independently of each other and together form a working system. The implementation of Smart Grids has been increasing worldwide, as result from the large distributed generation incorporated in the network [5]. With all these changes market, participants are concerned with the forecasting of the behavior of markets, as this knowledge can anticipate and enable them achieving the best results from trading.

Multi-agent simulators have emerged as suitable tools to support players' decision in energy markets. Multi-agent simulation allows modeling different entities, such as independent agents, with specific objectives and characteristics. It also facilitates the expansion of the used models and the integration of new models. MASCEM (Multi-Agent Simulator of Competitive Electricity Markets) [6] is an agent base simulator of electricity markets, which is integrated with AiD-EM (Adaptive Learning Strategic Bidding System), a decision support system that aims at providing market players with appropriate suggestions on what actions should be performed in every time and in different negotiating contexts [7].

Despite all the advances in the electricity markets field, the ability to learn to adapt to new situations and make the best possible outcomes for electricity market players are still far from being achieved. A less explored area is the option of multiple markets participation, which can be optimized to give players greater profitability in their market operations. This work proposes a portfolio optimization model for multiple markets participation. This model offers the possibility to buy and sell electricity in the same period in different markets. A Simulated Annealing approach is proposed to solve the optimization problem, and the achieved results are compared to those using a previous implementation with Particle Swarm Optimization [8].

After this introductory section, section 2 presents the mathematical formulation of the portfolio optimization problem, and section 3 describes the proposed Simulated Annealing approach. Section 4 presents the achieved results using real electricity market data from the Iberian electricity market operator – MIBEL [9]. Finally, section 5 presents the most relevant conclusions of this work.

2 Portfolio Optimization for Multiple Electricity Markets Participation

2.1 Portfolio Optimization

The first recognized work in the portfolio optimization area has been published the first work by Markowitz [10]. The addressed problem was a multiobjective portfolio optimization that considered: maximizing the profit and minimizing the risk. The work of Markowtiz enables finding the balance between the fulfillment of two goals.

The problem addressed by this paper considers a real-time approach, which differs from that presented by Markowitz. With this methodology we intend to support the decision of players on the negotiation of Electricity. For this different scenarios are presented to the player so that it can analyze and make its decisions. With this approach it is also possible to purchase and sale power in the same period in different markets, as introduced in [8], thus building on the Markowitz approach, which does not support such feature. With this, the negotiation methodology adapts itself to the so-called spot market as it no longer considers buyers and sellers as independent players, rather seeing them as players (able to perform both actions).

With the support of these tools it is possible to enable players changing their negotiation profiles (possibility of participating in different types of markets and negotiating different amounts of electricity). The optimization considers real data obtained from different European markets. However, it also enables expanding the optimization to other horizons, making use of several available Electricity market prices forecast and estimation tools [11], [12] and [13].

The optimization process required forecasts of the expected Electricity prices for each period. The work presented in [12] proposes a market prices forecast methodology, which is provided through the use of a neural network, which was used for the same purpose in this work. The participation of the player in different markets is possible, where each market has different rules of trading. For example in bilateral contracts and the smart grids market the negotiated amount may interfere with the asking price, so the price of Electricity depends on the negotiated amount.

One way to try to estimate the variable price of energy is to use a function that calculates the price of electricity in view of the possible amount of electricity traded. The work published in [11] presents an electricity price estimation methodology using fuzzy logic techniques. This paper proposed the application of clustering to split the price profile / quantity. Using these clusters, fuzzy logic is used to create a function for each created interval.

2.2 Mathematical Formulation

The formulation presented in (1) is used to represent the optimization problem, as proposed in [8]. In (3) d represents the weekday, $Nday$ represent the number of days, p represents the negotiation period, $Nper$ represent the number of negotiation periods, $Asell_M$ and $Abuy_S$ are boolean variables, indicating if this player can enter in negotiation in each market type, M represents the referred market, $NumM$ represents the number of markets, S represents a session of the balancing market, and $NumS$ represents the number of sessions. Variables $ps_{M,d,p}$ and $ps_{S,d,p}$ represent the expected (forecasted) prices of selling and buying electricity in each session of each market type, in each period of each day. The outputs are $Spow_M$ representing the amount of power to sell in market M and $Bpow_S$ representing the amount of power to buy in session S.

$$f(Spow_{M\dots NumS}, Bpow_{S1\dots NumS}) = Max\left[\begin{array}{l}\sum_{M=M1}^{NumM}\left(Spow_{M,d,p} \times ps_{M,d,p} \times Asell_M\right) - \\ \sum_{S=S1}^{NumS}(Bpow_S \times ps_{S,d,p} \times Abuy_S\end{array}\right] \quad (1)$$

$$\forall d \in Nday, \forall p \in Nper, Asell_M \in \{0,1\}, Abuy \in \{0,1\}$$

$$ps_{M,d,p} = Value(d, p, Spow_M, M)$$

$$ps_{S,d,p} = Value(d, p, Bpow_S, S)$$

The formulation considers the expected production of a market player for each period of each day. As explained in section 2.1, the price value of electricity in some markets depends on the power amount to trade. With the application of a clustering mechanism it is possible to apply a fuzzy approach to estimate the expected prices depending on the negotiated amount. Equation (2) defines this condition.

$$Value(day, per, Pow, Market) = Data(fuzzy(pow), day, per, Market) \quad (2)$$

Equation (3) represents the main constraint to be applied in this type of problems, and imposes that the total power that can be sold in the set of all markets is never higher than the total expect production (TEP) of the player, plus the total of purchased power [8]. Further constrains depend on the nature of the problem itself, e.g. type of each market, negotiation amount, type of supported player (renewable based generation, cogeneration, etc.).

$$\sum_{M=M1}^{NumM} Spow_M \leq TEP + \sum_{S=S1}^{NumS} Bpow_S \tag{3}$$

3 Proposed Simulated Annealing Approach

This paper proposes a simulated annealing algorithm to solve the electricity market participation portfolio optimization problem defined in section 2. More specifically, the objective is to allocate in an optimal way the resources that provide the best profits for the player in selling its available power in the market. This type of meat-heuristic methods have the particularity of being not accurate, which means that the exact best global solution is hardly achieved.

3.1 SA Methodology

Simulated annealing is an optimization method that imitates the annealing process used in metallurgic. The final properties of this substance depend strongly on the cooling schedule applied, i.e. if it cools down quickly the resulting substance will be easily broken due to an imperfect structure, if it cools down slowly the resulting structure will be well organized and strong. When solving an optimization problem using simulated annealing the structure of the substance represents a codified solution of the problem, and the temperature is used to determine how and when new solutions are perturbed and accepted. The algorithm is basically a three steps process: perturb the solution, evaluate the quality of the solution, and accept the solution if it is better than the new one [14]. Fig. 1 shows the flowchart of the simulated annealing meta-heuristic.

The temperature minimum, the acceptance maximum value and the maximum number of iterations are parameters defined by user. As shown in the diagram of Fig. 1 the algorithm requires an initial solution to start. This is defined through a set of random numbers. When the searching process begins, the search does not stop until the stopping criteria are met. The considered stopping criteria are: the current temperature and the maximum number of iterations. As can be seen by Fig. 1, if the current temperature is minor than the minimum temperature the algorithm stops its search, similarly to what happens if the number of iterations exceeds the maximum number. Simulated annealing is known for two particular factors of this algorithm, namely the decrease of the temperature and the probability of acceptance. As shown by the diagram of by Fig. 1, the temperature only decreases when the number of acceptances is greater than a stipulated maximum. This acceptance number is only incremented when the probability of acceptance is higher than a random number, which allows some solutions to be accepted even if their quality is lower than the previous. When the condition of acceptance is not satisfied, the solution is compared to the previous one, and if it is better, the best solution is updated.

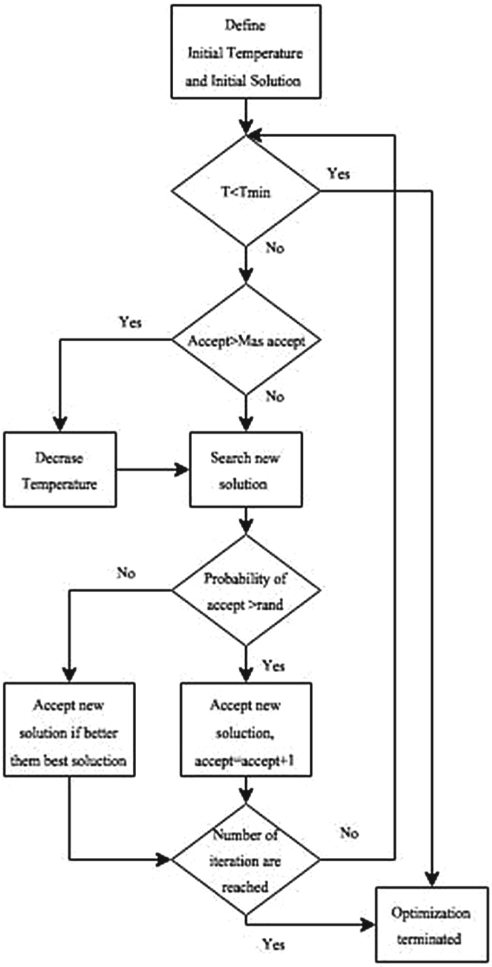

Fig. 1 SA flowchart

Each iteration is necessary to seek a new solution, this solution is calculated according to the equation (4).

$$new\ solution = solution + S \times N(0{,}1) \quad (4)$$

solution in equation (1) refers to the previous solution, because this may not be the best found so far. $N(0{,}1)$ is a random number with a normal distribution, the variable S is obtained through equation (5).

$$S = 0.01 \times (upbound - lwbound) \quad (5)$$

The $upbound$ and $lwbound$ are the limits of each variable, which prevent from getting out of the limits of the search problem.

3.2 SA Parameters

The decisive parameters in SA's research are: the decrease of temperature and the likelihood of acceptance. Considering this, 4 different variants of the simulated annealing algorithm have been implemented in this work, combining different approaches for calculating these two components. It is expected that this will bring different results for different groups, as these components introduce a strong randomness in SA, which makes them reflect in the final results.

Table 1 Different temperature decreasing and probability of acceptance calculation methods

Group	Temperature decreasing	Probability of acceptance	Ref.
1	$T_i = T_{i-1} \times \alpha$	$P = (2\pi T)^{-\frac{D}{2}} e^{\left(\frac{-\Delta x}{K \times T}\right)}$	[15]
2	$T_i = \frac{T_0}{i}$	$P = \frac{T_0}{(\Delta x^2 + T^2)^{\frac{(D+1)}{2}}}$	[15]
3	$T_i = T_0 e^{-ci^{\frac{1}{D}}}$	$P = \prod_{d=1}^{D} \frac{1}{2(\|y_d\| + Ti) \ln\left(1 + \frac{1}{T_i}\right)}$	[15]
4	$T_i = T_0 \times \alpha^i$	$T_i = \frac{1}{1 + e^{\frac{\Delta x}{T_{max}}}}$	[16]

Where:

- $\alpha = 0.95$;
- i is the current iteration;
- $\Delta x = y(x^{max} - x^i)$ is the difference between best solution and current solution;
- $K = 1$ is the Boltzmann constant ;
- $T_0 = 1$ is the initial temperature;
- D is the number of variables;
- $c = 0.1$;
- $|y_d|$ is the abs of solution current;
- $T_{min} = 1 \times 10^{-10}$;
- $acceptance_{max} = 15$.

Besides from these two main parameters, there are issues that may affect the searching process of this algorithm, taking into account that the process of disturbing the solution can determine the search. When the temperature value is high, the search can easily scroll through the search space and leaving important points without being explored. For example, if the initial temperature is too high the search will fall to a point near the ideal very rapidly. However, it is also very likely that the search process could skip this point to points where the solution is worse than the previous. Then the application of too much disturbance is useless and should be avoided [14].

Another important factor is the decrease of temperature. At high temperatures, the simulated annealing method searches for the global optimum in a wide region; on the contrary, when the temperature decreases the method reduces the search area. This is done to try to refine the solution found in high temperatures. This is a good quality that makes the simulated annealing a good approach for problems with multiple local optima. Simulated annealing, thereby, does not easily converge to solutions near the global optimum; instead this algorithm seeks a wide area always trying to optimize the solution. Thus, it is important to note that the temperature should come down slowly allowing the search method to pass through a large part of the search space [14].

4 Case Study

This section presents a case study that illustrates the application of the proposed methodology. The market price forecasts are performed using an artificial neural network (ANN) [12], which is trained using the historic log of electricity market prices from the Iberian Market – MIBEL; further details about this market can be consulted in [9]. With the use of MIBEL data, simulations become realistic because data are taken from a real environment, which makes results reliable. Four different markets based on MIBEL are considered: day-ahead spot market, bilateral contracts, a Smart Grid (SG) market, and the balancing market, with two negotiation sessions, which in the total makes it possible to carry out negotiations in five market sessions. In the spot and balancing markets, the expected prices are forecasted using the ANN, while the expected price in bilateral contracts and SG market are adjusted using the fuzzy logic estimative presented in [11].

Simulations are undertaken concerning 1 day with 24 hourly negotiation periods. The TEP value is 10 MW. Additionally, the supported player can buy up to 10 MW in each market where purchase is allowed to a seller. In the balancing market sessions each player is only able to do one action (buy or sell) in each period. The optimization using the proposed simulated annealing (SA) approach is executed 1000 times, which can ultimately result in 1000 different optimization results, depending on the random variables. Table 2 and Table 3 present the optimization outputs (respectively purchases and sales of electricity) for the first period of the considered simulation day. These results concern the simulation that has registered the highest objective function value using each of the groups presented in Table 1.

Table 2 Sales scheduling in the different markets

SA Variation	Sales (MW)				
	Spot	Bilateral	Balancing 1	Balancing 2	Smart Grid
SA Group 1	20,08	11,5168	0	0	8,5464822
SA Group 2	19,24	11,7707	0	0	8,0711197
SA Group 3	19,03	11,6413	0	0	9,0258825
SA Group 4	20,29	11,5001	0	0	8,6843312

As shown by Table 2, which shows the sales made in the different markets, the four implemented variants present very similar results. In this case the balancing sessions assume values of zero because as shown in Table 3, these markets are used to purchase electricity. Table 3 shows the electricity purchase in the various markets.

Table 3 Sales scheduling in the different markets

SA Variation	Purchases (MW)				
	Spot	Bilateral	Balancing 1	Balancing 2	Smart Grid
SA Group 1	0	4,8456	10	10	5,298138
SA Group 2	0	4,59959	10	10	4,4853613
SA Group 3	0	4,78831	10	10	4,9050412
SA Group 4	0	4,99057	10	10	5,4875652

From Table 3 one can see the results recorded for electricity purchases. As can be observed, since the spot market has been used to sell electricity, it cannot be used to purchase as well, according to the restriction defined in the model. All four SA groups also show very similar results regarding the electricity purchases. Table 4 presents the comparison between the objective function results of the group variants implemented in SA and the results of a previous implementation based on a particle swarm optimization (PSO) approach [8]. The minimum, maximum and mean results are shown, as well as the standard deviation (STD) registered in the 1000 simulations. Additionally, the average execution time of each method variation is also displayed.

Table 4 Objective function results of the proposed SA approach, compared to the PSO

Algorithm	Objective value (€)				Time (seconds)
	Minimum	Mean	Maximum	STD	
PSO	935,0451386	1802,21	2000,6456	160,423489	1,024635318
SA Group 1	1781,480543	1884,04	1927,2421	55,5014797	0,51910964
SA Group 2	1782,445013	1882,49	1933,5664	56,4381753	0,507367551
SA Group 3	1782,519507	1883,28	1930,1467	56,0204514	0,508814344
SA Group 4	980,9189744	1616,23	1925,3661	203,592965	0,174417698

Table 4 shows that SA Groups 1, 2 and 3 present very similar objective function results and execution time as well. SA Group 4, on the other hand, presents worse objective function results, but in a much faster execution time (3 times faster than the other SA approaches, and 6 times faster than PSO). SA Groups 1, 2 and 3 also present a higher mean value of objective function, which is around 5% higher than PSO. This is also reflected on the much higher minimum achieved value that SA Groups 1, 2 and 3 are able to achieve when compared to PSO (almost doubling the value of PSO), and also on the STD, which is three times lower. PSO is, however, the algorithm that records the highest objective function value, with a value about 3 % higher than that achieved by SA Groups 1, 2 and 3. This very small difference is largely compensated by the great gain in execution time and reliability. Fig. 2 expands the explanation on this question.

Fig. 2 shows a Box Plot for the implemented algorithms. With this representation it is intended to give the information on which of the algorithms is positioned in the best cost benefit ratio. These plots are built at the expense of five parameters of which three (median, 1st and 3rd quartile) are calculated on the results of the simulations and the other two (maximum and minimum) derive from a simple observation data. With this graph we get insightful information on how the data are distributed to as: greater or lesser concentration, symmetry and the existence of outliers. In the Box Plot, the analysis is done taking into account the length of the line joining the minimum point to the maximum and the size of the box. The median value gives skew indications of the data.

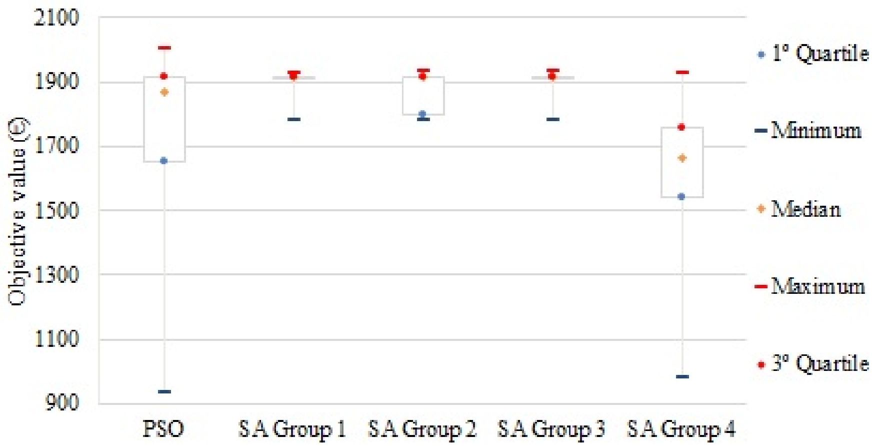

Fig. 2 Box plots for the different methods

As presented in Fig. 2, the range from the minimum value to the value of the 1st quartile represents 25% of the data. Similarly, from the value of the 3rd quartile to the maximum value are also represented another 25% of the data. Amidst the values of the 1st quartile and 3rd quartile are represented 50% of the data. As can be seen from the data, the results from SA groups 1, 2 and 3 are much more concentrated than the other algorithms, which means that they are more reliable. Although the figures provided by PSO are not as concentrated as the result of SA, this approach cannot be ruled out because this is the algorithm that presents the highest value of objective function, which represents the possibility of achieving the highest profit.

Fig. 3 shows the 95% confidence interval for the results of SA groups 1, 2 and 3.

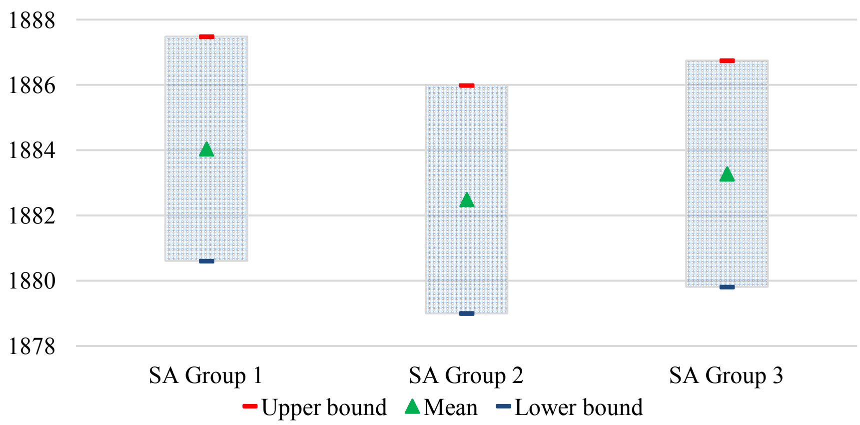

Fig. 3 Confidence interval of SA Groups 1, 2 and 3

As can be seen by Fig. 3, the confidence intervals of the three SA groups have similar amplitudes. In this case, by performing the analysis of the figure and applying the theory of confidence intervals, there is a 95% chance of a simulation result being between the minimum and maximum with a certain error, in this case SA Group 1 shows a 3.4382 error, SA Group 2 shows 3.4963, and SA Group 3 presents a 3.4704 error; this error can also be called tolerance. Although the presented results regard the first period of the simulation day, the 1000 samples in the other periods for each algorithm keeps a very similar performance.

Fig. 4 shows the convergence performance of the four SA groups.

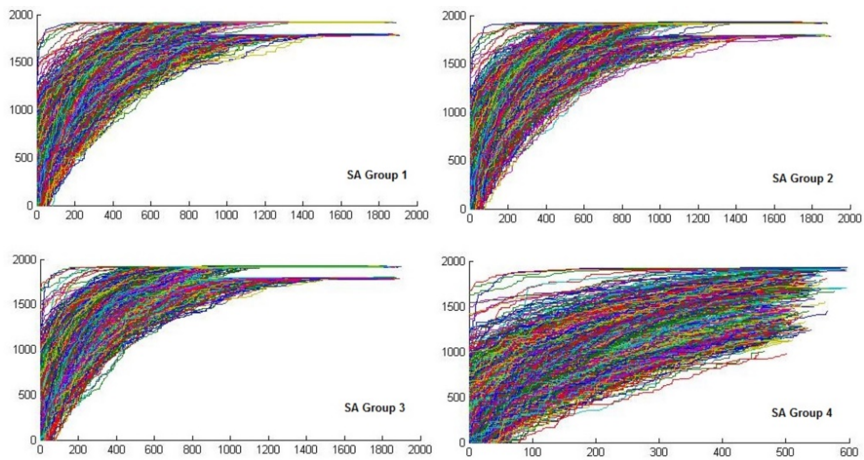

Fig. 4 Convergence performance of the SA algorithms

Each line in Fig. 4 represents the convergence of each simulation in each of the1000 simulations. The evolution of the objective function (€) (yy axis) is represented along the iterations (xx axis). In Fig. 4 it is visible that, as seen before, SA Group 4 is the approach that shows the worst results. One important fact is that in SA Groups 1, 2 and 3, in the final part of the convergence process, results are concentrated in two lines, as it is possible to see from the respective graphs of the figure. This strongly indicates the possibility of the existence of a local optimum, in this case a local maximum. The proposed SA approaches, as it is possible to note, have proven to be able to work around this situation and present the best solution.

5 Conclusions

This paper presented a SA approach to solve the portfolio optimization problem, for multiple electricity markets participation. The proposed approach is composed by four different groups regarding the calculation of the most important variables required by SA algorithms. The proposed SA approach has been compared to a previous implementation of a PSO based approach.

Similarly the PSO, SA also has been able to solve the problem of portfolios optimization in the electricity markets, as it was possible to observe the results. By comparing the results of the proposed SA approach with the previous PSO implementation, it is demonstrated that the SA results presented more homogenous results than the PSO, although the highest objective function result was found by PSO. SA has also shown much lower execution times, which, together with the much larger credibility of the SA, as shown by the analysis of the staggering of sales and purchases, supports the conclusion that the SA methods are more reliable, and safer to being used in real cases. The proposed methodology is intended to be used to generate scenarios so that market users can use them in order to maximize their results from negotiating in the market. It should be noted that the results presented are only a period, but the methodology is prepared to be extended to other periods as well as other markets.

As future work other algorithms will also be used to solve this problem, so that results can be compared, such as genetic algorithms and other variants of PSO. A methodology that can measure the risk trough the prediction error of electricity prices will also be formulated and integrated in the current approach. As here shows the results for a period of one hour, you can choose other periods where the scenario is completely different, because in electricity markets, and especially in the spot market, there is a lot of volatility in electricity prices. This means that totally different scenarios can be found, which should be studied in order to show the adaptability of algorithms.

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Part II
Special Session on Advances on Demand Response and Renewable Energy Sources in Agent Based Smart Grids (ADRESS)

Detection of Non-technical Losses in Smart Distribution Networks: A Review

Anna Fragkioudaki, Pedro Cruz-Romero, Antonio Gómez-Expósito, Jesús Biscarri, Manuel Jesús de Tellechea and Ángel Arcos

Abstract With the advent of smart grids, distribution utilities have initiated a large deployment of smart meters on the premises of the consumers. The enormous amount of data obtained from the consumers and communicated to the utility give new perspectives and possibilities for various analytics-based applications. In this paper the current smart metering-based energy-theft detection schemes are reviewed and discussed according to two main distinctive categories: A) system state-based, and B) artificial intelligence-based.

Keywords Advanced metering infrastructure · Electricity theft · Smart grid · Smart meter

1 Introduction

As power demand increases in modern societies, the need for an advanced and reliable power grid becomes increasingly imperative. In fact, the traditional power grid, which is still remarkably based on a design already existing for more than 100 years, can no longer satisfy the present-day needs and requirements [1]. The current emergence of smart grids aims to increase the reliability, quality and security of supply, especially in the face of the increased penetration by renewable energy sources in the form of distributed generation [2]. The concept of a smart grid has also come into existence, bringing into the state-of-the-art scope relative advancements in information systems and communication technologies, one of whose cornerstones is the present large-scale

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deployment in many countries of advanced metering infrastructure (AMI) in order to upgrade the aging energy metering system [3].

One of the principal problems which impacts the efficiency and security of the power distribution networks are the power losses occurring within the process of delivering energy to the consumer. These losses can be decomposed into two categories: i) Technical losses (i.e. losses due to naturally occurring phenomena in the power system, such as power dissipation within transmission lines and transformers), and ii) Non-technical losses (NTL), which can be attributed to the following reasons: a) Actions of utility employees or an operator, such as administrative losses due to accounting errors and record keeping, b) Customer theft, c) Customer non-payment, and d) Theft by non-customers [4].

A critical issue for the distribution utility is that NTL cannot be precisely calculated, only global losses; they are usually estimated as the difference between the total amount of energy fed into the distribution system and the total amount of energy recorded as sold to customers [5]. The excess of unbilled energy is energy that is not scheduled or expected by the utility, thus it can severely affect the power system operation [6]. Critical operational problems that may arise include overloads of generation units and the stressing of network equipment due to congestion and/or over-voltages. These result from the fact that the utility cannot schedule sufficient active and reactive power due to system dynamic uncertainty and insufficient load flow information. Furthermore, these over-loadings can have an impact on the equipment of honest consumers. In extreme cases of excess unplanned load, blackouts and brownouts may also occur. Concerning the distribution utilities, apart from the directly incurred economic losses as a consequence of purchasing energy that is not billed for, maintenance costs also increase due to the aforementioned stressing of the equipment. Hence, NTL deprive utilities from investing in the upgrading of their equipment. Last but not least, the environmental impact of NTL is also considerable due to the increase in CO_2 emissions (the price signal is not considered in the defrauder decisions). A 10% reduction in NTL in India (around 83,000 GWh) would result in 9.2 million tons CO_2 reduction annually [7].

The nature of NTL poses serious challenges to utility companies in detecting dishonest customers. It should also be pointed out that technical losses are correlated with NTL, since the delivery of unbilled energy creates further physical losses on the power system. Thus minimizing NTL contributes to the overall reduction of power losses. ENEL, the Italian electricity utility, was motivated to initiate a large scale roll-out of smart meter-based infrastructure in order to minimize NTL of their distribution network. After the installation of smart meters (SMs) on the consumers' premises, the theft hit-rate raised from 5% to 50% [9]. This massive deployment of SMs is now extended to Spain, being facilitated by Endesa -one of the Spanish distribution utilities- with 6.8 m SMs and 77,000 concentrators having been installed by the end of December 2015. The data provided by the SM devices give a new perspective and unveil numerous possibilities to develop efficient and effective theft detection methods. Research in this respect has recently shown significant progress. As a result, the authors felt motivated to investigate and present in this paper the state-of-the-art in NTL detection methods within the framework of AMI, including artificial-intelligence techniques.

An important part of the implementation of an AMI is the replacement of the legacy mechanical meters with SMs. The bidirectional communication capability of the SM allows remote meter data-reading, recording of higher resolution measurements, as well as outage reporting. SM and AMI data analysis remains a challenging task for several reasons. Support databases with SM data "as is", is infeasible over long time periods due to storage limitations. Those data are processed, depending on the purpose of their use, and compressed before storage. The compression may result in precision reduction of data, which could potentially be useful for future re-analysis. Additionally, real- or nearly real-time data processing can be computationally heavy and resource-consuming. Last but not least, detailed measurements from SMs allow the utility companies to extract the consumer load profile, which is considered sensitive private data and even forbidden by some regulations. There are confidentiality issues arising, with the possibility that such private information can be sold to third-parties such as insurance companies, marketing companies etc. Moreover the consumers may become easier targets for criminals, such as burglars that can infer the victim's daily habits by analyzing their load profile [8].

2 NTL Detection Techniques

There are various ways that the data retrieved from SMs have been analyzed and exploited in order to detect NTL. Existing methods are categorized in this paper in three groups: system state-based, artificial-intelligence-based and game-theory based. In this review we will not consider the last one (see [4, 19] for more information).

2.1 System State-Based Methods

These methods are based on the coherence of data measured by SMs with respect to the data collected from the network (probably performed on a routine basis by the distribution system operator) and the features of the network (topology and line parameters). Chen et al. present in [10] an electricity anti-theft method based on state estimation (SE) algorithm [11], using redundant data from SM. It is claimed that whichever the technology of stealing may be, the method is applicable. Other advantages of this method include small-scale investment, wide-area and real-time monitoring. It is also suggested that considering that the false voltage, current, or power measurements due to stealing are the bad measurements, then for a limited-size network its status can be estimated with high accuracy, while at the same time localization of the electricity theft point can be achieved. The method was tested on a 10 kV medium voltage (MV) network. However, the authors claim that the theoretical model can be applied on 400 V low voltage (LV) networks as well. A power balancing is initially performed to determine whether there is really need to further investigate a feeder. If the difference between the total of power supply and the sold power exceeds a threshold, then the following methodology is applied. The collected three-phase real-time voltage, current, active and reactive power measurements at the MV/LV transformers are used as inputs to a weighted-least-squares (WLS) three-phase state estimation algorithm. This is applied in order to estimate the loading of the distribution transformer. Note that it was considered that the phases are decoupled in ungrounded MV networks. If the deviation of the estimation from the measurement is greater than a threshold, this suggests the existence of possible electricity theft. No results were presented to validate the performance of the method Another SE approach is developed by Huang et al. in [9, 12] for almost real-time localization of irregular energy consumption and NTL reduction. However, in [9] the SE is complemented with an analysis-of-variance (ANOVA) model, constituting a more detailed two-stage approach. The first-stage includes the implementation of the MV-level SE, as in [12], for load estimation of the MV/LV distribution transformer. This stage aims to identify feeders with tampered or defective meters. Abnormalities within the feeder level in electricity consumption are determined by examining a measure of overall fitting of the estimates to pseudo-measurements on the feeder bus, calculated by aggregated customer data from SM at the MV/LV transformers. Following this phase, ANOVA is performed in order to distinguish suspect customers with abnormal measurements records. A WLS-based, three-phase polar form SE algorithm is implemented to estimate the MV/LV distribution transformer load. This algorithm requires, aside from the network parameters and configuration: a) the hourly LV bus voltage and demand data from SMs at the points of power delivery (aggregated to provide pseudo-measurements at the LV side of the MV/LV transformer), b) outage management system (OMS) data, and c) customer information system (CIS) data in order to examine customer connectivity and construct the feeder framework. When the estimates from the SE are obtained, irregular usage at the distribution transformer level is detected via the examination of the normalized residuals at the point of delivery. Following the identification of bad data, the corresponding LV network is closely investigated by applying ANOVA. To this purpose, for all consumers that belong to that network, their load baseline curves (as estimated by old data dating back a few weeks) are compared with curves obtained by recent SM measurements. The aforementioned method was validated using data from a typical distribution feeder of the Taiwan Power Company. Several NTL cases are demonstrated: a) defective SM with zero reading, b) defective SM with higher reading, and c) electricity theft. The SE was able to identify in every case the bad measurement data. Moreover, when they were replaced by their estimates and the SE was run again, the results were very accurate and close to the actual values. For the ANOVA, two datasets, one of normal and one of fraudulent customers were used, of 8 hours and their baselines for 3 weeks were considered. The model distinguished which was the fraudulent dataset from the 5 ones. Niemira et al. in [13] implement a SE model to detect malicious data attacks by comparing the active and reactive power measurement residuals of a nonlinear SE with those of a linear one (DC model). The main difference of the proposed SE from the traditional ones is that it is designed not only to handle random sensor noise or errors, but also isolated, random bad data. It is assumed that the attacker has partial knowledge of the topology, such as a column of the Jacobian H (which is constant for the DC SE), to prepare an attack measurement vector z. Then, his own measurement and a suitable subset of measurements are modified so as to leave DC residuals unchanged. DC models disregard losses, uneven voltage profiles and reactive power. Thus, if a measurement vector designed for a DC SE is used with an AC one, there will be an increase in the residuals. Baseline residuals are required for comparison with the current residuals. A 24-bus IEEE network was used to examine the performance of the model. When Monte Carlo noise was added to real measurements, in order to produce data for baseline construction, it was concluded that the active power injection residues of the generators are impacted the most by the attack. Weckx et al. in [14] propose a linearized load flow algorithmic approach using SM data for electricity theft detection via illegal connections, when line lengths are unknown or uncertain. At the same time, basic information of the topology can be extracted and the phase of consumers can be identified in an automatic way. The LV, three-phase, four-wire, radial distribution networks are considered. Active and reactive power, as well as voltage magnitudes, are the required measurements from the SMs to be used in the linear model for the execution of this algorithm:

$$V_{h,k} = V_k^0 + \sum_{\tilde{h}=1}^{N} a_{h,\tilde{h}} P_{\tilde{h},k} + \sum_{\tilde{h}=1}^{N} b_{h,\tilde{h}} Q_{\tilde{h},k} \ , \tag{1}$$

where k is the time step, h the hth residential consumer and N the total number of houses; V_k^0 is the voltage magnitude at the LV side of the MV/LV transformer, $P_{\tilde{h},k}$ and $Q_{\tilde{h},k}$ the active and reactive power of the consumer $\tilde{h}$ at time step k respectively, and $a_{h,\tilde{h}}$ and $b_{h,\tilde{h}}$ the influence factors of the active and reactive power respectively of consumer $\tilde{h}$ on the voltage magnitude of consumer h.

If there are historical measurements from SMs which are free from fraud, then $a_{h,\tilde{h}}$ and $b_{h,\tilde{h}}$ in 1 can be considered as the unknowns and an ordinary least squares problem is defined. After the influence factors have been determined, then the voltage at each consumer premises can be calculated from (1), using new measurements from SMs that possibly entail electricity theft and can then be compared with the voltage measurement of the SM.

The parameters $a_{h,\tilde{h}}$ and $b_{h,\tilde{h}}$ are also indicators of the relative location of the SM and the phase they are connected to. If the SM h is connected at the same phase as the $\tilde{h}$ the parameter $a_{h,\tilde{h}}$ will be negative since the active power has created a voltage drop. If it is connected to another phase, then the parameter will have a low positive value.

The results of this approach were validated with the simulation of a LV, 4-wire residential feeder in Flanders with 32 customers. The first customer was far away from the substation and the feeder does not have side branches. 1000 steps were required to calculate the influence factors and the identification of the phases was successful. A comparison between the errors of an exact load flow with a 10% uncertainty of cable lengths and the linearized one with unknown cable lengths is also presented; the second case study was found to yield significantly smaller errors (less than 1 V).

In [15] Berrisford describes, within the context of electricity theft detection via SM data, a linear programming optimization method to confirm the network topology by estimating the feeder section impedances, and to provide estimates for the MV/LV transformer LV-side voltage, which in many cases is not measured. The algorithm uses hourly load and voltage measurements. The main idea behind this algorithm is that the voltage of the transformer is equal to the sum of the voltage of any SM and the voltage drop from the transformer to the SM. A set of equations, as many as the SMs, estimating the voltage of the transformer can be formed. The unknown variables in these equations are the line impedances since there are measurements for the SM voltages and active powers. The criterion to obtain the most accurate values for the impedances is the minimization of the transformer voltage variance. This is achieved by using linear programming. When there is theft at a SM, the model exhibits poor convergence. In the simulation, a virtual unknown load with known impedance was added parallel to the irregular SM to represent theft, and the model converged in this case. The method was tested on two transformers of BC Hydro in Canada for hourly measurements of 4 weeks providing promising results. During the first week, for transformer A, the mean standard deviation (MSD) was 0.016% for voltage. The line impedance estimates were consistent for about 4 weeks testing, which implies that the model is accurate. Transformer B had a 0.437 V MSD. This was attributed to the fact that one of the SM had a completely different voltage trend, and it was concluded that it belonged to another transformer. After the SM was removed the MSD was 0.315 V but it was observed that for 2 SM the estimates were not in step with the others. At this point, the virtual load to model theft was added and the MSD decreased to 0.092 V.

Salinas et al. in [16], taking into account customers privacy preserving, propose three distributed algorithms based on peer-to-peer computing in order to calculate customers "honesty coefficients". The distributed LU and QR decompositions are employed to solve a linear system of equations (LSE) while preserving each node's information. For a small network, LU decomposition (LUD) can localize the thieves: unfortunately, the same methodology can prove to be unstable for large networks. For the latter ones, LUD with partial pivoting (LUDP) is implemented, as well as QR decomposition (QRD). The aforementioned methods are applied in cases with constant fraud. In addition to this case, adaptive LUD, LUDP and QUD for scenarios with variable theft activity are also presented.

Those algorithms are intended to be implemented in the SM firmware. An assumption that there is a SM at the concentrator is made, in order to know the overall energy consumption of an area. For a neighborhood with n consumers, let SP be the sampling time, $p_{t_i,j}$ and $\bar{P}_{t_i}$ the recorded energy consumption by the user j at time t_i and the overall consumption recorded at the concentrator level respectively, and k_j the honesty coefficient of the j customer such that $k_j p_{t_i,j}$ gives the actual energy consumption of jth customer for the time period t_i. The sum of all consumers' actual energy at time t_i should be equal to the energy consumption at the concentrator level, thus

$$k_1 p_{t_i,1} + k_2 p_{t_i,2} + \ldots + k_n p_{t_i,n} = \bar{P}_{t_i} \quad (2)$$

The aim is to determine the k_j coefficients. If $k_j = 1$ then the customer is considered honest, if $k_j > 1$ then the recorded energy from that SM is lower than the realized one, and the customer is characterized as fraudulent, and if $0 < k_j < 1$ then the recorded energy is more than the consumed one, suggesting that this SM is defective. With n equations like (i.e. energy measurements for n points in time), a LSE is formed:

$$Pk = \bar{P} \ , \quad (3)$$

where the jth column of P is the recorded energy of the jth SM. Then the data in P are factorized in a lower triangular matrix L and an upper triangular matrix U, so that $P = LU$. A new system is then derived:

$$Ly = \bar{P} \quad (4)$$

$$Uk = y \quad (5)$$

The L, U and y are collaboratively and sequentially calculated by the SMs. For this task, the concentrator has to transmit $\bar{P}_{t_j+1}$ to each SM while each SM calculates only one column of L and y. In order to perform this task it needs the previously calculated columns of these matrices to be transmitted to it by the previous SM. Then backward substitution is used to determine the honesty coefficients k_j. Each SM sends to the previous one the product of one column of U and the calculated honesty coefficient. Additionally, each SM encrypts k_j using the concentrator's public key and the concentrator decrypts all the k_j after the LSE has been solved and the fraudulent SM locations are identified. The LUDP is based on partial pivoting which refers to the exchange of rows of the P matrix in order to arrange all the elements with the greatest absolute value in each column in the diagonal positions. In comparison to LUD, this algorithm requires greater execution time. The QRD algorithm decomposes P into an orthogonal matrix Q ($Q^{-1} = Q^T$) and an upper triangular matrix R, so that,

$$Rk = Q^T \bar{P} \quad (6)$$

The adaptive LUD, LUDP and QRD algorithms consider variable honesty coefficients. In the area of n consumers, it is assumed that each one may commit fraud with the same probability p. If X is the total number of energy thieves in the area, then X is a random variable with a binomial distribution. When the concentrator decrypts k, it can find the elements that are not equal to 1, denoted as Y, and thus it can calculate the probability of this event happening:

$$P(X = Y) = \binom{n}{Y} p^Y (1 - p)^{n-Y} \quad (7)$$

Then, if the customer j commits fraud with different probability p_j, X is a random variable with an expectation $E[X] = \sum_{j=1}^{n} p_j$. By setting a threshold, the concentrator can decide whether a k is valid or not if P is lower than the threshold in which case the SP is reduced, and the process is repeated until the obtained k is the same as the previous one. The performance of the algorithms was verified with simulations where the power measurements were generated using some surveys. LUD performed well with 15 and 30 users with constant honesty coefficients but with 50 users it became unstable, QRD and LUDP however gave good results with 50 users. With variable coefficients, LUD is stable for 25 users and LUDP, QRD performed well even with 100, 200 and 300 users. Lo and Ansari in [17] deal with false data injection (FDI) attacks by suggesting the combination sum of energy profiles (CONSUMER) attack, involving a number of consumers' SM aiming to achieve a lower consumption record for the attacker and a higher one for the other consumers. The proposed CONSUMER attack model minimizes the number of the violated SMs. This detection technique is based on a grid-sensor placement algorithm that provides increased monitoring to achieve higher hit-rates. In this work, it is assumed that grid operators have complete knowledge of the network topology while radial networks are considered. Let H denote the network configuration matrix, z a set of measurements $z = [P_G, P_1, P_2, \ldots, P_i]^T$ where P_G is the power at the supply point and P_i the power measured by the SM. It is assumed that no irregularities are detected by the traditional bad data detectors. The attacker is considered to have knowledge of H and the state estimation error. With this information, the attacker can build a strategy such that for the normalized residuals applies $\|z_b - H\hat{x}_b\| = \|z - H\hat{x}\| < \delta$, where δ is a pre-determined threshold, z_b and x_b are respectively the measurement and state vectors modified by the attacker. A vector c is designed such that $\hat{x}_b = \hat{x} + c$ and a vector a can be fabricated so that $z_b = z + a = [\bar{P}_G, \bar{P}_1, \bar{P}_2, \ldots, \bar{P}_i]^T \neq 0$ and $a = [a_G, a_1, a_2, \ldots, a_i]^T$, $\sum_{\forall i \in N_{SM}} a_i = a_G = 0$, where N_{SM} is the number of SMs in the examined area. In other words, there are load alterations, and some a_i values will be negative, thus the corresponding SM will exhibit lower energy consumption, and some will be positive by the same overall amount; these will refer to the compromised SMs. The state estimation performed by the grid operators cannot detect the linear alteration of a. The proposed intrusion detection system with power information requires sensor placement across the distribution network. These sensors are of a more simplified design in comparison to SMs, and they belong to the utility. They build a sensor network which is less vulnerable to attacks, as it is designed for grid monitoring. The data of the SMs will be compared with the ones obtained from these sensors. In order to avoid placing sensors in all grid nodes and having an over-determined system, an algorithm that identifies the optimal nodes where sensors should be located is presented. Han et al. in [18] propose a NTL Fraud Detection (NFD) method based solely on data obtained from SMs; no other information of the consumers is required. The criterion used to identify dishonest customers is the difference between the billed energy and the realized consumption. Assuming that technical losses have been estimated by the utility company and excluded, there is also a SM at the distribution transformer recording the overall energy supplied to n customers in a neighborhood. Let E_j denote the energy measured at the distribution transformer and $E_{i,j}$ the actual energy at the ith SM, and $x_{i,j}$ the electricity reported to the utility by the ith SM. By performing energy balance, considering that the technical losses have been calculated and removed, yields

$$E_j = \sum_{i=1}^{n} E_{i,j} \tag{8}$$

If the consumer is honest, then $E_{i,j}/x_{i,j} \approx 1$; for a dishonest customer $|E_{i,j}/x_{i,j} - 1|$ will be very large. For each SM an accuracy coefficient is defined as $a_{i,j} = E_{i,j}/x_{i,j}$. While the reported energy is available, the actual values are not. There is a function for each SM such that $f_i(x_{i,j}) = E_{i,j},\ \ j = 1, 2, \ldots, m$. Based on Taylor approximation $f_i(x) = \sum_{k=m}^{o} a_{k,i} x^k$. By replacing the previous two equations in (8) yields

$$E_j = \sum_{i=1}^{n} \sum_{k=m}^{o} a_{k,i} x_{i,j}^k \tag{9}$$

With m samples of x^k for each SM and E_j known, the accuracy coefficients can be estimated. Simulations were performed to examine the performance of the model.

2.2 Artificial Intelligence-Based

Artificial Intelligence-based theft detection techniques are the most popular ones, since they were available to use before the deployment of SMs, and because now they can further advance and improve remarkably within the framework of SMs. These methods usually refer to the classification of the consumers load profile. The aim is to determine irregular patterns in the electricity consumption over time, based on a training dataset that includes normal and irregular cases. The main steps followed in a classification approach are: a) data acquisition, b) data preprocessing, c) feature selection, d) classifier training, e) data-of-interest classification, f) data post-processing, and g) theft-suspects identification.

Nagi et al. in [20] approach the electricity theft detection problem by developing an artificial intelligence technique, namely a support vector machine (SVM). In this method historical consumption data and additional consumers attributes are used to identify irregular consumption profiles that are highly correlated with NTL. The consumers are classified either as "normal" or "fraud" by the SVM model. The consumers' consumption patterns are determined by employing data-mining and statistical analysis tools trying to identify sudden changes in the consumption profiles. Specifically in this paper, the SVM solves a binary classification problem by finding the optimal $f(x)$ =sgn$(g(x))$, where $g(x)$ is the decision boundary between the two classes, that accurately classifies new data into the two classes while minimizing the classification error. The method of structural risk minimization is exploited.

The method was tested using historical data of three Malaysian cities for 265,870 customers and for 25 months. The features that were eventually chosen include: a) 24 daily average energy consumption values for each customer, which correspond to their load profile (estimated as the monthly consumption divided by the number of days between two consecutive measurements), and b) the credit worthiness information CWR (this is produced by the utility's billing system automatically for customers that do not pay their bills) for each customer. The data were normalized, formatted and then used for the training and testing of the SVM model. After collaboration and on-site inspection with Tenaga Nasional Berhad, it was found out that the expected hit rate increased from 3 % to 60 %.

In Nagi et al. [21] the work of [20] was extended, introducing a fuzzy inference system (FIS) in the form of IF-THEN rules. For each customer, an output ranging from 0 to 1 is produced by the FIS. The customers with outputs from 0.5 and higher are considered to have higher probability to be fraudulent. This method seemed to improve the previously 60 % hit rate to 72 %. It is worthy to mention the work of [24], where a method to identify the features that best describe possible illegal consumers is proposed.

Babu et al. in [22] use fuzzy C-Means clustering to categorize consumers based on their consumption patterns. The difference of clustering to classification is mainly that the latter one has a training dataset where the response of the observations is already known and classifies new data. Clustering is the grouping of observations into classes of similar objects. In fuzzy clustering, an observation can belong to more than one class, with a different degree-of-membership. The fraud identification relies on the fuzzy membership function and the normalized Euclidean distances of cluster centers ordered by unitary index score. The highest score represents fraudulent consumers. The method uses five attributes that are considered to describe a consumption pattern. These attributes include: a) the average consumption, b) the maximum consumption, c) the standard deviation of consumption, d) the sum of inspection comments during the last six months, and e) the average consumption of the neighborhood. Data of another twelve months are required for the clustering process. The method was tested with real data from one neighborhood with 57 consumers from India and it achieved a hit rate of 80 %.

Faria et al. in [23] utilize the consumer baseline load calculation methods that have been developed within the context of demand response. For each period of the historical data, the expected consumption is estimated, then this is compared with the realized one and if there is considerable difference the consumer is characterized as a possibly fraudulent one. The baseline types that were used are the following: a) type I, which uses load historical data and may include other data such as weather, and b) type II, which is used for aggregated loads. After the expected energy consumption calculation, statistics regarding the expected and measured consumption are produced and compared. These statistics include whole data average (WDAVG), whole data standard deviation (WDSTD), past data average (PDAVG) and past data standard deviation (PDSTD). Whole data refers to the overall data of the examined consumer, and past data refers to the past data of each calculation period. The performance of the proposed method is demonstrated by a case study.

3 Conclusions

Non-technical losses detection is a hard and challenging issue for the distribution operators. With the massive deployment of SMs, new possibilities to detect electricity theft are opened up. This paper has discussed the challenging issues in energy theft detection and provided some research directions. In addition, NTL detection methods within AMI have been investigated and categorized in three groups. After examination of existing approaches, it can be concluded that each proposal addresses only a few aspects of the multidimensional problem of electricity theft. Therefore, the authors believe that energy-theft detection robust methods of the future will include both system state-based techniques that lie in the Kirchhoff laws applied to low voltage circuits and artificial-based methods that lie in the detection of anomalies in the consumption pattern of consumers. With the assistance of both methods, the weaknesses of each technique, related mainly with lack of information, could be compensated successfully.

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A Multi-agent System Architecture for Microgrid Management

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Abstract Microgrids aim at providing reliable and optimised energy for all the grid participants. This requires the integration of technology solutions, especially for the management of the grid. Existing technologies, such as multi-agent systems, demonstrated their applicability in such fields by providing distributable, reliable, secure, and flexible solutions. We propose a reference architecture for microgrid approaches based on multi-agent systems with the aim of guiding software engineers and researches in the design and implementation of such solutions. Our reference architecture was validated by means of two case studies.

Keywords Microgrid · Multi-agent system · Architecture

1 Introduction

A microgrid can be defined as a small-scale localised grid with multiple energy resources such as storages, generators or loads. Microgrids usually contain a remarkable number of renewable power suppliers and can operate independently or jointly within the main electrical grid.

The growing demand of energy and the global drive to reduce emissions is leading to a commitment for microgrids. Such grids are becoming more viable by the introduction of the latest technologies for renewable energies. Microgrids are expected to achieve low carbon emission, cost reduction, distributed intelligence, and reliability, among others. Achieving such objectives requires the deployment of an energy management system in the grid.

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The goals of an energy management system include providing the grid with intelligence, scalability, and stability when the grid topology changes. A way to achieve these goals is by working with the systems that operate from a distributed point of view; i.e., that allow the information exchange between any device and any actor in the system. This means that the control is not only performed from one node that has a global view (centralised system), but can come from a collective and co-operative behaviour among different nodes (decentralised system with distributed control). Moreover, such kind of control system is more suitable in microgrids with distributed energy resources and consumers.

In the last decades, Multi-Agent Systems (MAS) have been widely used to provide intelligence to distributed systems. Instead of developing a system with components, agents are implemented in order to reach some specific goals. Consequently, only the tasks that help to achieve these goals are executed. Moreover, the MAS platforms make modelling and developing of distributed systems more intuitive, since it is closer to the human thought. Such technology is crucial in optimising and stabilising the grid.

Multi-Agent Systems may operate in a decentralised manner since they allow communication and synchronisation among agents. This feature makes them a good approach to deal with such kind of problems, one of the reasons why they are gaining track in this area. Recent surveys in the literature, as the ones performed by Farhangi [8] and by Amin and Wollenberg [1], confirm the suitability of multi-agent systems for the emerging smart grid applications. Currently, working groups from IEEE, such as "IEEE Power and Energy Society Multi-Agent Systems Working Group (MASWG)"[1], created by the "IEEE Power Engineering Society Intelligent Systems Subcommittee" which is in charge of identifying the key technical challenges for the correct use of MAS within this area.

The lack of a reference architectural for agent-based microgrid solutions in the literature, amounts to little reuse and the focus is usually blurred because of irrelevant details. In this paper, we present a reference architecture for devising MAS solutions for microgrids. It provides the basis for researchers and developers by covering the major requirements for microgrid solutions based on MAS paradigm. Our architecture is composed of layers each of which has a well defined responsibility. We have validated the architecture by means of a platform, which is tested by means of two well-known case studies from the literature. Another contribution of this architecture is that it includes reusable components, such as the optimisation algorithms, further than the possibility to extend its layers by using user-defined classes.

The rest of the paper is organised as follows: Section 2 reviews the most relevant proposals in the literature for energy management and control, based on Multi-agent systems; Section 3 provides the most important requirements for a microgrid management system; Section 4 describes our proposed architecture, which is validated in Section 5; finally, Section 6 concludes our work.

[1] http://sites.ieee.org/pes-mas/

2 Related Work

A reference architectural guides software engineers in the design and implementation of agent-based microgrid solutions by providing a primary design of the needed components and specifications, whereas a software platform is generally a specific implementation of a given architecture. The literature reports on many specific proposals that are intended to apply multi-agent paradigm on microgirds. Unfortunately, these proposals were presented as platforms and not as architectures; i.e., none of the existing proposals provided a reference architecture. For this reason, in this section we focus on reviewing the relevant platforms for microgrids based on multi-agent systems.

Dimeas and Hatziargyriou [6] and Xiao et al. [22] defined a hierarchical MAS platform for microgirds; i.e, they proposed a three-level MAS for Virtual Power Plants (VPP) and microgrids management, respectively, by defining different levels to control the microgrid. They grouped agents in three levels, namely: the field level, the management level, and the enterprise level. Similarly, Xiao et al. [22] defined a three-level platform that included a terminal level, a substation level, and a master station level.

Kumar Nunna and Doolla [15] proposed a two-layer platform: a field level in charge of managing individual microgrids matching supply and demand, and a market level which is responsible of the energy market among the microgrids. Similar to [22], the system performs the management of several microgrids. Wang et al.[20] presented a hierarchical multi-agent control system with an intelligent optimiser for smart buildings. The optimiser was used to optimise the operation of different devices in order to enhance the intelligence of the microgrid system.

Pipattanasomporn et al. [18] presented an Intelligent Distributed Autonomous Power System that integrates demand side management techniques as well as Distributed Energy Resources (DER) control in microgrids. In this platform four types of agents were defined, namely: the control agent, the DER agent, the user agent and the database agent. Despite implementing the communication among agents, the main disadvantage of this model is that it only considers one control agent. A similar MAS architecture with four types of agents was also proposed by Manickavasagam et al. [16], but without implementing demand side management.

Oyarzabal et al. [17] proposed a MicroGrid Agent Platform, which is based on generation schedules. It provided: (i) a MicroGrid Central Controller (MGCC), whose agents are in charge of getting measurements from the grid; (ii) a database management, for load shifting and selling bids; (iii) and local controllers for micro sources and loads. In addition there is a secondary regulation control system, running at the MGCC, which is in charge of adjusting the power schedules of the generators taking into account real time measurements.

Finally, Gomez-Sanz et al. [9] developed a multiagent platform for microgrids optimisation and management. Optimisation task is done offline, which generates a pool of “best profiles” for each different situation. Agents are in charge of online management and control by synchronising among each other.

Although the literature provides many proposals for using MAS for microgrids, these solutions include predefined types of agents without providing reusable or extensible components. In this paper we propose a reference architecture for microgrid platforms based on MAS paradigm and that provides different reusable and extensible components.

3 Requirements for a Microgrid Management Platform

Grid management requirements have been extensively studied in the literature [12, 21]. A grid management software platform is expected to collect, analyse energy usage and communicate with the metering devices. Its design must be modular, where different components can be reused or replaced, and follow the different microgrid standards. Furthermore the network between the measurement devices and business systems must allow collection and distribution of information to customers, suppliers, utility companies and service providers. This enables these businesses to participate in the demand/response services.

Grid management is supposed to be intelligent and distributed, and it should also allow the different grid components to communicate among each other. Distributed Intelligence (DI) is dedicated to the development of distributed solutions for complex problems regarded as requiring intelligence. DI is closely related to, and a predecessor of, the field of Multi-Agent Systems.

Besides the previous requirements, the management platform should be highly secure by avoiding intruders and message interception. Devices connected to the grid management platform software must authenticate before sending any information. Furthermore, the management platform is supposed to collect events and log them for their analysis, if necessary. Finally, grid Management platform software must be able to receive the monitoring data and provide parameters such as, voltage, current, active and reactive power.

4 Our Proposal

Our reference architecture is built upon a layered system to enable clear separation between layers (c.f. Figure 1). Each layer represents a reusable component that is composed of a collection of conceptually related classes, which implement specific functionality and provides services to the other layers. In the following lines we describe each layer, namely: the user interface, the grid model, the agents model, the security component, the optimisation algorithms, and the utilities and services layer.

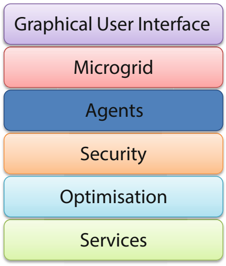

Fig. 1 Platform architecture layers

4.1 Graphical User Interface Layer

This layer provides a graphical user interface (GUI) to show a 3D graphical and interactive interface of the grid. It displays CityGML information in 3D, a 2D model of the grid (including electric, heating, and gas), and real time information from the agents, by means of a multilayer representation.

A factory class is used to create the entities that represent the components that are part of the grid, place them on the CityGML map, and connect them with their agents in the MAS model. Furthermore, by using user-friendly reporting tools, it creates an information panel for each of them in order to display the information and events on real time. Such tools allow color-stated visualisation on a map of the entire network, including some metric parameters for statistical and historical reporting.

4.2 Microgrid Layer

It includes the user-defined profile for the electrical grid, which is based on the standardised CIM of IEC61970 model and its extensions for microgrids[7]. CIM has standardised the semantics of the interfaces for energy planning, maintenance and finance. However, it is still under modification and amendment. It can be extended by adding attributes to existing classes, adding new classes by succession or association, and adding new packages.

In this layer, the user is expected to define the grid model and connections by using the user-defined profile. The defined grid is validated by defining restrictions on the devices and their connections; i.e., connected components are checked to see if they can be connected or not.

4.3 Agents Layer

This layer is considered as the core of the platform. It implements the distributed runtime environment that supports the entire platform and its tools. The base of this layer is Jade platform [3], which is extended to provide more functionalities to the other layers. Furthermore this layer proposes a paradigm in which agents are made of modular and reusable components.

This level contains the classes needed to define the particular agent (reasoning) model; i.e., it provides a set of classes that allow expressing the objectives and constraints of an agent. It also allows defining variables, the objectives, and the constraints over the variables.

We have defined an AgentFactory, which allows creating JADE agents given an agent specification; an agent specification includes the set of predefined behaviours an agent shall implement depending on the device it is representing. Furthermore, the user can extend this layer by defining new behaviours, which are specific for each scenario. This factory receives a collection of AgentSpecification objects, creates the agents, adds their behaviours and the data they will be working on, and starts the JADE platform. This layer also includes the packages that allow the agents to communicate (by means of ontologies to define the messages) and the security services, such as the authentication of users over encryption and the authorisation of the access to services.

4.4 Security Layer

This component includes the classes necessary for the authentication of the agents in the platform and for message encryption, which are needed for the communication between agents. This layer provides the following security services for the multi-agents system:

- Agent authentication: It is used to authenticate agents and can be connected to a number of login modules, which allows checking the agent credentials following an authentication protocol.
- Permission service: It provides a set of rules defined in an access control list. The organisation of the rules revolves around the concept of principals, roles and resources. All actions that agents can perform in the platform, except for mobility, can be permitted or denied based on this control list.
- Message signature: It enforces message integrity and non-repudiation; i.e., each agent owns a public and a private key pair by means of which it can sign in and encrypt messages. The verification of the messages integrity is done automatically, whereas non-authenticated messages produce a failure message.
- Encryption: It provides message confidentiality by encrypting the agent messages with SSL.

4.5 Optimisation Layer

This layer is intended to include optimisation algorithms that may be used by agents to optimise the performance of the devices and the grid. Agents layer is the one that makes use of this layer through an interface that connects both of them. It contains several reusable optimisation algorithms, such as:

- Multi-objective optimisers (problems with just one objective function): Evolutionary algorithms such as NSGA-II [5] or SPEA2 [23].
- Mono-objective optimisers (two or more objective function): Convex algorithms (CVX) [10, 11] or genetic algorithms like PSO [4], DE [19], or CMAES [2].

User can extend this layer by adding other optimisers. Furthermore, counting on many optimisation algorithms in this layer shall allow comparing the performance achieved by the different techniques.

4.6 Services Layer

At the bottom of the layers of our architecture resides the utility and services classes that can be used by the other layers. These services and utilities allow the connection to the real world by including web services connectors. Since one of the first steps to validate a microgrid includes a simulation phase, several connectors to simulation toolkits and other tools, such as Matlab, are also included in this package.

Finally, as the previous connectors need to deal with different data models, adapters for merging and wrapping data are also included in this layer. Furthermore, the architecture allows event registration by providing loggers: these loggers can be configured and adapted for each case and can be used by the other layers for the analysis of the registered information, when necessary.

5 Architecture Validation

To validate our reference architecture, we developed a platform to check its viability. The platform was also used to devise two test studies from the literature. In order to help the reader to understand the implementation and validation of this architecture, and since these tests drive to a complex object deployment, we firstly show a running example based on a simplified test.

5.1 Running Example

This section is intended to illustrate how the platform works from various points of view. A simple scenario was used to obtain the agents deployment and the exchanged messages. Figure 2 shows graphically how this example is instantiated in our platform.

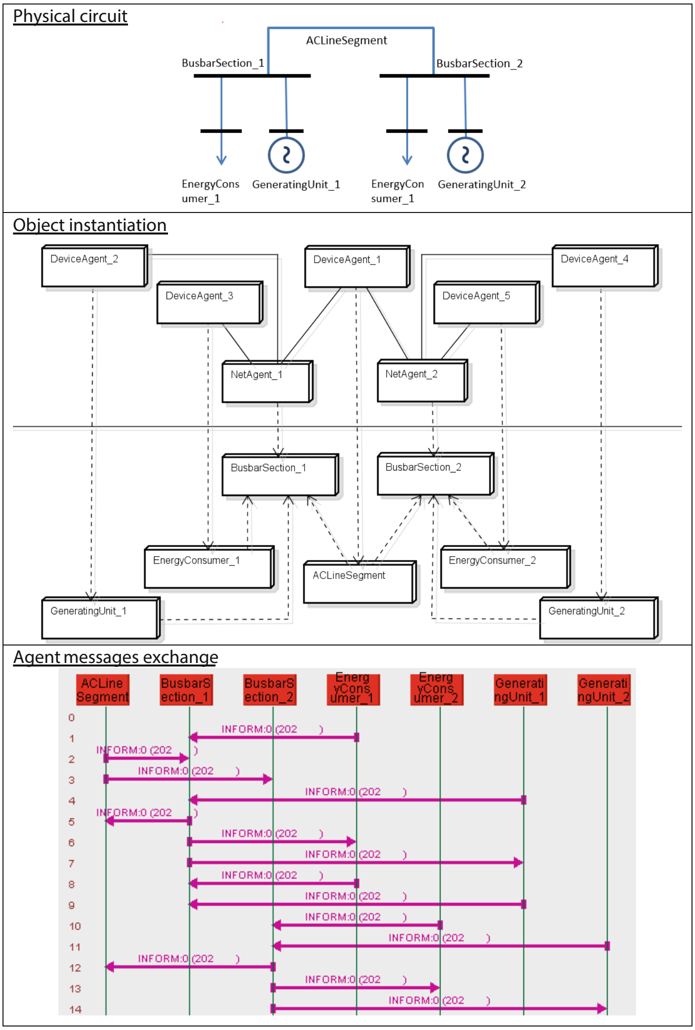

Fig. 2 Running Example

The first level in Figure 2 illustrates the physical circuit, which represents two houses connected by an alternate current line, where each of them has an energy consumer and a supplier. Devices of the same house are connected by means of a bus. Energy losses are only considered in connection between houses. Since this microgrid works in low level voltage, no transformers are needed.

Second level in the figure presents the instantiation of the objects in our platform. The upper side contains the agent objects (managed by the Agent layer) and the lower side contains the grid model objects (which belong to the microgrid layer). A continuous line between two objects means that these agents communicate, whereas the discontinuous arrow indicates that the object of the initial point of the arrow references the instance of the end point. Every agent of the upper side wraps an object from the microgrid model, and performs some communication and negotiations tasks. Electrical devices (consumers, generators and the line) are managed by so-called Device agents and the buses by so-called Net agents.

Finally, the third level of Figure 2 shows the messages exchange for the first iteration of an decentralised optimisation algorithm. Communication is started by the Device agents, which send a message to their linked Net agent(s) and then wait for their replies. On the other side, Net agents wait to receive the messages from all their devices and then prepare and broadcast a new message. This process is repeated until the algorithm is converged.

5.2 *Test Implementation*

First, we have implemented a software platform using Java 1.8, and following the proposed architecture. Then, we implemented the "Proximal Message Passing" algorithm (PMP) Kraning et al. [14] inside the platform as the main approach for solving microgrid management. PMP is a decentralised and iterative algorithm in which, at each step, the devices in the microgrid exchange simple messages with their neighbours. The idea is that each device solves its local optimisation problem by minimising its own objective function (with a penalisation computed from the information that it receives). The agent layer encodes the main PMP and the solving for the local function is implemented in the optimisation layer.

Two main entities that exchange messages in the system are created, namely: devices and nets, which are represented as agents. Each kind of agents has its own behaviours, which are define the identity of the agent. Therefore, two sets of behaviours can be assigned to an agent: the first one is to use the agent as a device, whereas the second one is for net agents.

In the following, we briefly describe how the problems were modelled in the platform. Since optimisation is not our focus in this paper, the aim of the optimisation task in this platform is to calculate the best microgrid profile for any situation. These profiles must meet the objectives (which may be totally or partially in conflict) defined in the system. PMP is used as a decentralised message exchange for optimisation whose goal is to jointly minimise a network objective to local constraints on the devices and lines. The network objective is computed as the sum of the objective functions of the devices. These objective functions extend over a given time horizon and encode operating costs, such as generation costs, and constraints such as limits on power generation or consumption. In addition, the objective functions encode dynamic objectives and constraints such as limits on ramp rates for generators or charging and capacity limits for storage devices. Furthermore, the variables for each device consist of its consumption or generation in each time period and can also include local variables which represent internal states of the device over time, such as the state of charge of a storage device. Each device will solve its own local function by using any of the optimisation algorithms available "optimisation layer".

For experimental purposes, two microgrids from public test repositories were chosen, namely:

– WSCC 9-bus: This microgrid is a test case with 9 buses that represents a simple approximation of the "Western System Coordinating Council" (WSCC) to an equivalent system with 9 buses, 2 consumers, 2 generators and the connection to the external power system K. [13].
– IEEE 14-bus: This test case represents a simple approximation of the "American Electric Power system" as of February 1962[2]. It has 14 buses, 2 generators, 11 loads and the connection to the external power system.

5.3 *Validation Test*

We describe below how we mapped each of test cases into our platform. Since our aim is to show how the proposed architecture helps to easily design and run any topology in the platform, we do not focus in numerical results but in the followed steps to implement a given microgrid. The microgrid was modelled using the standardised CIM as explained in section 4.

5.3.1 WSCC 9-Bus

For implementing this test, the different types of devices were firstly identified. Then, by extending the standardised CIM, we created the microgrid model that contains the devices with their cost functions and constraints. Loads are represented as fixed loads (3 loads), Generators as simple generators (2 generators), the external connection as a "external tie" device (1 connection) and lines that connect the buses as "transmission line" devices (9 buses). Furthermore, there are the buses where devices are connected (9 buses). These devices encode some properties and constraints as follows:

– Bus: lossless electrical conductor, where devices are connected. It must meet its power limits constraint.
– Fixed load: device with a fixed planning of consumption.

[2] http://www.ee.washington.edu/research/pstca/pf14/pg_tca14bus.htm

– Generator: energy supplier. Some of them have a fixed power planning and some other allow self-controlling. It works with power limits constraint.
– External tie: external connection to the utility. It defines some exporting/importing power limits.
– Transmission line: lines that connect two buses. Such lines may have energy losses and power limits.

At the multi-agent level, we identified and created the corresponding types of agents for each component of the microgrid. Each bus of the system is managed by a net agent and connected to other nets through transmission lines (device agents). Buses are always managed by net agents and the rest of the devices by device agents. By exchanging messages with their neighbours, agents share useful information that drives the optimisation and management algorithms. A total of nine net agents and fifteen device agents were deployed.

Once the microgrid topology is identified, we just need to insert it in the system and run the platform. Agents are deployed and they perform the microgrid management and optimisation.

Each device agent must solve its own local function, those ones that cannot be directly derived are optimised by using any optimisation algorithms available in "optimisation layer". These algorithms solve the proximal function and provide solutions that also meet the constraints imposed by the model.

5.3.2 IEEE 14-Bus

Further than the previous test, a second and bigger microgrid was also successfully tested in the platform. Since the topology and distribution are different compared to the previous one, the number of agents and their definition is different as well. However, the main behaviours remain the same and the platform behaviour shall not change.

In this test, 48 agents were automatically generated and deployed. 14 net agents to represent the 14 buses and 34 device agents. Regarding the last group, 10 agents are used to encode the loads (set as fixed consumers), 4 agents for generators with full self-control, and 20 to map the transmission lines. Each of these components keep the same definition as described in previous test case.

Optimisation algorithms from "optimisation layer" were used for solving local function in case of generators or transmission lines. Local function of the fixed loads or the nets may be directly computed.

6 Conclusions

The increasing number of microgrids in the real world is keeping the energy management research field quite active. These power grids are composed of distributed energy resources like consumers, suppliers or storages. This characteristic encourages the use of decentralised control systems, such as Multi-agent ones, which have been proved to be suitable for these kind of problems.

Despite the large number of proposals that apply MAS paradigm for microgrids, there is still a lack of a reference architecture in the literature for this purpose. This paper proposes a novel reference architecture for guiding engineers in the design and implementation of microgrid managing solutions. Our reference architecture is a six-layer architecture that includes: a graphical interface, a microgrid layer,an agents layer, an optimisation layer and a services layers. It provides reusable components that can be extended or applied to other domains.

Finally our architecture was validated by means of two test cases from the literature. Two power grids of 9 and 14 buses were successfully implemented in the platform. By just defining the microgrid topology, the platform deployed a full agent system that managed the grid with optimised energy plans. Furthermore, a graphical interface allowed to monitor the state of the tested systems. As a future work, the platform is being enriched by extending the number of optimisation algorithms and adding different management approaches besides PMP.

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Dynamic Energy Management Method with Demand Response Interaction Applied in an Office Building

Filipe Fernandes, Luis Gomes, Hugo Morais, Marco Silva, Zita Vale and Juan M. Corchado

Abstract The intelligent management systems of the end consumers are endowed with advanced functions being one of them the interaction with external entities through the automatic participation in demand response programs. The development of the intelligent management systems is to reduce the energy consumption based on internal information and on the interaction with an external entity. Moreover, the management approaches results in an active participation of the consumers in the operation of the smart grids and microgrids concepts. The paper developed presents the application of a dynamic priority method in SCADA Office Intelligent Context Awareness Management system to manage the energy resources installed in an office building. The intelligent management method allows the dynamic active participation of the office building in the DR events considering the real data of consumption and generation of one building in Polytechnic of Porto. The main goal of the methodology is to obtain a dynamic

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scheduling for all energy resources with little interference in the comfort of users. The results of dynamic management model in office building are discussed for the participation in 8 hours demand response event. The power limit of the scenario depends on the consumption and micro-generation power of an October day.

Keywords Demand Response · Dynamic priority method · Energy management · Office building · Energy resources

1 Introduction

Several approaches have been proposed to the consumers in view of an active participation in the operation of the Smart Grids (SG) and Microgrids (MG) with capability to manage their own energy consumption, generation and storage systems [1]. The main cause for the faster SG development requirement is the high penetration of the distributed energy resources, making the energy management decision more decentralized, allowing the means for coordinating a wide range of players [2]. The players aggregated in small areas represent the MG that allows the management of several consumers, distributed generation and the connection with main grid [3].

With development of the SG and MG, it emerged the development of other systems: the smart meter, the smart home or smart buildings [4]. The smart home can be defined as a house which comprises a network communication between all devices of the house allowing the control, monitoring and remote access of all application and services of the management system. The management system should include advanced functions, such as, the management of electric vehicles and the interface with external operators, among others [5], [6]. A smart home include the internal communication network, intelligent control systems and home automation [7].

The advanced functions should be integrated on the House Management Systems (HMS) or on the Building Automation Systems (BAS) allowing the interaction with external entities through the automatic participation in Demand Response (DR) events [8], [9]. The HMS and BAS systems need to reduce the energy consumption based on internal information and on the interaction with an external entity according with DR events [10]. The development of sophisticated management systems has become the main goal of modern intelligent houses/buildings [9]. The actual developments of the HMS and BAS consider the management of the consumption, generation, electric vehicles and DR programs [11]. With this programs, it is possible to obtain a reduction of the electricity consumption without a substantial change in the comfort levels [12].The comfort level in the management of the HMS and BAS systems is so important and depends of each context, the minimum energy consumption and operation costs [13]. To the better management, the ability to autonomously acquire knowledge about the user's behavior adjusting the consumer's preferences arises as an essential role [14].

The present paper focuses in management of the energy resources installed in an office building of a university campus implemented by the SCADA Office Intelligent Context Awareness Management (SOICAM) system. The energy management of the building results by the application of an optimization algorithm developed for the SCADA House Intelligent Management (SHIM) platform to manage dynamically the active participation of the houses/buildings in the DR events considering, for the applied case, the loads, micro-generation and grid connection. The main contribution of the paper is the application of the dynamic priority method in real data of an office building from Polytechnic of Porto considering the consumption and generation. In the proposed methodology, the main goal is to obtain a dynamic scheduling for all energy resources presented in an office building from the university campus with little interference in the comfort of users.

After the introduction, Section 2 summarizes the simulation platform for energy management system and the dynamic priority method for the considered energy resources. For your side, Section 3 presents the SOICAM system and Section 4 describes the office building to implement the dynamic method. Section 5 shows the case study and the advantages of the model in the office building. The conclusions and contributions of the work are presented in last section.

2 SCADA House Intelligent Management System

The SHIM system has been developed in the Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD), located in the Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Portugal. SHIM is a testbed platform with the main goal of testing, simulating, and validating new algorithms and methodologies to apply into house/buildings' management.

The section presents an overview of SHIM system and a short description of the dynamic priority method developed for the SHIM including the optimization algorithm.

2.1 Energy Management Platform for Domestic Consumers

SHIM comprises real equipment such as several types of loads, micro-generation (photovoltaic panels, wind generator), and storage systems that allow the simulation of the electric vehicles behavior. The SHIM platform is presented in Fig. 1.

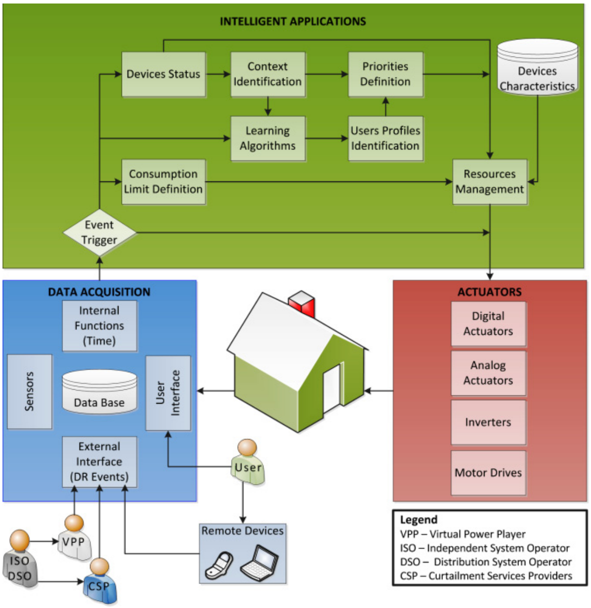

Fig. 1 Structure of the SHIM simulation platform [15].

SHIM is part of a large simulation platform based on multi-agents systems: Multi-Agent Smart Grid Simulation Platform (MASGriP) is a test platform that simulates a competitive environment in future power systems. SHIM platform comprises hardware equipment to control loads through programmable logic controller and the measurement of the power consumption through several power analyzers in the management system. The interface with the users is implemented for example, in a smartphone. For the complex scenarios simulation, SHIM is able to control real and virtual loads simulating the real data saved [16]. Different modules composing the SHIM that are grouped into three parts: the Data acquisition, the Actuators, and the Intelligent Applications. The detailed information is presented in [15].

2.2 Resources Management Methodology

The dynamic method presented in [15] only considers the loads scheduling. To increase the capacities of the SHIM platform, the method was updated with more energy resources. The Dynamic Energy Resources Priority (DERP) method developed in [17] is summarized in this sub-section. The method, like in the work [15], focuses in an optimization problem to manage dynamically the domestic consumers in the DR events. The problem of the work was developed to be implemented in the SHIM system. The DERP method includes loads, micro-generation and grid connection. These different types of energy resources increase the smart home capacities to have a strong influence over the SG or MG operation in context with the grid and consumer conditions.

The objective of the optimization module of the dynamic model concerns in dynamic resources management. The detailed problem formulation and the respective nomenclature applied in the optimization process for every minute is presented in [17]. In this paper is only presented the objective function:

$$Minimize\ f = min \left\{ \begin{array}{l} \sum_{Load=1}^{nLoad} \lambda_{Load} \times P_{Load} + \lambda_{Grid} \times P_{Grid} + \lambda_{Down} \times Reg_{Down} \\ -\sum_{DG=1}^{nDG} \lambda_{DG} \times P_{DG} - \lambda_{UP} \times Reg_{Up} \end{array} \right\} \quad (1)$$

3 SCADA Office Intelligent Context Awareness

The SOICAM is implemented in real facilities also in GECAD research center located in the ISEP/IPP. The system is implemented in real facilities used by several researchers in a daily basis, aiming the energy monitoring and the energy management inside the laboratories. This system enables the test and use of several communication protocols [18], [19]. The section presents an overview of SOICAM system and a short description of the real office building.

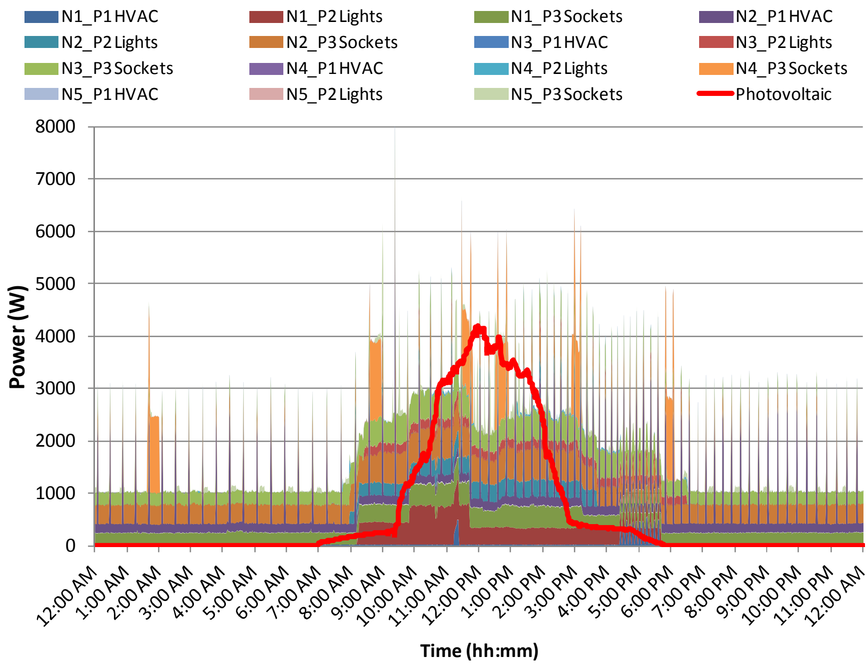

Fig. 2 Consumption and generation data of the office building.

Table 1 Loads description for each analyzer of the office building.

Analyzer	Division	Type	Loads	Quantity	Total Power (W)	Electrical Circuit
N1	N101	Office	HVAC	1	1000	P1
			Fluorescent lamp	4	232	P2
			Compact lamp	2	36	P2
			Monitor	5	1357	P3
			Computer	2	950	P3
			Laptop	1	90	P3
	N102	Office	HVAC	1	1320	P1
			Fluorescent lamp	4	232	P2
			Monitor	8	2438	P3
			Computer	4	1900	P3
			Laptop	1	90	P3
	N103	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	4	1311	P3
			Computer	2	950	P3
N2	N104	Support	HVAC	1	2500	P1
			Fluorescent lamp	2	116	P2
			Computer	1	475	P3
	N105	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	6	1909	P3
			Computer	3	1425	P3
			Laptop	2	180	P3
	N106	Boardroom	HVAC	1	1320	P1
			Fluorescent lamp	4	232	P2
			Televison	1	345	P3
N3	N107	Office	HVAC	1	1320	P1
			Fluorescent lamp	2	116	P2
			Compact lamp	2	36	P2
	N108	Office	HVAC	1	910	P1
			Fluorescent lamp	4	232	P2
			Monitor	7	2231	P3
			Computer	3	1425	P3
	N109	Office	HVAC	1	1000	P1
			Fluorescent lamp	4	232	P2
			Monitor	2	713	P3
			Laptop	1	90	P3
			Printer	1	920	P3
N4	Hall	Common Services	HVAC	2	1920	P1
			Fluorescent lamp	4	232	P2
			Compact lamp	2	36	P2
			Water heater	1	1500	P3
N5	N110	Kitchen	HVAC	1	1000	P1
			Halogen lamp	2	50	P2
			Compact lamp	1	14	P2
			Refrigerator	1	130	P3
			Coffe machine	1	1300	P3
			Kettler	1	2280	P3
			Microwave	1	2250	P3

3.1 SOICAM General Structure

The SOICAM system is divided in two levels: the infrastructures (physical level) and the operational level where is used a Multi-Agent System (MAS) approach to represent, control and manage the 3 integrated facilities. The system includes a microgrid agent to aggregate the facilities, their services and energy resources [18].

For this reason, the SOICAM uses simulation in order to integrate more agents that otherwise cannot be placed in the system, for example, Houses 1, 2 and 3 are simulated facilities. Buildings I, N and F are ISEP/IPP buildings. The simulated facilities use real electrical energy consumption measurements, enabling the profile simulation of the simulated facility. More detailed information can be viewed in [19].

3.2 Energy Resources Description of the Office Building

The building is equipped with a system considering a programmable logic controller that communicates with five analyzers to read the data consumption of the several specific divisions. Also, the building has installed in the roof, a photovoltaic system with 30 panels (250 Wp for each one). The information of the building divisions is presented in Table 1. In the building information is indicated the type of the division, the loads presented and the quantity for each one, the total consumption for each load type, and the electrical circuit where each one is connected. The electrical circuit of the loads is divided in three types like presented in: P1 HVAC; P2 Lights; P3 Sockets (equipments connected in electrical sockets). Fig. 2 presents the consumption and generation data from October 22, 2015.

The SOICAM data is stored in a SQL database. The register of the office building (building N) includes the consumption reaching more than 30 researchers daily and the generation. The consumption data register has started in July, 2014. The generation data register has started in October, 2015.

4 Case Study

The case study applies the methodology developed for the SHIM platform in the SOICAM system, contemplating the management of the consumption and generation resources. The methodology is applied for an office building described in Section 3 with several loads and one photovoltaic system. The results of the resources scheduling in the SOICAM system are presented in the following sections.

The case study was tested on a computer compatible with 2 processors Intel® Xeon® W3565 3,20GHz, each one with 4 Cores, 6GB de RAM and the operating system Windows Server 2007 64bits. The optimization module is implemented by a deterministic approach based on Mixed-Integer Non-Linear programming (MINLP) implemented on the General Algebraic Modelling System (GAMS) platform, interfaced with the computing tool MATLAB® R2009 64bits.

The present case study is applied according with a DR event with 8 hours time duration, starting at 9:00 AM. Table 2 shows the values of the power limit that corresponds to the power supplied by the grid and depends on the conditions according with power consumption (P_{Load}) and power generation (P_{DG}).

Table 2 Conditions to the power limit in DR event.

Condition DR Limit	Power Limit (W)
$P_{DG} < P_{Load}$	$P_{Load} - P_{DG}$ - 100
$P_{DG} > P_{Load}$	0

4.1 Office Building Characterization in Management System Context

The case study section presents the data of loads and micro-generation that were used based on office building of the GECAD/IPP. The generation system is composed by 30 photovoltaic modules and the consumption represents 116 loads divided by three types: HVAC, Lights and Equipments like presented in Section 3.

The energy resources are characterized in the resources management module considering different characteristics that are presented and summarized in Fig. 3.

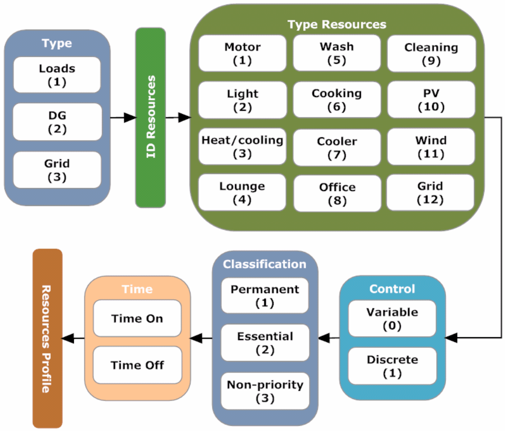

Fig. 3 Diagram to identify the characteristics of the energy resources [16].

According with Fig. 3, the resources information are presented and described in Table 3. For the three types of loads, the loads that allow the variable control of the consumption are the lights (fluorescent type) through the use of electronic ballasts, implemented and tested in GECAD laboratory. Others loads type are discrete loads.

Table 3 Energy resources information of the consumer.

Resource	Resources Type	Control	Classification	Ton	Toff	T	Maximum Power (W)
N1_P1 HVAC	3	1	2	6	4	10	3230
N1_P2 Lights	2	0	2	1080	360	∞	732
N1_P3 Sockets	8	1	1	∞	0	∞	8996
N2_P1 HVAC	3	1	2	6	4	10	4730
N2_P2 Lights	2	0	2	1080	360	∞	580
N2_P3 Sockets	8	1	1	∞	0	∞	4334
N3_P1 HVAC	3	1	2	6	4	10	3230
N3_P2 Lights	2	0	2	1080	360	∞	616
N3_P3 Sockets	8	1	1	∞	0	∞	5379
N4_P1 HVAC	3	1	2	6	4	10	1920
N4_P2 Lights	2	0	2	1080	360	∞	268
N4_P3 Sockets	8	1	1	∞	0	∞	1500
N5_P1 HVAC	3	1	2	6	4	10	1000
N5_P2 Lights	2	0	2	1080	360	∞	64
N5_P3 Sockets	8	1	1	∞	0	∞	5960
Photovoltaic	10	1	1	∞	0	∞	7500
Grid	12	0	1	∞	0	∞	7500

4.2 Energy Resources Scheduling Results

The methodology applied in SOICAM system should manage a photovoltaic system with all loads of office building. According to the generation profile, the photovoltaic power has more generation between 10:40 AM and 2:00 PM. The results of the energy resources scheduling are presented in Fig. 4. The first figure shows the detailed scheduling for each type of load and compared with the initial consumption. The second figure presents the scheduling of the loads consumption and the injected power in the grid compared with the power generation of the photovoltaic system and the supplied power by the grid (that corresponds to the power limit).

The results show a reduction of the loads consumption in the moments when the consumption is limited only by the generation power, i.e., in moments when generation is higher than consumption ($P_{DG} > P_{Load}$). With application of the DERP in SOICAM, the management system reduces the power consumption when the generation is higher allowing higher power injection in the grid and consequently higher remunerations.

When the power generation is not enough to fulfill loads consumption ($P_{DG} < P_{Load}$), the DERP method limited the consumption owing to defined condition presented in Table 3: $P_{Load} - P_{DG} - 100$. The condition requires that the supplied power by the grid is reduced 100 W.

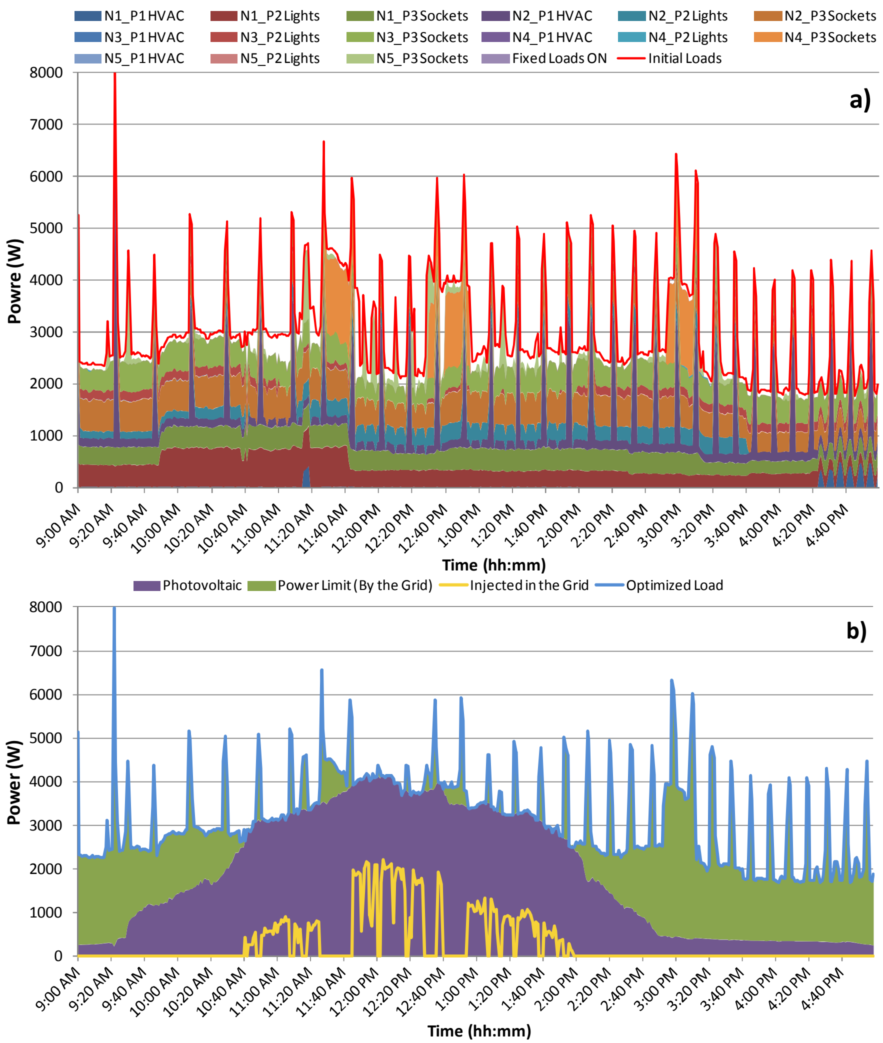

Fig. 4 Resources power results during DR event: a) Detailed scheduling for each type of load, b) Scheduling for each type of energy resources.

The case study shows the applicability of the DERP method in the SOICAM system in both moments: overgeneration and overconsumption. In both moments, the capacity to reduce the consumption of the lights through the electronic ballast shows an important advantage of the system. Consequently, the capacity to reduce the power consumption has two different situations:

- When the generation is higher than consumption (overgeneration): the consumption reduction increases the capacity to injected power in the grid and increases the energy remunerations;

- When the consumption is higher than generation (overconsumption): the consumption reduction allows the reduction of the power supplied by the grid (reduce the energy costs) not compromising too much the comfort of users.

The main important result is the interaction between the SOICAM system and the grid through the power injected during the DR event. Thus, it takes advantage of the high generation and also, the consumption reduction obtained with lights and HVAC. With application of the DERP method is possible to reduce the consumption of the loads, in specific divisions of the building, sending energy to the grid or reduce the power supplied by the grid. Fig. 5 illustrates the consumption of each loads type in the analyzer N1 installed in the office building. The figure compares the initial consumption with the consumption obtained by the application of the DERP method in the SOICAM system.

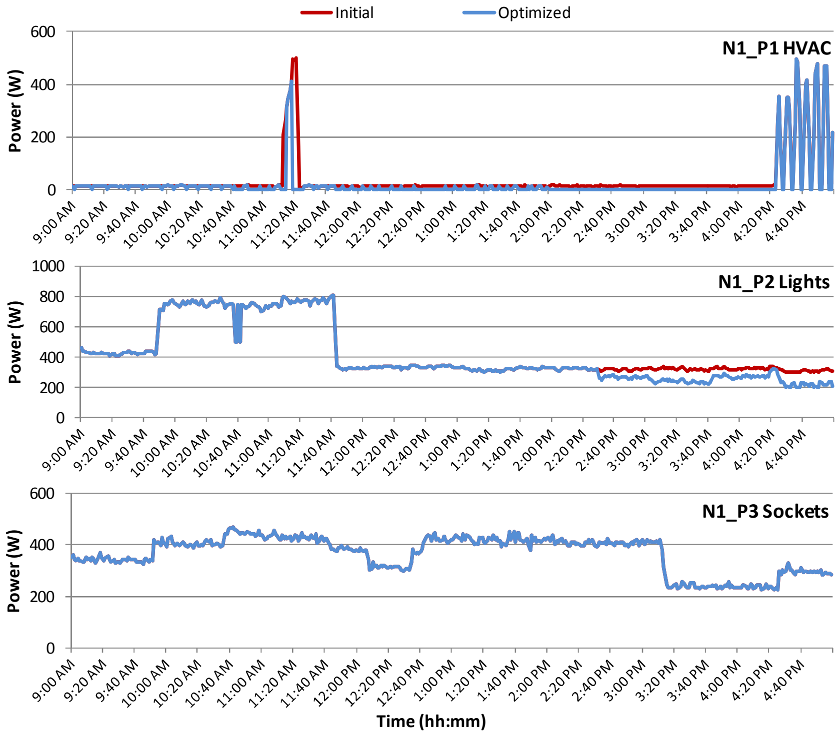

Fig. 5 Initial and optimized consumption for each loads type of the N1 analyzer installed.

The results show the sockets as the loads with higher priority for the office users' because the consumption is not modified. In the other hand, the HVAC and lights are the loads with less priority of the office users'. For example, between 2:30 PM and 4:59 PM, the consumption of the lights is reduced, but not completely turned off. This is possible with installation of the electronic ballasts for fluorescent lamps (the main lamps used in the office building). In the case of the HVAC system, this load type is turned off in some moments of the DR event.

According with the context of the day and the needs of the users, the comfort of the users is not affected so much. For example, the lights are reduced just slightly to minimize users' discomfort; and in the case of the HVAC, it is turned off in short periods of time to minimize the impact in the temperature comfort. The temperature comfort will be more affected if the HVAC is turned off for long periods according with others works developed in GECAD laboratories that involved HVAC systems.

5 Conclusions

The interaction between the end consumer and the grid operator is possible with application of an energy management system improving the effectiveness of the consumer‘s participation in a demand response events. In this context a SCADA system must support a decentralized structure to control, monitor and optimize all energy resources in any type of consumer.

The paper presents a method applied in SOICAM system to manage the consumption and generation used in an office building. The main goal of the Dynamic Energy Resources Priority method, developed in previous work for an energy management platform of the domestic consumer, is to change the resources priority during a demand response event through an optimization algorithm. It is considered the data saved in real time of the energy resources installed in an office building, and the resources scheduling obtained is analyzed to show the applicability of the dynamic priority method in a different type of consumer.

The novelty presented in the work consists in the application of the dynamic management method of the SHIM system in the energy management system of the office building, implemented in SOICAM, and contributes to the following advantages:

- DERP method applied in SOICAM system allowing better performances during a demand response event considering different types of energy resources in context of smart grids and micro grids operation, and obtains more flexibility by the interaction between the users and grid;
- In the building application, the resources scheduling is adapted every minute, ensuring the comfort levels needs, having the lights and HVAC systems an important role;
- With application of the DERP method, the case study shows that it is possible to reduce the consumption of the loads, in specific divisions of the building, sending energy to the grid or reducing the power supplied by the grid.

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Overview of Frequency Regulation Profitability Using Vehicle to Grid: Market Remuneration and Prosumer Behavior Impact

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Abstract Electric Vehicles are particularly adapted for frequency regulation service regarding their batteries features and their availability when not used for mobility. Many parameters have an important impact on the revenue and the cost of the service. On the one hand, the Electric Vehicle or Fleet owner behavior with the plugin hours, the driving patterns and the investments on the Vehicle to Grid technology may highly affect the service availability and cost. On the other hand, the service remuneration based on capacity remuneration and energy payment is highly dependent on the grid location, renewables penetration and Electric Vehicles presence. The aim of this study is to highlight various parameters variation depending on the context as well as their effect on the profitability of the service. The proposed tool allows apprehending the profitability for various markets situations from the contract level to the decision for the service delivery depending on the profit.

Keywords Frequency regulation · Profitability calculation · Prosumer behavior · Regulation market remuneration · Vehicle to Grid

1 Introduction

On the one hand, the energy demand increases according to world population growth and people higher standard of living. The challenge lies in providing this energy from dependable and sustainable sources while maintaining environmental consideration

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as stated by the European Union in 2030 goals.

In order to face these issues, all the research and enhancements aim to build the future electric grid, which will be more sustainable, reliable and efficient using a smarter control. It is possible with an optimized use of the renewable energy sources characterized by their unpredictable and intermittent state. Thus, their implementation must be associated with smart management as well as storage support in order to use the produced power when needed and avoid power waste.

On the other hand, the widespread use of Electric Vehicles (EVs) faces many difficulties due to their high prices and their limited autonomy. According to French previsions, the development of EVs will increase electricity consumption of 4 TWh in 2020 (CRE) for 2 million EVs [1]. It is therefore essential to anticipate the charging problem as well as the possibilities of smart reutilization of the EVs batteries power. In fact, a good storage potential will be available and may support renewable sources of energy and help the grid for balancing production and consumption. For instance, the peak power managing (peak shaving) appears to be more suitable with hybrid vehicles [2] and other ancillary services more adapted to EVs features like frequency regulation.

At the beginning, Kempton and Letendre introduced the Vehicle to Grid (V2G) concept in 1997. Then, the viability of V2G for frequency regulation has been proved in many contexts [3, 4, 5, 6, 7, 8]. An EV fleet acting like a generation unit is an interesting actor in the energy markets like in Germany and Sweden [9], Texas [10], California [11, 12] or France [13]. Some studies also highlighted that even for a single-vehicle, an EV is able to provide ancillary services under real-time conditions [14] in the PJM market which coordinates electricity in 13 states in USA and the District of Columbia.

The frequency regulation is one of the most interesting ancillary services regarding the profitability [15, 16] and the EV battery features:

- The EV is used 5% of the time for mobility and is available for other purposes during the remaining time [3].
- The initial capital cost of the battery may not be totally assigned to the V2G use because the battery was purchased for driving [3], [18]. Thus, only V2G additional costs have to be taken into account.
- The battery response time is quick [3], [12], [17, 18].
- Low quantity of power and shallow cycling, thus extended life cycles [19].

However, in order to push EVs batteries use for frequency regulation, it is necessary to ensure the profitability for all the actors: DSO, EV owner, EV aggregator… It is also mandatory to ensure a sufficient availability of the service with batteries plugged and with an adequate State Of Charge (SOC).

The profitability is highly dependent on many parameters like the service remuneration, the battery wear and the EV owner behavior. For instance, studies calculates a gain of about 2000 euros a year for a RAV 4 in the American context [11] and about 100 euros in the French context [13].

This paper proposes a useful tool at the contract setting level allowing the service profitability study. The first part of this article describes the frequency regulation service and some regulation markets in the world. The second one presents a detailed description of the profitability calculation methodology with the parameters description. It also introduces the profitability per request and the minimum selling price of energy for the service. The third part presents an overview of the parameters values with a wide range of possibilities depending on the geographical situation and the EV owner behavior. Finally, the profitability variation depending on the main parameters is studied. It illustrates the possibility of using the proposed tool to predict the profitability variation depending on the context evolution.

2 Frequency Regulation

2.1 Frequency Regulation Definition

The main aim of the DSO is to manage in real time the balance between the electric consumption and the production while ensuring power quality with rated voltage, frequency, harmonics level…. There are different means to keep this balance, either with the frequency (image of the active power) or with the voltage (image of the reactive power). In Europe, it is necessary to maintain the frequency around 50Hz and in USA around 60 Hz.

The frequency decreases if the consumed active power exceeds the generated one. In fact, if a power plant breaks down or the consumption raises, the frequency drops and a "regulation up" is necessary. In contrary, if the generation exceeds the consumption, frequency rise and a "regulation down" is made. Thus, it is necessary to anticipate a permanent frequency regulation to avoid that the grid delivers a poor quality of power or worse becomes unsteady. Moreover, this regulation has to be done as fast as possible. In order to achieve these operations, three frequency reserves exist: the primary and the secondary reserves which are generally automatic and the tertiary reserve or long term reserve which is triggered manually.

The primary reserve is for an instantaneous adjustment (seconds) and activated automatically. Today, this regulation is implemented automatically via the speed regulation of the production groups and the frequency of use is high, around 400-500 times per day in the USA [20]. The secondary reserve which relieves the primary reserve after a few minutes is also activated automatically. In an interconnected grid, the solution is to import or reduce the electricity export whereas in an isolated grid, it will be a fast start generator. Finally, the third reserve can be brought by generators with longer start-up time (≈15-60 min). It is used to relieve the primary and secondary reserve and is activated manually. According to the country or the region (for example California), we can also speak about the spinning reserve which includes a part of the secondary and the third reserve.

In this paper, the provided service with EV batteries is the primary reserve. Obviously, as EVs batteries can offer the primary regulation, they are also able to offer secondary and tertiary ones. However, this study will concentrate on the primary regulation.

Regarding the high amount of needed power at grid level compared to each EV battery capacity, new actors like EV aggregators [3], [21] will allow optimizing EV resources as storage. From the fleet manager point of view one of the main issues is the real available power for the service. In fact, for 15kW batteries, a 1MW contract would require about 100 available vehicles. In fact, all the fleet vehicles will not be plugged in and with the right SOC, thus, it is necessary to use a security ratio of 1.5 to guarantee the needed power [3]. At the aggregator level, various studies treated the real power capacity of EVs for the V2G using the stochastic modeling of the vehicle behavior. The aim is to decide about the size of the contract power capacity taking into account probability distribution of the power capacity [22, 23, 24]. They showed the reliability of the frequency regulation service despite the mobility constraints.

2.2 Regulation Markets

As presented in the previous section, the regulation services have been historically provided by generation facilities with automatic generation control (AGC). The voltage regulation is realized by action on the alternator excitation voltage and the frequency regulation by action on the turbine speed. In the smart grid context, many other grid components may offer these services: controllable loads, electric storages… Thus, actors offering regulation services appeared in the market. For example, Enbala Power networks, in Ontario, proposes grid balancing services by managing the loads of their network.

Regarding the regulation market, we talk about Automatic Generation Control Market AGC market in most of the countries. There are three main AGC markets [25]: Flat-rate, price-based and response based. Flat rate is the simplest one and the most widespread with uniform price payment at the rate of market clearing price (MCP). Response based AGC market offers a payment based on the ramp rate performances with fast ramp regulation (5 min market) and slow ramp regulation (10 min). Finally, price based market depends on the varying electricity price.

Batteries are well positioned in the AGC market by nature because the time response of the electric storage is fast and adapted to high quality frequency regulation. Moreover, the California Energy Commission presented storage resources as at least twice as effective as a combustion turbine for the grid regulation purposes [26]. This statement confirms the potential of EVs as storage resource in the grid and some markets like CAISO's one defined Non-Generator Resource (NGR) such as batteries and flywheels, to bid in the regulation market.

Generally, the payment of regulation services is linked to capacity, utilization and opportunity costs. Consequently, we can talk about various prices depending on the markets [25] like fixed allowance paid in every instance or availability price when the unit is ready to provide. Moreover, some markets introduce energy price for the energy made available for the system and/or utilization payment for the current delivery of the system.

Sometimes, the utilization frequency payment based on the number of calls to provide the service over a time period is also introduced.

The opportunity cost payment linked to the extra costs due to the service calls is included by some markets like NYISO, California ISO, and PJM [27].

The performance represented by the response ramp dynamic is taken into account in the service remuneration in markets like PJM and California ISO [27, 28]. Depending on the energy markets, the performance can be taken into account by introducing a penalty if the ramp speed does not match the specifications. Or, as a specific price for the service depending on the ramp speed. It may also be considered as a total amount of power capacity limited by the ability to ramp up or down [27].

Generally, most of the markets take into account capacity price and service price or only one of the two. For instance, in the ISO New England (ISO-NE), the payment includes capacity price and service price [29]; and in France, the primary reserve payment is provided by a fixed tariff and the payment is limited to a capacity price whereas secondary reserve includes both of the capacity and service prices [13].

The regulation market functioning and payment structure is different from a country to another. It is highly dependent on the geographical location. It also depends on the electric grid with its specific features like big power plants presence, Renewables penetration, EVs presence and finally in the advancements in the smart grid installations with possibilities of grid services offers based on storages, load management and others. Many markets are under development or are currently changing depending on the grid situation.

3 Annual Frequency Regulation Net Profit Calculation

In this part, we present Kempton method for annual net profit calculation [11, 12] extended to minimum selling price calculation per grid request.

The algorithm is implemented using Matlab with the inputs and outputs in excel sheets. This form allows the algorithm to be available on the SEAS Shared Intelligence Platform developed by GECAD laboratory under SEAS project. The goal of this platform is to allow the execution of multiple algorithms. The user can execute the stored algorithms, compare them and use some algorithms outputs as inputs for others.

3.1 Annual Revenue Calculation

The revenue derives from two sources, the capacity payment and the energy payment. In the case of V2G, the capacity is for power being available to support the grid. Whereas the energy payment is for the energy in kWh exchanged in real time. The revenue is calculated using the following equation:

$$R_{reg} = R_{cap} + R_{ene} = \left(p_{cap}\, P\, t_{plug}\right) + (p_{el}\, R_{d-c}\, P\, t_{plug}) \tag{1}$$

The first term R_{cap} concerns the capacity payment and the second term R_{ene} is the energy payment for regulation up. The capacity payment R_{cap} is calculated using p_{cap}, the capacity price which is in €/kW-h. Contrary to the usual €/kWh, it means $ per kW capacity available during 1 h whether used or not.

This capacity price p_{cap} is the price for the service availability, it means the remuneration fixed by the contract for the participation to the service. Hence, each time the battery is plugged and available, there is a remuneration even if there is no service. It has a huge importance because it can become the principal source of revenue under some economic conditions [22, 23].

The energy payment R_{ene} is calculated using, the following parameters:

- t_{plug} is the time in hours per year when the EV is plugged in.
- p_{el} is the market selling price of electricity in €/kWh.
- $R_{d\text{-}c}$, is the ratio of the energy dispatched over the regulation contract period assumed to be 10% of the contracted power capacity [11, 12], [29].
- P is the contracted capacity available for the V2G, in kW. It is the smallest value between vehicle power P_{veh} and the line power P_{line} because both of them limit the power. P_{veh} is calculated using:

$$P_{veh} = \frac{(E_s - \frac{d_d + d_{rb}}{\eta_{veh}})\eta_{inv}}{t_{disp}} \tag{2}$$

Where E_s is the total energy storage of the battery, in kWh. d_d is the distance driven in km since the energy storage was full, this variable depends on the driving pattern, the vehicle type, and the driver's strategies to sell power. We assume here that half the average daily vehicle travel would have been drained when the vehicle is parked and power is requested. The d_{rb} refers to the "range buffer" in km, it is the minimum remaining range specified by the driver and/or the EV aggregator. The dispatched time t_{disp} depends on the electricity market and is expressed in hours among the plug-in time. η_{inv} is the efficiency of the inverter of others power electronics in % and finally, η_{veh} is the vehicle driving efficiency in km/kWh.

The available energy may also take into account a part of the EV battery used for some local loads at the house level. However, in this study we will not consider this constraint.

In regulation down, we assume that the operation is always financially positive because the battery will have to be charged anyway. The only question is if the SOC matches with the demand. When the regulation down is achieved, it is possible to calculate the saved money. Basically, it is just the amount of energy delivered for storage E_{ds} (kWh) multiplied by the price of buying the electricity c_{pe} (€/kWh).

3.2 Annual Cost Calculation

The cost from regulation up is defined as:

$$C_{reg-up} = \left(c_{en}\, P\, t_{plug}\, R_{d-c}\right) + c_{ac} \tag{3}$$

c_{ac} is the annualized capital cost for additional equipment needed for V2G calculated using:

$$c_{ac} = c_c\, CRF = c_c \frac{d}{1-(1+d)^{-n}} \tag{4}$$

c_c is the capital cost i.e. the one-time investment in €. CRF is the capital recovery factor calculated using (d) which is the discount rate in % and n the amortization duration in years thus the lifetime of the V2G hardware.

c_{en} is the cost per energy unit in €/kWh which includes: the cost of electricity, losses, plus battery degradation cost:

$$c_{en} = \frac{c_{pe}}{\eta_{conv}} + c_d \tag{5}$$

Where c_{pe} is the cost of purchased electricity for recharging in €/kWh. η_{conv} is the two-way electrical efficiency and c_d is the cost of battery degradation calculated using :

$$c_d = \frac{c_{bat}}{L_{ET}} \tag{6}$$

Where c_{bat} is the total battery replacement cost in €, and L_{ET} is the battery Lifetime Energy Throughput for a particular cycling regime in kWh, calculated using:

$$c_{bat} = (E_s\, c_b) + (c_l\, t_l) \tag{7}$$

$$L_{ET} = 3\, L_{ET0} = 3\, L_c\, E_s.DOD \tag{8}$$

c_b is the cost of the battery per energy unit in €/kWh. c_l is the cost of labour in euros and t_l the labour time required for battery replacement in hours.

In order to calculate L_{ET} a factor 3 is used due to shallow cycling having less impact on battery lifetime than the deep cycling [11], [15]. L_c is the battery lifetime in cycles for a specific DOD, which is the maximum Depth Of Discharge of the battery.

In contrast, we assume that the cost from regulation down is null because there is no need of additional equipment (V2G).

3.3 Minimum Selling Price and Net Profit per Request

Regulation down is always interesting because there are no additional costs and it represents free charging for the EV. But, in case of regulation up, an average minimum selling price have to be calculated to judge the profitability according to the contract level using the following equation:

$$p_{el0} = c_{en} + \frac{c_{ac}}{R_{d-c}\, P\, t_{plug}} - \frac{p_{cap}}{R_{d-c}} \tag{9}$$

It is possible to calculate the minimum selling price for the whole year depending on a single EV or the whole fleet. Thus, we deduce if it is interesting for them to set a contract with an energy storage operator or with another kind of aggregators.

In a context where the electricity price may vary during the day [30], the most important criterion to create a reliable decision argument when the grid asks for energy at a defined electricity price is the minimum selling price p_{s0}. It is interesting to calculate the minimum selling price dynamically for each request, in order to define under which conditions the EV will lose money if it delivers regulation up service.

Based on the previous calculations, the per request revenue is:

$$R_{regs} = R_{caps} + R_{enes} = \left(p_{cap}\, P\, \frac{h_{plug}}{T_{day}}\right) + (p_{el}\, Q_{request}) \tag{10}$$

For the remunerated produced energy per request (R_{enes}), the delivered energy $Q_{request}$ (kWh) is multiplied by the electricity price $p_{el.}$ And for the capacity part (R_{caps}), the per request revenue is calculated for one transfer with an estimated value of T_{day} which is the number of transfers per day. h_{plug} is the number of hours during the day when the EV is plugged in and available for the service.

The per request cost can be calculated using the following equation:

$$C_{regs} = C_{en}\, Q_{request} + \frac{C_{ac}}{T_{day}\, d_{plug}} \tag{11}$$

With d_{plug}, the number of days in the year when the EV is plugged in and available for the service.

The minimum selling price per request represents the threshold from which the prosumer does not lose money.

$$p_{so} = \frac{C_{regs} - \left(p_{cap}\, P * \frac{h_{plug}}{T_{day}}\right)}{Q_{request}} \tag{12}$$

Regarding the other parameters like T_{day} and h_{plug} estimated values (contract values) are used depending on the average behavior of the EV owner and a reference of the grid request (T_{day}) depending on the grid situation during the day and the period of the year. Obviously, the accurate values may be calculated at the end of the day to compare the real result to the estimated one.

The main interest of p_{s0} is to indicate if the service is profitable for each grid request and if it is not, a new selling price can be proposed to the grid. In case of a contract with an aggregator or a storage operator, the contract sets a minimum value of power capacity ($P\ t_{plug}$). If this value is not reached or if the service is refused too many times, a penalty may be paid by the EV owner and can be included as a new cost of the service.

4 Parameters Influence

4.1 *The Main Parameters Values*

Table 1. synthesizes the main parameters values as well as their variations according to the context which are detailed in the "Comments" column.

In the inputs excel sheet, a detailed description of each parameter is available as well as the default value. The algorithm user can change some or all the values depending on his specific point of interest. In our following study, the used parameters are in the "Value" column.

Table 1 Inputs for net profit calculation

Revenue		Value	Comments
p_{cap}	€/kW-h	0.017	USA: 40 $/MW-h [16], [11], France: 17€/MW-h [33], 16 €/MW-h [13]. In some markets it may not exist [29].
P_{el}	€/kWh	0.1	In USA 0.1 $/kWh [11]. This value may vary during the day and in some markets it does not exist [13].
t_{plug}	h/year	5840	EV plugged in 16 hours subtracting charging hours and mobility 365 days a year. 18h in [11].
R_{d-c}	-	0.10	The dispatched power is assumed to be 10% of the total power capacity [11, 12], [29].
d_d	km	20	16 miles in [11]. Daily trips in France [31], Germany [8] or New York City [32] between 30 and 50km. Thus average driven distance home to work 40/2=20 km.
d_{rb}	km	20	20 miles in [11]. Equal to d_d (work to home travel) but people will probably overestimate their needs [33].
η_{inv}	%	0.92	93% in [11].
η_{veh}	km/kWh	6	Toyota RAV4: 3.65miles/kWh [12], rated value 2.5 miles/kWh [11], driving efficiency in winter: 5,4km/kWh [33], in summer: 7.75km/kWh [33].
t_{disp}	hour	0.33	Dispatch hours: 20 min (20min/60min) [11].
P_{line}	kW	15	95% of the principal charging station are slow charging 3kW [33], but for V2G participation fast charging is better 7-22kW with 15kW [11].
Cost		**Value**	**Comments**
c_b	€/kWh	300	Assuming annual production of 100,000 batteries per year: USA 350$/kWh [11], France: 300€/kWh [33].
E_s	kWh	22	Toyota RAV4: 27.4 kWh battery [11], 64% of EV in France in 2013 had a 22kWh battery [33], [34].
c_l	€/h	35	USA: 30 $/h [11], average of the labor cost in 2015 in Europe 35€/h [35].
t_l	h	8	Replacement labor 8 hours [12], 10 hours [11].

Table 1 (*continued*)

L_c	cycles	2000	NiMH battery achieves 2,000 cycles under deep cycle testing [11].
DOD	%	0.80	Maximum DOD is usually 80% for NiMH [11], [33].
c_{pe}	€/kWh	0.045	Dependent on the grid electric market from 0.1 $/kWh in USA [11] to 0.045 €/kWh EPEX cost of energy in 2015 (average for 1 day by season) [36].
η_{conv}	%	0.73	Round trip electrical efficiency, grid-battery-grid [11].
c_c	€	1800	On-board incremental costs: 400$ and wiring upgrade for 15kW: 1,500$ [11].
N	Year	10	Assuming n=10 years [11], [13].
D	%	0.10	Assuming d=10% [11], [13].

In our scenario, the EV is fully charged during the night using low electricity price before the first trip of the day, which is house to work with V2G possibilities in both of home and work. The half of the daily trip is done when EV owner arrives to work (d_d) and then he comes back home with the other half at the end of the day (d_{rb}). T_{day} is fixed to 300 according to [11].

4.2 *The Parameters Influence*

It is very interesting to highlight the main parameters impact on the storage profitability using the studied algorithm. In fact, the calculation allows deciding about the storage profitability regarding the prosumer behavior, the service cost and the service remuneration. These calculations are helpful for the business model definition and contract conditions. In fact, the storage service may be more or less profitable according to each micro-grid's or prosumer's characteristics. The following figures present the annual net revenue of frequency regulation up per EV (R_{reg} - C_{reg}).

Influence of Market Electricity Selling (p_{el}) and Capacity (p_{cap}) Prices

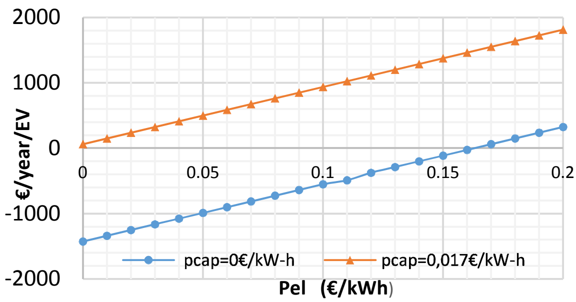

Fig. 1 Net revenue according to p_{el} variation with p_{cap} = 0 €/kW-h and 0.017 €/kW-h

The calculation shows that the cost of the service is mainly dependent on the energy trough the battery. It does not depend on p_{el} and p_{cap} and is about 1426€ per year per vehicle. It has a huge impact on the profitability.

When there is no capacity remuneration, the minimum selling price will only be influenced by the electricity selling price p_{el}. This price is proposed by the grid as the price to buy the electricity for the service. In this case, Fig.1 shows that, to be profitable, the minimum selling price p_{s0} is 0.16 € /kWh. Under this value the EV is loosing money while delivering the frequency regulation up service. At p_{el} = 0.2 €/kWh the net profit is 325€ per EV per year whereas for p_{el} = 0.05 €/kWh the net profit is negative -988€. Under our assumptions presented in Table 1. with p_{el} = 0.1 €/kWh and p_{cap} = 0.017 €/kW-h, the annual net profit is 939€ per vehicle per year.

In a regulation market without capacity payment, the revenue is highly dependent on the market selling price of electricity. Knowing that this price will certainly vary during the day, it is necessary to ensure an average selling price to guarantee the profitability.

According to Fig.1, when there is a capacity price of p_{cap} = 0.017 €/kW-h, the profitability is always ensured even if there is no remuneration for the provided energy. In fact, the revenue for availability is a certified source of income. If there is no need for regulation service, there is no remuneration for electricity selling neither. We can notice that in the case of high value of p_{el} = 0.2 €/kWh, the net profit is 1814€, and for low value p_{el} = 0.05€/kWh it is 500€ per EV per year and the profit is still interesting.

Another point must be taken into account, which is the number of transfers per day and thus the energy trough the battery for regulation up service. It is necessary to note the importance of the remuneration segmentation regarding the future evolution of the frequency regulation service. In fact, over time, the number of requests may decrease due to a more equilibrated grid or many service offers. Fewer requests means that in the one hand the electricity price will have less impact in the revenue calculation, and so in another hand the remuneration for availability will have a lot more importance.

Influence the Owner Behavior: Plugin Hours h_{plug}, Mimimun Range for Mobility d_{rb} and Installation Limit P_{line}

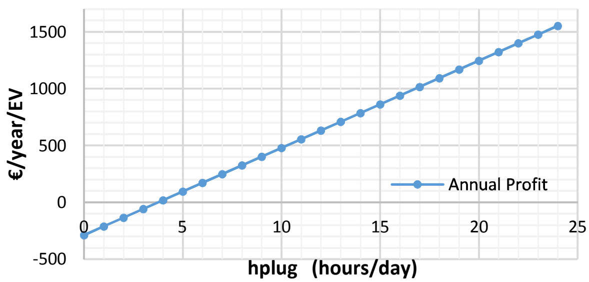

Fig. 2 Net profit according to h_{plug} variation with p_{el} = 0.1 €/kWh and p_{cap} = 0.017 €/kW-h

The contracted plugin time per day (h_{plug}) is one of the prosumer behavior characteristics. It could be fixed when the contract is established. It represents the time in hour when the electric vehicle is plugged in and available for service during a day and it is the basis for the calculation of the capacity remuneration. This parameter affects both of the revenue and the cost of the service. Fig. 2 shows that the service becomes profitable for a number of plugin hours superior to 4 hours. This conclusion confirms that even with a company fleet with high use for mobility or for vehicles without possibilities of connection during working hours [13], the service remains interesting. In fact, for 12 hours of plugin, the net profit per year per EV is 1774€ - 1142€ = 632 €. Another parameter, which is the human behavior, is of huge interest. Even with a right SOC and a right installation for the service, if the EV owner forgets to connect his car, the annual revenue will decrease.

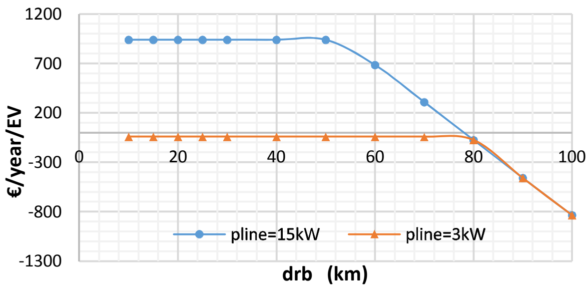

Fig. 3 Net profit according to d_{rb} variation with p_{el} = 0.1 €/kWh and p_{cap} = 0.017 €/kW-h

The Fig. 3 represents the impact of the minimum range set by the EV owner to allow him using his EV for mobility. The figure presents the impact for two installations limited to 3kW and 15 kW. The EV owner may overestimate his needs but the curve for an installation limited to 3kW shows that the net revenue which is close to zero will be more impacted by the installation than by the minimum range d_{rb}. In case of an installation limited to 15kW like in our previous calculations, the net profit is about: 2365€ - 1426€ = 939€ until a d_{rb} set to 50km and then it decreases to become negative.

Influence of the Battery Cost of Replacement c_b

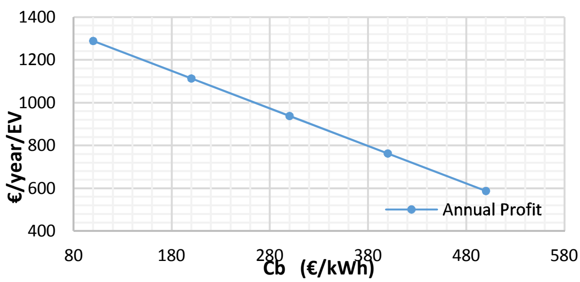

Fig. 4 Net profit according to c_b with p_{el} = 0.1 €/kWh and p_{cap} = 0.017 €/kW-h

Batteries technologies have evolved and the cost decreased a lot during these last years. In the profitability calculation, we do not take into account the cost of the battery because it has been purchased for mobility purposes. However, the replacement cost is taken into account. Fig. 4 shows the battery cost impact on the profitability. The used cost for c_b in our study is 300 €/kWh but if we compare the net revenue of 2365€ - 1426€ = 939€ in case of an important decrease of the battery price 100 €/kWh, we can see that the profit increases to 2365€ - 1076€ = 1289€.

The battery cost has a significant impact on the service cost but in our calculation, the battery wear represents the main part of the service cost.

5 Conclusion

In the various regulation markets, there are several grid situations and thus various needs of regulation. In the smart grid context, new actors appeared in the market offering ancillary service to the grid like frequency regulation. Among these actors with storage capabilities, EVs batteries are one of the most interesting thanks to the electric storage adapted features for frequency regulation and the batteries availability as long as the EV is not used for mobility.

The profitability calculation for frequency regulation service takes into account the EV owner behavior with his driving pattern, the battery cost and wear as well as the service remuneration in the various markets. Two main revenues have been studied: the first one comes from the availability of the EV (power capacity) and the second one from the electricity sold to the grid during the service (market electricity selling price).

The study highlighted the important effect of the capacity remuneration when it exists. In order to ensure the service profitability, the minimum value of the electricity selling price may vary a lot depending on the value of the capacity price. Moreover, the capacity price may represent the most import part of the remuneration especially in a market with low number of requests during the day.

Regarding the EV owner behavior, even a few number of plugin hours may be sufficient for the service profitability. In fact, EVs with no adapted connection point at work or with high utilization for mobility can offer interesting revenues. Finally, the minimum range set by the EV owner does not limit the frequency regulation profitability because it remains interesting until high values (around 50km). However, the V2G installation and more precisely the line limit may have a huge negative impact on the service viability.

It is necessary to note the importance of the remuneration segmentation regarding the future evolution of the frequency regulation service. In fact, the number of requests may decrease because the grid may be steadier using a smartest management or because the offer in the regulation market will be more important than the needs. Fewer requests means that in the one hand the electricity price will have less impact in the revenue calculation, and so in another hand the remuneration for availability (capacity price) will have more importance in the profit if it is maintained in the market.

The calculation tool is very interesting to apprehend the profitability at various smart grid development levels: short, medium and long term from the contract level to decisional algorithm delivering the service depending on the profit.

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Intelligent Control of Energy Distribution Networks

Pablo Chamoso, Juan Francisco De Paz, Javier Bajo and Gabriel Villarrubia

Abstract There has been continuous research in the energy distribution sector over the last years because of its significant impact in modern societies. Nonetheless, the use of high voltage power lines transport involves some risks that may be avoided with periodic reviews. The objective of this work is to reduce the number of these periodic reviews so that the maintenance cost of power lines is also reduced. This work is focused on the periodic review of transmission towers (TT) to avoid important risks, such as step and touch potentials, for humans. To reduce the number of TT to be reviewed, an organization-based agent system is proposed in conjunction with different artificial intelligence methods and algorithms. This system is able to propose a sample of TT from a selected set to be reviewed and to ensure that the whole set will have similar values without needing to review all the TT. As a result, the system provides a web application to manage all the review processes and all the TT of Spain, allowing the review companies to use the application either when they initiate a new review process for a whole line or area of TT, or when they want to place an entirely new set of TT, in which case the system would recommend the best place and the best type of structure to use.

Keywords Power lines management · Intelligent systems · Agents · Virtual organization · Data analysis · Case based reasoning · Artificial neural networks

1 Introduction

Power line maintenance is a problem that has generated a variety of research lines [9][4][3]. The transmission towers (TT) that support the power lines must be

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reviewed on a regular basis depending on their characteristics. In these reviews it is necessary to determine the ground resistance, as well as the step and touch potentials. These reviews involve a significantly high cost. However many of the reviews could be predicted, as most of the TT share the same features and are located on similar terrain. Therefore, the possibility of reducing the costs associated to this kind of maintenance is not only attractive, but quite reasonable.

As technology has continued to advance, there have been different approaches that attempt to apply innovations both in the review and the maintenance processes, resulting in a common need to reduce costs. Indeed, this is precisely the reason for having created the proposed predictive maintenance system.

There are 4 common maintenance types for TT: i) corrective, to solve existing problems; ii) preventive, to prevent the system from failures; iii) predictive, to predict possible irregularities; iv) proactive, which is a combination of preventive and predictive maintenances. The present work is focused on the predictive maintenance, where different techniques are already being used. Some authors have used artificial neural networks to model the environment, including [11], while other authors use neural networks to set failure times of the devices [13]. In addition, data mining or machine learning techniques are used to model different systems.

This study proposes a virtual organization of software agents capable of carrying out a predictive maintenance of TT by selecting only a sample for review. This selection is completely autonomous and is based on different TT parameters that make it possible to determine the status of the analyzed lines of the TT. The system has built-in statistical sampling techniques combined with neural networks to estimate the ground resistance, as well as the step and touch potentials. In addition, the system provides different geopositioning tools to facilitate the search and selection of the TT and lines to be sampled.

The paper is organized as follows: section 2 includes a revision of related work, Section 3 describes our proposal, and finally section 4 provides the preliminary results and conclusions obtained.

2 Proposed System

As mentioned before, there are different kinds of maintenance types [1]: corrective, preventive, predictive and proactive.

Predictive maintenance refers to the capacity of generating assumptions or estimations about the status of a component. When predicting well-known processes, especially in Control Theory [10], it is possible to generate a mathematical model which represents reality in a reliable way [8]. However, in other processes experimental techniques are needed, for example classification algorithms [7] or artificial neural networks [11]. This approach tries to extract and model the system features from historical data.

Support vector machines are used in [14] to predict the amount of ice that will be accumulated in aerial power lines. This is a serious problem that can interrupt the electrical service for a significant time, and the solution could be really expensive. Because of that proposed work, it is possible to estimate the level of ice (with a minimum error) by using historical meteorological data. More recently, [6] proposes an ice-shedding model for overhead power line conductors while considering adhesive/cohesive forces.

Another point to take into account is the machine performance (generators and current transformers). Due to the natural deterioration or machines over time, reviews are required over their useful lifespan. Periodic maintenance can be carried out, so machine performance is evaluated regularly, regardless of their status. This solution is not optimal when the review period is short and the machines are in perfect working condition. An alternative is based on monitoring the status of the equipment and evaluating some of their parameters. From the combination of these two options, a new model is presented in [15], where performance loss is predicted by the using failure rate and the performance degradation in conjunction with their derivatives and a Weibull distribution [13].

In other works such as [1], current transformer failures are analysed by Dissolved Gas Analysis (DGA). The currently existing methods are based on monitoring every substance ratio in oil; limit values are then established to determine all the possible failures [2]. The possibility of applying artificial neural networks and similar techniques to try to predict values is also presented in [1]. [12] applies Principal Component Analysis (PCA) and back-propagation artificial neural networks (BP-ANN) to obtain a discrete transformer status (normal, waiting for confirmation, abnormal). The accuracy levels reached are between 92% and 96% largely due to the input data PC treatment. Without this technique, the accuracy varies from 69% to 75%.

3 Proposal

The objective of this study is twofold: first, to predict the resistance of existing TT with unknown values, and second, to reduce the number of TT to be reviewed with samples. To carry out these tasks, we propose a multi-agent system (MAS),

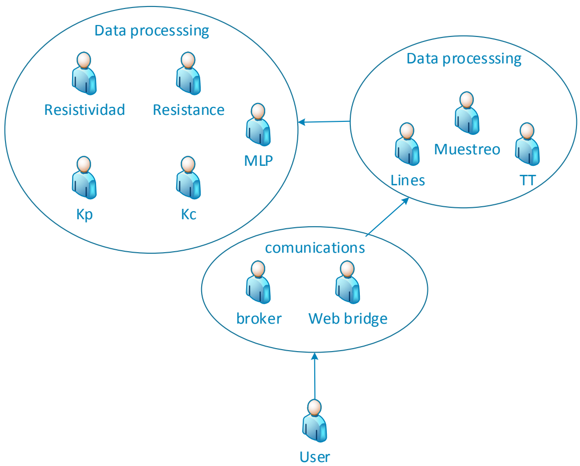

Fig. 1 Virtual organization of agents

which follows the structure shown in figure 1. The organization data processing includes agents to process the information. In this organization there are 4 agents to predict the resistance, resistivity, Kp (step potencial) and Kc (touch potentials). An additional agent provides a MLP to carry out these predictions. The Kp and Kc are calculated according to the Kr with the MLP and resistance and resistivity are calculated with the algorithm in section 3.1

3.1 Resistance and Resistivity

To estimate resistance as related to the different measured parameters, the only parameters used are those that were shown to influence the final value. To determine what the most influent parameters are, the correlation analysis and Kruskal Wallis methods were used. Once these parameters were known, the estimation was carried out by a CBR system, as shown in figure 1. The cases memory is grouped by the TT types as defined by their Kr value. To group them by their Kr value, PAM (Partitioning Around Medoids) is applied; the Henning and Liao [5] proposal is then used to determine the number of clusters. More specifically, three clusters are generated. In these three clusters, the cases base is organized whereby every case contains: resistivity, temperature, humidity, Kr and resistance values.

Every cluster has a trained multi-layer perceptron (MLP) where the inputs are resistivity, humidity, temperature and Kr, and the output is the resistance. In the recovery phase, the system recovers the previously trained network associated to the new Kr value. In the adaptation phase the network is used to generate the prediction. Finally the data and training are updated in the revise phase.

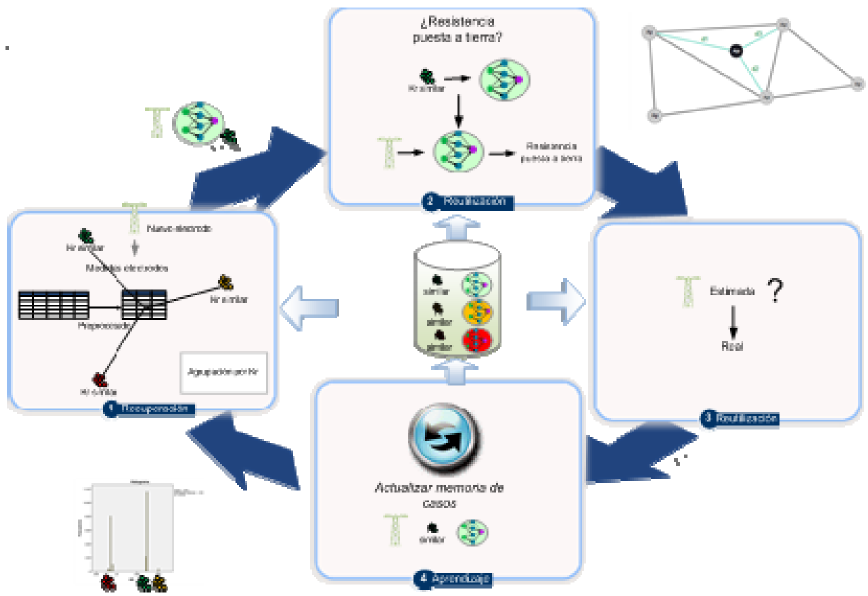

Fig. 2 CBR cycle for the resistivity and resistance estimation.

With regards to the proposed algorithm, its input is based either on the known information about a TT that already exists in the system, or a fictitious TT to be placed in a determined location. The only difference for the algorithm is the evaluation of the nearest neighbors.

First, the nearest neighbors have to be found and identified depending on different established parameters such as the maximum distance to be considered a neighbor, or the maximum number of neighbors to use.

Once determined, if the TT resistivity is unknown, it is estimated by the Inverse Distance Weighting (DW) method by applying this equation:

$$\bar{\rho} = \sum_{1}^{n} \rho(TT_i) * \frac{D_{max}/d_i}{\sum_1^n D_{max}/d_i}$$

Where: $\rho(TT_i)$ is the resistivity of the ith TT, D_{max} is the largest distance, d_i is the distance of the ith TT.

The equation provides the resistivity value with an estimated deviation of σ^2, where:

$$\sigma = \sqrt{\frac{1}{n}\sum_{1}^{n} (\rho_i - \bar{\rho})^2 \frac{D_{max}/d_i}{\sum_1^n D_{max}/d_i}}$$

When the resistivity value and range of the TT are obtained, the value of the resistance can be estimated. In order to estimate the resistance, an artificial neural network is used, specifically, an MLP with four inputs: resistivity, Kr value, ground humidity and temperature. The hidden layer consists of 9 neurons and provides a single output with the value of the estimated resistance.

3.2 Sampling

The main objective of this work is to reduce the number of reviews in order to reduce the TT maintenance cost. To attain this objective, a new algorithm was proposed. It uses several TT parameters as inputs, such as the Kr value, which determines the type of the TT, and the TT resistivity value to create stratums which are defined based on both parameters. The proposed algorithm follows these steps:

1. The sample provided as an algorithm input is analyzed to determine how many Kr intervals will be generated. For every interval, a list with the corresponding TT is created, so TT are now grouped by type (Kr value).
2. All lists are sorted in ascending order according to TT resistivity.
3. Once the lists are sorted, the deciles are calculated for each of the lists created according to the resistivity of similar Kr TT groups (step 2). The lowest and highest resistivity values of every list are also stored.

4. For every list of Kr groups (step 2) there are 10 sublists (step 3) containing TT with similar structure (associated to the Kr value) and similar resistance. The algorithm will now contain 10 n lists (equal to the number of Kr intervals selected in step 1), which are in turn divided into 10 sublists, which are generated after calculating the deciles in the lists found at the first level.
5. Variance is calculated and stored for every sublist created in step 4.
6. The maximum error e is calculated and stored for every sublist from step 4. This error is considered as the maximum between 0.1 mid-point of two consecutive deciles and 0.1 distance between two consecutive deciles:

$$e = Max[0.1 * \frac{d[i] + d[i+1]}{2}, 0.1 * (d[i+1] - d[i])]$$

7. From the sublists generated in 4, the variance calculated in 5, and the maximum error calculated in 6, the number of TT to be reviewed for every sublist n is defined by the following equation:

$$n = N * z^2 * \sigma^2/((N-1) * e^2 + z^2 * \sigma^2))$$

where: N is the size number of TT, n: Number of TT to review for every sublist, z= 1.9599, σ deviation, e is máximum error allowed

8. The output of the algorithm, n is provided for every sublist.
If the output number is too high the interval is divided recursively to reduce the elements in the sample.

4 Results and Conclusions

As a result, the system offers a web application with a series of tools for companies in charge of reviewing the TT. For example, the user can select a set of lines of an area to be reviewed and the system will show the user a subset of TT to review that would ensure that the system works fine with a confidence level of 95%. This makes it possible to reduce the number of TT to be reviewed, with the added benefit of improving efficiency and reducing costs. Figure 2 shows the process to execute the algorithm and obtain the result. For example, in figure 119, the TT selected close to the region of Murcia (Spain) are selected, as seen in “2.Selected towers are shown on the map”. When the algorithm is run, the system proposes the review of 42 TT from the initial 119 (“4a.Number of towers to review”) and shows exactly which TT have to be reviewed in “4b.Towers to be reviewed”. Finally, the user can see where the proposed TT are on the map or the output, as well as the details of every algorithm step in “5.Algorithm details, steps and outputs can be shown”.

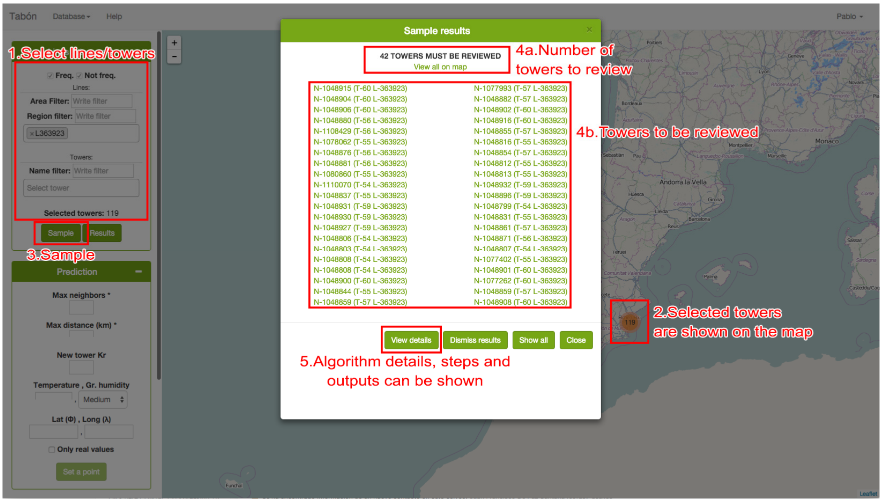

Fig. 3 Web application, sampling process

The web application provides an additional tool. Since one part of the required calculations is already included in the previously implemented sample algorithm, it would be worthwhile to include a tool that could determine the best structure to use in each location. In addition, unknown resistivity and resistance values of existing TT can be estimated. This is a very frequent situation because there is no information of most TT throughout Spain. Figure 3 shows an example of this functionality, where values for a new TT are estimated by taking into consideration just 3 neighbors (this is for demonstration purposes only, since 3 is a really poor number for real cases).

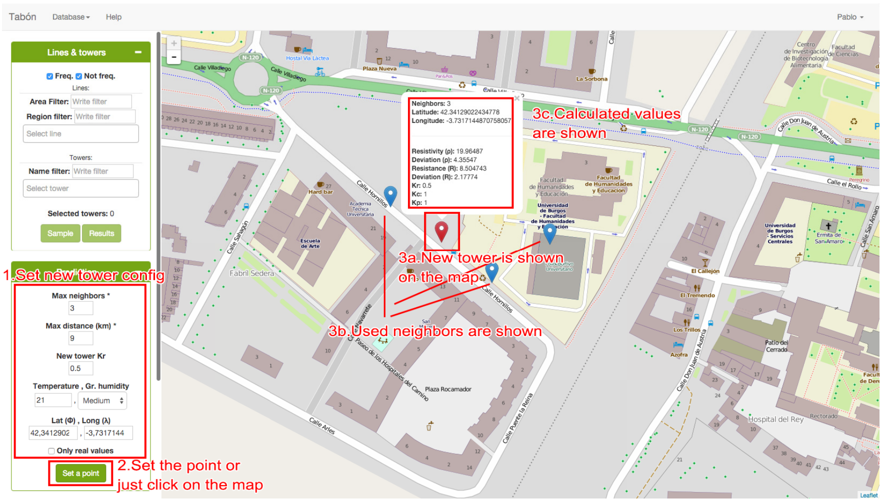

Fig. 4 Web application, new or existing TT values prediction process.

In general, the efficiency on of the algorithm is evaluated according to the reduction percentage, which can be seen in table 1.

Table 1 Reduction percentage depending on the number of selected TT and the average distance.

TT	Average distance (km)	Proposed TT	Reduction (%)
100	~50	27	73
200	~50	35	82.5
500	~50	64	87.2
800	~50	83	89.625
800	~300	154	80.75

The best results are achieved when selecting the more TT and the closer the average distance is.

The efficiency and accuracy of the system is expected to increase with future work as the information and the values of existing TT become more complete.

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Part III
A Comparison of Accurate Indoor Localization of Static Targets via WiFi and UWB Ranging

A Comparison of Accurate Indoor Localization of Static Targets via WiFi and UWB Ranging

Stefania Monica and Federico Bergenti

Abstract This paper compares Ultra-Wide Band (UWB) and WiFi technologies as sources of information for accurate localization of static targets in indoor scenarios. Such technologies offer different localization accuracy and they are also characterized by different applicability. UWB provides very accurate localization information, but it requires a dedicated infrastructure and it is not yet widely available in mobile appliances. WiFi gives less accurate localization information but it is integrated in all modern mobile appliances and it does not require a dedicated infrastructure. This paper details on accuracy versus wide applicability trade-off and it provides quantitative criteria to choose one technology or the other. The discussed results are obtained using a new add-on module for JADE which allows embedding diverse sources of ranging information and localization algorithms.

1 Introduction

The close relationship between agent technology and mobile technology has been evident since the early attempts to bring agent technology to mainstream software engineering. The *Foundation for Intelligent Physical Agents* (now *IEEE FIPA*, www.fipa.org) was originally proposed in 1996 by a group of researchers from Telecom Italia, at the time when all major telecommunication operators were entering mobile telephony. FIPA included all major mobile device manufacturers (e.g., Motorola, Siemens, and Ericsson) since its very beginning, and the fact that the second Chairman of FIPA, after the leave of Leonardo Chiariglione, was from Motorola Labs in Paris is a clear sign of the tight relationship between agent and mobile technologies.

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One of the major achievement that contributed to connect agent and mobile technologies even tighter was the European project *Lightweight and Extensible Agent Platform* (*LEAP*) [1, 2] which was led by Motorola since 2001 and brought JADE [3] to mobile devices with the help of Siemens, Broadcom, Telecom Italia, British Telecom, ADAC and the University of Parma. The focus of the project was on downsizing JADE to meet the tight constraints that mobile devices of the early 2000's imposed in terms of available memory and processing power. Most of such constraints are no longer actual and mobile appliances of today offer sufficient resources to host a JADE container with minor restrictions [4]. The challenges that mobile appliances vividly push today on agent technology are mostly due to the formidable opportunities that the availability of sophisticated on-board sensors open. Such sensors can now enable agents on mobile appliances to sense the physical environment of the user, interact with it possibly using high-level abstractions [5], and offer to the user context-aware services.

We have already started exploring the opportunities of enabling agents to use the sophisticated sensors of mobile appliances with the development of an add-on module for JADE and its evolutions [6] meant to provide agents with their physical location in a known indoor environment [7] using *Ultra-Wide Band* (*UWB*), a ranging technology which ensures accuracy and robustness. This paper extends such a work and it uses the possibility of the developed module of accommodating different sources of ranging information and different localization algorithms to explore indoor localization scenarios using WiFi ranging and to compare the performance of WiFi against the performance of UWB. The presented results are meant to give quantitative criteria to choose between UWB and WiFi on the basis of their specific characteristics: UWB ensures accurate localization but it requires a dedicated infrastructure and specific mobile appliances; WiFi provides less accurate localization information, but it requires no dedicated infrastructure and it can be used with commodity appliances. The experiments presented in this paper are obtained using a specific mobile appliance (`www.bespoon.com`) that embeds both UWB and WiFi modules.

This paper is organized as follows: Section 2 describes the considered set-up and the localization algorithm implemented in the JADE add-on module. In Section 3, selected experimental results are shown and a comparison between the accuracy of WiFi-based and UWB-based localization is performed. Section 4 concludes the paper.

2 JADE Agents with Localization Functionality

A specific add-on module was added to JADE in order to allow JADE agents to estimate the position of the appliance which hosts them [7]. The module is configurable and it can embed different sources of localization information and different localization algorithms. The main point of this paper is precisely to analyze the localization performance guaranteed by the add-on module of JADE with different sources of localization information, namely UWB and WiFi. The rest of this section explains the configuration used to support the experiments for both WiFi and UWB.

We assume to know the positions of M (static) nodes, denoted as *Anchor Nodes* (*ANs*) in the following. By measuring pairwise range estimates between each one of such nodes and the user appliance, denoted as *Target Node* (*TN*), the position of the latter can be estimated according to a proper localization algorithm. The agent in charge of performing localization has two tasks: first, it estimates the distances from a sufficiently large number of ANs; then, it uses such range estimates to feed a proper localization algorithm to obtain its position estimate.

Concerning the first step, in the experiments presented in this paper two different ranging technologies are used, namely WiFi and UWB. When using WiFi communication, the range estimates between an AN and the TN are derived from the received power of the WiFi signal using Friis formula, according to which the average received power $\bar{P}(r)$ at distance r can be expressed as

$$\bar{P}(r) = P_0 - 10\beta \log_{10} \frac{r}{r_0} \quad (1)$$

where P_0 is the known power at the reference distance r_0 and β depends on the transmission frequency and the actual antennas in use. An estimate of the average received power $\bar{P}(r)$ yields the value of the distance r by inverting (1). When using UWB communication, instead, the range estimates between an AN and the TN are obtained on the basis of the *Time of Flight* (*ToF*) of the signals traveling between such nodes [8].

Once the range estimates are available, the second step can be applied, in which the agent responsible for localization applies a proper localization algorithm to the range estimates previously acquired, obtaining a position estimate for the TN.

Many distance-based localization algorithms are available in the literature [9, 10]. The experiments discussed in next section are performed using the *Two-Stage Maximum-Likelihood* (*TSML*) algorithm, which has been widely studied in the literature [11]. In order to describe such algorithm, we first need to define a proper notation. The coordinates (in a three-dimensional environment) of the ANs are denoted throughout the paper as

$$\underline{s}_i = [x_i, y_i, z_i]^T \qquad i \in \{1, \ldots, M\} \quad (2)$$

where M is the number of available ANs. In the following scenarios, we consider the same ANs positions both for WiFi access points and for UWB beacons. This assumption is only meant to make a fair comparison between WiFi-based and UWB-based localization.

We remark that the coordinates of the ANs are assumed to be known to the agent in charge of localization, which is also able to associate distance estimates with the corresponding ANs. This is possible because each communication between the TN and an AN allows obtaining not only an estimate of the distance between them, but also other valuable information, such as the *Basic Service Set IDentification* (*BSSID*) of the responding WiFi access point and the ID of the responding UWB beacon. By associating each mapped BSSID and/or ID with the coordinates of the corresponding AN, each range estimate can be related to the spatial coordinates of the corresponding AN.

The (unknown) TN position and its estimate are denoted as $\underline{u} = [\bar{x}, \bar{y}, \bar{z}]^T$ and $\hat{\underline{u}} = [\hat{x}, \hat{y}, \hat{z}]^T$, respectively, so that the exact and estimated distances between the TN and the i-th AN can be written as

$$\rho_i = ||\underline{u} - \underline{s}_i|| \qquad \hat{\rho}_i = ||\hat{\underline{u}} - \underline{s}_i|| \qquad i \in \{1, \ldots, M\}.$$

From now on, we make an additional assumption which allows simplifying the description of the localization algorithm. We assume that we know the exact height $\bar{z}$ of the static TN whose position is to be estimated. Defining as

$$h_i = |\bar{z} - z_i| \qquad i \in \{1, \ldots, M\} \tag{3}$$

the difference between the height $\bar{z}$ of the TN and the height z_i of the i-th AN, it is possible to correct the distances $\{\rho_i\}_{i=1}^M$ according to the Pitagora theorem, obtaining

$$r_i = \sqrt{\rho_i^2 - h_i^2} \qquad \hat{r}_i = \sqrt{\hat{\rho}_i^2 - h_i^2} \qquad i \in \{1, \ldots, M\} \tag{4}$$

which represent the projections of the distances $\{\rho_i\}_{i=1}^M$ on the plane $\{z = \bar{z}\}$ where the TN lies. This assumption allows simplifying the localization algorithm as if the considered scenario was a bidimensional one (i.e., as if the coordinates of the i-th AN were $[x_i, y_i, \bar{z}]$, $\forall i \in \{1, \ldots, M\}$).

The starting point for the TSML localization algorithm is the system

$$\begin{cases} (\hat{x} - x_1)^2 + (\hat{y} - y_1)^2 = \hat{r}_1^2 \\ \ldots \\ (\hat{x} - x_M)^2 + (\hat{y} - y_M)^2 = \hat{r}_M^2 \end{cases} \tag{5}$$

where the equations of the M circumferences $\{\hat{\mathcal{C}}_i\}_{i=1}^M$ lying on the plane $\{z = \bar{z}\}$, centered in $\{\underline{s}_i\}_{i=1}^M$, and with radii $\{\hat{r}_i\}_{i=1}^M$ are shown. If the radii of such circumferences were the exact distances $\{r_i\}_{i=1}^M$, they would all intersect in the same point, corresponding to the exact TN position. Instead, the circumferences $\{\hat{\mathcal{C}}_i\}_{i=1}^M$ do not intersect in a unique point due to the errors that affect their radii and, therefore, a proper localization algorithm is needed.

Defining

$$\hat{n} = \hat{x}^2 + \hat{y}^2, \tag{6}$$

the system (5) can be reformulated in matrix notation as

$$\underline{\underline{G}}_1 \, \underline{\hat{\omega}} = \underline{\hat{h}}_1 \tag{7}$$

where

$$\underline{\hat{\omega}} = \begin{pmatrix} \hat{x} \\ \hat{y}, \\ \hat{n} \end{pmatrix} \quad \underline{\underline{G}}_1 = -2 \begin{pmatrix} x_1 & y_1 & -0.5 \\ \vdots & \vdots & \vdots \\ x_M & y_M & -0.5 \end{pmatrix} \quad \underline{\hat{h}}_1 = \begin{pmatrix} \hat{r}_1^2 - a_1^2 \\ \vdots \\ \hat{r}_M^2 - a_M^2 \end{pmatrix} \tag{8}$$

and

$$a_i \triangleq \sqrt{x_i^2 + y_i^2} \qquad i \in \{1, \ldots, M\}. \tag{9}$$

We remark that (7) is not a linear system since the third element of the solution vector $\underline{\hat{\omega}}$ depends on the first two according to (6). Neglecting this dependence, the solution $\underline{\hat{\omega}}$ of (7) is determined through a *Maximum-Likelihood* (*ML*) approach as

$$\underline{\hat{\omega}} = (\underline{\underline{G}}_1^T \underline{\underline{W}}_1 \underline{\underline{G}}_1)^{-1} \underline{\underline{G}}_1^T \underline{\underline{W}}_1 \underline{\hat{h}}_1 \tag{10}$$

where $\underline{\underline{W}}_1$ is a positive definite matrix [11]. For the sake of simplicity, we set $\underline{\underline{W}}_1$ equal to the identity matrix.

Given the solution $\underline{\hat{\omega}}$ of (7), in order to take into account the dependence of $\hat{n}$ on the first two elements of the solution vector, the following system of equations can be considered

$$\underline{\underline{G}}_2 \underline{\hat{\phi}} = \underline{\hat{h}}_2 \tag{11}$$

where

$$\underline{\hat{\phi}} = \begin{pmatrix} \hat{x}^2 \\ \hat{y}^2 \end{pmatrix} \quad \underline{\underline{G}}_2 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{pmatrix} \quad \underline{\hat{h}}_2 = \begin{pmatrix} \hat{\omega}_1^2 \\ \hat{\omega}_2^2 \\ \hat{\omega}_3 \end{pmatrix} \tag{12}$$

and $\hat{\omega}_j$ denotes the $j-$th component of $\underline{\hat{\omega}}$. The solution of the (rectangular) system (11) can be determined, using a ML approach, as

$$\underline{\hat{\phi}} = (\underline{\underline{G}}_2^T \underline{\underline{W}}_2 \underline{\underline{G}}_2)^{-1} \underline{\underline{G}}_2^T \underline{\underline{W}}_2 \underline{\hat{h}}_2 \tag{13}$$

where $\underline{\underline{W}}_2$ is a positive definite matrix. We set $\underline{\underline{W}}_2$ equal to the identity matrix, as done for $\underline{\underline{W}}_1$. Finally, the position estimate can be expressed as

$$\underline{\hat{u}}_{[1,2]} = \underline{\underline{U}} \left[\sqrt{\hat{\phi}_1}, \sqrt{\hat{\phi}_2} \right]^T \tag{14}$$

where $\underline{\underline{U}} = \mathrm{diag}(\mathrm{sign}(\underline{\hat{\omega}}))$, $\hat{\phi}_j$ denotes the $j-$th component of $\underline{\hat{\phi}}$, and $\underline{\hat{u}}_{[1,2]}$ is the vector with the two first components of $\underline{u}$, namely the true abscissa and ordinate of the considered TN.

In the following section, experimental results obtained using the proposed localization framework are shown. The number of WiFi access points and the number of

UWB beacons acting as ANs are both equal to four in the considered scenario. Three different TN positions are considered, for each of which 200 localization estimates are performed.

3 Experimental Results

In order to test the validity of the agent-based localization framework previously described and to assess the performance of WiFi and UWB signaling as sources of localization information, we performed experiments in an illustrative indoor scenario, namely a rectangular room whose sides are 20 m and 10 m, respectively. Four WiFi access points were positioned in the room and their coordinates, expressed in meters in a proper coordinate system, are

$$\begin{aligned} \underline{s}_1 &= [5, 0, 2]^T \qquad \underline{s}_2 = [5, 10, 1]^T \\ \underline{s}_3 &= [15, 0, 1]^T \qquad \underline{s}_4 = [15, 10, 2]^T. \end{aligned} \tag{15}$$

We attached four UWB beacons to the WiFi access points so that ANs of both technologies have the same coordinates. With this configuration of ANs, we positioned the target smartphone in three different positions inside the room. The coordinates of such positions, expressed in meters, are

$$\underline{u}_1 = [3, 2, 1]^T \qquad \underline{u}_2 = [3, 8, 1]^T \qquad \underline{u}_3 = [10, 5, 1]^T. \tag{16}$$

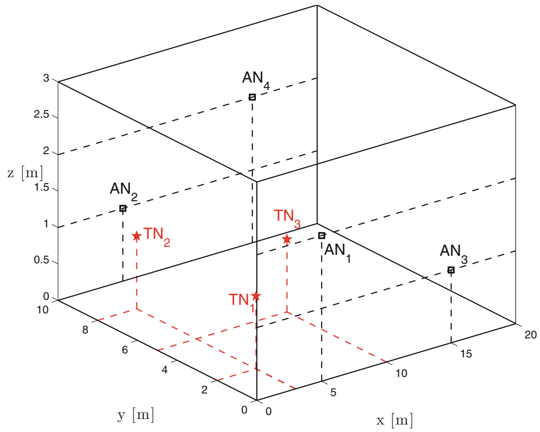

Fig. 1 The positions of the four considered ANs (black squares) and of three different TNs (red stars) are shown.

Fig. 1 shows the positions of the four ANs (black squares), denoted as $\{\text{AN}_i\}_{i=1}^4$, and the three different positions of the TN (red stars), denoted as $\{\text{TN}_i\}_{i=1}^3$.

Observe that all TNs are positioned on the plane $\{z = 1\}$. For this reason, regardless of the considered TN, from (15), the values $\{r_i\}_{i=1}^4$ can be expressed as functions of $\{\rho_i\}_{i=1}^4$, according to (4), as

$$r_1 = \sqrt{\rho_1^2 - 1} \qquad r_2 = \rho_2 \qquad r_3 = \rho_3 \qquad r_4 = \sqrt{\rho_4^2 - 1}.$$

Similar relations hold for range estimates.

We are interested in comparing the performance of WiFi-based localization with that of UWB-based localization. For this reason, we first acquire range estimates from the four WiFi access points and we estimate the TN position on the basis of such range estimates. This procedure is iterated 200 times. The WiFi-based range estimates obtained in the j-th iterations from the four WiFi access points are denoted as $\{\hat{r}_{i,j}^{(\text{W})}\}_{i=1}^4$ and they allow obtaining 200 WiFi-based position estimates of the considered TN, which are denoted as $\{\underline{\hat{u}}_j^{(\text{W})}\}_{j=1}^{200}$. Then, we acquire 200 range estimates, denoted as $\{\hat{r}_{i,j}^{(\text{U})}\}_{i=1}^4$, from each of the four UWB beacons and we use them to estimate the TN position. The 200 UWB-based position estimates of the considered TN are denoted as $\{\underline{\hat{u}}_j^{(\text{U})}\}_{j=1}^{200}$. We remark that $\{\underline{\hat{u}}_j^{(\text{W})}\}_{j=1}^{200}$ and $\{\underline{\hat{u}}_j^{(\text{U})}\}_{j=1}^{200}$ are bidimensional vectors representing the estimated abscissa and ordinate of the considered TN. The height, instead, is assumed to be known (and equal to 1 m), according to previous remarks.

The performance of the proposed localization approaches is evaluated in terms of the distances between the true TN position and its estimates. More precisely, we denote as $d_j^{(\text{W})}$ the distance between the true TN position and the position estimate obtained using the WiFi technology in the j-th iteration, and as $d_j^{(\text{U})}$ the distance between the true TN position and the position estimate obtained using the UWB technology in the j-th iteration, namely:

$$d_j^{(\text{W})} = ||\underline{\hat{u}}_j^{(\text{W})} - \underline{u}_{[1,2]}|| \qquad d_j^{(\text{U})} = ||\underline{\hat{u}}_j^{(\text{U})} - \underline{u}_{[1,2]}|| \qquad \forall j \in \{1, \ldots, 200\}. \tag{17}$$

Given the notation defined in (17), the average distance $d_{\text{avg}}^{(\text{W})}$ between the true TN position and its WiFi-based estimates and the average distance $d_{\text{avg}}^{(\text{U})}$ between the true TN position and its UWB-based estimates can be defined as

$$d_{\text{avg}}^{(\text{W})} = \frac{1}{200}\sum_{j=1}^{200} d_j^{(\text{W})} \qquad d_{\text{avg}}^{(\text{U})} = \frac{1}{200}\sum_{j=1}^{200} d_j^{(\text{U})}. \tag{18}$$

Similarly, it is possible to define

$$d_{\text{max}}^{(\text{W})} = \max_{j\in\{1,\ldots,200\}} d_j^{(\text{W})} \qquad d_{\text{max}}^{(\text{U})} = \max_{j\in\{1,\ldots,200\}} d_j^{(\text{U})} \tag{19}$$

which represent the maximum distances between the true TN position and WiFi-based and UWB-based position estimates, respectively. In the following, the performance of the proposed localization approaches is investigated in terms of the average distance and of the maximum distance defined in (18) and (19).

First, the TN is positioned in the point with coordinates $\underline{u}_1$ defined in (16). Such a point is denoted as TN_1 in Fig. 1. The 200 WiFi-based position estimates $\{\hat{\underline{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ are shown in Fig. 2 (blue circles), together with the 200 UWB-based position estimates $\{\hat{\underline{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ (magenta triangles). The true position of TN_1 is also shown (red star). From Fig. 2, it can be observed that while UWB-based position estimates are accurate enough for many applications, WiFi-based position estimates can be far inaccurate.

In order to improve the performance of WiFi-based localization, we decided to evaluate different approaches. First, instead of applying the localization algorithm to single range estimates $\{\hat{r}_{i,j}^{(\mathrm{W})}\}_{i=1}^{4}$, we acquire $K > 1$ range estimates from each AN and we perform localization on the basis of

$$\hat{r}_{i,j,K}^{(\mathrm{W})} = \frac{1}{K} \sum_{h=j}^{j+K-1} \hat{r}_{i,h}^{(\mathrm{W})} \qquad i \in \{1, 2, 3, 4\} \quad j \in \{1, \ldots, 200\} \tag{20}$$

which represent the averaged range estimates (from the i-th AN) obtained by averaging $\{\hat{r}_{i,j}^{(\mathrm{W})}\}_{i=1}^{4}$ over K consecutive iterations. The position estimates obtained using this approach are denoted as $\{\hat{\underline{v}}_{j,K}^{(\mathrm{W})}\}_{j=1}^{200}$. We remark that the j-th position estimate $\hat{\underline{v}}_{j,K}^{(\mathrm{W})}$ relies on the four averaged range estimates $\{\hat{r}_{i,j,K}^{(\mathrm{W})}\}_{i=1}^{4}$, and, therefore, on the $4 \cdot K$ range estimates $\{\hat{r}_{i,h}^{(\mathrm{W})}\}_{i=1}^{4}$ with $h \in \{j, \ldots, j+K-1\}$. For this reason, the first position estimate $\hat{\underline{v}}_{1,K}^{(\mathrm{W})}$ can be obtained only after an initial phase, during which K range estimates from each of the four ANs are acquired. Once $\hat{\underline{v}}_{1,K}^{(\mathrm{W})}$ is evaluated, the position estimates that follow can be determined as soon as a new 4-uple of range estimates from the four ANs is acquired. The case without range averaging considered initially corresponds to $K = 1$ in (20). We now show localization results obtained with $K = 10$ and $K = 100$. In both cases, we perform 200 position estimates—therefore, we acquire $200 + K - 1$ range estimates from each of the four ANs. Fig. 2 shows the true TN position (red star) and: the 200 position estimates $\{\hat{\underline{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ (blue circles) which correspond to $K = 1$ in the definition of $\{\hat{\underline{v}}_{j,K}^{(\mathrm{W})}\}_{j=1}^{200}$; the 200 position estimates $\{\hat{\underline{v}}_{j,10}^{(\mathrm{W})}\}_{j=1}^{200}$ (black crosses); the 200 position estimates $\{\hat{\underline{v}}_{j,100}^{(\mathrm{W})}\}_{j=1}^{200}$ (yellow triangles). A visual comparison among the results obtained with $K = 1$ (i.e., without range averages), $K = 10$, and $K = 100$ shows that the greater is K, the more accurate are the position estimates. This result is not surprising since, intuitively, averaging over a larger number of range estimates allows obtaining more accurate averaged range estimates and the more precise are the averaged range estimates used to feed the localization algorithm, the more accurate are the obtained position estimates.

For the sake of completeness, also the 200 position estimates $\{\underline{u}_j^{(\mathrm{U})}\}_{j=1}^{200}$ obtained using the UWB technology are shown (magenta pluses). Observe that such position estimates are obtained without any kind of range averages. From Fig. 2 it can be

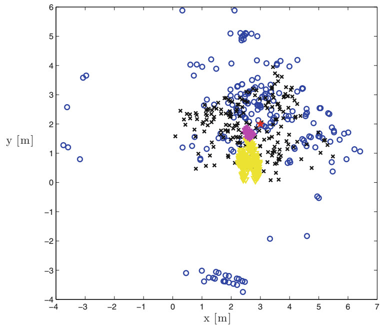

Fig. 2 The position estimates $\{\underline{\hat{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ (blue circles), $\{\underline{\hat{v}}_{j,10}^{(\mathrm{W})}\}_{j=1}^{200}$ (black crosses), $\{\underline{\hat{v}}_{j,100}^{(\mathrm{W})}\}_{j=1}^{200}$ (yellow triangles), and $\{\underline{\hat{u}}_j^{(\mathrm{U})}\}_{j=1}^{200}$ (magenta pluses) are shown. The true position of TN_1 is also shown (red star).

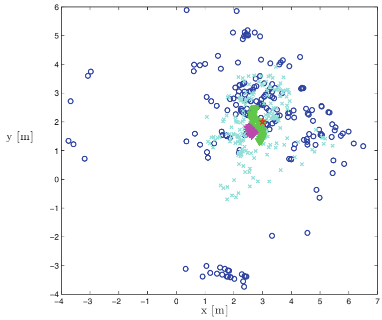

Fig. 3 The position estimates $\{\underline{\hat{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ (blue circles), $\{\underline{\hat{u}}_{j,10}^{(\mathrm{W})}\}_{j=1}^{200}$ (cyan crosses), $\{\underline{\hat{u}}_{j,100}^{(\mathrm{W})}\}_{j=1}^{200}$ (green triangles), and $\{\underline{\hat{u}}_j^{(\mathrm{U})}\}_{j=1}^{200}$ (magenta pluses) are shown. The true position of TN_1 is also shown (red star).

concluded that the performance of UWB-based localization is not only better than that obtained on the basis of WiFi range estimates (with $K = 1$), but also than those obtained using the averaged range estimates (20) acquired via WiFi.

A second approach consists in performing localization on the basis of single range estimates $\{\hat{r}_{i,j}^{(\mathrm{W})}\}_{i=1}^{4}$ and averaging over the obtained position estimates. More precisely, we define the averaged position estimates in the j-th iteration as

$$\underline{\hat{u}}_{j,K}^{(\mathrm{W})} = \frac{1}{K}\sum_{h=j}^{j+K-1} \underline{\hat{u}}_h^{(\mathrm{W})} \qquad j \in \{1, \ldots, 200\}. \tag{21}$$

Obviously, in order to obtain 200 averaged position estimates such as those defined in (21), $200 + K - 1$ position estimates $\underline{\hat{u}}_j^{(\mathrm{W})}$ need to be evaluated. Once the first K position estimates $\{\underline{\hat{u}}_j^{(\mathrm{W})}\}_{j=1}^{K}$ are acquired, the first averaged position estimate $\underline{\hat{u}}_{1,K}^{(\mathrm{W})}$ can be determined. From then on, each new position estimate $\{\underline{\hat{u}}_{j+K-1}^{(\mathrm{W})}\}_{j=2}^{200+K-1}$ allows deriving a new averaged position estimate $\underline{\hat{u}}_{j,K}^{(\mathrm{W})}$. The position estimates $\{\underline{\hat{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ initially considered correspond to $K = 1$ in (21). Fig. 3 shows the true TN position (red star), the 200 position estimates $\{\underline{\hat{u}}_j^{(\mathrm{W})}\}_{j=1}^{200}$ (blue circles) which correspond to $K = 1$ in the definition of $\{\underline{\hat{u}}_{j,K}^{(\mathrm{W})}\}_{j=1}^{200}$ and the 200 position estimates $\{\underline{\hat{u}}_j^{(\mathrm{U})}\}_{j=1}^{200}$ obtained using the UWB technology (magenta pluses). Such position estimates are also shown in Fig. 2 and are shown here again in order to better compare them with the 200 averaged position estimates $\{\underline{\hat{u}}_{j,10}^{(\mathrm{W})}\}_{j=1}^{200}$ (cyan crosses) and the 200 averaged position estimates $\{\underline{\hat{u}}_{j,100}^{(\mathrm{W})}\}_{j=1}^{200}$ (green triangles). As observed in Fig. 2, the greater is K, the more accurate are the position estimates.

Table 1 shows selected results relative to the proposed localization approaches, in terms of the average distance and the maximum distance between the true TN position

Table 1 Values of average distances (first row) and maximum distances (second row) between the true position of TN_1 and its estimates relative to: $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (first column); $\{\underline{\hat{v}}_{j,10}^{(W)}\}_{j=1}^{200}$ (second column); $\{\underline{\hat{v}}_{j,100}^{(W)}\}_{j=1}^{200}$ (third column); $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ (fourth column); and $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ (fifth column).

TN_1	$\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$	$\{\underline{\hat{v}}_{j,10}^{(W)}\}_{j=1}^{200}$	$\{\underline{\hat{v}}_{j,100}^{(W)}\}_{j=1}^{200}$	$\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$	$\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$
$d_{avg}^{(W)}$ [m]	2.19	1.33	1.33	1.18	0.37
$d_{max}^{(W)}$ [m]	6.78	2.94	1.99	2.96	0.70

and its estimates. More precisely, the first column shows the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the range estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$. It can be observed that the average distance between the true TN position and its estimates obtained without considering any average is 2.19 m, with a maximum distance of 6.78 m. The second and third columns show the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the range estimates $\{\underline{\hat{v}}_{j,10}^{(W)}\}_{j=1}^{200}$ and $\{\underline{\hat{v}}_{j,100}^{(W)}\}_{j=1}^{200}$, respectively. As expected from the results in Fig. 2, in these cases the average distance $d_{avg}^{(W)}$ is reduced with respect to previous cases and it is equal to 1.33 m. Analogous considerations can also be made for the values of the maximum distance $d_{max}^{(W)}$, which, in the case of $K = 100$, is nearly 2 m. Finally, the fourth and fifth columns of Table 1 show the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the averaged position estimates $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ and $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$, respectively. The average distance d_{avg} is smaller than those obtained in previous cases and becomes equal to 0.37 m when $K = 100$. This last case also corresponds to the smallest value of d_{max}, which is nearly 10% than the corresponding value shown in the first column relative the position estimates obtained without any average. According to the results shown in Figs. 2 and 3 and in Table 1, the best approach for WiFi-based localization is that obtained by averaging over $K = 100$ position estimates. Such results are also competitive with those obtained using the UWB technology, as shown in Fig. 3. As a matter of fact, the values of $d_{avg}^{(U)}$ and $d_{max}^{(U)}$ relative to UWB-based position estimates are 0.52 m and 0.67 m, respectively.

In the following, we consider only the averaged position estimates denoted as $\{\underline{\hat{u}}_{j,K}^{(W)}\}_{j=1}^{200}$, since, according to previous results, they are more accurate than those obtained by averaging over the range estimates denoted as $\{\underline{\hat{v}}_{j,K}^{(W)}\}_{j=1}^{200}$.

We now consider the TN position denoted as TN_2 in Fig. 1. Fig. 4 shows the true TN position (red star) and: the 200 position estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (blue circles) which correspond to $K = 1$ in the definition of $\{\underline{\hat{u}}_{j,K}^{(W)}\}_{j=1}^{200}$; the 200 averaged position estimates $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ (cyan crosses); the 200 averaged position estimates $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ (green triangles); and the 200 position estimates $\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$ (magenta pluses). The true TN position is denoted as a red star. As observed in Fig. 3, the greater is K, the more accurate are the position estimates. This is confirmed by the results shown in Table 2, where the first column shows the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the range estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$. Such values are comparable with

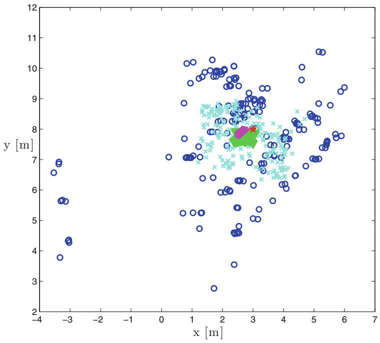

Fig. 4 The position estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (blue circles), $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ (cyan crosses), $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ (green triangles), and $\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$ (magenta pluses) are shown. The true position of TN_2 is also shown (red star).

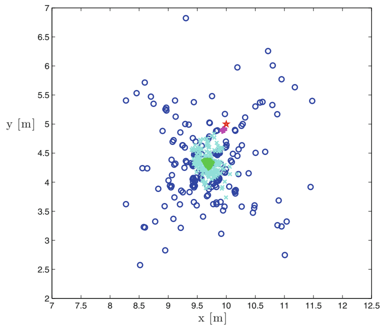

Fig. 5 The position estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (blue circles), $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ (cyan crosses), $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ (green triangles), and $\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$ (magenta pluses) are shown. The true position of TN_3 is also shown (red star).

Table 2 Values of average distances (first row) and maximum distances (second row) between the true position of TN_2 and its estimates relative to: $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (first column); $\{\underline{\hat{v}}_{j,10}^{(W)}\}_{j=1}^{200}$ (second column); $\{\underline{\hat{v}}_{j,100}^{(W)}\}_{j=1}^{200}$ (third column); and $\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$ (last column).

TN_2	$\{\underline{\hat{u}}_j\}_{j=1}^{200}$	$\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$	$\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$		$\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$
$d_{avg}^{(W)}$ [m]	2.05	1.07	0.42	$d_{avg}^{(U)}$ [m]	0.35
$d_{max}^{(W)}$ [m]	7.61	2.10	0.76	$d_{max}^{(U)}$ [m]	0.56

those relative to TN_1. The second and third columns show the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the averaged position estimates $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ and $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$, respectively. As expected from Fig. 4, the average distance $d_{avg}^{(W)}$ and the maximum distance $d_{max}^{(W)}$ become smaller as K increases. According to the results shown in Fig. 4 and in Table 2, the best approach for WiFi-based localization is that obtained by averaging over $K = 100$ position estimates. Table 2 also shows the values of $d_{avg}^{(U)}$ and $d_{max}^{(U)}$ relative to UWB-based localization (last column). Such values are comparable with those relative to $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$.

Finally, we consider the TN position denoted as TN_3 in Fig. 1, which corresponds to a TN positioned in the middle of the considered room. Fig. 5 shows the true TN position (red star) and: the 200 position estimates $\{\underline{\hat{u}}_j^{(W)}\}_{j=1}^{200}$ (blue circles) which correspond to $K = 1$ in the definition of $\{\underline{\hat{u}}_{j,K}^{(W)}\}_{j=1}^{200}$; the 200 averaged position estimates $\{\underline{\hat{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ (cyan crosses); the 200 averaged position estimates $\{\underline{\hat{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ (green triangles); and the 200 position estimates $\{\underline{\hat{u}}_j^{(U)}\}_{j=1}^{200}$ obtained using the UWB technology (magenta pluses).

Table 3 Values of average distances (first row) and maximum distances (second row) between the true position of TN_3 and its estimates relative to: $\{\hat{\underline{u}}_j^{(W)}\}_{j=1}^{200}$ (first column); $\{\hat{\underline{v}}_{j,10}^{(W)}\}_{j=1}^{200}$ (second column); $\{\hat{\underline{v}}_{j,100}^{(W)}\}_{j=1}^{200}$ (third column); and $\{\hat{\underline{u}}_j^{(U)}\}_{j=1}^{200}$ (last column).

TN_3	$\{\hat{\underline{u}}_j\}_{j=1}^{200}$	$\{\hat{\underline{u}}_{j,10}^{(W)}\}_{j=1}^{200}$	$\{\hat{\underline{u}}_{j,100}^{(W)}\}_{j=1}^{200}$		$\{\hat{\underline{u}}_j^{(U)}\}_{j=1}^{200}$
$d_{avg}^{(W)}$ [m]	1.03	0.76	0.74	$d_{avg}^{(U)}$ [m]	0.10
$d_{max}^{(W)}$ [m]	2.84	1.26	0.79	$d_{max}^{(U)}$ [m]	0.14

Table 3 shows some results relative to the proposed localization approaches, in terms of the average distance and the maximum distance between the exact TN position and its estimates. More precisely, the first column shows the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the range estimates $\{\hat{\underline{u}}_j^{(W)}\}_{j=1}^{200}$. It can be observed that such values are smaller than those obtained with the same localization approach relative to TN_1 and TN_2. The second and third columns show the values of $d_{avg}^{(W)}$ and $d_{max}^{(W)}$, expressed in meters, relative to the range estimates $\{\hat{\underline{u}}_{j,10}^{(W)}\}_{j=1}^{200}$ and $\{\hat{\underline{u}}_{j,100}^{(W)}\}_{j=1}^{200}$, respectively, while the last column shows the values of $d_{avg}^{(U)}$ and $d_{max}^{(U)}$ relative to UWB-based position estimates. Table 3 shows that the most accurate WiFi-based localization is obtained with $\{\hat{\underline{u}}_{j,100}^{(W)}\}_{j=1}^{200}$, namely when considering averaged position estimates based on $K = 100$ position estimates. Moreover, Table 3 shows that in this case the accuracy of UWB-based position estimates is approximately 65 cm better than that relative to $\{\hat{\underline{u}}_{j,100}^{(W)}\}_{j=1}^{200}$ in terms of average distance and maximum distance.

4 Conclusion

This paper presents experimental results intended to give quantitative criteria to choose WiFi technology or UWB technology as sources of accurate indoor localization for static targets. The lower level of accuracy of WiFi is compensated by its availability in all modern mobile appliances and by the cost reduction of using commodity infrastructures. On the contrary, the higher level of accuracy of UWB are obtained only at the cost of a dedicated infrastructure and only by assuming users are equipped with an UWB-enabled appliance. Notably, the proper processing of range and position estimates from the WiFi network can lead to an accuracy varying (in terms of $d_{avg}^{(W)}$) from 37 cm to 74 cm which is often comparable with that obtained using the UWB technology and which is sufficient for many indoor applications in large environments.

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New Architecture for Electric Bikes Control Based on Smartphones and Wireless Sensors

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Abstract During the last years, great advances has been produced in the automotive industry, a strategic sector both nationally and internationally with a high socioeconomic impact. Many efforts have focused on providing smart environments to the final user in vehicles such as cars, capable of detecting contextual vehicle's conditions and adapting automatically to the user needs. This paper proposes an innovative solution in the automotive field consisting of a new product family which allows the transformation of a traditional bicycle to an electric bicycle by an architecture that provides the user intelligent adaptive environments and significantly improve the driving experience design enabling value-added services.

Keywords Electric vehicle · Ebike · Ebikemotion · Smartphone

1 Introduction

Bicycle are vehicles with a tremendous importance throughout history in our society, combining the advantages of a personal vehicle of small size with lowering emissions and promoting sports and physical exercise. The bike design has been altered in recent years with the development of accessories such as motors and batteries that turn it into an electric vehicle. In recent years there has been a gradu-

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al migration in the technological development of urban mobility, focusing on the development and expansion of the electric bicycle [3][2]. Nowadays, companies involved in bicycle and automobile sector, are investing in the production of new models of bikes, with lower production costs that make the number of sales grow each month. We can highlight that the bicycle market is continuously growing, being competition between companies higher every moment. The key reason for the growth in the number of sales is due to the widespread growth of urban centers [8], where the motor vehicle takes the lead due to the agile development of transport infrastructure [9]. Another reason lies in the pollution generated by the user of hydrocarbon-based vehicles [1], where electric ones take center stage but high powered are at the very early stage of development yet.

Electric bikes are in the process of expansion, attracting the attention of researchers and manufacturers [5]. Nowadays, one of the aspects that needs attention and is an effort to design is the development of robust and flexible in terms of hardware, software and communications architectures. Likewise it is important to identify a model of integration for all these elements that will allow building a system of interaction and control between the user and the electric vehicle [11]. Especially, it is of particular interest the design of systems for the active integration of users in the system, optimizing the performance of all components through algorithms and systems using new communication technologies (geolocation, telephony, mobile messaging, etc.).

To achieve this objective we propose define and design a comprehensive control system and a wireless mechanism (joystick) of human-machine interaction.

The development of a flexible and open architecture will allow the gathering of information about the user, road and environment, being able to detect unusual situations such as accidents or theft. The architecture in this article will serve as a basis for a future where users can share experiences and racing with other users without direct vision between cyclists. Information about physical phenomena such as wind, dangerous zones, etc., will be able to be gathered in real time. In addition, the state of the system, like battery status and motor faults, should be monitored so that the user has a comprehensive control of the vehicle and its environment.

This article is organized as follows: section 2 shows a review about the state of the art and related projects, section 3 describes the architecture proposal, section 4 describes a case study, which will be used to evaluate the system, and finally section 5 exposes the results and conclusions obtained.

2 Background

Currently on the market exists a wide range of integrated systems for the management and monitoring of electric bicycles. Most of these systems are composed of several modules interconnected together via standard protocols, both wired and unwired.

For reading and processing data and information coming through the own electric bicycle (voltage, amperage, instantaneous power consumption, etc.) are included with the installation on the bike of a series of reading sensors that send, through a single bus, all the information in real time.

For sending information, as described in [6], the CAN-Bus (Control Area Network) standard is used which enables hardware devices (microcontrollers) to communicate with each other without the need for a computing unit core, as shown in Figure 1, which due to its inherent characteristics it has been shown to be an efficient and reliable method for exchanging real-time data in a system [12].

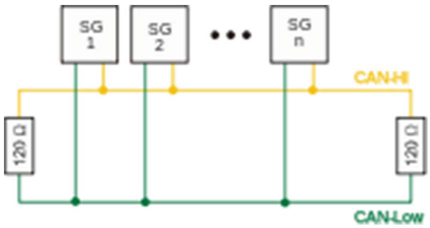

Fig. 1 Architecture of a CAN-Bus.

This protocol was originally introduced in 1983 by Bosch and later was approved as an ISO standard (ISO11898 and various revisions and subsequent variants).

This protocol is already widely used in vehicles for communication between devices and the features described above make it ideal for a bike to have sensors that are transparent and are abstracted from the hardware to which they are connected by sending the system's relevant information without worrying about the hardware.

The architecture that make up these CAN-Bus enabled systems are usually of two main types:

Centralized: the system counts on a central hardware device that collects information on a single node which can be active if it performs processing and interpretations of the information received; or passive, if its role is gather the information and forward it somewhere else.

Decentralized: these systems have a single bus which carries the information without worrying about where it's going or what is going to be done with it.

The centralized architecture offers advantages over decentralized related to the capability to process the information in a real time basis which allows the system to make decisions without the need for additional equipment in the architecture, as well as adding new devices with new bus that are connected to the central node, as well as the independence between the different elements of the system. However, the main disadvantage is the dependence of the entire system on the hub or central node, as otherwise the system would be isolated.

The limitation of this type of implementation is its closed and wired nature of the communication of the integrated devices in the system. The popularization of smartphones and its low cost with increasingly higher computing capabilities and wireless communication [7] make it suitable of being the bridge element between the wired system which conforms the electric vehicle itself with the outside. Due to the characteristics of the system to which we refer, low power consumption and medium range communication properties become keys to communicate the vehicle system with foreign elements. That is why Bluetooth becomes the focus for communication devices interconnected by CAN-Bus with an external device outside the vehicle system itself.

Both 2.0 and 3.0 versions of the Bluetooth protocol [4] was designed for the data transmission to low range but at high rate, without being possible to operate the protocol and the hardware in a low power mode until the Bluetooth Low Energy (BLE) was introduced in the 4.0 protocol update. This review focused on the operation in situations of very low consumption at lower rate and the possibility of data failures in the transmission.

The low cost of integrating such hardware into existing CAN-Bus systems have made major manufacturing companies have integrated accessories and ebikes such as Bosch and COBI, as can be shown in Fig. 2.

Fig. 2 Bosch information display and joystick to hands-free manipulation on operation.

The main problem which faces the integration of the solutions proposed by different companies is the proprietary communication protocols and the requirement of its solutions for interaction throughout the vehicle system. Besides these closed systems include the capability of pairing with a smartphone via Bluetooth BLE, restricting the user experience to the tool provided by the brand.

In this paper we propose the use of a central hardware device that can be used with existing CAN-Bus systems for the communication of the system devices and its external communication through an open protocol Bluetooth BLE based, but also a software system for both iOS and Android that offers a customizable user experience in response to the needs of users of the systems.

On the other hand, there is a need for the presence of an element of human-computer interaction to provide the user the ability of modify, make decisions and control the system status. The majority of market systems have a main element of interaction like a joystick, as shown in Fig. 3.

Fig. 3 Example of a human-computer interaction device for electric bicycles.

The joystick is a hardware device connected to the electric bicycle system and, by operating the integrated controls, allows the user to set the system parameters and interact with it.

These interactive elements have similar problems of integration as the CAN-Bus ones, its closed protocol and the inability to adapt the user experience to the needs of each individual. Therefore, in this article, also a hardware device is proposed, that enables the integration of an interface with the rest of the system through human interaction that is capable of operate with most of CAN-Bus based systems applied to electric bicycles.

3 Proposal

This sections describes the architecture that connects universally an accessory to control the bicycle turning it into an electric vehicle [10].

The realization of the idea proposed is proposed by means of an architecture has shown in Fig. 4 and whose components are described below:

- Human Communication Interface.
- EBM Communication Module – Gateway.
- Intelligent System for Social Computing.
- Joystick.

In the Fig. 4, a component diagram that conforms the architecture is shown. It includes the wireless communication between the Communication Module (EBM – Gateway) and the Human Communication Interface as well as the different wired connection between each installed reading device in the electric vehicle with the central node. Every communication of the system with the external devices is made through Bluetooth BLE and the proposed protocol.

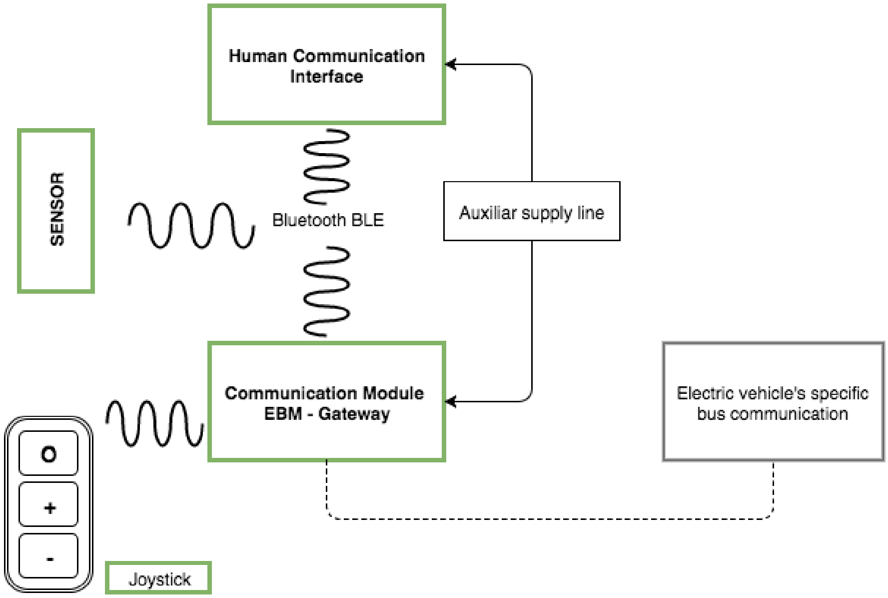

Fig. 4 Architecture of the proposed platform.

Control System / EBM Gateway: The aim of the proposed system is to provide an effective and efficient management of an electric vehicle (bicycle) and adapted to the need of the user through a human-machine interface incorporating innovative features as context awareness. It provides a new design which incorporates a communication module EBM (Bluetooth) which performs as gateway between the electric motor and the human communication interface (and additional devices that may be connected).

Joystick: A differential architecture aspect in the introduction of a mechanism of interaction with the user based on a joystick. Although nowadays joysticks can be found in science and market that allows the user to interact with the bicycles, you cannot find a joystick like the one proposed in this project: wireless, symmetrical (for both left-handed and right-handed users) that allows an adaptive mapping functions of the power unit of the vehicle.

The proposed architecture aims to provide the system with communication capabilities through the smartphones available in the market, so it can monitor the information from the engine, set its parameters (wheel size or battery type and number of cells) and put them combined with context sensitive and social information. Such information can be obtained through sensors such as GPS or advanced calculations from third-party computers connected by Bluetooth BLE (pulse bands, clocks, etc.).

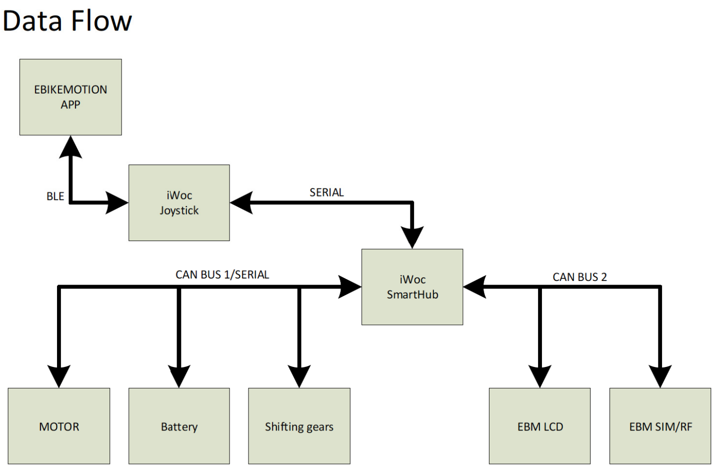

Fig. 5 Proposed communication between devices.

To fetch the engine information, the human communication interface receives several information chunks of information related to the battery or the motor status through the Bluetooth interface in the user's communication device (typically a smartphone), as shown in Figure 5, so there will be a hardware device that may be connected to the serial bus engine and will pack and send the information to the human communication interface through a standard protocol. Also it makes necessary to exist the design and construction of a physical interaction device such as the joystick, which guarantees the user's capability to interact with the system without taking its hands off the handlebars.

The communication protocol proposed is based on the BLE's own characteristics. The system emits periodic messages, as shown in Table 1, without confirmation and around a 2Hz rate each one, with the state of each one of the components that are connected to the system. The creation of the communication protocol of message exchange is accompanied by a software system precompiled that remain available for most mobile platforms (Android and iOS), allows the interpretation and synthesizing information provided by the system and allows developers perform actions (show and hide information) and decision-making through the communication interface.

Table 1 Information exchanging protocol.

Message	Action
0x01#bYX#@	Button pulsation
#lXY#@	LED status
sA#000000#@	Bike autonomy
mT#000#@	Engine temperature
mV#000#@	Instantaneous speed
mP#000#@	Instantaneous power

The fundamental component which conforms the human interaction interface is the development of a smartphone application supported in the architecture and services provided through the Bluetooth BLE and CAN-Bus communication systems.

The proposed application has unprecedented modularity that allows full customization of the user experience form deciding the components of information visible on the screen at all times to maximize the user's attention in driving the bike and show the information relevant to each individual.

Also features offline operation, consistent with the nature of the common profile of mountain biker that can rarely have a reliable connection for browsing the internet for directions. For this reason, the application has the ability to install map packages that can be used offline, ensuring total user experience even in offline environments.

4 Conclusions and Future Work

The proposal exposed by this article are taken from different software and hardware products that together provide a driving experience management and interaction with an electric bike system that gives the user complete freedom of customization according to individual characteristics.

Fig. 6 Shot of the electric bicycle.

To create the system and in order to prove that the system is open and fully compatible with devices already on the market a conventional bike brand Orbea was used to which was added a battery band Epro model Yoku YK3611ZDDR1 compatible with CAN-Bus protocol as well as a motor brand 8FUN, elements shown in Fig. 6.

Both hardware elements CAN-Bus compatible were connected following a centralized architecture with a central node that has the Bluetooth BLE communication system that lets the user interact with external devices.

The main external device that the system can communicate with is an Android or iOS smartphone Bluetooth BLE compatible that have the application installed, the interface of which can be seen in Fig. 7. This implementation achieves the goals of providing the user the ability to customize their experience on the bike in the most flexible way possible and provide services such as navigation with voice instructions through tracks and bike trails as well as installing maps of territories in offline mode so Internet connection is no longer required for the operation of the application.

Fig. 7 Fully customizable interface of the Ebikemotion app.

Finally, to address the objective of offering the user an interaction way with the system (including the smartphone itself) a human-machine interaction integrated hardware device has been designed, as shown in Fig. 8, comprising a joystick that has three buttons for controlling with pulses of short and long term, different aspects of the behavior of both the electric bike (level of assistance, turning on and off the system, pairing mode) and the application (navigation between screens, repeat navigation instructions, spoken summary of the tracking, etc.).

Fig. 8 Human-machine interaction device proposed.

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Smart Waste Collection Platform Based on WSN and Route Optimization

Álvaro Lozano Murciego, Gabriel Villarrubia González, Alberto López Barriuso, Daniel Hernández de La Iglesia, Jorge Revuelta Herrero and Juan Francisco De Paz Santana

Abstract In this paper, we present the design and implementation of a novel agent-based platform to collect waste on cities and villages. A low cost sensor prototype is developed to measure the fulfilling level of the containers, a route system is developed to optimize the routes of the trucks and a mobile application has been developed to help drivers in their work. In order to evaluate and validate the proposed platform, a practical case study in a real city environment is modeled using open data available and with the purpose of identifying limitations of the platform.

Keywords WSN · Smart cities · ESP8266 · IoT · Route optimization · CVRP

1 Introduction

Nowadays the number of cities that integrate new systems to improve the public services offered is exponentially increasing. More and more cities and towns have a network infrastructure that provides Internet access to citizens and sensors that can be placed throughout the city. This makes possible the implementation of systems providing the cities with intelligent features to turn them into smart cities. There are several descriptions of potential systems which may be included in smart cities [1], such as energy grids, public lighting, water management, public security, transport mobility and logistics, healthcare, etc. This paper focuses on the design of a smart waste collection platform in all these systems.

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Thanks to the emergence of new, cheap and efficient sensors on the market, as the ESP8266 sensor [2], it is possible to design new devices that can be easily integrated into the Internet of Things (IoT) and can be used to create affordable wireless sensor networks (WNS) [3]. This allows the development of the infrastructure of low cost intelligent systems and enables its deployment in cities and towns with very low budgets. This paper describes how to develop a wireless sensor network based on devices that have a volumetric sensor for detecting the filling level of containers. It also explains how they communicate with the smart platform through a network infrastructure.

Furthermore, one of the fundamental objectives of smart cities is savings in transport and city logistic. Having more information about the city and its state makes possible the development of intelligent systems to optimize transport and routes. This paper describes how to include frameworks as Optaplanner [4] with algorithms in order to solve the classic Capacitated Vehicle Routing Problem (CVRP) [5] and optimize routes that followed by the trucks follow when collecting waste.

To complete the platform, an application has been developed. This application al-lows truck drivers to follow the daily planned route as well as notify the location of each truck to the system in real time. Additionally, a geographic information system (GIS) has been added to store a history of the routes taken by trucks and all data related to routes such as average speed, etc.

Finally, the city of Málaga has been chosen as a case study for a first approximation of the system. An open dataset [1] has been used to perform a simulation of the system on a real environment.

2 Background

2.1 Current Systems

Nowadays there are several studies in the literature [2, 3] concerning smart systems for collecting waste in cities [6]. The European Union has already funded projects focused on designing these systems, such as project LIFE E-WAS [7].

There are numerous professional solutions on the market like Enevo [8], which offers a similar system with robust sensors but with a very high cost. This paper is intended to design a system that uses new low-cost sensors and open source route optimization frameworks in order to reduce costs and make possible the implementation of the system in cities and towns at a reduced price.

2.2 CVRP Problem

A fundamental part of the system, apart from sensor network in the city or town, is the optimization of the routes that must be followed by the truck when it comes to collect waste.

The main objective is the optimization of the distance travelled by trucks to collect waste. This will reduce fuel costs and increase the useful life of the vehicle fleet. This is a classic optimization problem called Vehicle Routing Problem (VRP) [9].

The VRP [10] is a nonspecific name given to a whole class of problems in which a set of routes for a fleet of vehicles based at one or some depots must be determined for a number of geographically disseminated cities or customers. The objective of the VRP is to deliver a set of customers with known demands on minimum-cost vehicle routes starting and finishing at a depot. In this case, the customers are the city containers and their demand is the filling level. Fig. 1 shows a usual input for a VRP problem and its possible outputs:

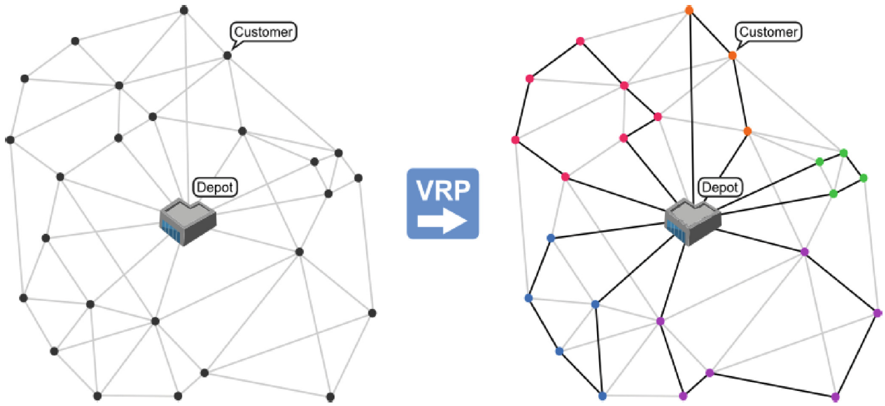

Fig. 1 Classic VRP input. (Figure from Networking and Optimization Group) [7]

A variant of this case is a Capacitated Vehicle Routing Problem (CVRP), which is the same problem as VRP, but with the additional constraint that every vehicles must have uniform capacity of a single commodity. In this case, this restriction refers to the maximum load that each one of the trucks in the fleet can store.

There are a lot of VRP variants, as VRP with Pick-Up and Delivering, VRP with Time Windows, etc. For this work we assume the case of study as a CVRP[11].

There are several solution methods for VRP. Most of them are heuristic and metaheuristic solutions because the exact approaches cannot guarantee optimal solutions in a reasonable time whit a high number of containers, like in this case. Some of these methods are indicated below:

- **Exact Approaches:** This computes every possible solution until one of the best is gotten. Such us Branch and bound [12] or Branch and cut [13, 14].
- **Heuristic methods:** This methods perform a limited exploration of the search space and they normally obtain good quality solutions within modest computing times.

- **Metaheuristic methods:** Generic methods of exploration of the search solution space for search and optimization problems. This methods provide a line of design that is adapted in each context, and can generate more efficient algorithms. In general, metaheuristic methods outperform classical heuristic methods, but incur higher runtimes. Some of these methods are:
  - Ant Algorithms [15][16]
  - Constraint Programming [17][18]
  - Genetic Algorithms [19]
  - Tabu Search [20][21][22]

3 Smart Waste System

3.1 Proposed Architecture

The overall architecture proposed (Fig. 2) for the system consists of the following parts:

- **Wireless Sensor Network:** based on a Wi-Fi infrastructure. The developed sensors are installed in the containers and they send the filling level of the containers using the MQTT [23] communication protocol.

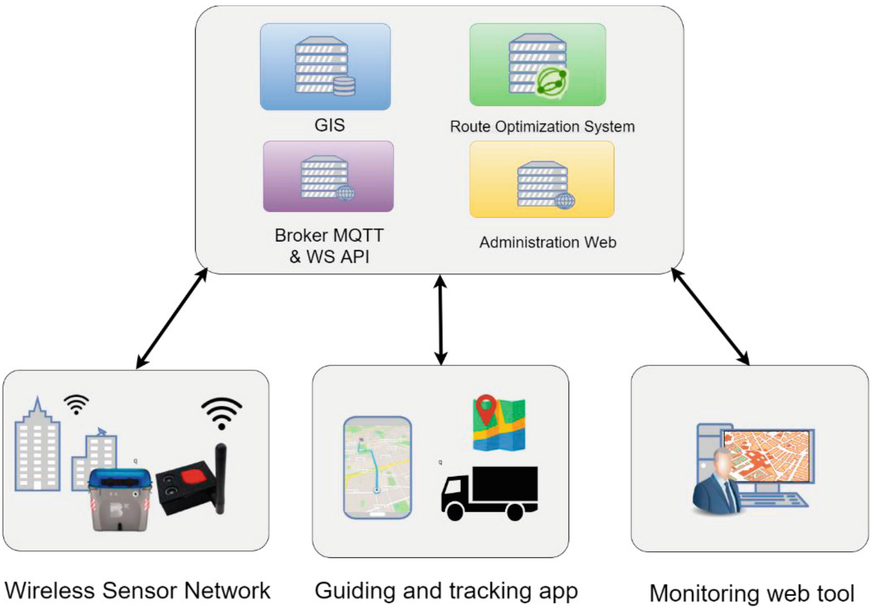

Fig. 2 Platform diagram

- **Broker MQTT & Web Services API:** the system has a MQTT broker in which each sensor of the WSN publishes its messages and the system stores it. The system also has a Web services API which is used by the mobile app and the administration website.
- **Mobile Application:** This application guides drivers through the planned route for each working day. The application also records information about the route followed by each truck and sends it to the server.
- **Administration web:** Website that shows the route calculated for each day and the location of the trucks in real time during the waste collection.
- **GIS:** Collects information on planned routes for each collection, routes that the trucks have followed, information regarding the location and status of sensors, etc.
- **Route Optimization System:** system in charge of calculating the route planning to be followed each day based on the information from the sensors and the fleet of vehicles available for collection.

3.2 Developed Sensor Device

A Wi-Fi volumetric sensor prototype has been developed trying to minimize the cost. The Table 1 shows the components used in the prototype development and their market prices:

Table 1

Component	Price
LiPo Battery 7.4V (1500 mAh)	8.93€
ESP8266 12E	3.08€
Power Supplies	1.20€
Wifi Antenna 5dB	1.03€
Ultrasonic Sensor HC-SR04	0.79€
Resistors & wires	2.00€
Board	1.00€
3D printed case	1.30€
Total	19.33€

The figures below show some of the components without soldering on the board (Fig. 3 a) and the prototype assembled in a printed 3D case (Fig. 3 b).

The prototype is placed on the top part inside the container. This makes possible to obtain the approximate filling volume of the container with the ultrasonic sensor. When the device performs a measurement and sends it over the network its maximum consumption is about 250 mAh. The rest of the time, the ESP8266 device disables the other sensors and parts of the board and enables the Deep Sleep mode [21]. The consumption of the whole board in *Deep Sleep* mode is about 128μA. It is important to consider these values to select the battery capacity of the prototype. The device must be operating every day between cleanings. The periods between the containers cleanings are usually marked by the city council and the concessionaire cleaning company.

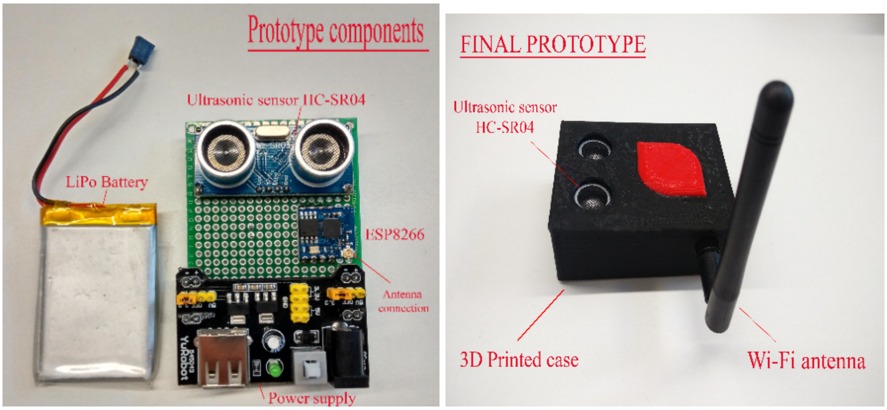

Fig. 3 a) Prototype components b) Final prototype

3.3 Routing Optimization System

The routing optimization system has been built on the open source framework Optaplanner. This is mathematical optimization framework that solves constraint satisfaction problems with construction heuristic and metaheuristic algorithms.

The following figure (Fig. 4) shows a diagram of the process of route optimization.

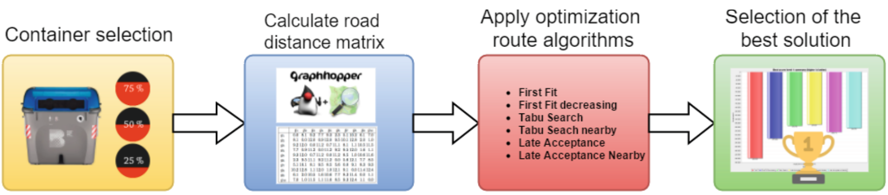

Fig. 4 Diagram of optimization route process

- Firstly, the filled containers previously defined and threshold are selected. The locations and the filling level of selected containers are obtained.
- Secondly, the road distance matrix of all selected containers is obtained. To perform this process the real distances are extracted using the framework GraphHoper. [22, 23] with stored geographic data. The result of this process will be a N x N distance matrix.
- Subsequently, several algorithms are applied for a fixed time period. At this point, the possible routes to be followed by trucks will be calculated.
- Once the solution is obtained, the best score is selected. This solution is stored as waste collection planning for the next workday.

3.4 Mobile Application

A mobile application has been developed to allow truck drivers use it while performing waste collection. This application consists of two main features:

- **Guiding:** At the time of the collection of waste, the application gets the route that has been assigned by the routimg optimization system for that day (Fig. 5). The application provides a guide for the working day.
- **Tracking:** The application records information about the GPS location of the truck and storing data related to the speed and journey. This information is used by the website administrators to monitor trucks and stored for later studies.

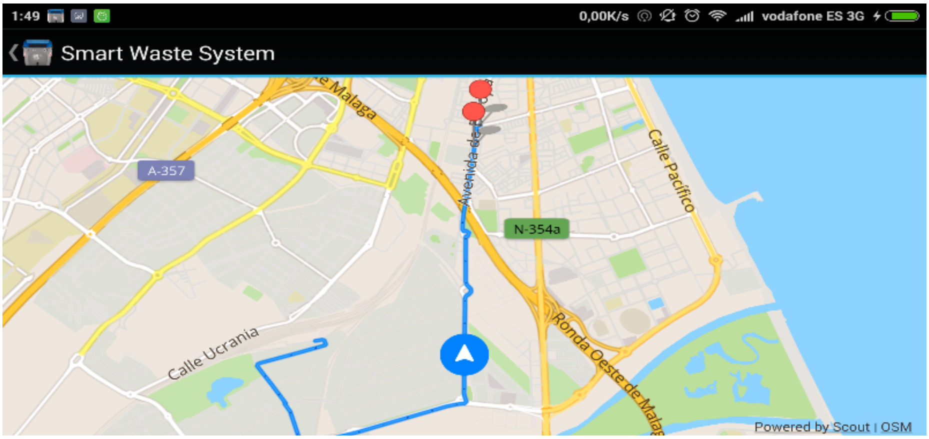

Fig. 5 Smart Waste System App

4 Case of Study

In order to validate the operation of the platform in a real environment, a case study has been performed in Málaga. Málaga City Council has an open data portal in which there are several sets of data regarding waste from the city. We have chosen a data set of paper and paperboard containers including a total of 1473 containers of three different types: bell, underground and lateral load. We have done a simulation of the collection process of side loading containers (640 containers) and we have established a recycling center as a depot. The following figure (Fig. 6) shows the system administration page showing lateral load containers and recycling center.

The load levels of containers have been generated randomly to perform the simulation. It has been set a fleet of 10 vehicles that can pick up lateral load containers.

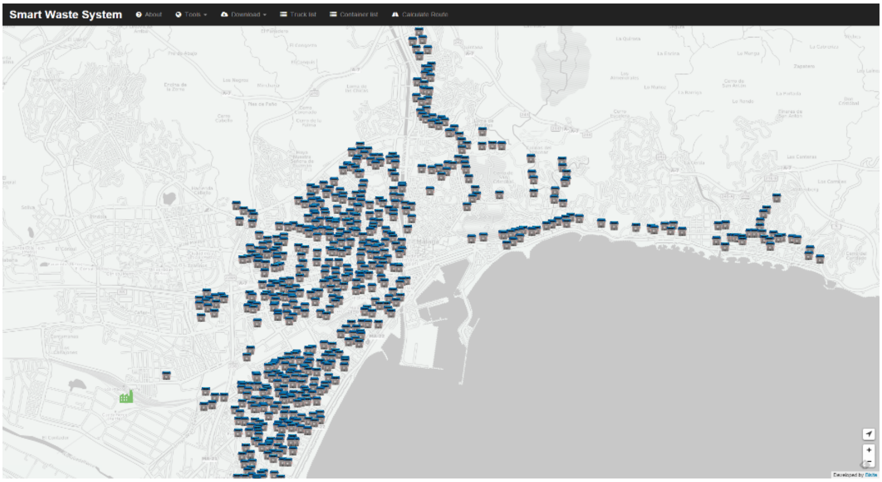

Fig. 6 Locations of lateral load containers

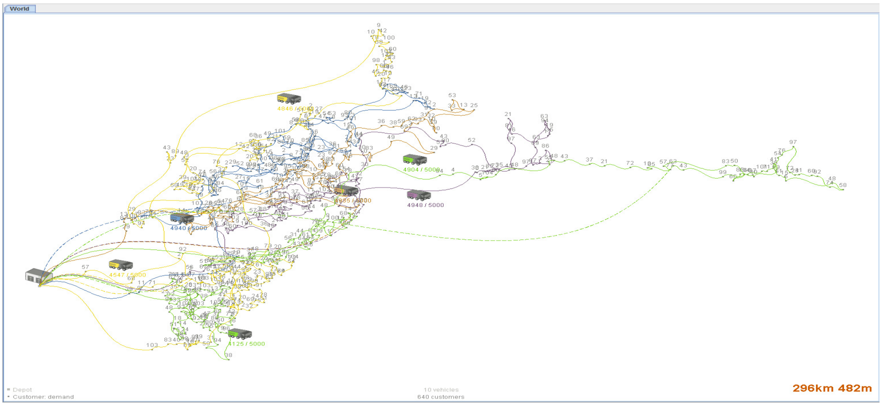

Fig. 7 Optaplanner simulation

The following figure (Fig. 7) shows a simulation of the route calculation performed by the Tabu Search algorithm using a tool provided by Optaplanner. The simulation shows the containers filled levels randomly generated and shows how the algorithm finds solutions during its execution. The tool draw curved lines to emphasize that in this case is road distances. The tool also showed (in the lower right corner) the total distance that involves the obtained solution.

The figure below (Fig. 8) shows the above solution but already represented in the web management system.

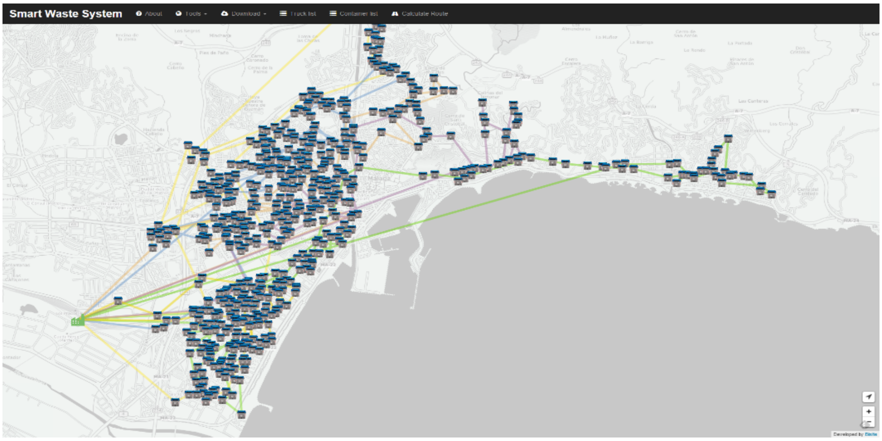

Fig. 8 Simulation on web administration page

5 Conclusions and Future Works

In the case study has been proven the performance of different algorithms implemented in the framework Optaplanner. It can be seen in the following charts the score obtained by the algorithms after 5 minutes (Fig. 9 a) and 2 hours of execution (Fig. 9 b).

Tabu Search algorithm to find the best solution after 5 minutes of execution, while after 2 hours of execution the best solution is found by Latte Acceptance algorithm.

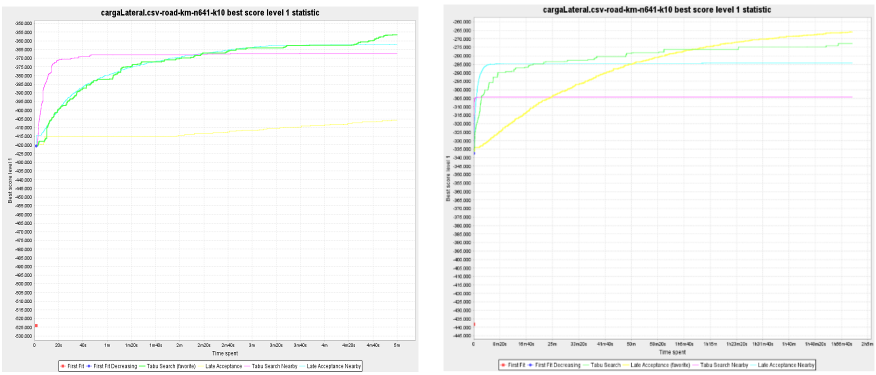

Fig. 9 Algorithms score benchmark results: a) 5 minutes b) 2 hours

This aspect should be kept in mind when implanting the final system as the time dedicated to the calculation may offer a better solution. Therefore there must be a balance between time and best score.

After testing in the case study, the proper performing of the optimization routing platform in an environment with real data has been evaluated. In this work we have also demonstrated the feasibility of building a low cost prototype able to be a part of a WSN and get data from the containers located in the city.

Subsequent studies should evaluate and identify potential weaknesses of this prototype as well as evaluate potential adverse conditions that the prototype may suffer as well as evaluate potential adverse conditions that the prototype may suffer. Testing should be performed in real working environments.

In conclusion, the system optimizes the waste collection of a city and reduces the consumption of the vehicle fleet, and increases its life. The system and its use subsequently generate data that will be used to perform studies on areas producing more waste which will help to identify the city needs.

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Using Computer Peripheral Devices to Measure Attentiveness

Dalila Durães, Davide Carneiro, Javier Bajo and Paulo Novais

Abstract Attention is strongly connected with learning and when it comes to acquiring new knowledge, attention is one the most important mechanisms. The learner's attention affects learning results and can define the success or failure of a student. The negative effects are especially significant when carrying out long or demanding tasks, as often happens in an assessment. This paper presents a monitoring system using computer peripheral devices. Two classes were monitored, a regular one and an assessment one. Results show that it is possible to measure attentiveness in a non-intrusive way.

Keywords Attentiveness · Learning activities · Mental fatigue · Stress

1 Introduction

Our society, in permanent change, requires a continuous adaptation of the human being to the surrounding environment. We live in a global, multicultural and hyper-connected world where technology is present in all spheres of life and is the backbone for the transformation of society.

In the education field, ICT should be considered as an innovation, since it involves a personal and collective work of reflection, realization and change. So ICT has expanded the range of possibilities of teaching and implementing innovative methodologies.

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Scientific studies have shown the influence of states attention on student learning [1-3]. These indicators are useful to predict the behavior of a student and i dentify potential problems in the course of their learning. By using behavioral biometrics, especially Keystroke and Mouse Dynamics, it's possible analyze the type of the task performed by each user, the time spent performing it, as well as the mental workload of the task. With this information it's also possible for classifiers to distinguish situations in which each user shows signs of attentiveness and where higher or lower mental workload is measured [1].

This technique is based only on the observation of the use of the mouse and the keyboard, which allows an assessment of the user's performance. Consequently, we considered both non-invasive and non-intrusive approaches. In this way we can use this technique to develop the attention level and management initiatives in the context of learning activities, allowing teachers to perceive the student's state of mind and adjust the teaching process to the student's needs and behavior.

Teaching should be solidly grounded to the absolute understanding of how the process of learning occurs so that instructional strategies could be efficient and lead to persistent knowledge. This is especially true when learning activities involve technologies. In such cases, some of the previously mentioned issues can negatively affect the acquisition of knowledge and the persistence of that same knowledge since students have other technologies and applications that they can use and this can distract them.

In this article we focus on a new field of application of ICT techniques and technologies in learning activities. The goal is to determine the level of attentiveness in normal and assessment lessons and compare it with results achieved by students.

This paper is organized as follows. In the next Section theoretical foundations of attention where scientific literature is reviewed, Section 3 analyzes keyboard and mouse for attentiveness detection. Finally, in Section 4 and 5 some initial results and conclusions of this work are presented.

2 Theoretical Foundations

The concept of attention has had different definitions since the nineteenth century. Initially, it was only a study field of psychology. However, in recent years it was object of study in different areas including biology, education science, psychiatry, and computer science.

Being a cognitive process, attention is strongly connected with learning [2]. When it comes to acquiring new knowledge, attention can be considered one of the most important mechanisms [1]. The level of the learner's attention affects learning results. The lack of attention can define the success of a student. In learning activities, attention is also very important to perform these tasks in an efficient and adequate way.

When students are using technology, and especially when connected to the Internet, distractions can occur. This happens because they have access to messages from chats, social networks and emails; and other applications like music applications and news sites, which can be more attractive to students. Moreover, these applications can constantly run in the background. When these activities are prolonged for a long period they may have decreased the level of attention [4].

2.1 Features That Influence Attention

Generally, there are some factors that influence attention level: stress, mental fatigue, anxiety, emotions, different environment and human health [16].

Stress may have a positive or negative influence. On the one hand it is generally accepted that stressful events increase the level of attention [5 - 9]. On the other hand, there are cases in which stressful events cause depression or aging [10, 11].

When some activities are prolonged for a long period of time, our brain may feel overheaded with such amount of information, and this leads to a potential emergence of mental fatigue, which decreases the level of students' attention.

A substantial literature shows that anxiety affects perceptual and related processes of attention [12]. Anxiety has an impact on cognition and attention because it is often associated with adverse effects on attention of cognitive tasks [13].

Finally, health problems, mood, and the surrounding environment can also influence the level of attentiveness. Figure 1 presents a design of factors that influence attention.

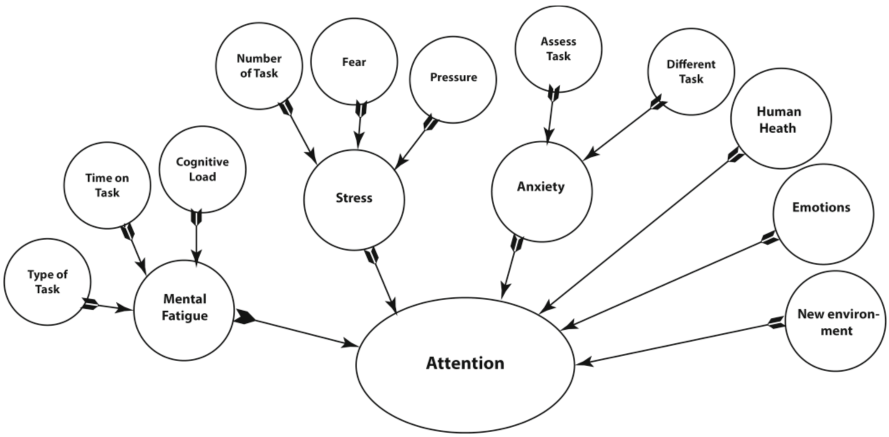

Fig. 1 Conceptualization of the set of factors that influence attention.

3 Study Outline

The purpose of this work is to compare a normal and an assessment class at the Secondary School of Caldas das Taipas, Guimarães, Portugal. We want to determine if classes with different goals have a significant effect on mouse and keyboard dynamics and how can we estimate attention level.

3.1 Methodology

For this purpose, a group of 13 (10 girls and 3 boys) art students were selected to participate, whose average age is seventeen years old. In different weeks, they have a normal and an assessment lesson, where they have access to an individual computer and three hours to complete a task. The lesson started at 8:30 and finished at 11:00 a.m. Students received, at the beginning of the lesson, a document with the goals of the task. The normal and the assessment lessons contained tasks to be completed using Photoshop.

Data collection was carried out using a logger application developed in previous work [4]. The data collected by the logger application, characterizing the students' interaction patterns, is aggregated in a server to which the logger application connects after the student logs in. This application runs in the background, which makes the data acquisition process, a completely transparent one, from the point of view of the student.

3.2 Data Analysis

In this section we show the existence of different behaviors in the two different lessons. Data was analyzed in two different ways. First was carried out a general analysis in which statically methods are used to obtain preliminary conclusions. Second, an individual analysis was made in order to compare the different moments.

Although the collected data describes the interaction with both the mouse and the keyboard [14], only data from the mouse was considered in this analysis. This is due to the characteristics of the task, which was based on Photoshop that requires mostly the interaction with the mouse The amount of data collected from the keyboard was too small to allow sound analyses. Another important aspect worth mentioning is that Photoshop requires a precise use of the mouse, which makes it a suitable application to the current study.

In a preliminary analysis of the data, we concluded that there are indeed different interaction patterns depending on the type of lesson analyzed indeed. To conclude this, we looked at the distributions of the data collected and analyzed the statistical significance of their differences. To this end, we used the Kruskal-Wallis test. Table 1 details the mean value of each feature in each class (evaluation and normal). It also details the *p*-value of the Kruskal-Wallis test.

Table 1 Results of the Kruskall-Wallis test and mean values for ech class and each feature.

Feature	Symbol	Significance	Mean Evaluation	Mean Normal
Mouse Velocity	mv	0,0011	0,49	0,53
Mouse Aceleration	ma	0,0010	0,54	0,57
Click Duration	cd	0,0035	245,38	159,83
Time Between Clicks	tbc	0,0966	1964,19	3063,11
Distance Between Click	dbc	0,0001	150,83	206,12
Duration Distance Clicks	ddc	0,0545	143,04	143,97
Excess Distance Between Clicks	edbc	0,0000	154,00	309,48
Absolute Excess Distance Between Click	aedbc	0,0000	1,54	2,05
Absolute Sum Distance Between Clicks	asdbc	0,0094	4006,31	5038,24
Distance Point to Line Between Clicks	dplbc	0,0169	21611000,00	37026200,00
Absolute Distance Point Between Clicks	adpbc	0,1361	157647,00	208223,00

When data from the two classes is compared, the first conclusion is that the differences observed are statistically significant in nearly all features, with the exception of Time Between Clicks, Distance During Clicks, and Average Distance Point Between Clicks.

Moreover, mean values of the features are consistently lower in the evaluation class. In most of the features, this indicates an increased performance (e.g. a smaller average distance between clicks means that the student moved the mouse in a more efficient manner). However, in the case of mouse velocity, for example, a smaller velocity could point out a slower, and thus less efficient, movement. In past work we concluded that a slower mouse velocity is indeed necessary for the student to achieve increased accuracy in mouse movement: moving the mouse too fast would make precise movements more difficult to carry out. This is especially true in tasks such as those of this study. A similar trend happens with mouse acceleration and click duration. The remaining features consistently show increased performance in the evaluation class.

The Figure 2 shows the distribution of the values for all the users and for each feature. We can see that the results of each feature are very different in the two lessons. The students react in different ways in the assessment and normal lesson. We can also consider that, in general, they are more focused on the assessment lesson because they have a mouse velocity, mouse acceleration, and distance point to line between clicks slower and the click duration was higher.

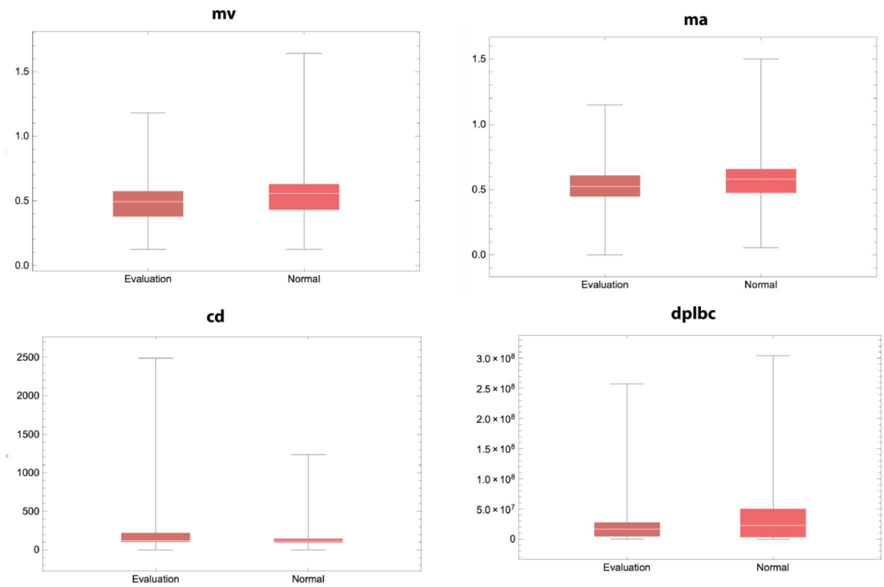

Fig. 2 Distributions of the data collected in the two different classes (Evaluation vs. Normal), in four different features: Mouse Velocity, Mouse Acceleration, Click Duration and Distance of the Pointer do the Line Between Clicks.

The selected of features characterize several aspects of interaction on normal and assessment lesson. However, this doesn't mean that they are all affected equally or that they are all affected at all when they have an assessment. A curious property of these features comparing the normal and the assessment lesson was that the mouse velocity and the mouse acceleration are lower and the click duration is higher in the assessment lesson. Figure 3 compares the histograms of mv, ma, and cd and evidences the differences between the two classes.

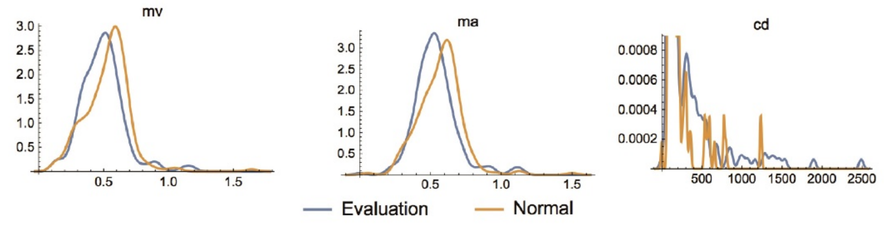

Fig. 3 Comparing mv, ma, and cd during the lessons.

From these studies we conclude that the most significantly affected features are mv, ma, cd, tbc, dbc, ddc, edbc, ssdbc, and dplbc. In all these features almost all students show statistically significant differences when comparing the two lessons.

4 Preliminary Results

During the two lessons, the monitoring system was used to assess the interaction of the students with the computer and to quantify their level of attentiveness, as well. To quantify attentiveness the following methodology was followed. Asides from capturing the interaction of the students with the computer, the monitoring system also registers the applications with which students are interacting. We analyzed all the applications used by all students and labelled each one of them as belonging to the task or not. We then quantify the amount of time that each student spends interacting with applications related to the task versus other applications.

Table 2 details the results of this quantification. Students have a clearly different attitude in the two lessons: when being evaluated, they spend more time interacting with task-related applications, a sign that they are more focused on the task. The results thus point out, not only, that it is possible to quantify student attentiveness in a non-intrusive way, but also that attention is higher when under evaluation. This was an expected conclusion but it nonetheless validates the proposed approach.

We also analyzed the correlation between the level of attentiveness and the score of the students in the task. There is a weak positive correlation (0.41) between the two variables. We believe that this value is not higher for two reasons: (1) this class is mostly composed by "excellent" students and (2) the task was of average difficulty. Thus, there were not many differences in the scores. In future work we will study this relationship in more detail, namely in different classes and with tasks of different levels of difficulty.

Table 2 Total time (seconds) devoted to the task and percentage of total time devoted to the task, while being assessed and while in a normal class, for each student.

Student	Assessment		Normal	
	Total Time (s)	% Time	Total Time (s)	% Time
T7110001	3156,22	67%	690,20	31%
T7110003	2416,01	55%	1253,07	32%
T7110005	2475,14	63%	1807,26	40%
T7110006	1571,11	36%	494,07	19%
T7110007	3177,28	53%	701,26	30%
T7110008	2492,51	58%	783,33	26%
T7110009	4264,73	72%	2130,49	53%
T7110010	3239,52	74%	1451,13	40%
T7110011	3845,71	71%	737,86	20%
T7110012	3581,57	58%	157,73	30%
T7110013	835,24	48%	1588,86	40%

5 Discussion and Future Work

It is imperative to mention that these features aim to quantify the student's work and estimate the level of attentiveness. These experiments allow drawing some interesting conclusions about students and their behavior during the assessment. However, this test was implemented in a good class with higher scores in all subjects. Yet, they react in different ways during normal or assessment lessons. We can see that they are more focused on the assessment lesson so they have a higher attention level in these situations. We also concluded that there are also significant differences in the interaction patterns when comparing the two classes.

In future work we will determine if there is a relationship between these two phenomena or if they are both dependent on other factors, such as the level of stress. We will also implement similar studies in other classes with overall worse scores and using tasks of different complexities. With this we will train classifiers that can estimate the level of attention of students, in real-time, to provide an important source of information for teachers to act accordingly and in a timely manner [15].

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Mobile Sensing Agents for Social Computing Environments

Javier Bajo, Andrew T. Campbell and Xia Zhou

Abstract During recent years, research in smart cities and internet of the things has acquired a notable relevance. Current research is mainly focused on wireless sensor networks and data analysis. However, it is still necessary to provide new solutions for social problems based on mobile intelligent devices connected to the city. Mobility is a key factor for social environments in smart cities in which humans wear intelligent devices that can also be installed in vehicles and continuously vary their positions in the city. Social computing envisions a new kind of computation where humans and machines collaborate to compute and resolve a social problem. The role of mobile intelligent actors in social computing is still a challenge and require new solutions. In this paper, we present a multi-agent architecture that incorporates a new mobile sensing agent model and virtual organizations of agents for information fusion and machine learning, as well as contextual information to enrich the social knowledge representation.

Keywords Multi-agent systems · Human-agent societies · Social computing

1 Introduction

For the first time in human history, more people now live in cities than in rural areas, and in the next 20 years the urban population is expected to grow from 3.5 billion to 5.0 billion people [22][11][14]. The social, economic, environmental, and engineering challenges of this transformation will shape the 21st century. The lives of the people living in those cities can be improved – and the impact of this

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growth on the environment reduced – by the use of “smart” technologies that can improve the efficiency and effectiveness of urban systems. A smart city can be defined [28] as the integration of technology into a strategic approach to achieve sustainability, citizen well-being, and economic development. While there are many innovative pilot studies and small-scale developments that are looking at the smart city from a holistic perspective, there are not yet any examples of a smart city that supports hundreds of thousands people, much less millions. The smart city offers a coherent vision for bringing together innovative solutions that address the issues facing the modern city, but there are still many challenges to be dealt with. If the smart city is to truly become a blueprint for urban development, then a number of technical, financial, and political hurdles will need to be overcome.

Social computing is a new paradigm for computation that is concerned with the intersection of social behavior and computational systems. Social computing is basically the use of computers for social purposes, and the Internet has a big influence on this new way of computation. Computers were largely used as tools for increasing productivity, however, the Internet introduced a social element that allows the users to collaborate, share interests, publish personal insights and use the computers in a social way. Some authors define Social Computing as the computational facilitation of social studies and human social dynamics as well as the design and use of ICT technologies that consider social context [29]. For Robertson *et al.* [20] the power of the Social Computer resides in the programmable combination of contributions from both humans and computers: On the one hand, within organized social computation workflows, humans bring their competences, knowledge and skills, together with their networks of social relationships and their understanding of social structures. On the other hand, ICT can search for and deliver relevant information. Humans can then use this information within their contexts to achieve their goals and, eventually, to improve the overall environment in which they live. Social Computing has evolved during recent years to to improve social behaviors and relationships using computer science. The existing solutions have focused on theoretical underprintings, technological infrastructure and applications [29]. However, it is necessary to provide tools to facilitate the cooperation between humans and computers.

In this paper, we present a platform, designed as a social machine where humans, sensors and machines collaborate to provide services in smart cities. The platform is aimed at solving social problems with the support of a Cloud Computing system and a Big Bata environment. The platform is open and therefore able to work with any linked data, given sensor, actuator or robot. It incorporates an organization based system to facilitate the behavior adaptation to any given environment. The proposed platform is designed as a social machine, which provides more realistic way to improve social behaviors and relationships using computer science. The platform incorporates two innovative concepts: Mobile sensing and information fusion, which are designed based on virtual organizations of agents [13].

The rest of the paper is organized as follows: section 2 revises the related work. Section 3 presents the proposed platform. Finally, in section 4 the preliminary conclusions obtained are presented.

2 Related Work

According to Harrop and Raghu [7] the Wireless Sensor Networks (WSN) market is expected to grow rapidly worldwide from $0.45 billion in 2011 to $2 billion in 2021 [7]. WSN are being used for automating meter readings in buildings, for manufacturing, and in process control [2] [19]. They also have the potential to be used to automatically monitor storms, avalanches, fires, failure of country wide utility equipment, hospitals, traffic, etc. The same report indicates that the USA dominates the development and use of WSN, in part because of the heavier funding available there. Microsoft and IBM are investing enormous amounts of money on the development of WSN and the US Force is also very interested on their use. The American industry is leading the investment in this area [7]. According to Marketsandmarkets [7], the global smart cities market is expected to reach $1 trillion by 2016 [7]. The smart transportation and smart security market are also expected to reach $68.8 billion and $307.2 billion by 2016. According to this report there are approximately 700 cities with over half a million people, each one expected to invest over $30 trillion in technology over the next 20 years [7]. Pike Research also said that investment in smart city technology infrastructure will grow to a total of $108 billion between 2010 and 2020 [17].

This potential market requires innovative solutions that should provide advanced capacities for learning, adaptation and mobility. One of the possibilities is the use of multi-agent systems. Some benefits of using a multiagent system to manage sensor networks have been demonstrated in several projects [20][15]. However, it is not possible to find in the literature platforms designed from a social point of view. In this regard, the proposed multiagent platform proposes an innovative perspective based on social computing and virtual organizations of agents. Social Computing is a new paradigm based on a user-centered design and organizational aspects to create computational systems. On the other hand, some of the existing architectures incorporate information fusion techniques [9] [26][18][25][19][8][2], but none of them take organizational aspects or adaptive and dynamic behavior into account to achieve their goals. In this sense, the proposed platform provides an innovative alternative to current options. Given the present growth of sensor networks and automated environments, an architecture of this kind could notably improve the dynamicity for deployment and management of WSNs. Last but not least, the platform makes a contribution to mobile sensing in smart cities. Mobile sensing is becoming a common element in our lives thanks to rapid evolution of smartphones that can be used as sensing elements. Most of smartphones are equipped with a good quantity of sensors and can be used to monitor different activities or situations of our daily life. The use of sensors such as accelerometers, compass, gyroscopes, GPS, microphones or cameras has led to apps specialized in individual or collective sensing, mainly focused on sport, transport, health or social networks [11]. Besides, it is possible to easily connect external sensors to the smartphones using wireless communication. However, there are several open challenges in mobile sensing including those related to human-machine interaction or machine learning [11][9] and it is necessary to design new platforms and model for mobile sensing. One of the aspects that require innovative solutions is the design of mobile sending mechanisms for electrical vehicles in smart cities [11][26]. Another aspect to be explored is the analysis of human behavior that can be extracted from the data and can be used in different scenarios as security, health care, tourism [2][5], and in many cases combined with social netwtorks [15]. Although significant progress has been made in the development of platforms for smart cities, at present there is no single open platform that efficiently integrates heterogeneous WSNs, and provides both intelligent IF techniques and mobile sensing services. Therefore, there is no platform in the market that facilitates the communication and integration of the wide variety of existing sensors, providing intelligent IF facilities, intelligent management of user services. The proposed Virtual Organization (VO) of multiagent architecture is based on the social computing paradigm and will provide intelligence to the platform with adaptation to the needs of the application problem, while the cloud environment will ensure the availability of the required resources at all times.

3 Multi-agent Platform for Smart Cities

People and things are becoming more and more interconnected. Smartphones, buildings, vehicles and other devices are transformed to incorporate digital sensors to capture data, which is stores and processed. The term Big-Data is related to the information that can not be processed using traditional tools due to its volume, variety and speed. Thus, it is necessary to provide new platforms for this new kind of environments. These platforms should not only take into account the information that can be obtained from sensors, but also the information available from open linked data sources of information [2]. Besides, it is important to take into account the importance of the social networks and collaborative scenarios between humans and machines. In this section we present a multi-agent platform for smart cities designed as a social machine with capacities for self-organization and self-adaptation. The social machine will be connected to a big amount of sensors and actuators, gathering information from smart cities and facilitating the interaction with humans. Besides, a social machine requires new models for knowledge representation and information storage. In this sense, on the one hand it is necessary to work on new Cloud Computing models, where virtual organizations of agents can contribute to dynamically manage and adapt the resources in the Cloud from a social point of view, improving the elasticity and the scalability and providing capacities for learning and adaptation. On the other hand, it is necessary to investigate in new algorithms and techniques to explore and analyse the huge amount of information that will be stored in the cloud, providing storage and mining capacities for Big Data. The use of virtual organizations of agents constitutes a step ahead in the design of platforms oriented to combine IoT, Cloud Computing and Big Data.

The platform is divided into a layered architecture as shown in Figure 1. As can be seen in Figure 1, the platform is composed of different layers associated with the different functional blocks. The fusion levels of information are distributed along the different layers that can be found in the description of the JDL fusion model [23][1]. As defined in JDL, existing levels of data fusion from 0 to 6 are Data Assessment, Object Assessment, Situation Assessment, Impact Assessment, Process Refinement, User Refinement and Mission Management. These levels are distributed in the different layers of the architecture shown in Figure 1.

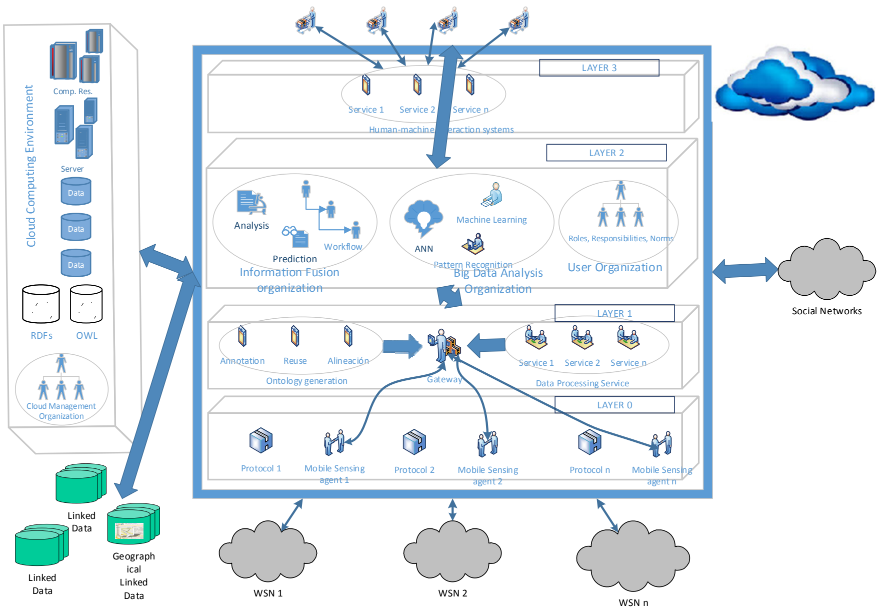

Fig. 1 Layered architecture for a multi-agent platform for smart cities

The following section describes the components and main features of the architecture:

- **Layer 0. Integrate sensing/performance technologies.** The platform facilitates integration of sensing technologies currently available, regardless of their nature, and provides an open environment that allows the dynamic addition of new sensor systems and technologies. In order to accomplish this, the platform will provide mobile sensing agents, data encapsulation mechanisms that standardize the information received from sources such as Wi-Fi, ZigBee, etc. In this way the platform will have sufficient dynamism to allow emerging technologies to be easily incorporated. The layer will be designed to interact with linked open data present in the environment by means of Linked Data agents as well as with social networks through Social agents. The main novelty of this layer is the definition of a mobile sensing agent with ability to provide the platform and the upper layers with openness regarding the connection to sensor networks of different natures, and thus ensure that upper layers of the architecture have access to information and are able to perform data fusion at different levels. Mobile sensing agents can be installed in smartphones or intelligent devices and caputre data from different sensors.

- **Layer 1. Low-level services.** Given the information exchanged with the environment through layer 0 as described above, the existing functional requirements and a set of low-level services will now be defined; specifically, those that depend on the types of networks and technologies integrated into every deployment. After obtaining the raw data, a gateway is provided, defined through adapters that allow the information received to be standardized. The data processing corresponds to *Level 1 - Object Assessment* as indicated by the JDL classification shown above. In this first stage, the platform provides services such as filtering of signals, normalization services or other treatment services at the basic level signals. These services are provided by the adapters and will be associated with algorithms that perform initial treatment of the data, so that these data can be presented to higher layers in a more homogenized way. Each of these services will expose an API to higher layers which will allow interaction with each low-level service, and thus, with the underlying sensing/performance technologies. In this layer, the information is processed and represented by means of semantic structures.
- **Layer 2. Information fusion, Big Data Analysis and User Organization algorithms.** This layer includes le*vels 2 to 4 of IF displayed on the JDL model.* The platform is structured as a VO of MAS and the layer 2 includes organizations for information fusion management, organizations for big data analysis and organizations for user interaction. Each organization includes the roles required to facilitate an intelligent management of the information obtained from the lower levels of the architecture. The virtual organization incorporates agents specifically designed to interact with low-level services and to manage and coordinate the platform. In addition, we propose the design of intelligent agents specialized in IF and in data analysis. For this purpose, roles that allow merging information automatically through supervised learning and previous training, as well as roles for machine learning have been included. The knowledge obtained in this layer will be presented to the top layer, as a high-level API specific to each service, so that it is possible to use them in an easy and simple way.
- **Layer 3. High-level services.** The top layer of the platform provides an innovative module that allows management and customization of services to end users, due to the capabilities of the MAS which is deployed over the cloud computing environment. In this layer, *levels 5 and 6 corresponding to the JDL model* are included. The tasks associated with the man-machine interfaces are performed at these levels in order to adapt according to the

characteristics of the user and facilitate decision making by the user. This intermediate layer of Cloud services allows high-level applications (apps) to use the information from lower layers in a homogenous way, thus facilitating the development of applications in the context of automated environments. And this, in turn, makes it possible to extend the proposed platform with the ability of service composition, different marketing models based on quality, underlying technologies, and other parameters to be determined during the initial phases of the project.

3.1 Mobile Sensing Agents

In this section, we focus on the layer 0 of the platform, and more specifically in the design of mobile sensing agents. We provide a general design for a mobile sensing agent taking into account the mobile sensing architecture defined by Lane *et al.* [11]. In [11], a mobile sensing architecture is characterized by 3 elements: sensing, learn and share-inform-persuade. Some of these elements will be modelled as capacities of the mobile sensing agents, while elements such as persuasion or social participatory sensing will be modelled in upper layers of the platform.
In our proposal, we define two kind of mobile sensing agents:

- Lightweight mobile sensing agent, designed to be embedded in resource-constrained devices. This agent is aimed at sensing information, which is processed in the different layers of the platform. The agent gathers data coming from the different sensors installed in the device (i.e. in an electrical bicycle).
- Smart mobile sensing agent, designed to be installed in smartphones or tablets. This agent incorporates interaction mechanisms with different sensing technologies, as well as individual human behavior classification and prediction techniques. This agent has capacities for:
    - Communication. The agent has to be able to communicate with the rest of the agents in the platform as well as with the different sensing technologies present in a smart city.
    - Sensing. This is one of the most important capacities of the agent. The agent should be able to obtain information from different sources of information.
        - Sensors. The agent should be able to gather data from the different sensors installed in the smartphone as well as from the sensing technologies present in a smart city.
        - Linked open data. The agent should be able to capture information from linked open data. The agent will make use of information obtained from sensors, such as location to take advantage of the information available as linked open data. In the future, we will include an organization of agents in the layer 2 of the platform

specialized in obtaining information from linked open data.

    - Sentiment analysis. A sensing agent should be able to capture information from social networks and take advantage of techniques for sentiment analysis to obtain information of interest. In the future, we will include an organization of agents in the layer 2 of the platform specialized in obtaining information from social networks and sentiment analysis.

- Learning. Learning is an advanced capacity for the intelligent agent. In this case, we focus on learning from individual behaviors. In the future, we will include an organization of agents in the layer 2 of the architecture specialized in learning from social collective behaviors, scaling models and participatory sensing.
    - Context modelling. An important aspect for a mobile sensing with capacities for learning and adaptation is how the knowledge is represented and, more specifically, how the user context is modelled. In this sense, in this capacity, the agent incorporates a model to represent contextual information (such as location, previous experiences, problem description, objectives, etc.) that can situate the agent in a specific context.
    - Human behavior analysis. This capacity is focused on classification and learning of individual human behavior. In this capacity the agent makes use of the information obtained by the sensing capacity to establish classification for human behaviors. Besides, this capacity makes use of the knowledge defined in the contextual model. The agent will incorporate decision trees and similar techniques to classify the behaviors. Besides, in this capacity the agent will incorporate a case-based reasoning system, providing the agent with capacities for learning and adaptation from previous experiences.
- Inform, Share, Persuasion. This is a high-level capacity for the agent that will make use of the previous defined capacities to provide services for personalization, recommendation and persuasion. Some of this services are designed from the basis of individual human behaviors, but in the future, we will include an organization in the layer 2 of the architecture specialized in providing these services from a social perspective.
    - Personalization. This capacity is focuses on personalizing services to the user based on the human behavior analysis as well as in the contextual information available. The personalization will be based on previous

experiences and will make use of a case based reasoning system to personalize the services.
- Recommendation. This capacity will provide suggestions or recommendations to the user based on previous experiences.
- Persuasion. This capacity will make use of negotiation and argumentation techniques to try to persuade the user. This is a complex process and it would be necessary to have an organization specialized on social behaviors to obtain acceptable results.

The proposed mobile sensing agent is deployed into a layered architecture as shown in Figure 1. The agent is allocated in the layer 0 of the architecture and is mainly focused on sensing information from heterogeneous sources.

4 Conclusions

This paper has presented a platform, designed as a social machine where humans, sensors and machines collaborate to provide services. The platform is designed from a social point of view and incorporates a Cloud Computing system and a Big Bata environment to manage the big amount of data that can be gathered in social environments. The platform is designed to integrate linked open data, information gathered from sensors, actuators or robots and social networks. The proposed platform is designed as a social machine, which gives a new perspective for the design of platforms for smart cities. The platform incorporates two innovative concepts: Mobile sensing and information fusion, which are designed based on virtual organizations of agents.

The paper is focused on the layer 0 of the platform, and more specifically in the design of mobile sensing agents. We make use of previous studies on mobile sensing technologies [11] to design a multi-agent architecture focused on mobile sensing and social computing. For [11] a mobile sensing architecture is characterized by 3 elements: sensing, learn and share-inform-persuade. We design a mobile sensing agent that incorporates capacities for sensing, learning and share-information-persuasion. The agent incorporates interaction mechanisms with different sensing technologies [24], as well as individual human behavior classification and prediction techniques. The agent incorporates a context-aware module in the architecture that can help us to represent and analyze contextual information and patterns related to interaction and collaboration behaviours that usually are hidden in real societies. The proposal is in its early stages and a more detailed design of the architecture including virtual organizations of agents specialized in linked open data, sentiment analysis, social learning, personalization, recommendation and persuasion will be defined in our future work.

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Part IV
Special Sessions on Multi-Agent Systems and Ambient Intelligence (AMIRA)

A Proposal of a Multi-agent System Implementation for the Control of an Assistant Personal Robot

Dani Martínez, Eduard Clotet, Javier Moreno, Marcel Tresanchez and Jordi Palacín

Abstract This paper proposes a control system design for a mobile robot assistant based on a multi-agent architecture. The robotic platform used in this paper is a second generation Assistant Personal Robot (APR-02) with an own design. The control implementation is distributed among different agents in which each one is designed to fulfill a specific functionality such as localization, navigation, task managing, vision, hearing, communications, and environmental supervision. In addition, a set of shared memory instances are implemented to ensure the cohesion among all the agents while working together. The proposed methodology provides robustness and effectiveness by assigning each agent on a single CPU thread.

Keywords Robot agent · Personal Robot · Multi-agent

1 Introduction

Since last decades robotics has advanced from performing limited and particular tasks to become more flexible being capable of realizing different applications with high levels of adaptability. Agents have the leadership of this evolution by means of providing autonomy, reactivity, collaboration, and initiative to robotics [1]. Moreover, from such new concepts new challenges have emerged which are very popular among researchers in robotics such as navigation, localization, and mapping. The simultaneous location and mapping method (SLAM) is a popular probabilistic technique that estimates relative robot displacements by environmental observation at the same time the robot is building a virtual map[2]. So, this

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method allows the robot the possibility of using the estimated poses and the virtual map to perform complex navigation procedures. In [3] localization and navigation algorithms are presented for autonomous robots that can patrol multiple floors of the building. Furthermore, spatial representation is also important in autonomous navigation to recognize the area in which the robot is [4]. A multi-agent framework for autonomous systems was proposed in [5] that provides a fluid operation of multiple control loops within an agent.

Assistant robots have also take advantage of the agent concept and have been enhanced to become so much more operational. This field in robotics is one of the most interesting due to its deep challenge and its final application that can help common people in their homes. The robot methodologies presented in [6] are applied on some of the first developed assistive robots for home care and museum guidance. Elder people and persons with reduced mobility are a special motivation on developing assistant robots. In [7] is presented a home assistive mobile robot capable of tracking the user, engage a remote supervision, and other robot services. Moreover, there are other applications which use similar platforms such as for ambient intelligence services as the robot described in [8].

This paper proposes a practical methodology to implement a control system for an assistive robot based on a multi-agent design. The main platform used in this paper is an Assistant Personal Robot (APR) as the one described in [9]. Several agents are implemented in order to engage different functionalities to the mobile robot. The motivation of implementing a multi-agent architecture in a mobile robot is to provide independence, versatility, and reliability among different robot sub-systems. The agents are described in this paper and are based on a modular architecture with a complete collaborative behavior. The proposed tests are based on measuring the overall performance of the whole system on the robot computational unit. Each agent is assigned to a single processing thread and their computational requirements can be quantified.

2 Agent Methodology

The methodologies presented in this paper are implemented on an APR platform which has several onboard sensors and actuators: laser range sensor (LIDAR), a 3D camera, a motor control board, a main display, and the robot main computational unit. The APR computational unit implements several robot agents, each one assigned to perform a single dynamic function. Furthermore, such robot agent processes require a constant communication among them to engage a correct development of its tasks by means of using shared memory spaces. Fig. 1 shows a diagram of the proposed multi-agent system implemented in the APR. Most of the described robot agent processes have a direct connection to a hardware device. So, the communication between the robot and an external device is exclusively restricted to a single robot agent.

The agents are designed to work independently, they only have to publish their results and gather information needed while performing their tasks. Such exchange of information among agents is managed by using shared memory instances subject to continuous querying and publishing operations. Although agents are independent, the global effectiveness of the robot system depends on the cooperation among all of them. The agents implemented in the APR platform are: task manager agent, SLAM agent, navigation agent, face recognition agent, voice recognition agent, sensor acquirement agent, and communications agent.

2.1 *Assistant Personal Robot*

The Assistant Personal Robot is a robotic system focused on implementing assistive services for reduced mobility people. Furthermore, this robotic design (fig. 2) allows its use into many other different applications such as a guide robot, a measurement platform, for surveillance services, and more. The design of the robot shape is focused to imitate a person maximizing the human comfort level provided by the robot presence and its social interactions. The motion of the robot is performed by three omnidirectional wheels providing high mobility in any situation. Such wheels are connected to three DC motors which are guided by an

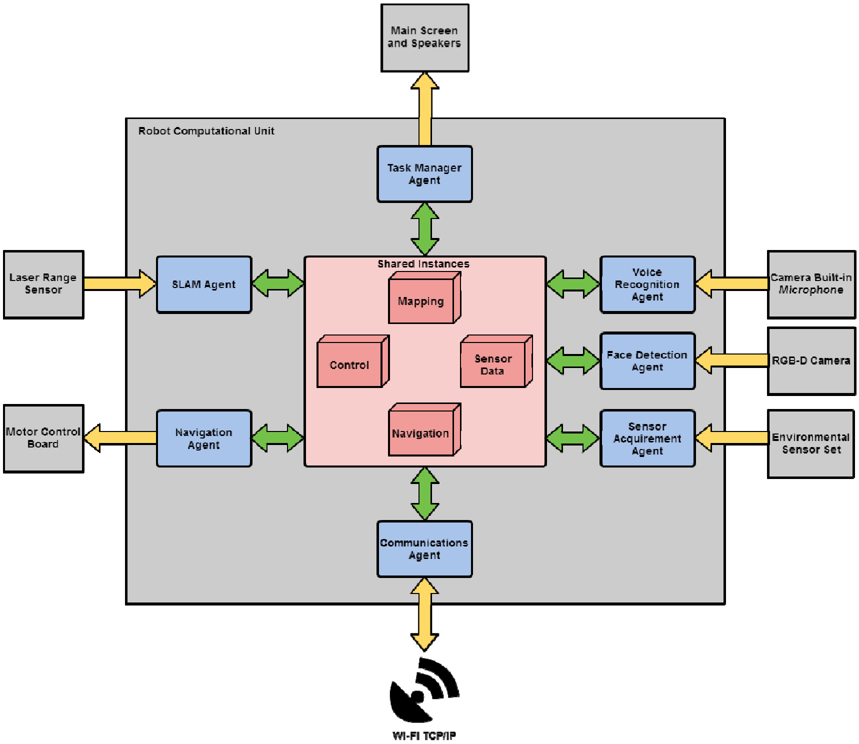

Fig. 1 Diagram of the proposed APR multi-agent architecture.

ARM-based motor control board. Moreover, this electronic board also control other motors such as the ones placed in the arms and in the head which handles the main screen. In this paper the APR-02 is used whose main computational unit is a domestic high-performance computer with reduced dimensions (ITX motherboard) running Windows. The whole system is powered by three 12V 12Ah DC batteries placed at the robot base. Additionally, the platform has a several sensors attached in order to obtain profitable environmental information. A Hokuyo UTM-30LX laser range sensor placed on the base provides the information used by the SLAM procedure as well as for the obstacle avoiding procedure. Furthermore, a Creative Senz 3D Camera is placed at the top of the platform which obtains RGB-D images for the object/face recognition process. This camera also has a dual built-in microphone which is used to perform a voice recognition process to decode simple vocal orders.

Fig. 2 Prototype of the Assistant Personal Robot: APR-01.

2.2 Task Manager Agent

The main process of the proposed system is the task manager agent. This agent manages the lifecycle and the main decisions of the rest of the agents by means of a task queue system. The robot routines are predefined by atomic tasks which can be also used by other routines such as “going to somewhere”, “find persons”, “look at face”, “show advice”, “request assistance”, “answer yes”, “say hello”, “perform something with arms”, “follow someone”, “check ambient conditions” and so on. Such actions are assigned to the task queue in order to execute them in an established order; however, they can be interrupted depending on the task priority. In order to ensure the fulfillment of the tasks, the agent uses the shared instances to check and control the different requirements of the task. Moreover, this agent also manages the output communication features of the robot by means of displaying images on the main screen and playing simple sounds through the embedded speakers.

2.3 SLAM Agent

The implementation of the Simultaneous Localization And Mapping (SLAM) procedure is based on processing occupancy grid data [2] by applying a template matching method. The laser range sensor is continuously obtaining scans which are processed by this procedure returning new updated location of the robot coordinates and orientation. In order to reduce the computational cost of this process, the mapping part of this procedure is only applied in unknown or previously unexplored areas. In this way, the robot saves computational resources for other robot agent processes executed in the control system. The SLAM agent has an embedded obstacle avoiding procedure that detects unexpected static and dynamic obstacles. Once an obstacle has been detected, the SLAM agent requests the navigation agent an attempt to recalculate the robot path.

2.4 Navigation Agent

The autonomous path planning process is defined in the navigation agent that is directly connected with the motor control board. This agent computes the path to reach the actual robot destination and emits motion orders. The path planning method implemented in the agent is based on a graph shortest path algorithm [6] applied with a discretized version of the virtual area map. So, this agent works simultaneously with the SLAM agent which is permanently obtaining new relative poses of the robot inside the virtual area map. The information used by such agents is available at the navigation and mapping shared instances. Figure 3 shows an example virtual map built by the APR with its actual destination marked. Additionally, the robot agent has some simple exploratory routines to create a new virtual map for first-use in unknown environments based on wall-following and remote-controlling.

Fig. 3 An example of a virtual map used by the navigation agent of the APR.

2.5 Face and Voice Recognition Agents

The face and voice recognition agents are planned to simplify the interaction with the APR. The face recognition agent obtains images from the RGB-Depth camera and will detect and identify the existing faces on the images by using a pre-loaded face template database [10]. Figure 4 shows an example of a segmented image taken from the RGB-D camera in which the depth has been limited to 75cm. Once the person is identified, the personal profile is loaded for the assistive routines. The voice recognition agent detects single word instructions by computing the voice signal in time-domain and identifying the vocals [11]. At this point, the vocalized instructions are notified to the task manager agent in order to execute the formulated order of instructions.

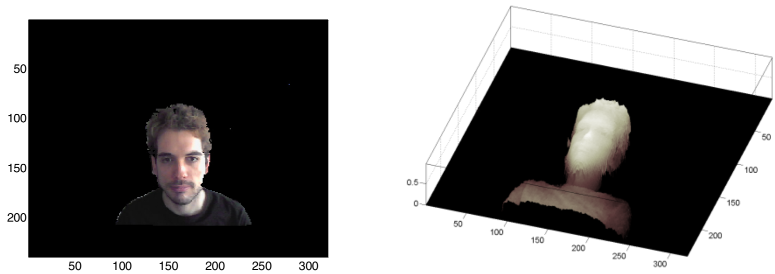

Fig. 4 Example RGB (left) and Depth (right) images.

2.6 Sensor Acquirement Agent

The environmental conditions can be monitored by the APR by means of a set of sensors attached to the platform. The sensor acquirement agent keeps executing constantly and gets the data from the connected sensors such as a thermometer, an odor sensor, an anemometer, and more. Such data is published at the sensor data shared instance for further use from other robot agents. Additionally, the agent can create a log register from the gathered sensory data. Figure 5 shows the measurements from different sensors while the robot was patrolling indoors.

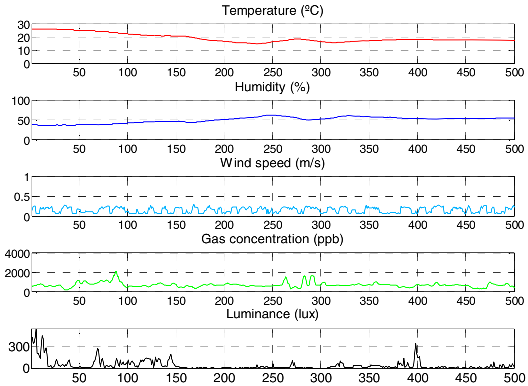

Fig. 5 An example of different acquired sensor data from the APR.

2.7 Communications Agent

An agent dedicated to external communications is included in order to engage a wireless connection with a remote terminal for external supervision. This system allows a user to visualize in real-time the robot location, the area map, the sensor lectures, the actual task, and images from the RGB-D camera.

3 Results

This section presents the results on performance and feasibility of the methodology proposed in this paper. The APR platform used for the tests is the APR-02 which central processing unit is an Intel Core i7-6700 3.40GHz with 16GB of DDR4 memory and a solid state drive hard disc. This microprocessor has 8 execution threads from 4 physical cores in which its computational load is managed and measured by the operating system. In this paper the agent processes are assigned as a single execution tread in order to isolate them and avoid disturbances on other agents which may require high computational requirements. In this paper, each agent is executed in an individual Java virtual machine. All agents are working even when the robot is stopped. Table 1 shows the agent assignment by execution threats and the average computational load measured by the operating system.

Table 1 Agent assignment table.

Agent	Average CPU thread load							
	#0	#1	#2	#3	#4	#5	#6	#7
Task manager	8%	0%	0%	0%	0%	0%	0%	0%
SLAM	0%	86%	0%	0%	0%	0%	0%	0%
Navigation	0%	0%	13%	0%	0%	0%	0%	0%
Voice recognition	0%	0%	0%	7%	0%	0%	0%	0%
Face recognition	0%	0%	0%	0%	14%	0%	0%	0%
Sensor acquirement	0%	0%	0%	0%	0%	4%	0%	0%
Communications	0%	0%	0%	0%	0%	0%	7%	0%

Table 1 shows that each agent runs on a unique CPU thread and that the most demanding task at this moment is the SLAM procedure because the implementation of the face recognition system does not processes all images acquired by the APR. Further tests performing simple routines show that the mobile robot offers robustness and coordination among all the implemented agents. The robot keeps executing all the agents at full operability without any delay or complications caused by other agents. The state of the robot and some important information is visualized from a remote application installed to a personal computer.

4 Conclusions

This paper presents a multi-agent architecture designed to control an Assistant Personal Robot. Different robot agents are defined as independent processes for an effective operability. In this paper the agents are executed on Java virtual machines in unique CPU threads but can also be implemented on any other platform that provides modular programing such as ROS nodes. The first tests with the APR have demonstrated that the proposed multi-agent architecture operating in individual threads has improved the robustness and the applicability of the control system. Furthermore, the modular implementation of the robot features simplifies the development and debugging of tasks while avoiding irregular behaviors or inconsistent processes due to instantaneous CPU usage by an individual agent. Future work will be focused on the full development of all assistant robot routines. Field experimentation will be also performed in order to obtain reliable results from different APR services.

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Task Allocation in Evolved Communicating Homogeneous Robots: The Importance of Being Different

Onofrio Gigliotta

Abstract Social animals have conquered the world thanks to their ability to team up in order to solve survival problems. From ants to human beings, animals show ability to cooperate, communicate and divide labour among individuals. Cooperation allows members of a group to solve problems that a single individual could not, or to speed up a solution by splitting a task in subparts. Biological and swarm robotics studies suggest that division of labour can be favoured by differences in local information, especially in clonal individuals. However, environmental information alone could not suffice despite a task requires a role differentiation to be solved. In order to overcome this problem, in this paper, we analyse and discuss the role of a communication system able to differentiate signals emitted among a group of homogeneous robots to foster the evolution of a successful role allocation strategy.

Keywords Collective robotics · Neural networks · Division of labour

1 Introduction

Social animals rule the world we live in thanks to their ability to cooperate so as to form teams of individuals able to solve tasks too difficult or impossible to be solved by single individuals [15]. Complex animals from human beings to insects like ants are capable of forming very complex social networks and dividing labour among members of a group. Ants of the genus Atta, for example, are able to differentiate their role during foraging activities: a group of ants climb a tree and start cutting leaves while another one gather and transport fallen leaves to the nest [3]. Very often

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collective robotics have taken inspiration from biological systems, for example Ferrante and colleagues [2] reproduced the astonishing behaviour of Atta ants in wheeled robots. In contrast to biological systems, robotics models mostly rely on homogeneous individuals. This is due to the fact that engineering one type of ideal robot is easier than engineering a heterogeneous team and secondly because, especially by using an evolutionary robotics approach, it is a way to avoid the fitness assignment problem [12]. For division of labour to occur, both in natural and artificial systems, a source of variation is needed. In homogeneous individuals the source of variation is the environment (different individuals may experience different local information) [1, 2, 14], whereas in heterogeneous individuals genetic differentiation could suffice in expressing behavioural differentiation [13]. A common problem of heterogeneous group of robots is represented by the sensibility to the loss of a member of the group as highlighted by Tuci [13], in this case other individuals may likely fail to replace the lost one. On the other hand, homogeneous robots do not present this issue but may fail in role differentiation due to lack of sufficient environmental information. The dual patrolling scenario developed in [4] exemplifies this problem. In particular, a team of 4 homogeneous robots controlled by a neural network, placed in a square arena attached to a long corridor, have to split in two groups: 3 robots have to patrol the square room whereas only 1 robot has to patrol the light source placed at the end of the corridor. Since robots cannot detect light information from the square room, this information cannot be used to segregate the group. In the aforementioned study we demonstrated how by rewarding signalling differentiation, among communicating robots, is possible to ignite the development of an effective role allocation strategy; but how complex, in terms of computational power, a neural controller has to be to provide enough information for role differentiation was left out of the scope of that study as well as the ability of a segregated team to tolerate the loss of its light warden robot.

In this paper, we extend the original work by a) running new evolutionary experiments to evaluate the effectiveness of communication-based role differentiation in neural networks with less computational power; and b) evaluating resilience of the evolved controllers when a member of the team is lost.

2 Materials and Method

2.1 Task and Environment

The experimental environment consists in two communicating rooms, a square representing a "home" room and a rectangular corridor presenting a source of light at the extremity. A group of four simulated communicating e-puck robots is initially placed in the home room, robots are then requested to split up in two groups: three

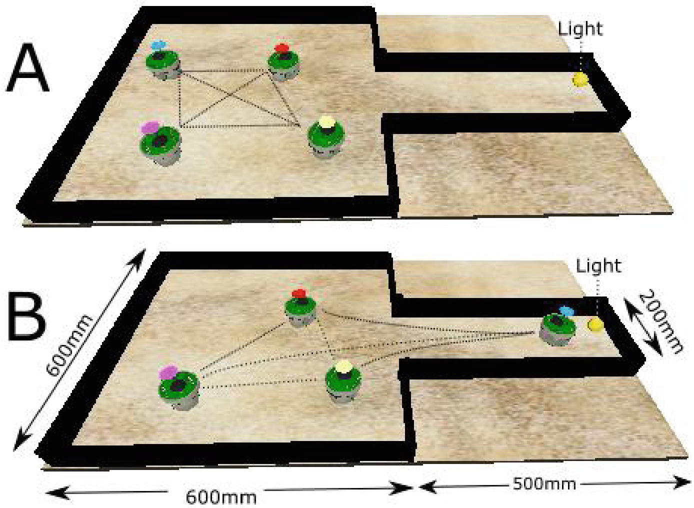

Fig. 1 Initial condition (A) and desired solution to the double patrolling task

robots have to patrol the home environment while only one individual is allowed to enter the alley in order to patrol the source of light (see Fig. 1), moreover the light cannot be perceived from the home room.

2.2 Robot and Neural Controllers

Simulated e-puck robots were used within Evorobot*, a simulator developed for running evolutionary robotics experiments [10]. Evolutionary robotics is a methodology that puts together genetic algorithm, neural networks and robotic bodies, for developing controllers of autonomous robots for designing [11], modelling [7] and even edutainment purposes [8]. The e-puck robot is a small differential wheeled mobile robot [9], its simulated counterpart is provided with 18 sensors, 2 motor outputs and a signal emitter. The sensory apparatus includes 8 infrared sensors able to detect nearby obstacles, 8 light sensors, 1 communication/role input fed with the highest signal emitted by the neighbours and a input receiving a copy of its own emitted signal (see Fig. 2). For each sensor reading, ranged between [0,1], a pseudo random number drawn from the range [-0.1, 0.1] was added.

Robots' behaviour was controlled by means of a three-layer neural network having an input layers of 18 units, an output layer of three units and a hidden layer constituted by recurrent leaky neurons (see Fig. 2, right). Two output units encode the speed of the two wheels, the remaining output unit controls the signal emitter, which can broadcast a signal ranged [0,1]. Output neurons are logistic units, whose activation o_i is given by

$$o_i = \phi(I_i), \phi(x) = (1 + e^x)^{-1},\ I_i = \sum_j^N a_j \times w_{ij} - b_i \quad (1)$$

where a_j is the activation of the unit j projecting connection w_{ij} to output i, b_i is the bias of unit i and N, the number of neurons. The activation of each motor unit (ranges [0, 1]) is remapped in [−8, +8] and sent to the motors. Internal neurons are leaky integrator units, whose activation is computed by

$$o_i^t = (1 - \tau_i) \times \phi(I_i^t) + \tau_i \times o_i^{t-1} \quad (2)$$

where τ_i is the time constant (ranged [0, 1]) of unit i.

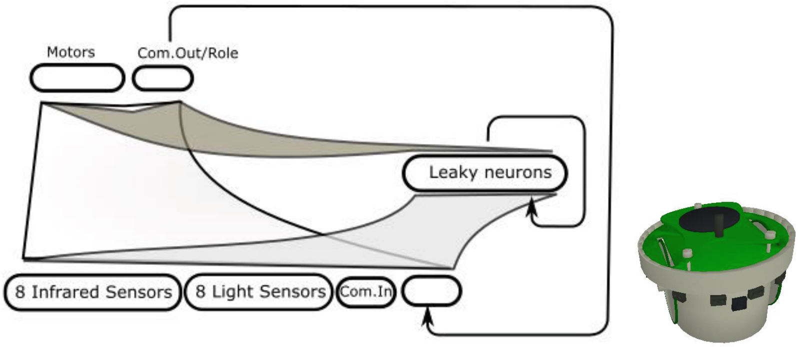

Fig. 2 Right. Simulated e-puck robot in Evorobot*. Left: Neural network. Hidden neurons were varied in the experiments from 0 to 8.

2.3 Evolutionary Algorithm and Fitness Function

The whole team of robots shares the same genome, a string of 8 bit genes encoding connection weights, biases and time constants of the neural units. Each 8 bit parameter is uniformly mapped in the range [−5.0, +5.0] for weights and biases, whereas time constants in the range [0, 1]. For each evolutionary experiment an initial population, of 100 randomly generated genomes is created. Then, each genome is mapped to a neural controller and tested for 15 trials lasting 2000 time steps (parameters chosen in order to optimize the required time to carry out simulations). At the beginning of each trial, a set of four robots is equipped with the same neural controller and randomly placed in the home room aforementioned. Robots are evaluated for their ability to patrol the home room as well as the light source placed at the end of a corridor (see Fig. 1) After the fitness of each genome in a generation has been computed (see below for further details), the best 20 genomes undergo to an evolutionary process whereby they are copied 5 times each (reproduction phase to form a new population of 100 individuals) and mutated by flipping 1% of the bits.

In this work we try, by expanding previous works [4, 5, 6], to better understand the beneficial role of communication mediated differentiation in a group of homogeneous robots when a division of labour is requested for a given task. To this aim we ran 6 additional evolutionary experiments complementing those reported in [4]. In particular, 3 neural network architectures, with growing computational power (provided by an increasing number of hidden units: 0,4,and 8 neurons), were tested in two conditions characterized by two fitness functions differing only for a component rewarding communicated mediated differentiation.

The first fitness function presents the following two behavioural fitness components

$$BFC1(g) = \frac{\sum_t^T \frac{max(0,(M-d(L,light)))}{M}}{T} \tag{3}$$

where M is a maximal distance, set to 900 mm and $d(L, light)$ is the distance between the light warden and the light, and T are all the time steps of all the trials of a genome's life.

The second component (BFC2) measures the average distance of the home room wardens from the light, normalised in [0, 1]:

$$BFC2(g) = \frac{\sum_t^T \sum_i^F \frac{min(1,d(F_i,light))}{M}}{T \times F} \tag{4}$$

where F_i is home warden i and F is the total number of home wardens requested, i.e. 3. Being the behaviour of the light warden more important than the behaviour of the rest of the group, the global behavioural fitness (BF) gives more weight to BFC1 than to BFC2, in particular:

$$BF(g) = 0.75 \times BFC1(g) + 0.25 \times BFC2(g) \tag{5}$$

The second fitness function contains the the same component described above plus a new component rewarding communication mediated differentiation. In particular, this component was first used in [6] and [5] to differentiate, in terms of communicative produced output, a team of homogeneous robots. Importantly, although the differentiation was not directly linked to non-communicative behaviours it happened to play a role in determining it.

The new component rewards the genome, shared by the team of robots, for having only one robot sending a high value signal (the light warden) and the rest sending a low value signal (home wardens). More precisely, the communication fitness component (CFC) is computed as follows:

$$CFC(g) = \frac{\sum_t^T \sum_i^N O_{max} - O_i}{T \times (N-1)} \tag{6}$$

being O_{max} the highest signal value, O_i the value of the signal of robot i, and N the number of robots in the group, i.e. 4. Finally, the global communication rewarded fitness (CRF) is computed according to the following equation

$$CRF(g) = 0.8 \times BF(g) + 0.2 \times CFC(g) \quad (7)$$
$$= 0.2 \times BFC1(g) + 0.6 \times BFC2(g) + 0.2 \times CFC(g) \quad (8)$$

Each experiment was replicated 20 times with different initial conditions for 500 generations.

3 Results

3.1 Neural Architectures

Table 1 reports the number of successful and unsuccessful evolutionary experiments, in the case in which communication based differentiation was rewarded, ranked by the number of hidden units of the neurocontroller used. In the other cases where communication differentiation was not rewarded none of the experiments produced a successful solution. χ^2 goodness of fit test revealed a statistical significant difference between controllers evolved by rewarding communication based differentiation and those not rewarded ($p<0.0001$). The number of hidden units, i.e the computational power of the neural network used, did not affect the emergence of successful solutions $\chi^2(2, N=60)=1.29$, $p=0.92$. By analysing for 100 trials the ability to solve the dual patrolling task of best individuals equipped with 0, 4 and 8 hidden units, no differences emerged among neurocontrollers in time spent in the desired configuration (see Fig. 3, Kruskal-Wallis, $\chi^2=1.17$, $p=0.56$) although the presence of different behavioural strategies.

Notwithstanding the lack of differences in performance, we performed an investigation to analyse whether the neural architecture had an impact on the phenotypical behavioural strategy used by best individuals. Surprisingly, the strategy adopted by the best evolved teams varies by the number of roles switched by the robots belonging to the group (see Fig. 4).

Table 1 Number of successful evolutionary experiments for neurocontrollers provided with increasing number of hidden units in the case in which communication differentiation is rewarded

Hidden Units	Succesful Exp.	Unsuccesful Exp.
0	6	14
4	5	15
8	6	14

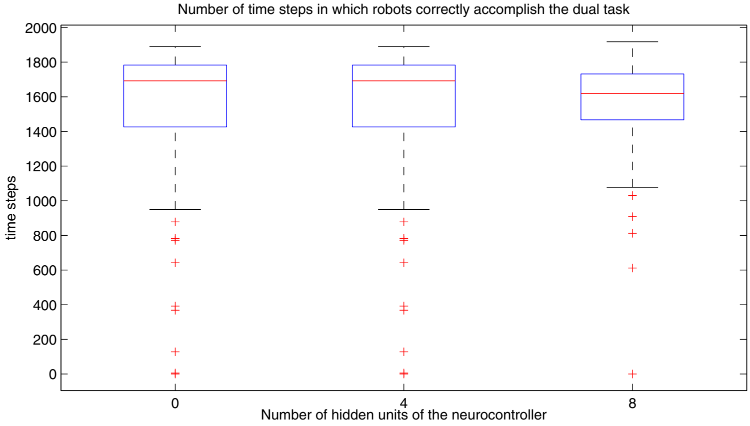

Fig. 3 Number of time steps in which the desired configuration of the team has been reached. Data were collected during 100 trials lasting 2000 time steps for each neurocontroller. The central line of each boxplot indicates the median, top and bottom edges the 75^{th} and 25^{th} percentiles respectively. Whiskers extends to the most extreme values that are not considered outliers (depicted as crosses).

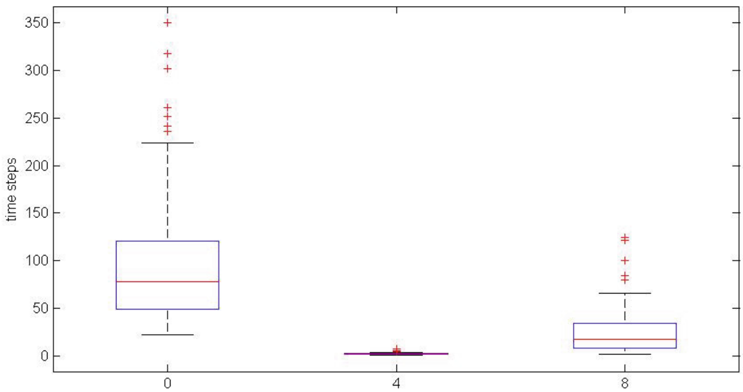

Fig. 4 Average number of time steps, collected during 100 trials, used for changing role by the robots belonging to the best evolved teams equipped with neural networks provided with 0, 4, and 8 hidden units.

3.2 Resilience

Homogeneous robots are often used in collective robotics among other reasons because, by sharing the same controller, every robot is fully replaceable by another one. In order to verify if this holds also in our evolved behaviour, we tested for 100 trials, in a post evaluation phase, the best evolved teams provided with neural networks having 0-, 4- and 8-units hidden layer, by removing the light warden individual from the arena as soon as the task was correctly solved for the first time. Figure 5 shows the percentage of successful trials in normal and loss condition (when a robot, due to a hypothetical fault, is definitively lost). Interestingly, the drop in performance in the network without hidden units, is statistically significant $\chi^2(1, N=200)=4.61$, $p<0.05$, while not significant in the other cases. In particular, the controller with 8 hidden units did not present any loss in performance when the first light warden was removed.

By visual inspection of the evolved behaviours, we found different and interesting strategies used by the three best evolved teams that can explain the differences in resilience. In the simplest case, in which robots are controlled by a network with no hidden units, each robot spends a lot of life time in changing role. Robots move across the square arena until a robot enters into the corridor to reach eventually the light. At this point the light warden robot is able to emit a signal that stops the other 3. By removing the light warden, the remaining robots start over the wandering behaviour, but since they are now fewer the chances to enter the corridor are reduced. The best team evolved with a neural network endowed with 4 hidden units quickly segregates as can be seen in Fig. 4. Immediately a light warden robot emerges that is able to follow the wall and stop near the light, whereas the other robots keep wandering in the middle of the home room. When the light warden is removed another warden immediately emerges that starts to follow the wall and avoid other robots that can

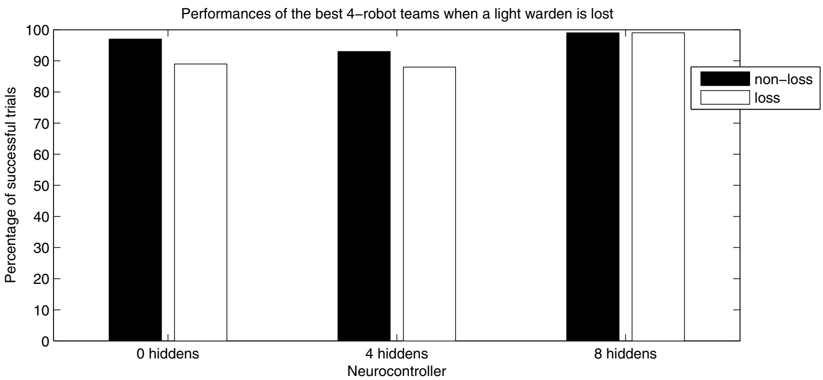

Fig. 5 Percentage of successful trials in normal and loss conditions. In the latter condition the light warden robot was removed after taking its role.

heavily slow down its pace. In the team equipped with the neural network endowed with 8 hidden neurons, the light warden robot emerges as quickly as for the 4 hidden units neural network. The difference relies on the fact that when a light warden finds another robot in its way, it does not waste time trying to avoid it but, surprisingly, it transmit its role/“baton” as in a relay race. This behaviour drastically reduce the time to reach again the light source by the newly elected light warden.

4 Conclusion and Discussion

In this paper, by extending a previous work [4], we have shown how effective can be a communication mediated signalling differentiation as a prerequisite for role allocation in a dual patrolling task. A task whereby a team of robots is requested to segregate in two subgroups of 3 home room warden robots and 1 light source warden robot. In particular, rewarding communication differentiation has proven to be effective in fostering the evolution of teams able to correctly allocate roles among its members even when equipped with simple neurocontrollers.

Moreover, the effectiveness of such a system is demonstrated by the absence of statistical significant differences in performances among best individuals equipped with neural networks provided with 0, 4 and 8 hidden units.

Finally, resilience tests, in which the light warden robot was removed, demonstrated a remarkable ability of the evolved teams equipped with three different neural networks to successfully reallocate roles within the group. Results show that the computational power of the neural controller has a significant effect on reallocation after a light warden robot is lost. In particular, resilience is positively related to the number of hidden units.

Team of homogeneous robots, thanks to their robustness, have been largely used in collective robotics. Even when a role allocation is required, homogeneous robots can accomplish this task by exploiting local information. In the case of simulated Atta ants, for example, robotic ants switch their role between leaves cutter and leaves collector on the basis of what they perceive in the nearby environment [2]. However, there are environmental conditions which are not enough rich to be exploited as a source of variation for a behavioural differentiation like in the dual patrolling task described in this work. In this and similar cases a differentiation mediated by communicative interactions can represent a powerful solution for evolving teams of robots able to solve tasks requiring role allocations. Future research work should a) shed light on the communication protocols emerged in the three conditions, especially for the team controlled by most complex network in which robots transmit the light warden role as a baton in a relay race; b) test the resilience of the team in case of degradation of the perception system; and c) extend to more complex behaviours the developed methodology.

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The Territorial Perception in Cooperative Harvesting Without Communication

Pasquale Caianiello, Giovanni De Gasperis and Domenico Presutti

Abstract We investigate the possibility of observing cooperative behavior in simple, autonomous, and non-communicating robotic agents when performing a harvesting task in a multi-agent environment. We evaluate a method to enforce a reflex-like territorial behavior in order to optimize individual and collective utilities.

Keywords Multi-agent systems · Cooperation · Swarm robotics · Territoriality

1 Introduction

Cooperation among agents is a key aspect of Multi-Agents Systems and Swarm Robotics, it is pervasive in Science and every social activity. Attention to cooperation arises whenever agents are expected to collectively achieve a common goal.

By and large distributed computing achieves cooperation by means of coordination and communications. Game Theory provides a solid playground for formal studies of cooperation and coordination [7, 8] and to distinguish cooperation from coordination. In particular in Agents Systems, coordination means that the behavior of the individuals must be reconciled with the behavior of the group: All actions performed, in the sequence that forms the behavior of every agent, are the execution of a common and coordinated group-level plan that takes into account (maximizes) individual utility while taking into account (maximizing) group-level utility.

While coordination requires some sort of information exchange or retrieval (say reasoning, sampling, committing, predicting,...) among agents in the group, cooperation may emerge as a group-level property. That is particularly true in situations where agents reactions to sensors sampling, whether strategic or reflex-like, do not

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depend on sampling or on inferring the group members internal state, and are established without explicit communication or any sort of information gathering.

Swarm Robotics studies groups of simple robots that interact and cooperate with each other so as to solve tasks together. The approach is motivated by the consideration that "sensorimotor intelligence is as important as reasoning and other higher-level components of cognition. Swarm-based robotics relies on the anti-classical-AI idea that a group of robots may be able to perform tasks without explicit representations of the environment and of the other robots; finally, planning is replaced by reactivity" [2], and cooperation emerges as a property of the swarm.

This work experiments about cooperation without communication [5] by investigating the possibility of observing cooperative behavior in simple, autonomous, environment reacting robotic agents trained for obstacle avoidance while going to a single goal area, once they are set in operation in a multi-target and multi-agent environment without communication infrastructure. We aim at verifying whether cooperation may emerge as a by-product of reflex-like reactions for robotic agents with no resources of any sort but their limited perception.

In the spirit of swarm robotics, we strive to keep the agent as simple as possible and such that their actions are simple reactions to sensors. Apart from sensors sampling and basic preprocessing, we avoid to provide the agents with high level knowledge about the environment, like complex representation maps, memory of past sensor situations, or high level capabilities like planning. Nonetheless our design remains compatible with possible improvements obtained by providing the agents with further higher level reasoning components.

We ran several simulations on a non-holonomic robot agent to conclude that simple collaborative behavior can be enforced with a perception distortion before reaction.

1.1 Motivations and Related Work

The task of collective harvesting and foraging for simple autonomous robotic agents gets a wide attention in the literature. Several approaches are explored for improving efficiency in performing the task by means of collaborative behavior, ranging from message exchange to information droppings -the analogous of pheromones for biological swarm agents- in order to approximate a known optimal centralized-control solution with a local coordination. Efficient cooperative strategies for several mobile agents that don't rely on communication, when targets are generated by a stochastic process, are proposed in [1]. Such strategies refer to the territoriality behavior of biological species [11], and do rely on knowledge of the environment and the agents ability in effectively orienting and localizing themselves in the territory. In nature, and specifically in robotics literature, it is well known that a territorial conduct is highly related to optimize usage of resources and task completion in particular for the foraging/harvesting problem.

The non-communicating agents approach, applied to space robot construction in [9], is specifically motivated for providing space robots with a fault-tolerant ability to complete a given task. In general, interest in cooperation without communication can be motivated whenever a team of robotic agents is engaged in a task of primary importance as rescuing, life-saving servicing, or toxic waste collection, and communication may be dangerous, costly, faulty, jammed, or anyway unavailable, as for instance in extreme, catastrophic, and war environments.

In [6] collaborative behavior in a foraging task is obtained by controlling the agents reactions *ex post*. On the other end, we try *ex ante* to implement *distorted perception* to induce a modulated cooperative reaction without communication.

2 The Multiagent Environment

We consider a virtual scenario where a team of realistic robotic swarm agents navigate in a 2-dimensional environment with obstacles towards multiple targets to be collected or serviced, and are expected, individually and as a team, to reach and service as many targets as they can, given their initial supply of energy that they consume by moving around. As soon as a target is reached by an agent, it will be marked as serviced and disappears.

2.1 The Agent

Agents behave according to the sensory-motor reaction loop *sense(environment)* $\rightarrow$ *action*. The ones we will be experimenting with are modelled, over their real counterpart, as robots with motor and directional abilities relying on two motors, and with a sensory equipment consisting of an ultrasonic sensor radar spanning the whole visual field over the environment, 3 proximity sensors each covering 60 degrees of the 180 degrees front visual field. "Vision", in their case represents the agents ability to map object as detected by sensors into their perceptive cortex, a polar map (angle sector, distance) centred in themselves. Obstacles, targets, and other agents are physical entities, as such they have the same effect on sensors. The only extra ability they have, at perception, is to tell targets apart from obstacles. In practice their vision is augmented with the ability to assign a obstacle/target tag -or, more suggestively, a bad/good cognition- to objects in the visual field at sensor preprocessing, allowing to selectively tunnel sensor information to two perceptive cortices consisting of two polar maps, one for obstacles objects and one for targets. Thus we modelled the virtual robot with the assumption that it actually had two different senses, with two different perception cortices, "vision" for obstacles and "smell" for targets. We designed the agent whose reaction to the environment state depends on the computation made by a perceptron with a single hidden layer sketched

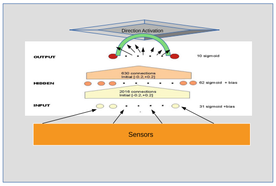

Fig. 1 The swarm robot agent sensory-motor reaction

in Fig. 1. Its sensor preprocessing provides 31 inputs for the neural net that provides 9 outputs for direction activation of the two motors control.

The 31 inputs computed by sensors preprocessing are organised as follows: 9 reals in the [0,1] interval of the front visual field, represent the distance of obstacles, in the 20 degrees sectors of the front visual field, as measured by the ultrasonic sensors; 18 reals in the [0,1] interval represent distance of a target in each of the 20 degrees sectors of the whole visual field, 3 bynaries represent proximal obstacles as returned by the proximity sensors in 3 sectors of 60 degrees in the front visual field; one input represents distance form the closest goal target.

The 10 outputs yield 9 directional and 1 velocity directives to the motor control. The 9 directional directives are to be considered as directional preferences in the 20 degrees sectors of the front visual field. The actual directional command given to the motor control is the result of a choice made by the Direction Activation function. We experimented with two possibilities, as a maximum preference choice and as a probabilistic choice depending on the preference.

2.2 Agent Training for Goal Oriented Obstacle Avoidance

In a preliminary study [3], we trained the agent for obstacle avoidance with a single goal area as a target, the same architecture with several supervised and unsupervised training protocols. The observation of the behaviors of on-training and trained agents, let us conclude that the training directives *achieve(target), avoid(obstacles)* where expressed.

In our experimentation that follows, we chose to use the agent trained with the error backpropagation protocol with training sets (TS) constructed in two different ways, the first (BPp) by sampling the control choices of a human pilot, the second (BPh) by recording the behavior choices of a heuristic evaluation function in a wide range of enumeration of input sensor patterns. The use of BPh allowed the easy construction of much larger virtual TS, while TS construction with BPp required synchronized reading the agent sensors and sampling the human pilot, who on the other hand was allowed to comprise higher level cognitive faculties, and was allowed to look at the environment map while making his decision.

To preserve generalization capabilities and avoid over-fitting of the ANN, the training process was stopped at predetermined network mean square error limit values. For this purpose, each training sets were split in two subsets of training subsets and test subsets, containing respectively 90% and 10% of the original TS samples. Optimal limit network error values were determined by training the network on training subsets and testing network response on the test subsets: when the error on the test subsets became stationary or increasing, training was paused and finally completed by using the full TS and the minimum network error limit.

Turning back to the suggestive interpretation that the agent perceptive abilities are wired so that it can distinguish bad from good, we can say that the agent was trained to *achieve(good), avoid(bad)* and that, after training, it acquired an *individual rationality*, though as a pure reflex reaction, and it behaved accordingly to achieve its own best interest.

By performing simulation tests we realised that a suitable direction activation function was a probabilistic choice with the Boltzmann probability distribution computed over the direction preferences. As a matter of fact, if the direction choice is made by choosing the maximal preference direction, the agent is prone to get trapped in idle energy-consuming states, for instance when it smelled a target just behind a wall.

Now that our agent is trained to go to a goal area and avoid obstacles we can use it to perform the harvesting task in a multi-target environment. As of now, since it is just behaving according to the *(sense → action)* loop, it will wander around getting targets until it will run out of energy. In Fig. 2 there is a sample of two simulation sessions.

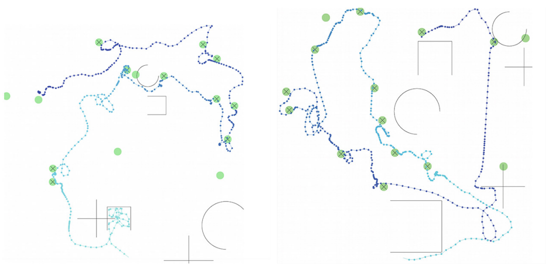

Fig. 2 Typical behavior of the agent IA in the harvesting task

2.3 The Multi-agent Environment

Several instances of this Individualistic Agent, that we name IA, and its real swarm robot counterpart, may be operating together in an environment with multiple target goals. As physical objects, other agents are mapped into the obstacle cortex and that helps in avoiding collisions.

Now, in the multi-agent environment, we can ask the question: Is IA a cooperative agent when performing a collective harvesting task? In other words: How does IA perform in regard of group-level utility while pursuing its individual utility?

For the harvesting task, group-level utility amounts to maximizing targets collected and its is well known, in nature and in scientific research, that it does benefit from collective operation. We can measure the gain obtained by performing the task in group by measuring the ratio of the collected target over the energy used by the group. In physical reality it is quite natural to expect, as it is observed, that it increases with group size up to a point where cumulative individual overhead consumption, waste, target scarcity, and harvesting area and nature relative to group size, will make it decrease.

2.4 The Territorial Agents

Since IA acts individualistically, and basically does not "care" about other agents as long as they don't constitute obstacles, if we want to improve its cooperative behavior we must force it to take into a special account the presence of other agents, not simply as obstacles.

Given the agent individual rationality that makes it *avoid(obstacles)*, we can enforce the reasonable cooperative rule to make agents avoid to run for the same target goals and design a new agent type, the Territorial Agent (TA), that mimics the territorial behavior in avoiding other individuals. The new agent TA is easily implemented with a simple modification of IA sensor preprocessing, a perception distortion, by making it perceive other agents as obstacles that seem closer than they actually are, hence by multiplying their actual distance by a $territoriality$ coefficient ϑ, $0 < \vartheta < 1$. In this way agents can turn their learned ability to avoid obstacles into a strengthened tendency to avoid other agents.

By the same token, we may decide instead, to map other agents into the target perception field but in the opposite polar sector, and this let us implement the Avoidant Territorial Agent (ATA). By doing so, ATA perception will map agents to their specular position into the target visual field, and will "smell" other agents as goals in the opposite direction.

3 Simulations

We run a wide range of simulations to evaluate the behavior of the agents that we designed in a multi-agent environment. Given the wide range of possibile situations that we considered, and the fact that results were consistent and didn't show inexplicable discrepancies, we can choose to report just about a few cases that we consider

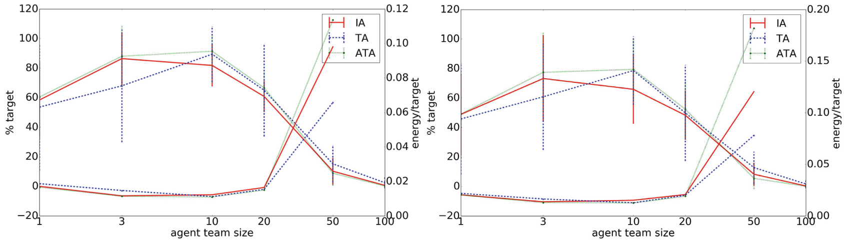

Fig. 3 Performance of teams of agents when targets are uniformly distributed over the environment. Graph lines above, scale on left: Average targets collected (percentage) by homogeneous teams of agents in easy (left graph) and hard (right graph) environments. Graph lines below, scale on right: Energy consumption per target

typical. The environments are selected in two complexity typologies, low complexity have few obstacles, high complexity have more, creating traps and unreachable regions. All agents started their task from the same initial position, the nest at the boundary of the environment. For each environment typology we run two different tests with different disposition of targets, one with the targets distributed uniformly in the environment, the other with the targets distributed in three clusters in a region of the environment distant from the nest. The three teams of homogeneous agents were asked to perform a harvesting task.

Robot agents are simulated according to a realistic, though rough, physical law by taking into account their physical real counterpart, a *4tronix Initio* robot that we used for real experiences of the agent design. Agents consume energy with positive acceleration, that is to say in any situations when they issue a velocity setting to the motor control that is higher then their actual speed. In this way energy consumption corresponds to battery usage. Friction is taken into account by making them consume a small amount of energy whenever they move. Moreover, since direction is enforced by a differential speed of the two motors, besides a natural momentum linked to velocity they also have a rotational momentum linked to the differential velocity of the two motors when turning. The depth of the agents visual field was limited to about one third of the environment.

In order to appreciate the advantage of their work as a team, and the relative performance of the three agents type, the total amount of energy they were given was fixed for every simulation and was shared in equal parts by the team members, thus the energy each agent had was less for larger teams. The results pictured in Fig. 3 and Fig. 4 represent the average percentage of targets collected by a team of homogeneous agents of type IA,TA,and ATA, of different size. The average was computed over ten test run over ten different random arrangements of environment and targets of the same typology.

Simulation results show the natural behavior of the agents populations in performing the task. Populations of territorial agents (TA and ATA) tend to perform better than populations of individualistic agents in most situations, but in the case when the presence of other agents is sparse. TA performs better that ATA when targets are

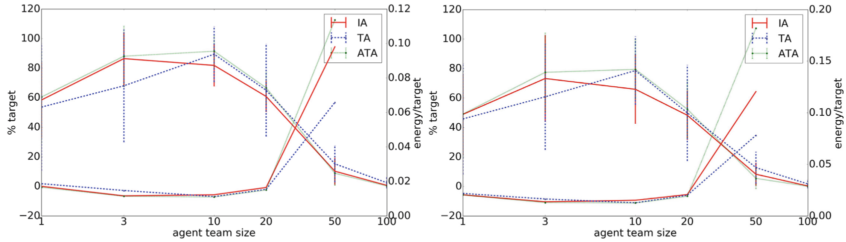

Fig. 4 Performance of teams of agents when targets are sparsely distributed in clusters. Graph lines above, scale on left: Average targets collected (percentage) by homogeneous teams of agents in easy (left graph) and hard (right graph) environments. Graph lines below, scale on right: Energy consumption per target

uniformly distributed. ATA performs better than TA when targets are distributed in clusters and the environment is not too crowded.

4 Conclusion

We designed a simple agent with two perception cortices, one for goals and one for obstacles. We connected its perception cortices to its motor cortex through a relatively simple neural net, and we trained the agent to achieve a goal area and avoid still obstacles. We let it run in an environment populated with other agents of the same type and we observed that it conserved its character as it was running for multiple targets and was avoiding obstacles and collisions. We introduced a mutation on its character by modulating its perception of other agents that induced a territorial personality with a better collective performance in pursuing their individual utility. A more radical perception distortion, that made them perceive an illusive goal when in presence of other agents, induced extreme territoriality that seems to be a better conduct in uncrowded environments with sparsely distributed and clustered resources.

The agent design is relatively simple, relies only basic computational resources and, at least in principle, doesn't even need digital computation and could be implemented with basic analog electronic components.

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Negotiating and Executing Composite Tasks for QoS-Aware Teams of Robots

Silvia Rossi, Claudia Di Napoli, Francesco Barile, Alessandra Rossi and Mariacarla Staffa

Abstract The problem of allocating tasks to a team of robots composing a complex activity with global performance constraints to be met, is NP-hard. Automated negotiation was proposed as a viable heuristic approach allowing for the dynamic adjustment of the performance levels provided by the single robots in the case of robots with limited resources. This approach leads to an improved exploitation of robots capabilities in terms of the number of composite activities that can be successfully allocated to the team. In the present work, the proposed approach is extended to include the possibility for the robots to negotiate for task allocation, and to execute the tasks in an interleaved way, so that the capabilities of the entire team can be better exploited, reducing the time the robots are inactive.

Keywords Multi-robot systems · Multi-robot task allocation · Market-based task allocation

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1 Introduction

There is a growing interest in the use of Multi-Robot Systems to perform complex missions composed of tasks that can be executed by the members of a team of robots. This is mainly due to the market expansion of low costs robots that are not able to execute different tasks. These robots are specialized in specific functions and only when they work in a team, more complex activities can be performed. In this context, the problem of assigning single tasks to the team of robots when global constraints on the global mission are known, becomes a crucial problem.

The Multi-Robot Task Allocation (MRTA) problem has been addressed for a long time, and several task allocation algorithms have been proposed in literature [9, 11]. Nevertheless, some important aspects of the MRTA problem, such as the allocation of composite tasks with global constraints, and the allocation constrained by limited robot capabilities, are still under investigation. Researchers have proposed several solutions for the problem of MRTA, applying principles of market economies to multi-robot coordination [6] using market mechanisms, dynamic vehicle routing [3], auction-based strategies [15], and optimization techniques such as negotiation [14], reinforcement learning [13], vector regression learning [8], Hungarian algorithm [7, 10].

However, among these, market-based approaches for task allocation have shown to efficiently produce sub-optimal allocations [4]. In such market-based approaches, tasks are viewed as goods to be traded, and robots are seen as the participants in the market who trade goods in exchange of a form of payment/reward.

In a previous work [1], the allocation of composite tasks to a team of robots, taking into account robot capabilities that can vary in time according to the available resources, was approached as a dynamic decision problem solved through an iterative negotiation mechanism among a set of agents representing both the task allocator and the robots belonging to the team. It was assumed that robots are equipped with the right functionality to execute a specific task of the composite activity, but they need to move to reach the position where the task has to be executed. Hence, they negotiate with the allocator upon the parameters affecting the performance they can execute the task with, i.e. their battery level determining the maximum velocity which they can move with. The allocation of tasks to robots occurs when the negotiation ends successfully, i.e. when the performance level the robots provide meets the performance requirements of the allocator on the complete composite task. The robots utility functions and concession strategies are designed to take into account both the robots task load, i.e. the tasks they have performed, and their attitude to obtain the task providing acceptable performance levels. It was shown that automated negotiation is a promising heuristic-based approach leading to an improvement in the number of constrained composite task allocations to the team of robots with limited resources with respect to a static task assignment. In the proposed approach, the robot model was simplified allowing robots to alternate task negotiation and task execution. Consequently, once an allocation occurs, the robots were assumed to start the task execution and to initiate a new negotiation after the execution was completed. With this assumption, the robots that were not allocated to tasks remain inactive during the time the other team members execute their tasks, so leading to a waste of resources.

In this work, the robot model is modified to include the possibility to negotiate and execute tasks at the same time to overcome this limitation. In order to model this behavior, the negotiation mechanism is slightly modified since constraints include not only the performance the robot proposes to execute the task, but also the time when the execution of the task may start. With these extensions, the trends of negotiation both in terms of the number of composite tasks allocated to the team, and the total time to execute them, are empirically evaluated to investigate whether the interleaving between task negotiation and execution results in a better exploitation of all team members.

2 A Composite Task Request

Following the approach proposed in [1], it is assumed that a composite task CT is represented as an acyclic oriented graph whose nodes are sub-tasks $\{T_1, \ldots, T_n\}$ that can be performed by different robots $\{R_1, \ldots, R_m\}$ (with $m > n$), and arcs are precedence relationships among sub-tasks determining their execution order. Each task T is characterized by a n-tuple $T =< pos, type >$, where pos is the location where to execute the task T, and $type$ is the required robot functionality to execute the task determining the needed robot typology.

Differently from the formalization proposed in [1], a request for the execution of a composite task, Req, is a n-tuple including the sub-tasks specifications, the required duration for the execution of the CT (CT_c), and also the time the execution of the CT is required to start (CT_s), as additional constraint, so $Req =< CT, CT_c, CT_s >$. Each robot R_j needs a certain amount of time $tct_{i,j}$ to execute the task T_i given by the sum of the time necessary to execute the required task, and the time necessary to reach the location pos_i where to execute the specific task. This time depends on the velocity the robot commits to perform the task with.

A request Req is issued by a Task Allocator Agent (TAA) that is the negotiation initiator, with the goal to assign each sub-task to a different robot in the team, once they provide performance values that meet the required global constraints.

3 The Robot Model

Robots are modelled as task providers, i.e. “market vendors” of tasks characterized by QoS values accounting for the performance levels they can provide. Robots can be heterogeneous, with different sensor capabilities, cost, efficiency and endurance. Their performance may be different, and can be modulated during negotiation in order to get a task assigned. The starting time of a single task can be also changed during the negotiation to meet the constraints coming from the precedence relations specified in the CT. This means that robots have to share a common global time they refer to, both to submit their offers and to concretely execute the tasks they have been allocated.

Tasks are assigned to robots that can complete them within a given deadline, so the task execution time is the only quality parameter the robots negotiate upon. It depends on the velocity the robot may provide to complete the task that, in turn, depends on the robot battery level. The battery of a robot is a limited resource, so it is an upper bound on the time the robot may execute the given task with, as in [11].

A robot R is modeled as composed of:

- a *negotiation state* describing the robot capabilities in terms of available physical resources, the robot task commitments (i.e., its agenda), and the time from when it is available to make new commitments;
- a *deliberative* layer responsible for negotiating with the TAA the allocation of tasks;
- an *execution* layer responsible for the actual execution of the allocated tasks according to its agenda.

Negotiation State. A negotiation state s of a robot R affects the offers it may provide for a specific task T_i. State transitions occur either after the execution of a committed task, or after a new task assignment for a successful negotiation. A negotiation state s is a n-tuple $s =< agenda, b, t >$, where *agenda* is a list of the sub-tasks the robot is committed to execute, b is a predicted available battery level, and t represents the next available starting time for a new task.

An agenda of the robot R_j is composed of a set of triple $\{< T_k, v_{j,k}, t_{j,k} >, \dots, < T_h, v_{j,h}, t_{j,h} >\}$, each one representing a task to be executed, the corresponding velocity, and the starting time the robot committed for its execution. The velocity is in a range $[v_{min}, v_{max}]$ and depends on the robot battery level available when R_j negotiates for a task. In particular, the predicted available battery level b in a state s is the battery level assumed by the robot after the execution of all the tasks in its agenda, and it is computed using a function determining the battery consumption for each task according to the velocity the robot committed to execute that task with. The robot initial state is $s_0 =< \{\}, b_{max}, t_0 >$.

Deliberative Layer. When replying to a request for a task $T_i =< pos_i, type_i >$, a robot R_j in the team makes an offer ($o_{j,i}$) with a possible start time $t_{j,i}$, the next available start time in its agenda, and a time interval $tct_{j,i}$ which it is able to execute the task within. In order to provide these values, the robot R_j evaluates its negotiation state, more specifically, the predicted available battery level b and the position assumed after the execution of the last committed task (T_k) in the agenda (i.e., pos_k). According to this information, it determines the distance d_i to cover for executing the new task, and the corresponding maximum speed $ms_{j,i}$ ($ms_{j,i} \in [v_{min}, v_{max}]$) it can execute the task with the available battery b (where $ms_{j,i} = b/d_i$).

In order to get the allocation of the task, at each negotiation iteration the robot adopts a concession strategy to reduce the proposed time interval by increasing the velocity. A stochastic selection of velocity values for the offers is made by using a Gaussian function, which represents the probability distribution of the velocity offers in terms of the robot utility, as proposed in [1, 12]. The mean value of the Gaussian function $U_{i,j}(v_{min})$ is the best offer R_j may propose in terms of its own utility (i.e., the v_{min}) with the highest probability to be selected. It corresponds to the maximum $tct_{j,i}$ it may execute T_i with. The rationale of this choice is that the robot prefers to use as less battery as possible when providing the task because it tries to maximize the number of tasks it may have assigned. This is why its most convenient offer is the one that minimizes its battery consumption. The standard deviation σ_j represents the attitude of the robot to concede during negotiation, and it is given, for the ith task, by $\sigma_{j,i} = ms_{j,i} - v_{min}$, if $ms_{j,i} \geq v_{min}$, 0 otherwise. It takes into account the load of the robot in terms of the number of tasks it already committed to execute, determining its concession degree. In fact, at each new negotiation the ms_j is computed according to the remaining battery due to previously committed tasks, so generating a new Gaussian for that negotiation.

When upon a successful negotiation, the robot R_j with a negotiation state $s =< agenda, b, t >$ is selected for executing a task T_i, it updates the state by adding T_i at the end of its agenda (with the corresponding velocity and start time), and it computes both the new predicted remaining battery level b', and the next available time ($t' = t_i + tct_{j,i}$) that will be used to negotiate the next allocation. The new state is $s' =< agenda', b', t' >$.

Execution Layer. This layer is in charge of executing, one after another, all the tasks the robot committed to execute that are in its agenda, if any. In case there are tasks to execute, it will read the first task T_k in the agenda and the robot will move to the corresponding position pos_k, with the committed velocity v_k. After the task is executed, it is removed from the agenda, so the negotiation state is updated.

4 Negotiating Task Allocation

The negotiation mechanism adopted in this work is a one-to-many iterative protocol, as in [5]. It consists of a number of *negotiation rounds* proceeding until either the negotiation is successful (i.e., all sub-tasks are allocated), or a *deadline* (i.e., a maximum number of allowed rounds) is reached. At each negotiation round, the TAA sends m *call for proposals* (cfp), one for each robot, and it waits for replies for a given time, known as the *expiration time* of a negotiation round. Each R_j of the ith typology replies with an offer $o_{j,i} =< j, t_{j,i}, tct_{j,i} >$.

In case of a sequential CT without branches, at each negotiation iteration, the TAA evaluates the received offers for each task T_i (starting from the first one), and it selects the one with the earliest end time. In case of an offer $o_{j,i}$ with a starting time $t_{j,t}$ that violates the precedence order (i.e., it starts before the end time of the precedent one), its starting time is shifted forward in order to respect the constraint. If a sequence of offers is found to meet the global constraints, the allocations (and the new starting times when necessary) are notified to each selected robots ($< j, t_{j,i} >$). Such selection, that is made in polynomial time, assures to find a solution with the earliest end time.

If there is no solution that meets the requirements and the deadline is not reached (it is not the final iteration), the TAA asks for new offers, so starting another negotiation round. If the deadline is reached without a success, it declares a failure to all robots that took part in the negotiation (final iteration).

5 A Case Study

The testing scenario is characterized by a simulated environment partitioned into 10 rooms, and a team composed of 9 robots located in the first room waiting for task assignments (see Figure 1).

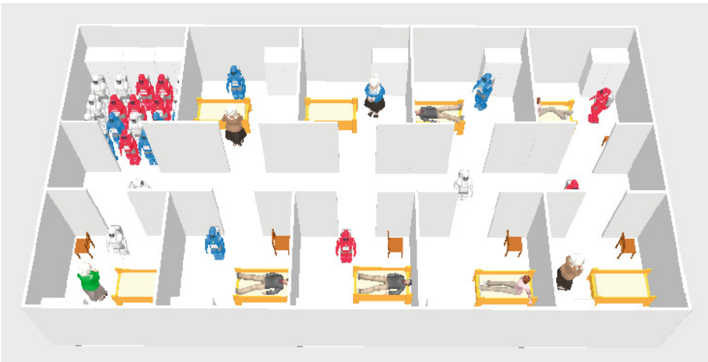


Fig. 1 Simulated scenario.

Our hypothesis is that by interleaving task negotiation and execution the capabilities of the entire team can be better exploited since the time the robots are inactive is reduced. We define a *task interval* as the time occurring between two successive requests of a complex task.

We simulated the negotiation process using Jade (Java Agent DEvelopment framework), a framework for the development of agent-based applications that provides a run-time environment implementing the supporting features required by the agents life-cycle [2], compliant with the FIPA (Foundation for Intelligent, Physical Agents) specifications, the most important standardization activity conducted in the field of agent technology[1].

In the experiments, the TAA issues a CT request, Req, with 3 sub-tasks T_1, T_2, T_3 that must be performed in a sequential order according to the transitive precedence relation $\{T_1 \prec T_2, T_2 \prec T_3\}$. Each robot is able to execute only one type of task, and each task can be executed by 3 of the 9 robots. The position of each task (i.e., where the task has to be performed) is randomly generated among the 10 rooms. The number of allowed rounds for each negotiation is set to 100. In each experiment, 200 requests of CTs are generated, with the same global time constraint $CT_c = 45s$, and a start time shifted according to the considered negotiation intervals between task negotiation and execution. Each experiment is repeated 100 times in order to perform a statistical analysis.

A robot R_j can perform a task T_i with a velocity $v_{i,j}$ to reach the task position in a range between $v_{min} = 0.05m/s$ and $v_{max} = 0.5m/s$ depending on its current battery level. It is assumed that, at the beginning, all robots have the same battery level b_{max} that corresponds to a level that is sufficient to make a complete visit of all rooms (by covering the distance d_{tot}) at v_{max}, hence, $b_{max} = d_{tot} * v_{max}$. At the end of each successful negotiation (i.e., when each tasks T_i is allocated to a robot R_j), the robot battery level is updated according to the following consumption function: $b'_j = b_j - (dist_{i,h} * v_{i,j})$, where $dist$ is the Manhattan distance between the robot last position (pos_h) listed in its agenda (or the current position in case of an empty agenda), and the T_i task position, computed as $dist_{i,h} = d(T_i, T_h) = |pos_{i,x} - pos_{h,x}| + |pos_{i,y} - pos_{h,y}|$.

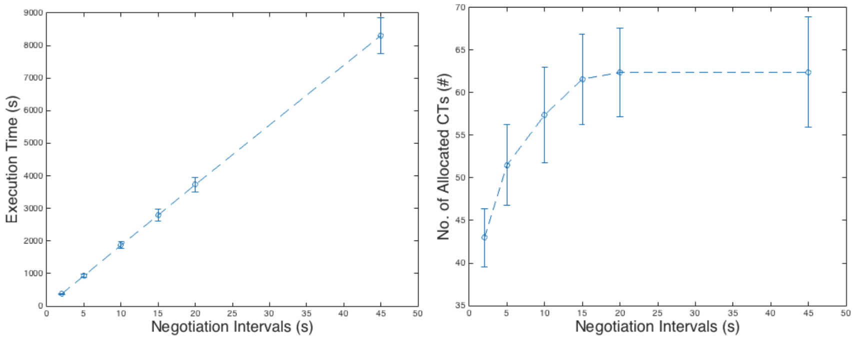
To test our hypothesis, we evaluated the trends of negotiation in terms of the number of allocated CTs, and their total execution time, varying the negotiation intervals. The considered negotiation intervals are $2s$, $5s$, $10s$, $15s$, $20s$, $45s$.

Table 1 shows the average number of allocated composite tasks (Allocated CTs), the average total execution time for each CT (CT execution time), the average number of rounds in case of successful negotiations (round), the average duration of the robots activity (Total execution time), that is evaluated as the time the last allocated complex task ends minus the time the first allocated one starts, for the 6 considered negotiation intervals.

Table 1 Negotiation results with different intervals.

Req negotiation intervals (s)	Allocated CTs (#)	CT execution time (s)	round (#)	Total execution time (s)
2	43±3	40.5±0.5	11±3	372±18
5	52±5	40.1±0.6	8±2	930±58
10	57±6	39.9±0.6	6±2	1867±106
15	62±5	39.7±0.6	5±1	2793±191
20	62±5	39.5±0.5	5±1	3728±220
45	62±6	39.6±0.6	5±1	8308±550

[1] FIPA specifications are available at the website http://www.fipa.org/repository/standardspecs.html



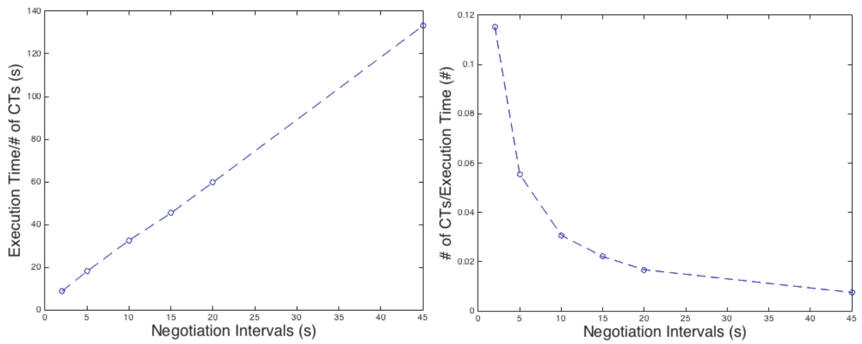
(a) (b)

Fig. 2 Trend of (a) the total execution time and (b) the number of allocated composite tasks, at different negotiation intervals.

As we expected, the possibility of interleaving task negotiation and execution results in reducing the idle time of unoccupied robots. Trends of the total execution time values w.r.t. the Req negotiation intervals are shown in Figure 2(a). When decreasing the time intervals between each request, a shorter total execution time for executing the allocated CTs is obtained with a linear trend. The average duration of each allocated CT does not change when varying the request negotiation interval. Note that with respect to a constraint $CT_c = 45s$, the average values are not optimal due to the stochastic behavior of the concession mechanism.

Moreover, as shown in Figure 2(b), the number of allocated CTs has a logarithmic trend with respect to the different negotiation intervals. More specifically, by increasing the length of the intervals, the number of allocated CTs reaches an asymptotic value that corresponds to the value that is obtained without the interleaving mechanism. It should be noted that when the negotiation interval is short ($< 15s$), some robots are executing tasks while the negotiation occurs, so reducing the probability for the negotiation to be successful. This is supported also by the trend of the number of negotiation rounds necessary to obtain a success that increases for shorter intervals.

As shown in Figure 3 (a), when increasing the length of negotiation intervals, the cost-benefit ratio follows the same trend as the total execution time since the variation in the number of allocated CTs is not relevant, w.r.t. the global total execution time. This is confirmed when considering the benefit-cost ratio, shown in Figure 3 (b), where the benefit obtained by decreasing the length of negotiation intervals, and so the total execution time, exceeds the loss in terms of a smaller number of allocated CTs, since this number is close to the "physical limit" due to the limited battery of the robots.



(a) (b)

Fig. 3 Cost-benefit ratio (a) and benefit-cost ratio negotiation intervals.

6 Conclusions

It is well known that the MRTA problem is NP-hard when global constraints have to be met, so requiring heuristics approaches to address it. Software agent negotiation was proposed as a viable approach when dealing with constraints that do not concern functional characteristics of a composite task to be executed and they can be modulated according to robot resources, its utility in performing the task, and its strategy to win the negotiation.

In this work, we extended the negotiation mechanism proposed in [1] in order to allow robots to negotiate and to execute tasks at the same time. At this purpose both the robot model and the negotiation mechanism were modified. First, the offers submitted to the allocator by the robots includes not only the performance that the robot proposes to execute the task with, but also the time when the execution of the task may start, meaning that the robot is not committed to execute other tasks from that time onward. Moreover, the allocator may accept a proposal informing the corresponding robot that the time for starting the task execution is moved forward in order to meet local and global constraints.

With these extensions, the negotiation trends in terms of both the number of composite tasks allocated to a fixed team of robots, and the total time to execute them, were empirically evaluated showing that the interleaving between task negotiation and execution leads to a better exploitation of all team members. In particular, even though the number of allocated composite tasks is constrained by the amount of battery of each robot in the team, the total time to execute all of them is improved according to the length of the interleaving between negotiation and execution. We plan to further investigating the negotiation trends by increasing the number of robots in the team, and by varying the required global constraints according to the intervals at which negotiation and execution are interleaved, to derive suitable values of the negotiation intervals.

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Part V
Special Sessions on Multi-Agent Systems and Ambient Intelligence (LAFL)

Core Features of an Agent-Oriented Domain-Specific Language for JADE Agents

Federico Bergenti, Eleonora Iotti and Agostino Poggi

Abstract This paper presents the core features of JADEL, an agent-oriented domain-specific programming language for the construction of JADE agents, behaviours and ontologies. The work on JADEL originates from the need to assist programmers by means of tools that reduce the complexity and speed up the construction of a JADE agents and multi-agent systems. The features of JADEL discussed in this paper include abstractions for the main entities of JADE—agents, behaviours and ontologies—and they also encompass the features needed for the construction of domain-specific tasks, thus enriching JADE APIs with novel and simple notations.

Keywords Agent-oriented programming · Multi agent systems · Agent programming languages

1 Introduction

Since the introduction of agents and agent technologies, the interest in agent-oriented programming languages has quickly grown and it rapidly became a very important topic of research mainly because they turned out to be particularly appropriate to model and implement complex multi-agent systems. In fact, agent programming languages are essential components in the development of agent-based software systems, also because traditional languages are not always appropriate for the agent-oriented paradigm. Agent programming languages allow developers to reason at a

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higher level of abstraction and they provide concepts and constructs that are specific for the agent model they describe.

The main objective of this paper is to summarize the current state of development of JADEL, a domain-specific agent-oriented programming language, whose main purpose is to help developers dealing with the complexity of building real-world JADE multi-agent systems. Besides its decennial life, JADE (Java Agent DEvelopment framework) [2] is still one of the most popular agent platform used for both academic and industrial purposes, as detailed in [12]. JADE is also the solid base for others software platforms such as WADE (Workflows and Agents Development Environment) [8], which supports agent-based business process management, and AMUSE (Agent-based Multi-User Social Environment) [4, 5], which focuses on multi player Android-based online games. Next to such projects, JADEL was added as a new way to reduce the complexity of building JADE-based systems, giving support during the implementation of agents, behaviours and ontologies. JADEL is meant to enable the effective use of agents as components (see, e.g., [3]) and it is the basis for envisaged higher-level extensions like the ones discussed in [6].

Approaching AOP with JADE is often difficult because of the continuous growth of the framework and of its inherent complexity. Moreover, a pure Java approach at the AOP paradigm is sometimes perceived as a limitation, mainly because general-purpose languages as Java are not meant for such kind of programming approach, forcing developers to adopt already prepared solutions and frameworks, which may not capture the essence of agent programs. To this extent, JADE APIs could help developers in creating agents and multi-agent systems, but there are no grants on the correct and efficient use of the avaliable agent technologies, because JADE does not force the programmers on a specific agent model, but it relies almost entirely on the Java object metamodel. This kind of considerations clarify that a simpler and more domain-specific way to approach JADE agents could give a consistent benefit in developing multi-agent systems: the actual challenge is to find a solution tailored on JADE own needs. The proposed solution aims to facilitate code understanding, dropping implementation details in favor of a lighter syntax that focuses only on the agent-oriented features. Another objective is to reduce the complexity of the framework, by proposing a solution that helps developers to deal with a small number of entities, which must be clear and easy to manage.

DSLs represent the natural approach to solve the above explained issues. First, a DSL provides appropriate and user-friendly notations for abstractions and constructs, which can overcome limits of general-purpose notations and syntax in a specific domain. A DSL for JADE agents would provide abstractions that would help in the definition of agents, behaviours or ontologies, and it might also provide specific constructs to manage message passing among agents. New notations could be useful in managing the agent behaviour list or the agent message queue. Second, DSLs are able to facilitate data representation, by means of specific descriptions of the allowed data structures for the targeted domain. For instance, JADE messages could be viewed as particular (and complex) data structures, and ontology propositions, predicates, actions and concepts became elements that can act as content of a message.

JADE APIs provide classes and methods for this scope, but their usage is often a tedious work, because there are repetitive parts that can be automated.

In the literature, the question of when and how developing DSL is brightly discussed in [13], where methodologies and patterns that are not only useful to implement a new DSL, but also to analyze reasons and motivations for actually make it, are explained. The proposed motivations are classified in so called decision patterns, whose scope is to help developers deciding in favor of a new DSL. This is important because the development of a DSL is often hard in terms of implementation and maintenance; moreover, the adoption of an existing DSL or an application library such as JADE is cheaper and simpler than build a new one. Nevertheless, a DSL gives consistent benefits for developer of a specific application domain, as explained above in case of JADE agents and multi-agent systems. We have found that JADEL ideas match some of the decision patterns in [13], e.g., notation, task automation and data structure representation patterns, and we believe that such decisions could give several advantages in the use of JADE.

2 Related Work

Since the introduction of agent language technologies, several languages have been formalized and implemented before JADEL conception. Results vary for agent mental attitudes, programming paradigm, agent platform integration, implementation language, and so on. A classification may help to describe JADEL, by comparing it with other existing languages. For example, according to Bădică et al. [1], agent languages classification depends on the usage of mental attitude of the agents. Thus these are divided into *Agent Oriented Programming* (*AOP*) languages, *Belief Desire Intentions* (*BDI*) languages, hybrid languages (that combines the two previous models) and other languages. As discussed in the rest of this paper, JADEL stands with AOP languages in the language subdivision of [1].

AOP was first introduced by Shoham in [17], together with his AGENT0 [18] language as a first example of a simple agent language. Such work is very important because Shoham presented there a new paradigm that affected most of the future developments of agent languages: in fact, he defined AOP as a specialization of the *Object-Oriented Programming* (*OOP*) paradigm, thus opening a wide and promising research area. Not only languages, but framework, platforms, complex systems were developed to match the AOP paradigm, but we believe that further improvements are still possible. To this extent, JADE is one of the platforms that contributed to AOP research, and it surely had a significant impact. Nevertheless, a specific language for JADE agents has never been created: JADEL was conceived to compensate this lack and to solve two main problems of JADE framework.

Moreover, there are BDI languages: a notable example of such a classic agent language is AgentSpeak(L), whose syntax and semantics were formalized by Rao [15]. Its first usable implementation, Jason [10], has become very popular, also because of its tight integration with the Java programming language, that makes it effectively a hybrid language. A BDI language that allows agent to run on the JADE platform already exists, it is JADEX [11]; for this reason, we have not considered a BDI model in our work.

Another discussion on agent programming languages that gave rise to a different classification can be found in [9], where languages are divided into *declarative*, *imperative* or *hybrid*. Declarative languages are the most common, due to the declarative nature of agent-oriented abstractions, both from the AOP and the BDI points of view. But imperative languages have also been implemented, mostly by adding syntax constructs to an existing procedural programming language, such as Java for the *JACK Agent Language* (*JAL*), based on JACK platform [19]. In fact, it is worth noting that an important comparison between agent languages regards the presence (or not) of an host language, and the applicative domain of the agent language: some of them was written from scratch or from theoretical formalization, others were built on top of existing agent technology. As said before, JADEL is built on top of JADE, and its host language is a dialect of Java called Xtend (www.eclipse.org/Xtend).

Another important feature that distinguishes agent languages is the intended domain: JADEL is a *Domain Specific Language* (*DSL*) because it relies entirely on JADE, and it serves only for developing JADE agents. Therefore, it definitely differs from general-purpose languages, which treat agents more generally, without any reference to a specific definition domain. The advantage and disadvantages of DSLs have been exhaustively covered in the literature, for example in [14] and [13]: both agree that special care must be put in the development of a DSL and that its making is often difficult in terms of conception, implementation and maintenance, but a well done DSL is worth the effort. For reducing such an effort, practical and useful tools have been developed: an effective way to build DSLs is Xtext (www.eclipse.org/Xtext), an Eclipse IDE plugin that permits the definition of a grammar and that provides utilities for translating such a grammar in Java code.

A number of languages have been made with Xtext, ranging over several different domains. An Xtext-based modern agent language is SARL [16], which claims to be general-purpose, architecture-agnostic, imperative and with an intuitive syntax. It is highly extensible and it permits the creation of holonic agents that can run into the Janus (www.janusproject.io) multi-agent platform. JADEL is also based on Xtext, and it presents some commonalities with SARL, even if the two languages have been developed independently [7] and they target different platforms. In details, they share a syntax for agent definition and both of them use specific (but different) constructs for events and agent capabilities (SARL), or behaviours (JADEL). Despite this, the two language are very different in terms of purposes and usage.

A first version of JADEL was presented in [7], where its main abstractions, namely, the *agent*, the *behaviour* and the *ontology*, are described and the overall motivations of the work are explained, but due to the early stage of the JADEL implementation, only a simple self-contained example was shown. This paper presents a new version of JADEL that enhances such concepts, by means of some syntax improvement, new features of the language, and a better integration with JADE-native code, as explained in details in Section 3.

3 JADEL Programming

The main purpose of JADEL is to help the developer dealing with JADE concepts and classes, on a high level of abstraction. In order to reach such a desired result, a small set of primary entities is chosen from all available abstractions (read: classes) that JADE provides. The chosen abstractions are: the *agent*, the *behaviour* and the *ontology*, which are presented in details in Section 3.1. With such abstractions only, JADEL is capable to provide all the needed tools to manage JADE agents in a correct and coherent view of its agent model. That is, define agents, make a list of behaviours for agents, and give agents suitable ontologies for communications.

Agents, behaviours and ontologies are not an exhaustive list of what a developer can do with JADE API. In fact, the selection of only such abstractions is a design choice for JADEL. The criteria to select features are *(i)* their significance for the JADE agent model, that is, the involvement in the creation of a single agent, *(ii)* their role in an agent life-cycle, and *(iii)* how much they are related to artificial intelligence issues, rather than platform architecture details. To this extent, scope of JADEL is to allow programmers to think in terms of single agents, rather than of a multi-agent system. Therefore, the most technical concepts and operations are left to the APIs. This is not a limitation, due to the underlying JADE platform: in fact, it permits developers to write their own implementations, e.g. of a message codec, or of an interaction protocol. Then, such implementations can be embedded in a JADEL project, as explained in the following sections. All in all, the adopted approach maintains JADEL code very simple and readable, without detracting from its expressiveness.

Agent set up, agent actions (which are encapsulated in behaviours) and message exchange are examples of domain-specific concepts. Programming in JADE each of these includes parts that are repeated almost identical in all implementations, turning the construction of some aspects of a multi-agent system a tedious and repetitive task. For example, Java code needed for an agent to wait for a message must follow closely a proposed pattern with very limited improvement opportunities. Obviously, such and similar patterns cannot be avoided, but they could made clearer and easier to develop and maintain, dropping most of the implementation details and all the repeated idioms. Thus, appropriate constructs with their own specific notations have been introduced. Their explanation can be found in Section 3.2.

3.1 Agents, Behaviours and Ontologies

As said above, in JADEL there are three main entities that can be defined. The first is the agent, that is an autonomous entity that belongs to a family and it could have its own ontology for communication; its life-cycle consists in an initialization of its capabilities, in a loop where it chooses from a list of tasks on its own initiative, and in a final phase of take-down. Thus, a JADEL agent can extend one or more existing agent classes, both JADEL or JADE-native, and it can use an ontology. It translates in an agent class, i.e., a precise definition of the agent properties and capabilities. For example, the declaration of an agent which uses a specific `DomainOntology` and whose characteristics extend those of `AgentFather` and `AgentMother` has the form below. The keyword `agent` is used to specify the agent entity.

```
agent NewAgent
    uses ontology DomainOntology
    extends AgentFather, AgentMother {
}
```

The set up of the agent and its take down, i.e., its specific cleanup tasks, can be coded inside the curly brackets just following its declaration, using the `on create` and `on destroy` syntax, respectively. Such expressions are borrowed from Android notations in order to ensure consistency and compatibility with mainstream nomenclature. Here is a classic example.

```
agent Hello {
    on create {
        log("Hello World")
    }
    on destroy {
        log("Goodbye")
    }
}
```

Some built-in function come with JADEL, as the `log` function in the previous example. As expected, `log` writes in the personal log of the agent. The `on create` and `on destroy` blocks may also contain user-defined code, written in Xtend (not Java). Moreover, inside the block of an agent there is the possibility to declare auxiliary variables (properties) and operations (methods), useful for specific tasks. It is worth noting that one can always put all algorithmic code in agent user-defined methods, but this isn't probably the most effective way to take advantage of the available agent technology. A better approach is the use of behaviours to encapsulate agent actions and leave the agent scheduler controlling their lifecycle.

The second entity that JADEL provides is the behaviour, that describes in details only one action, or task, which can be executed during the agent life-cycle one or more times. One-shot actions are deleted from the agent task list after the first run, on the contrary, cyclic actions remain in such list for the entire life of the agent. JADE users are already familiar with these notations, because there is a one-to-one mapping with JADE one-shot and cyclic behaviour. Due to the important role of communication and message passing, an ontology can be specified. Supertypes of a behaviour and an used ontology are declarated in the same way adopted for the agent. Moreover, a behaviour can use parameters, specified using parenthesis, and it can be owned by a certain agent, whose name is identified after the keyword `for`, as in the example below.

```
cyclic behaviour NewBehaviour(T1 x, T2 y)
    for NewAgent
    uses ontology DomainOntology
    extends Behaviour1, Behaviour2 {
}
```

Note that only the type of the behaviour, the keyword `behaviour` and its name are mandatory in the behaviour declaration. Behaviours can possibly be activated by a trigger event, such as the reception of a message, but they can also perform an action without any activation. The domain-specific construct `on-when-do` plays the role of descriptor of a behaviour action. The keyword `on` is optional and it serves to specify an event, as for the set up and take down of the agent. The second keyword `when` is used to put conditions to the event nearly happened, so it is available only in case an event was specified with `on`. For example, an event can be an incoming message, and it is possible to narrow it down to just messages with a certain performative, as follows.

```
on message msg
when {
    performative is INFORM and
    ontology is DomainOntology
} do {
}
```

The syntax of the `when` code block is explained in details later, but at first glance, it is worth noting that the language expressions are intuitive and similar to discursive English, in order to gain readability and ease of use. The closing block `do` is mandatory and it contains the intended action, i.e., the code, written in Xtend, that runs when the behaviour is chosen by the agent behaviour scheduler, after the occurrence of an appropriate event. As for the agent entity, a behaviour may need auxiliary methods and variables, which can be coded outside the `on-when-do` construct, and coded in Xtend.

Finally, ontologies are defined with the keyword `ontology`. In JADE, there are few examples of ontologies, and their use is often perceived as one of the main difficulties in the development of a multi-agent system. This could be caused by the abundance of implementation details in an ontology class definition, that distract from the correct semantics of the ontology itself. We try to ease such a definition by means of a clear and concise syntax, that is also coherent with other entities. As for behaviours, ontologies may refer to a specific agent class, by means of the keyword `for`. This means that only agents of such class can communicate with each other using that ontology. It may be useful if there is the need to refer to some specific agent features within the ontology, but it is optional.

```
ontology DomainOntology
    for NewAgent
    extends Ontology1, Ontology2 {
}
```

As usual, it is optional to indicate some base classes. Ontologies cannot have properties nor they can perform operations, as they are simple dictionaries of concepts and predicates that agents use to communicate. Thus, inside an ontology block, concepts, predicates and propositions can be specified. An example taken from the documentation of JADE and rephrased in JADEL is useful to illustrate the selected syntax, as follows.

```
ontology MusicOntology {
    concept Item(integer id)
    concept Track(string title, integer duration)
    concept CD(many Track tracks) extends Item
    predicate Owns(aid owner, Item item)
}
```

As we can see in this last example, concepts and predicates are defined inside the ontology block. Concepts are atomic or structured entities that describe an object or an entity used in the communication, and they may extends other concepts. Predicates set relationships among concepts. Some types, such as `string`, `integer` or `aid`, are basic types, always written in lowercase, and they can be used in the definition of atomic concepts: `id`, `title`, `duration` and `owner` in the example. Moreover, they all can be also used as parameters for predicates. The keyword `many`, available both for concept and predicate parameters, identify a list of such parameters. Both concepts and predicates translate in the respective JADE classes, therefore JADE-native code for them is also compatible with JADEL ontologies.

3.2 Domain-Specific Expressions

Entities alone are not sufficient in terms of expressiveness to efficiently manage all aspects of JADE agents. They do not provide shortcuts for making the agent behaviour list nor they helps dealing with one of the most used feature of JADE agents, i.e., the message passing, except for the `on-when-do` construct seen previously. In fact, the statement `when` together with its block of code is a first example of *domain-specific expression*, which translates more effectively the whole management of JADE message templates, by means of logical connectives. The body of a `when` expression is composed by one or more atomic expressions, which can set an available performative, an ontology or even a content of the message. The latter deserves a particular attention, as one of the benefit in using JADEL is that both strings and ontology elements are allowed to be a content and thus they are managed in the same manner.

Other domain-specific expressions that have been introduced with JADEL are `activate behaviour`, `send message` and `extract-as`. What we call behaviour activation is actually the creation of a new behaviour object and its insertion in the agent's list. A behaviour activation is only possible in the `on create` and `do` body, as putting it elsewhere would not make sense (for example, behaviours can not be activated during the agent take down). The syntax is exemplified below.

```
activate behaviour NewBehaviour(parameter1, parameter2)
```

The `send message` expression provides the definition of a message to be sent. This expression automates the creation and the sending of a message, by treating it as a sort of data structure with up to four fields, i.e., an optional ontology, a performative, a list of recipients and a content. These are enumerated as in the example below (or in a different order).

```
send message {
    ontology is DomainOntology
    performative is REFUSE
    receivers are AIDList
    content is NewContent
}
```

The syntax is very similar to the one of the `when` expression, in order to maintain readability and coherence. Again, a content can be a string or an ontology element (when an ontology is specified).

Finally, a useful expression is the `extract-as`, which permits to cast the content of a message in an useful type for further processing.

```
on message msg
when {
    performative is INFORM
} do {
    extract msg.content as NewContent
}
```

This is needed because of the nature of a JADEL content: as said before, it could be a string, thus it is easily accessible via the `getContent()` method of `ACLMessage` in JADE APIs, but it could also be a concept, a proposition or a predicate, which require more attention in their management and the use of the content manager of the agent. Therefore, both cases were put together in the `extract-as` expression. Such a union permits developers to manage all contents in the same way, thus facilitating reuse and obtaining a more readable code.

4 Asynchronous Backtracking in JADEL

At the current state of development, JADEL is ready for the definition of agents, behaviours and ontologies; moreover it simplifies some of the most often used operations in the programming of a JADE agents.

A nontrivial example that captures the advantages in using JADEL is the implementation of an agent which is able to cooperate in an *A*synchronous Back-Tracking (*ABT*) algorithm. The algorithm is often used to solve *Distributed Constraint Satisfaction Problems* (*DCSPs*), where it encompasses a set of variables $x_1, x_2, \ldots, x_n$, each of which can assume a values of finite domains $D_1, D_2, \ldots, D_n$, respectively, and a set of constraints, which are defined by predicates on such variables. For solving a DCSP, each agent owns a variable together with its constraints, and all agents communicates asynchronously by exchanging messages with each other, in order to set the correct value of their variables, taking constraints into account. In ABT, messages are parted into `OK` and `NoGood`, and they are used to communicate a new value or a new constraint, respectively. When each variable is associated with a correct value, no `NoGood` message is sent, and the algorithm terminates. For further details, see Yokoo et al. [20].

In order to manage agent communications, which is central in DCSPs, we choose to describe the main concepts of the ABT in an ontology. The `ABTOntology` permits to define a language in which `Assignments` are composite concepts that associate an agent (its variable) with the respective value; `OK`s are predicates used for communicate an assigment; `NoGood` are predicates that contain a list of incorrect assignments and finally, `NoSolution` is sent when finding a solution of the problem is not possible. Writing such an ontology is trivial in JADEL.

```
ontology ABTOntology {
    concept Assignment(aid variable, integer value)
    predicate OK(Assignment assignment)
    predicate NoGood(many Assignment assignments)
    proposition NoSolution
}
```

ABT agents can send `OK` and `NoGood` messages, and they can also wait for messages from other agents. Moreover, they can all have the possibility to check their constraints, when a new assignment is made. Sending messages, waiting for responses and checking constraints are all tasks that can be encapsulated within JADEL behaviours. For example, a cyclic behaviour is used to wait `OK`s from other agents.

```
cyclic behaviour ReceiveOK for ABTAgent
    uses ontology ABTOntology {
    on message msg
    when {
        ontology is ABTOntology and
        performative is INFORM and
        content is OK
    } do {
        extract recvOk as OK
        val assignment = recvOK.assignment
        theAgent.agentView.replace(assignment.variable,assignment.value)
        activate behaviour CheckAgentView
    }
}
```

The behaviour activates another behaviour, which is the core of ABT algorithm, simply written as follows.

```
oneshot behaviour CheckAgentView for ABTAgent {
    do {
        if(!theAgent.checkConstraint()) {
            if(!theAgent.assignVariable()) {
                activate behaviour Backtrack
            } else {
                activate behaviour SendOK
            }
        }
    }
}
```

After the definition of all behaviours, we write an agent that is able to use the chosen ontology and behaviours. The following JADEL code is cut for the sake of brevity, but the main parts are present.

```
agent ABTAgent uses ontology ABTOntology {
    var myVariable
    var agentView = <AID, Integer>newHashMap()
    var neighbours = <AID>newArrayList()
    on create {
        // cut: other agents are taken as arguments
        // cut: set of neighbours and myVariable
        activate behaviour CheckAgentView
        activate behaviour ReceiveOK
        activate behaviour ReceiveNoGood
        activate behaviour ReceiveNoSolution
    }
    boolean checkNoGood() { /* cut entirely */ }
    boolean checkConstraint() { /* cut entirely */ }
    boolean assignVariable() { /* cut entirely */ }
}
```

The methods `checkNoGood`, `checkConstraints` and `assignVariable` are coded in Xtend and they contain simple checks and operations that support the fuctioning of the algorithm. All other operations described in [20] are designed as behaviours. Informally, the JADEL ABT implementation seems to be simpler than its associated JADE version, because of the transparency of the agent model, especially for ontologies and messages. Moreover, such an implementation is much shorter than the equivalent Java one. We obtain a JADE implementation directly by the JADEL code generator, and for this reason it is equivalent to the JADEL one. Here is a comparison between the two mentioned implementations, based on Lines Of Code (LOC). We consider only non-comment and non-blank LOC. We also emphasize the fraction of domain-specific features and expressions over the total number of lines. Domain-specific features in JADEL are those presented in Section 3, while JADE domain-specific are the actual calls to specific APIs.

	JADEL (LOCs)	DS/JADEL (%)	JADE (LOCs)	DS/JADE (%)
ABTAgent	57	0.12	149	0.06
ABTOntology	7	0.86	113	0.23
Behaviours	138	0.41	380	0.20

The results show that the JADEL implementation is far lighter in terms of amount of code. Moreover, the fraction of domain-specific code over the total could be used as a measure of the expressiveness of the proposed language.

5 Conclusions

This paper provides an overview of the work that have been devoted to the development of JADEL, from motivations and main purposes to actual implementation. As a first result, note that with the core features that JADEL provides as described in this paper some simple, yet very well known, examples of JADE agents—such as the music shop agent—became trivial. Writing agents and behaviour in JADEL is far simpler than with JADE because of the complete decoupling between the agent metamodel and Java object metamodel. The ABT example shows how the resulting higher level of abstraction is important when developing nontrivial agents. Moreover, the relations among entities are explicit and clear, as they are defined in the declaration of the entity or obtained by using domain-specific construct, such as the activation of a behaviour. Another significant result is the avoidance of repetitive tasks: especially for the ontology and the behaviour actions. Concept, predicates and proposition are defined in an intuitive way, and the technicalities beyond them are left to the JADEL compiler. Reception of a message is treated with a specific construct and the developer no longer have to bother about the message templates and content extraction. JADEL and its compiler are not yet officially part of the JADE ecosystem because of the inherent complexity of the compiler, which is still not at the level of maturity that JADE users expect. Anyway, the compiler, related documentation and examples are freely available open source upon request.

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Forgetting Methods for White Box Learning

Anthony D'Amato and Matthieu Boussard

Abstract In the Internet of Things (IoT) domain, being able to propose a contextualized and personalized user experience is a major issue. The explosion of connected objects makes it possible to gather more and more information about users and therefore create new, more innovative services that are truly adapted to users. To attain these goals, and meet the user expectations, applications must learn from user behavior and continuously adapt this learning accordingly. To achieve this, we propose a solution that provides a simple way to inject this kind of behavior into IoT applications by pairing a learning algorithm (C4.5) with Behavior Trees. In this context, this paper presents new forgetting methods for the C4.5 algorithm in order to continuously adapt the learning.

Keywords Learning · Forgetting · Decision Trees · Classification · IoT · Data Mining · C4.5

1 Introduction

In the Internet of Things (IoT) domain, services must be more intelligent, to the extent that proposing a personalized service to the user has become one of the principal challenges; or to put it another way, ensuring that applications give the user an impression of uniqueness, by learning his/her behavior and acting in consequence, has become a primary objective. Moreover, as an end user never has the same behavior over the course of a year, a service that learns a specific characteristic of his/her behavior must be capable of adapting. In this domain, smart devices must quickly provide the service they claim to provide, otherwise they will have no utility in the

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eyes of their user, which reinforces the idea that the learning method offered within a service must rapidly satisfy end user needs.

This paper proposes an adaptive learning method for developers with a *White Box* approach. The *White Box* learning notion is a fully controllable, predictable, powerful and understandable learning algorithm, that does not just deliver an output depending on an input but also visually displays how this output was found. In contrast, *Black Box* algorithms remain very powerful, but are harder to explain. For instance, in Deep Learning algorithms, understanding how the weight of an artificial neuron will impact the output can be tricky. For the *White Box* approach, we choose the Behavior Trees (BTs) [4] mechanism widely used for Artificial Intelligence in video games [10] which are well suited to the characteristics of the *White Box* (Table 1) [8]. Introducing learning in BTs should not break this *White Box* approach. For instance, Q-Learning algorithms can be integrated in BTs [6, 7] but this integration is too *Black Box* by nature and has a very slow convergence. Learning algorithms that are quite capable of such characteristics are classifiers and more precisely algorithms inducing Decision Trees because they provide an easy way to read the rules generated. We chose the famous C4.5 classifier algorithm [13] to introduce learning in BTs while maintaining a *White Box* approach. Figure 1 shows the integration of learning in an AI designed by a Behavior Tree. All the learning capacity is concentrated in a limited part of the BT and as we use a classifier inducing a Decision Tree, this part also provides a graphical view.

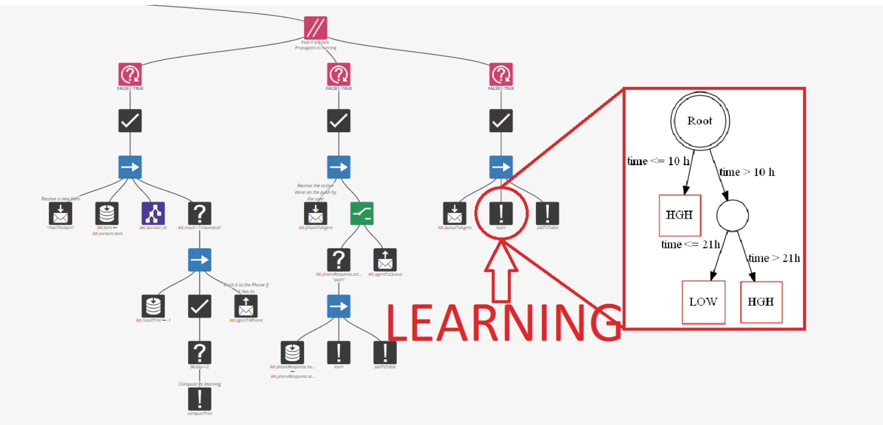

Fig. 1 Integration of learning in a Behavior Tree

This paper is organized as follows: Section 2 explains the choice of the C4.5 algorithm among other classifiers and adds some details on the algorithm itself; 3 proposes new forgetting methods to add adaptability to C4.5; and 4 presents an evaluation of each of these methods and their performance.

Table 1 Comparison of decision-making techniques.

	State Machines	Fuzzy Logic/ Markov Systems	Goal-Oriented Behavior	Rule-Based Systems	Behavior Trees
Simplicity	++	-	+	-	++
Separation of Game Design and Programming	++	+	+	++	++
Flexibility	-	+	+	+	++
Behavior Quality	-	+	+	++	++
Efficiency	++	-	-	++	+
Conclusion	Very Simple	Probabilistic	Great for planning	Limits not reached yet	High flexibility

2 Related Work

As previously mentioned, our research into a *White Box* learning led us to choose the classification algorithm C4.5. This algorithm induces a Decision Tree from a training set and is based on the information gain concept. It was identified as one of the top 10 algorithms in Data Mining [15] and other work led by Gracia and Herrera [9] used statistical tests over 30 database to show that the C4.5 algorithm is the best classifier, when compared to CN2, Naive Bayes, 1-Nearest Neighbors and a Kernel classifier.

Let D be the training set composed of samples x_i for the C4.5 algorithm such that:

$$D = \{x_1, x_2, \ldots, x_n\} \tag{1}$$

The samples are themselves composed of a set of predictive variables A named *attributes* and a predicted variable Y, that can have multiple values named *classes*. For example with T attributes as the input, the first sample is defined by:

$$x_1 = A_1 \cup \{y_1\} \;\; with \;\; A_1 = \left\{a_{1,1}, a_{1,2}, \ldots, a_{1,T}\right\}$$

In the above $a_{i,j}$ is the value of the j^{th} attribute of the i^{th} sample and y_j the predicted output value of the i^{th} sample.

To choose the right algorithm, which would form the foundation of our learning algorithm, we had three main criteria. The learning algorithm must have the following attributes: the *White Box* property, by inducing decision trees (2.1); the ability to handle multiple attribute values and continuous attributes (2.2); the ability to deal with dynamic training sets (2.3).

2.1 A **White Box** *Learning*

Since BTs are *White Box*, adding learning to them must keep this characteristic and therefore, the rules induced by the learning algorithm must be understandable. The first methods we considered were the Case Based Reasoning algorithms. Case Based Reasoning [11] is a process that aims to solve new problems using a database of solutions. Another option we considered was Boosting Algorithms, which are based on the creation of highly accurate prediction rules thanks to the combination of weak and inaccurate rules. One of the most famous and the most used is the AdaBoost algorithm introduced by Freund and Schapire in 1995[14]. Yet, neither Case based Reasoning nor Boosting algorithms provide simple visual output, something that Decision Trees do very well indeed.

2.2 Multiple Attribute Values and Continuous Attributes

A few years before the creation of the C4.5 algorithm, CART [3] was published. This algorithm handles both numerical and categorical variables and induces both a Decision Tree and a Regression Tree. Therefore, CART can propose continuous outputs thanks to this Regression Tree. However, CART is not adapted to attributes with multiple values because it creates binary trees, whereas C4.5 is well adapted for this. Indeed, if an attribute has more than two possible values the tree induced by C4.5 will have a branch for each possible value.

The predecessor of C4.5, ID3 (Iterative Dichotomiser 3) [12] induces also a Decision Tree from a training set but it was very hard to use on continuous data because searching for the best split was time consuming. The handling of continuous attributes by C4.5 was one of the numerous improvements on ID3.

2.3 Data Streams

C4.5 is used for the creation of Decision Trees from a static database. However, in our application the training set changes every time a new sample from the end users behavior arrives, which is a situation that is similar to Data Stream Mining [2]. A Data Stream consists of a sequence of data items arriving at high frequency, generated by a process that is subject to unknown changes. One of the major priorities of Data Stream Mining is its ability to adapt to these changes by predicting the goal or setting up forgetting methods on the incoming data. As in our application of learning there is a constant follow-up of the end user, and the use of C4.5 algorithm must be equivalent to a Data Stream Mining by applying forgetting methods without this data rate constraint, but with the problem of constant adaptation to the incoming information.

3 Forgetting Methods

As the end user behavior is variable, the learning must be able to adapt efficiently. However, the C4.5 algorithm is not suited to fast adaptation because, in order to counterbalance previous training samples, the algorithm needs as many new cases as previously encountered. For instance, if the training set is composed of 50 days of constant behavior no behavior variation during 50 days and if the user decides suddenly to change all his previous decisions, then it will take another 50 days for C4.5 to induce a tree with the new user behavior. Indeed the samples from the first 50 days give more information about the user behavior than the new ones because they are more numerous. And as C4.5 is based on information gain measurement, the first behavior is still induced by the algorithm. Therefore, in this section several methods are proposed to adapt the learning to variations. This paper proposes two new methods for forgetting, namely the *Random Forgetting*(3.2) method and the *Leaf Forgetting*(3.3) method.

3.1 Sliding Window

This method is based on the current algorithms used in the application of Clustering Algorithms on Data Stream [5] which consists in applying a Sliding Window to the incoming stream. This method makes it possible to remember all the recent events that occurred inside this window.

For the Sliding Window method, a maximum length N for the training set is chosen and if this upper limit is reached, every time a new sample is added the oldest (x_1) is deleted. Let z be a new sample, if $Card(D) = N$:

$$D = (D \setminus \{x_1\}) \cup \{z\} \tag{2}$$

3.2 Random Forgetting

For the newly introduced Random Forgetting method we define a maximum size N for the training set and once this ceiling is reached, every new case added to the data set leads to the random deletion of a stored case. Given the function $rand(N)$ picking randomly an integer between 0 and $N - 1$ and a new sample z, if $Card(D) = N$:

$$D = \left(D \setminus \left\{x_{rand(N)}\right\}\right) \cup \{z\} \tag{3}$$

The approach with this method is, compared with the Sliding Window, to introduce an unpredictable deletion in the training set in order not to forget necessary the oldest samples, which could be significantly important for the learning. It allows to remember important events relatively spaced in time.

3.3 Leaf Forgetting

The second method introduced in this paper is termed Leaf Forgetting. Here, each sample in the training set has at its disposal a weight, named w.

Once the tree is induced, the training set can be partitioned in accordance with the leaves of this tree. Let L_i be the set of training samples reaching the i-*th* leaf and k the total number of leaves, then D can be defined as follows:

$$D = \bigcup_{i=1}^{k} L_i \tag{4}$$

When a new sample is joined to the training set, it checks in which leaf of the previous tree this sample is arriving. All the data stored in this specific leaf of the tree have their weights increased by an update function f. Then if the weight of a case is higher than a maximum w_{max}, it is deleted from the training set, which can be defined by:

Let y be a new sample for the data set:

$$y \in L_i \Rightarrow \forall x \in L_i,\ w_x = f(w_x) \tag{5}$$

Let O be the set in which are the samples that must be deleted from the training set defined by:

$$O = \{z, w_z > w_{max}\} \tag{6}$$

Then the new training set is defined by:

$$D = D \backslash O \tag{7}$$

For a fast adaptation, it is important that no cluster be strongly preponderant on others and this is where this method has an advantage over others because increasing weights in each leaf favors over time a balance between learned behaviors.

4 Results

During this experiment, agents designed with BTs control the temperature in each room of an inhabited house and learn the temperature the user desires. For this simulation we focus on one room.

The available data are the outdoor temperature (*OutTemp*), the user presence (*Presence*), the time (*Time*)and whether or not the user is working on this day (*Working*). The temperature (*Temp*) in a room has 3 values: *"Low"*, *"Medium"* and *"High"*. Each time the user decides to change the temperature, the state of each sensor plus the desired action can be added to the training set:

$$A = \{OutTemp, Presence, Time, Working\}$$
and
$$Y = \{Temp\}$$

Furthermore, every 10 minutes the agent learns the current situation but also computes the tree previously induced and applies its decision for the temperature in the room. If the end user is not satisfied with this decision and changes the temperature to a preferred level, then the agent does not make any further decisions until its decision is the same as the users. These user interactions are recorded for the experiment. Then, when the day is over, we apply a forgetting algorithm and C4.5 is computed on the current training set.

The metric used to measure the efficiency of our smart agent is the number of user actions that occur during the simulation. This measure shows the number of actions an end user has to perform in order that the agent acts on his/her behalf. Indeed, the fewer interactions the user has to perform, the more efficient the learning adaptation.

4.1 Adaptation Speed

As a user can rapidly change his/her behavior, the learning algorithm must be able to adapt quickly to match the new behavior. The speed of adaptation is a strong criteria for forgetting because it is necessary to limit the number of human actions with the device that are required for it to suit his preferences. Performance in terms of speed for each forgetting method is evaluated in the following simulation:

This simulation (Figure 2) lasts 100 days during which the user has a constant behavior for 50 days and then inverses completely his previous actions if the user preferred a *"High"* level, he switches to *"Low"* and vice versa. The simulated user behavior is the following: the user is working from Monday to Friday and is not working at the weekend. His/her behavior changes, depending on whether the current day is a working day, or at the weekend. The user likes to sleep in a warm room and turn off the heating when he/she goes to work. At the weekend, when the user is at home, he/she likes to set the temperature at a medium level. For this first experiment the input of the classification algorithm is limited to:

$$A = \{Presence, Time, Working\}$$
and
$$Y = \{Temp\}$$

During this experiment five simulations are launched:

– Without any forgetting method
– Using a Sliding Window with $N = 720$ ($\simeq 5$ days)
– Using Random Forgetting with $N = 720$ ($\simeq 5$ days)
– Using Random Forgetting with a length of 20 days $N = 2900$ ($\simeq 20$ days)
– Using Leaf Forgetting with $f(w) = w + 1$ and $w_{max} = 100$

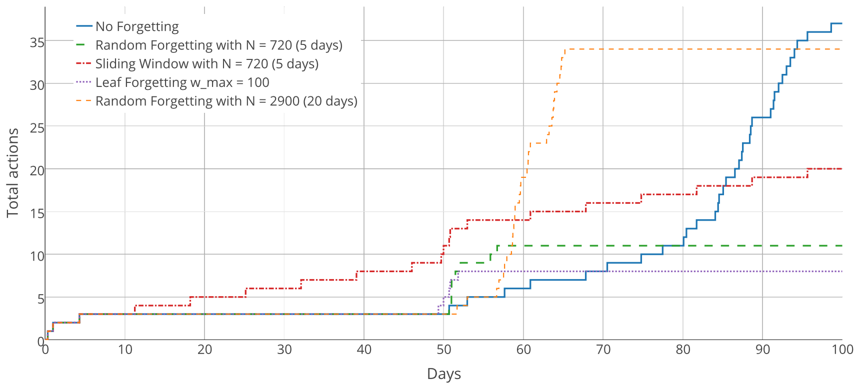

Fig. 2 Total number of user actions over a period of 100 days with a behavior change at the 50th day (the lower the better).

Results. As we can see in the Figure 2, without a forgetting algorithm, the number of human actions is not only high but it also takes a long time to learn new behavior. The explanation for this very long adaptation is that the training set has accumulated a lot of samples about the user behavior during the 50 first days, which produces a decision tree that is difficult to modify. Indeed, as the algorithm keeps all samples, it needs as many new samples about the inverse behavior as the samples accumulated during 50 days.

The Sliding Window is strongly dependent of its length: if it is small, its adaptation is fast but it forgets past actions like the behaviors during the weekends. Indeed, as we can see in Figure 2, every 7 days the user changes the temperature. This is due to the Sliding Window length that is less than five days, then at the end of the working interval, the weekend behavior is totally forgotten and must be learned again. With a larger size the Sliding Window would have remembered older events but would have had slower adaptation.

Random Forgetting is also dependent on N, indeed as we can see, the smaller N, the faster it becomes. This is explained by the fact that the smaller N is the higher the probability deletion of an old undesirable behavior becomes, and consequently it takes less time to learn a new behavior. For Random Forgetting with $N = 2900$ ($\simeq$ 20 days), as N is high, the number of samples representing the old behavior takes time to decrease and therefore a lot of user actions are necessary to delete this previous behavior.

Leaf Forgetting has the best performance in this experiment and therefore has the fastest adaptation of all methods. Increasing weights only in the leaves of the current behavior leads to explicitly forgetting targeted behavior and therefore makes it possible to rapidly counter the previous behaviors the user had. Through this forgetting method it is possible to balance the number of samples in each leaf induced by C4.5 and thus, it ensures that few leaves are preponderant over others.

4.2 Memorization Capacity

The device continuously learning the user behavior must not only have fast adaptation, but must also keep in memory events likely to occur a long time after they first occur. For example, in summer there are no low temperature levels equivalent to those likely to occur in winter, and therefore, even if the learning has to be adapted to the current season, it must not forget what it has learned during the previous season when adapting to the current one. Performance concerning the memorization of each forgetting methods is evaluated in the following simulation:

This simulation (Figure 3) lasts 2 years during which the user adapts the inside temperature in accordance with the outdoor temperature [1]. For this experiment, the outdoor temperature is added in the input:

$$A = \{OutTemp, Presence, Time, Working\}$$
$$\text{and}$$
$$Y = \{Temp\}$$

During this experiment, three simulations are launched:

– Using Random Forgetting with $N = 720$ ($\simeq$ 5 days)
– Using Random Forgetting with a length of 20 days $N = 2900$ ($\simeq$ 20 days)
– Using Leaf Forgetting with $f(w) = w + 1$ and $w_{max} = 100$

Results. As previously mentioned, the Random Forgetting method is strongly dependent on its length and this simulation highlights this constraint. In addition, as we can see,during the first year the Leaf Forgetting is faster in learning the user behavior than the Random Forgetting. This is related to the results concerning the first experiment and the fast adaptation of Leaf Forgetting.

What is interesting in this simulation is to see that Leaf Forgetting has a strong control of the house from the end of the first year to the middle of the second year, a

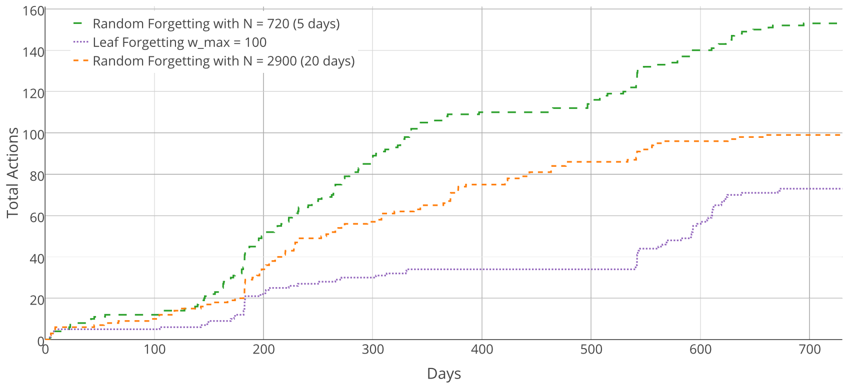

Fig. 3 Total number of user actions over a two years period considering outdoor temperature (the lower the better).

domain where the Random Forgetting flunks. But on the 545^{th} day, it has forgotten the previous year. This can be explained by the deletion of the leaves corresponding to the behavior on the 180^{th} day. Indeed, the number of samples in the corresponding leaves is not high enough to be relevant compared to all the new samples accumulated during the following year and these leaves are no longer induced.

4.3 Noise Resistance

Sometimes the user can have a different behavior for a few moments, or some disturbances can occur, such as the interaction with someone unfamiliar with the house. These kinds of events are isolated and must not have an impact on the future, unless they are definitive. Performance considering these noisy events for each forgetting method is evaluated in the following simulation:

This third simulation (Figure 4) has the same inputs as the first but adds noise on some days. The simulated user also has the same behavior but it is possible that for one or two days the user will completely change his/her behavior.

Results. Without any forgetting method, the learning is strongly resistant to noise because it accumulated enough samples to reinforce the learned behavior.

Concerning the forgetting methods, the Random Forgetting and the Sliding Window with short lengths are not resistant to noise because they do not have enough samples in their training set. Indeed, we can see that with a higher N Random Forgetting has a resistance to noise that is far better.

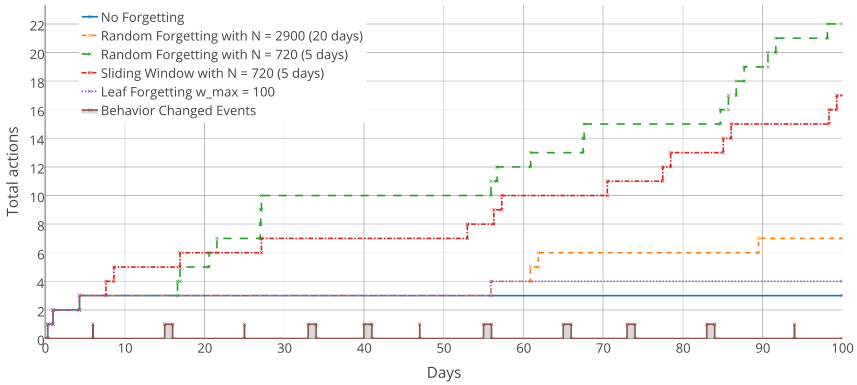

Fig. 4 Number of total user actions over 100 days with random behavior changes (the lower the better).

Of all methods tested, Leaf Forgetting is the method the most resistant to noise. The user interacted on a single occasion during the 100 day period, once the behavior had been learned. This is explained by the constant reinforcement of behaviors previously learned and the balance created between each leaf.

5 Conclusion and Future Works

In this paper we have presented several forgetting methods for the C4.5 algorithm and analyzed their performance. In the Internet of Things, proposing personalized and contextualized applications leads to the use of algorithms capable of adapting with forgetting methods. Forgetting is necessary in the IoT domain because of the user behavior inconsistency and the necessity to offer the user an impression of uniqueness. The methods implemented to propose such a learning must have a *White Box* namely a controllable and understandable learning. In this paper, three new methods are proposed, Sliding Window, Random Forgetting and Leaf Forgetting. As we can see from the results of a series of experiments, the Leaf Forgetting method has the best performance and meets the expectations of a learning that can be quickly adapted to the user.

In the future, an improvement for Leaf Forgetting would be to integrate the weight of every leaf directly into the computation of the C4.5 algorithm, like Data Stream Mining algorithms do with incremental classifiers [5]. This approach should improve the performance in terms of memorization and the balance between each leaf by normalizing the information of the leaves.

Another perspective to this work is to apply the *White Box* learning approach to new domains. We would now like to apply it to Data Streams. This will bring two new challenges: the larger number and size of samples and their incoming rate. The application of Leaf Forgetting to Data Streams will highlight its strengths and weaknesses with this type of data and will lead to improvement perspective.

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Underspecified Quantification by the Theory of Acyclic Recursion

Roussanka Loukanova

Abstract The paper introduces a technique for representing quantifier relations that can have different scope order depending on context and agents. The technique is demonstrated by classes of terms denoting relations, where each of the arguments of a relation term is bound by a different quantifier. We represent a formalization of linking quantifiers with the corresponding argument slots that they bind, across λ-abstractions. The purpose of the technique is to represent underspecified order of quantification, for computationally efficient and adequate representation of scope ambiguity in the absence of context and corresponding information about the order. Furthermore, the technique is used to represent subclasses of larger classes of relations depending on order of quantification or specific relations.

Keywords Recursion · Type-theory · Semantics · Algorithms · Denotation · Reduction · Quantifiers · Underspecification

1 Background

The formal theory of the technique introduced in the paper is a generalization of the theories of recursion introduced by Moschovakis [12, 13]. The formal languages and their respective calculi include terms constructed by adding a recursion operator along with the typical λ-abstraction and application. The resulting theories serve as a powerful, computational formalization of the abstract notion of algorithm with full recursion, which, while operating over untyped functions and other entities, can lead to calculations without termination. The untyped languages of recursion were then extended to a higher-order theory of acyclic recursion L_{ar}^{λ}, see Moschovakis [14], which is more expressive, by adding typed, functional objects. In another aspect, L_{ar}^{λ} is

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limited to computations that always close-off, by allowing only acyclic terms. I.e., the class of languages L^{λ}_{ar}, and their corresponding calculi, represent abstract, functional operations (algorithms) that terminate after finite number of computational steps. Such limitation is useful in many, if not most, practical applications. In particular, algorithmic semantics of human language can be among such applications, for which the simply-typed theory of acyclic recursion L^{λ}_{ar} was introduced in Moschovakis [14].

In this paper, we use an extended formal language and theory of L^{λ}_{ar}, with respective calculi, that gives better possibilities for representation of underspecified scope distribution of higher-order quantifiers. Firstly, we use the extended reduction calculus of L^{λ}_{ar} introduced in Loukanova [6], which employs an additional reduction rule, γ-rule, see Loukanova [6]. Secondly, we use restrictions over L^{λ}_{ar}-terms introduced in Loukanova [10]. This paper provides also a more general technique than Loukanova [10]. Here we represent a formalization of linking quantifiers with the corresponding argument slots that they bind, across λ-abstractions and reduction steps. In addition, the technique presented here is applicable for any abstract, i.e., mathematical, n-ary argument-binding relations, $n \geq 2$, while we illustrate it with human language quantifiers.

Detailed introduction to the formal language L^{λ}_{ar} of Moschovakis acyclic recursion, its syntax, denotational and algorithmic semantics, and its theory, is given in Moschovakis [14] and Loukanova [6]. The formal system L^{λ}_{ar} is a higher-order type theory, which is a proper extension of Gallin's TY_2, see Gallin [4], and thus, of Montague's Intensional Logic (IL), see Montague [15].

2 Brief Introduction to the Type Theory L^{λ}_{ar}

In this paper, we only give brief, informal introduction of L^{λ}_{ar}, for sake of space. For details, see Moschovakis [14] and Loukanova [6].

2.1 Syntax of L^{λ}_{ar}

Types of L^{λ}_{ar}**:** The set Types is the smallest set defined recursively (using a wide-spread notation in computer science): $\tau :\equiv e \mid t \mid s \mid (\tau_1 \to \tau_2)$.

The vocabulary of L^{λ}_{ar} consists of pairwise disjoint sets of: typed constants, $K = \bigcup_{\tau \in \mathsf{Types}} K_\tau$; typed pure variables, $\mathsf{PureVars} = \bigcup_{\tau \in \mathsf{Types}} \mathsf{PureVars}_\tau$; and typed recursion variables (called also locations), $\mathsf{RecVars} = \bigcup_{\tau \in \mathsf{Types}} \mathsf{RecVars}_\tau$.

The Terms of L^{λ}_{ar}**:** In addition to application and λ-abstraction terms, L^{λ}_{ar} has recursion terms that are formed by using a designated recursion operator, denoted by the constant where in infix notation. The recursive rules for the set of L^{λ}_{ar} terms can be expressed by using a notational variant of "typed" BNF, with the assumed types given as superscripts:

$$A :\equiv \mathsf{c}^\tau : \tau \mid x^\tau : \tau \mid B^{(\sigma\to\tau)}(C^\sigma) : \tau \mid \lambda(v^\sigma)(B^\tau) : (\sigma \to \tau)$$
$$\mid A_0^\sigma \text{ where } \{p_1^{\sigma_1} := A_1^{\sigma_1}, \ldots, p_n^{\sigma_n} := A_n^{\sigma_n}\} : \sigma$$

where $\{p_1^{\sigma_1} := A_1^{\sigma_1}, \ldots, p_n^{\sigma_n} := A_n^{\sigma_n}\}$ is a sequence of assignments that satisfies the following *acyclicity condition*:

Acyclic System of Assignments: For any terms $A_1 : \sigma_1$, ..., $A_n : \sigma_n$, and pairwise different recursion variables $p_1 : \sigma_1$, ..., $p_n : \sigma_n$ ($n \geq 0$), the sequence $\{p_1 := A_1, \ldots, p_n := A_n\}$ is an *acyclic system of assignments* iff there is a function $\mathsf{rank} : \{p_1, \ldots, p_n\} \longrightarrow \mathbb{N}$ such that, for all $p_i, p_j \in \{p_1, \ldots, p_n\}$, if p_j occurs freely in A_i then $\mathsf{rank}(p_j) < \mathsf{rank}(p_i)$.

The terms of the form A_0^σ where $\{p_1^{\sigma_1} := A_1^{\sigma_1}, \ldots, p_n^{\sigma_n} := A_n^{\sigma_n}\}$ are called *recursion terms*. We shall skip the type assignments when the types are clear.

2.2 *Two Kinds of Semantics of* $\mathbf{L}_{\mathbf{ar}}^{\lambda}$

Denotational Semantics of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$. The definition of the denotations of the terms follows the structure of the $\mathrm{L}_{\mathrm{ar}}^{\lambda}$-terms, in a compositional way. Intuitively, the denotation $\mathsf{den}(A)$ of a term A is computed algorithmically, by computing the denotations $\mathsf{den}(A_i)$ of the parts A_i and saving them in the corresponding recursion variable (i.e., location) p_i, step-by-step, according to recursive ranking $\mathsf{rank}(p_i)$.

The reduction calculi of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$ effectively reduces each term A to its canonical form $\mathsf{cf}(A)$: $A \Rightarrow_{\mathsf{cf}} \mathsf{cf}(A)$, which in general, is a recursion term:

$$\mathsf{cf}(A) \equiv A_0 \text{ where } \{p_1 := A_1, \ldots, p_n := A_n\} \quad (n \geq 0) \tag{1}$$

For each A, its canonical form $\mathsf{cf}(A)$ is unique up to renaming bound variables and reordering the recursive assignments $\{p_1 := A_1, \ldots, p_n := A_n\}$. The order of the recursive assignments is unessential since the order of the algorithmic steps in computations of the denotations are determined by the $\mathsf{rank}(A_i)$, for $i = 1, \ldots, n$.

Algorithmic Semantics of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$. The reduction calculi and the canonical forms of the terms play an essential role in the algorithmic semantics of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$. The algorithm for computing the denotation $\mathsf{den}(A)$ of a meaningful $\mathrm{L}_{\mathrm{ar}}^{\lambda}$-term A, is determined by its canonical form[1]. E.g., the sentence (2a) can be rendered into the $\mathrm{L}_{\mathrm{ar}}^{\lambda}$-term A, (2b), which then, by a sequence of reduction steps (not included here, for sake of space, and marked by $\Rightarrow \ldots$), is reduced to its canonical form $\mathsf{cf}(A)$, (2c).

[1] The symbol "$\equiv$" is a meta-symbol, which is not per se in the vocabulary of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$. We use it to specify orthographical identity between expressions of $\mathrm{L}_{\mathrm{ar}}^{\lambda}$ and definitional notations.

$$\text{John likes Mary's father.} \tag{2a}$$

$$\xrightarrow{\text{render}} A \equiv [like\big(father\_of(mary)\big)](john) \Rightarrow \ldots \tag{2b}$$

$$\Rightarrow_{\mathsf{cf}} like(f)(j) \text{ where } \{j := john,\ m := mary,\ f := father\_of(m)\} \tag{2c}$$

$$\equiv \mathsf{cf}(A) \tag{2d}$$

There is a rank function for the term (2c), which satisfies the acyclicity condition. For each such rank function, $\mathsf{rank}\, m < \mathsf{rank}(f)$, since m occurs in the term-part $father\_of(m)$ of the assignments $f := father\_of(m)$. E.g., $\mathsf{rank}(j) = 0$, $\mathsf{rank}(m) = 1$, and $\mathsf{rank}(f) = 2$. And, the term, which is in canonical form, determines the algorithm for computing A:

Step 1: Compute $\mathsf{den}(j) = \mathsf{den}(john)$.
Step 2: Compute $\mathsf{den}(m) = \mathsf{den}(mary)$.
Step 3: Compute $\mathsf{den}(f) = \mathsf{den}[father\_of(m)]$.
Step 4: Compute $\mathsf{den}(A) = \mathsf{den}\big[[like(f)](j)\big] = \mathsf{den}\big[[like(\mathsf{den}(f))]\big](\mathsf{den}(j))$

For the reductions of terms to their canonical forms that are used in this paper, we need the extended γ-reduction, which uses the (γ)-rule introduced in Loukanova [6]. While the detailed reduction steps of the terms A to their canonical and γ-canonical forms are part of the computational attire, we do not include them here, for sake of space limits. They are not essential for understanding the technique of underspecified semantic representation introduced in the paper.

3 Distributions of Multiple Quantifiers

3.1 Specific Instances of Quantifier Distributions

We represent the general problem with a sentence like (3) that represents a specific instance of a general problem. E.g., the sentence (3) is an instance of a whole class of human language sentences that have a head verb with syntactic arguments, which can be noun phrases interpreted as semantic quantifiers. In human language, such verbs are common, while verbs with more syntactic arguments are relatively limited. A verb similar to "give" denotes a relation with three semantic arguments. Each of these arguments can be filled up by a different quantifier. Furthermore, in general, each of the syntactic complements of the head verb in a sentence may have components that are also quantifiers, and thus contribute to the combinatorial possibilities of scope distributions. In this paper, we do not consider such additional quantifiers, since that is not in its subject. We focus on quantifiers contributed directly by the major arguments of the head relation and their scope distributions and corresponding binding of variables filling the argument slots of the relation denoted by the head verb. In a given, specific context, the speaker may intend an interpretation of the sentence S represented by the closed, i.e., *fully specified*, $\mathrm{L}_{\mathrm{ar}}^{\lambda}$-term T_1, with the scope distribution (4b)–(4e).

$$S \equiv \text{Every professor gives some student two papers.} \tag{3}$$

$$S \xrightarrow{\text{render}} T_1 \tag{4a}$$
$$T_1 \equiv \mathit{every} \quad (\mathit{professor}) \tag{4b}$$
$$\big[_3\, \lambda(x_3)\mathit{some}(\mathit{student}) \tag{4c}$$
$$\big[_1\, \lambda(x_1)\mathit{two}(\mathit{paper}) \tag{4d}$$
$$[_2\lambda(x_2)\mathit{give}(x_1)(x_2)(x_3)]_2\big]_1\big]_3 \tag{4e}$$

By using the reduction rules, we reduce the term T_1 to its canonical and γ-canonical forms (by suppressing the detailed, long, sequence of intermediate reductions). Note that, in the reductions and formulas, we use superscripts not only to distinguish variables, but also as counters of applications of (λ) and (γ) rules. The term (5g)–(5k) is obtained by three applications of the (γ) rule, once for $s^1 := \lambda(x_3)\mathit{student}$, and two times for $b^2 := \lambda(x_3)\,\lambda(x_1)\mathit{paper}$.

$$T_1 \Rightarrow_{\mathsf{cf}} \mathit{every}(p)(R_3) \text{ where } \{ \tag{5a}$$
$$R_3 := \lambda(x_3)\mathit{some}(s^1(x_3))(R_1^1(x_3)), \tag{5b}$$
$$R_1^1 := \lambda(x_3)\,\lambda(x_1)\mathit{two}(b^2(x_3)(x_1))(R_2^2(x_3)(x_1)), \tag{5c}$$
$$R_2^2 := \lambda(x_3)\,\lambda(x_1)\,\lambda(x_2)\mathit{give}(x_1)(x_2)(x_3), \tag{5d}$$
$$b^2 := \lambda(x_3)\,\lambda(x_1)\mathit{paper},\ s^1 := \lambda(x_3)\mathit{student}, \tag{5e}$$
$$p := \mathit{professor}\,\} \qquad \text{by (B-S)} \tag{5f}$$
$$\Rightarrow_{\gamma}{}^{3}\ \mathit{every}(p)(R_3) \text{ where } \{ \tag{5g}$$
$$R_3 := \lambda(x_3)\mathit{some}(s)(R_1^1(x_3)), \tag{5h}$$
$$R_1^1 := \lambda(x_3)\,\lambda(x_1)\mathit{two}(b)(R_2^2(x_3)(x_1)), \tag{5i}$$
$$R_2^2 := \lambda(x_3)\,\lambda(x_1)\,\lambda(x_2)\mathit{give}(x_1)(x_2)(x_3), \tag{5j}$$
$$b := \mathit{paper},\ s := \mathit{student},\ p := \mathit{professor}\,\} \tag{5k}$$

Similarly to the specified T_1, (4b)–(4e), depending on context, the sentence S can be rendered to T_2, (6b)–(7e), with a different distribution of quantification.

$$S \xrightarrow{\text{render}} T_2 \tag{6a}$$
$$T_2 \equiv \mathit{some} \quad (\mathit{student}) \tag{6b}$$
$$\big[_1\, \lambda(x_1)\mathit{every}(\mathit{professor}) \tag{6c}$$
$$\big[_3\, \lambda(x_3)\mathit{two}(\mathit{paper}) \tag{6d}$$
$$[_2\lambda(x_2)\mathit{give}(x_1)(x_2)(x_3)]_2\big]_3\big]_1 \tag{6e}$$

$$\Rightarrow_{\text{gcf}} some(s)(R_1) \text{ where } \{ \tag{7a}$$
$$R_1 := \lambda(x_1) every(p)(R_3^1(x_1)), \tag{7b}$$
$$R_3^1 := \lambda(x_1)\,\lambda(x_3) two(b)(R_2^2(x_1)(x_3)), \tag{7c}$$
$$R_2^2 := \lambda(x_1)\,\lambda(x_3)\,\lambda(x_2) give(x_1)(x_2)(x_3), \tag{7d}$$
$$b := paper,\ s := student,\ p := professor\,\} \quad \text{by 3 times } (\gamma) \tag{7e}$$

Note that by using indexed variables corresponding to the order of the argument slots of the constant *give*, i.e., $give(x_1)(x_2)(x_3)$, we maintain expressing the order of the quantifiers that bind the corresponding variables filling up those argument slots. Thus, the quantifier order is expressed by the order of the λ-abstracts in the recursion assignment for the constant *give* rendering the head verb of the sentence S in (3). In general, the variable names are irrelevant, in sense that we can rename them, as we wish, in the λ-sub-terms, without variable clashes. However, maintaining the corresponding indexes is not only simple mnemonics, since it represents quantifier order, and represents corresponding bindings. As we shall see in what follows, indexing facilitates the representation of respective bindings, which we will use in representing underspecified order of quantification.

Outside any context available, there may not be enough information to render an ambiguous sentence like (3) to a L_{ar}^{λ}-term with a single, specific, quantifier scope distribution. And even in a specific context, the scope distribution is still dependent on agents in it. From computational point, it is inefficient to render such a sentence to the set of all possible distributions of scopes. Even when impossible distributions of quantifier order are factored out, e.g., by lexical or other type incompatibilities, more complex sentences can have multiple, alternative quantifier scopes. For notorious examples, see, e.g., Hobbs and Shieber [5]. This topic continues to be one of the major difficulties in computational semantics and language processing, and here we present a formal approach to it.

3.2 Combinatorial Permutations of Quantifier Scopes

In the major Section 4, we develop technique for representing multiple, alternative terms, each representing a specific quantifier distribution, by a single, underspecified L_{ar}^{λ}-term. Such an underspecified term has free recursion variables for quantifiers, that leaves the scope distributions open, to be specified when sufficient information is available, by context. Before that, in this section, we make general observations, with formal representations by L_{ar}^{λ}-terms of the shared patterns in specific quantifier distributions. By this, we formalize the linkage over the argument slots that are bound by the corresponding quantifiers. These formal linkages are exhibited formally by the λ-abstractions over corresponding applications and are maintained during reduction steps. We use permutation functions that represent the specific quantifier distributions. The canonical forms of the above two rendering represent the common pattern of the quantificational structure.

Here, we will focus on the special case of $n = 2$, 2-argument generalized quantifiers, where $\sigma_i \equiv \mathsf{e}$, from which we can make generalization to n-argument quantifier relations between state-dependent sets of objects of state dependent types $\widetilde{\sigma}_i$, for any natural number $n \in \mathbb{N}$. In $\mathrm{L}^{\lambda}_{\mathrm{ar}}$, and in this paper, we use Curry coding of relations with unary functions and corresponding terms denoting them. A $\mathrm{L}^{\lambda}_{\mathrm{ar}}$-term Q denoting an n-ary, generalized quantifier is of type (8a), and we consider the 2-argument quantifiers of type (8b).

$$Q : \big((\widetilde{\sigma}_1 \to \widetilde{\mathsf{t}}) \to \cdots \to \big((\widetilde{\sigma}_n \to \widetilde{\mathsf{t}}) \to \widetilde{\mathsf{t}}\big)\big), \qquad \text{for } n \in \mathbb{N} \tag{8a}$$

$$Q : \big((\widetilde{\mathsf{e}} \to \widetilde{\mathsf{t}}) \to \big((\widetilde{\mathsf{e}} \to \widetilde{\mathsf{t}}) \to \widetilde{\mathsf{t}}\big)\big) \tag{8b}$$

A $\mathrm{L}^{\lambda}_{\mathrm{ar}}$-term Q for a 2-argument, generalized quantifier between individuals of type $\widetilde{\mathsf{e}}$, e.g., a constant *some*, *every*, *two*, etc., denotes the characteristic function $\mathbb{T}_{\left((\widetilde{\mathsf{e}}\to\widetilde{\mathsf{t}})\to((\widetilde{\mathsf{e}}\to\widetilde{\mathsf{t}})\to\widetilde{\mathsf{t}})\right)}$ of a relation $\mathbb{T}_{\left((\widetilde{\mathsf{e}}\to\widetilde{\mathsf{t}})\times(\widetilde{\mathsf{e}}\to\widetilde{\mathsf{t}})\to\widetilde{\mathsf{t}}\right)}$ between properties of entities of the domain $\mathbb{T}_{\widetilde{\mathsf{e}}}$. From the above template examples of quantifier distribution in Section 3.1, we can conclude a general pattern. The general pattern provides instantiations to specific instances of: (1) quantifiers, e.g., *every*, *some*, *one*, *two*, etc.; (2) quantifier scope distribution; (3) quantifier domains. e.g., *man*, *student*, *professor*, *paper*, etc.; (4) quantifier range, which can be provided by rendering of a head verb, e.g., *give* in the examples in Section 3.1, or other syntactic head construction.

Given a permutation $\pi : \{1, \ldots, n\} \to \{1, \ldots, n\}$, we take recursion variables $Q_i, R_i, q_i, d_i, h \in \mathsf{RecVars}$ that are appropriately typed.

By the extended γ-reduction, see Loukanova [6], the general quantification patterns in terms like (5g)–(5k) and (7e)–(7a) can be reduced to the term Q, (9a)–(9f). In a brief summary, the term Q has congruent forms with respect to renaming the pure variables in the λ-abstracts, as well as the recursion variables bound by the constant where. However, maintaining the indexes provides visualization of linking the quantifier bindings.

$$Q \equiv R_n \text{ where } \{ \tag{9a}$$

$$R^{(n-1)}_{\pi(n)} := \lambda(x_{\pi(1)}) \ldots \lambda(x_{\pi(n)}) h(x_1) \ldots (x_n) \tag{9b}$$

$$R^{(j-1)}_{\pi(j)} := \lambda(x_{\pi(1)}) \ldots \lambda(x_{\pi(j)}) Q_{\pi(j+1)}[\tag{9c}$$

$$\lambda(x_{\pi(j+1)}) R^{j}_{\pi(j+1)}(x_{\pi(1)}) \ldots (x_{\pi(j)})(x_{\pi(j+1)})] \tag{9d}$$

$$(\text{for } j = 1, \ldots, (n-1))$$

$$R_{n+1} := Q_{\pi(1)}[\lambda(x_{\pi(1)}) R_{\pi(1)}(x_{\pi(1)})], \tag{9e}$$

$$Q_i := q_i(d_i) \qquad (\text{for } i = 1, \ldots, n)\} \tag{9f}$$

While the term Q in (9a)–(9f) is underspecified with respect to the free recursion variables $h, q_i, d_i \in \mathsf{FreeV}(Q)$, the order of the relations Q_i, for $i = 1, \ldots, n$, is specified by any given, specific permutation π. One way to represent the underspecified quantification order could be to leave the permutation function π underspecified, i.e., without being instantiated. However, then the underspecified π is at meta-theoretical level outside of L^{λ}_{ar}.

There is a better technique, presented in the next section, which provides specific cases for π. It also is flexible with respect to imposing constraints on excluding some of the permutations π. Such constraints depend on specifications of the recursion variables $q_i, d_i, h \in \mathsf{RecVars}$ with specific relations. Such restrictions are not in the subject of this paper. Typically, they depend on the semantic properties of the properties and the relations, but also on lexical classifications of human languages.

4 Underspecified Scope Distribution

The expression (9a)–(9f) implicitly carries a pattern for underspecified L^{λ}_{ar}-term that represents underspecified scope of the relations Q_i. In this section, we introduce a technique for underspecified quantification in the case $n = 3$, which ten can be generalized to $n \in \mathbb{N}$. We bring again, temporarily the specifications of $q_i, d_i, h \in \mathsf{RecVars}$ as in Section 3.1 to illustrate the technique. Note that we use extended terms with additional sub-expressions (10e) that add constraints over free recursion variables, as introduced in [10]. The technique introduced here uses the formal representation of the links that maintain the binding argument slots corresponding to quantification across λ-abstractions and reductions to canonical forms, visualized via indexing. The formal definition of the constraints that Q_i λ-binds the i-th argument of h via R_i, (for $i = 1, \ldots, 3$), in (10e) is rather technical and spacious and we leave it outside the subject of this paper, for an extended paper.

Here we note that the definition formalizes the linking of each quantifier Q_i with the variable x_i that it binds, i.e, with the corresponding i-th argument slot filled up by x_i, by avoiding explicit usage of metalanguage symbols $Q_{\pi(i)}$ with a unspecified permutation $\pi : \{1, \ldots, n\} \rightarrow \{1, \ldots, n\}$. Loukanova [10] uses another kind of constraints, and the relation between them and the constraints in (10e) is also outside the subject of this paper. Here we only mention that the choice between them is open and depends on possible applications of the quantifier underspecification. An important difference is that the technique presented here is more general and applicable for any abstract, i.e., mathematical, n-ary quantifier relations, $n \geq 2$. Such quantifiers are abstract mathematical objects, in syntax and semantics of formal languages, not only those originating in human language NPs and sentences.

$$U \equiv R_4 \text{ where } \{ l_1 := Q_1(R_1),\ l_2 := Q_2(R_2),\ l_3 := Q_3(R_3), \tag{10a}$$

$$Q_1 := q_1(d_1),\ Q_2 := q_2(d_2),\ Q_3 := q_3(d_3), \tag{10b}$$

$$q_1 := \mathit{some},\ q_2 := \mathit{two},\ q_3 := \mathit{every}, \tag{10c}$$

$$d_1 := \mathit{student},\ d_2 := \mathit{paper},\ d_3 := \mathit{professor},\ h := \mathit{give} \} \tag{10d}$$

$$\text{s.t. } \{ Q_i \ \lambda\text{-binds the } i\text{-th argument of } h \text{ via } R_i, \tag{10e}$$

$$R_4 \text{ is assigned to a closed subterm with fully scope specified } Q_i \text{ (for } i = 1, \ldots, 3), \} \tag{10f}$$

Now, from the underspecified (10a)–(10f), we derive one of the possible closed L^{λ}_{ar}-terms, (11a)– (11j), having fully specified quantifier scopes: Note: 1. The λ-abstractions are the tool for linking the quantifiers with the respective argument slots that they bind, i.e., in satisfying the constraints (10e)–(10f). 2. The λ-abstracts are nested within the where-scopes, accordingly, by the dependencies.

$$U_{321} \equiv R_4 \text{ where } \{ \tag{11a}$$

$$R_4 := l_3,\ l_3 := Q_3(R_3),\ Q_3 := q_3(d_3), \tag{11b}$$

$$q_3 := \mathit{every},\ d_3 := \mathit{professor}, \tag{11c}$$

$$R_3 := \lambda(x_3)\Big[_3 l_2 \text{ where } \{_3\, l_2 := Q_2(R_2),\ Q_2 := q_2(d_2), \tag{11d}$$

$$q_2 := \mathit{two},\ d_2 := \mathit{paper}, \tag{11e}$$

$$R_2 := \lambda(x_2)\big[_2 l_1 \text{ where } \{_2\, l_1 := Q_1(R_1), \tag{11f}$$

$$Q_1 := q_1(d_1), \tag{11g}$$

$$q_1 := \mathit{some}, d_1 := \mathit{student}, \tag{11h}$$

$$R_1 := \lambda(x_1) h(x_1)(x_2)(x_3), \tag{11i}$$

$$h := \mathit{give}\ \}_2\big]_2\ \}_3\Big]_3\ \}\ \} \tag{11j}$$

By using reductions including the important (λ) and (γ) rules, similarly to the ones in Section 3.1, we reduce the term U_{321} in (11a)–(11j), to the γ-canonical form in (12a)–(12g). Note that these reductions use more applications of the (γ) rule, due to the additional assignments in the scope of the λ-abstractions, which are subject to the (λ) rule.

$$\mathrm{cf}_{\gamma}(U_{321}) \equiv R_4 \text{ where } \{ \tag{12a}$$

$$R_4 := l_3,\ l_3 := Q_3(R_3),\ Q_3 := q_3(d_3), \tag{12b}$$

$$R_3 := \lambda(x_3) l^1_2(x_3),\ l^1_2 := \lambda(x_3) Q_2(R^1_2(x_3)),\ Q_2 := q_2(d_2), \tag{12c}$$

$$R^1_2 := \lambda(x_3)\,\lambda(x_2) l^2_1(x_3)(x_2),\ l^2_1 := \lambda(x_3)\,\lambda(x_2) Q_1(R^2_1(x_3)(x_2)), \tag{12d}$$

$$Q_1 := q_1(d_1),\ R^2_1 := \lambda(x_3)\,\lambda(x_2)\,\lambda(x_1) h(x_1)(x_2)(x_3), \tag{12e}$$

$$q_3 := \mathit{every},\ d_3 := \mathit{professor},\ q_2 := \mathit{two},\ d_2 := \mathit{paper}, \tag{12f}$$

$$q_1 := \mathit{some},\ d_1 := \mathit{student},\ h := \mathit{give} \} \tag{12g}$$

Each pair of the first two assignments in (12b), (12c), and (12d) can be merged. Formally, this merging is via extending the reduction calculi of L^{λ}_{ar} by adding suitable reduction rules, which is not in the subject of this paper. The result is the term S_{321}, (13a)–(13g), that is not algorithmically (step-by-step) equivalent to the terms U_{321}, (11a)–(11j), and $\mathsf{cf}_{\gamma}(U_{321})$, (12a)–(12g), while U_{321} and $\mathsf{cf}_{\gamma}(U_{321})$ are algorithmically equivalent, i.e., $U_{321} \approx \mathsf{cf}_{\gamma}(U_{321})$. However, the term S_{321}, (13a)–(13g), is more simple, by avoiding the unnecessary computations denoted by the merged assignments. Otherwise, U_{321}, (11a)–(11j), preserves all other computational steps, represented by the assignments.

$$S_{321} \equiv R_4 \text{ where } \{ \tag{13a}$$
$$R_4 := Q_3(R_3),\ Q_3 := q_3(d_3), \tag{13b}$$
$$R_3 := \lambda(x_3) Q_2(R^1_2(x_3)),\ Q_2 := q_2(d_2), \tag{13c}$$
$$R^1_2 := \lambda(x_3)\,\lambda(x_2) Q_1(R^2_1(x_3)(x_2)),\ Q_1 := q_1(d_1), \tag{13d}$$
$$R^2_1 := \lambda(x_3)\,\lambda(x_2)\,\lambda(x_1) h(x_1)(x_2)(x_3), \tag{13e}$$
$$q_3 := \mathit{every},\ d_3 := \mathit{professor},\ q_2 := \mathit{two},\ d_2 := \mathit{paper}, \tag{13f}$$
$$q_1 := \mathit{some},\ d_1 := \mathit{student},\ h := \mathit{give}\,\} \tag{13g}$$

5 Conclusions and Future Work

In this paper, we have introduced a technique of underspecified, acyclic recursion, for representation of a class of relations, belonging to the same class as quantifiers, that can bind arguments by multiple, ambiguous binding scope. Several, e.g., n, quantifiers, can interact and bind the arguments of n-arguments relations ($n \geq 2$), in alternative orders depending on context and agents in context. The technique gives possibilities for leaving the order of quantifiers underspecified, in the absence of relevant information.

The order of the quantifier scopes, i.e., the order in which several quantifiers bind arguments of a relation, or a function, having n-arguments ($n \geq 2$), is typically dependent on specific contexts and agents. The quantifiers, and the relations whose argument slots they bind, can also be underspecified. Thus, the term Q, (9a)–(9f), is a computational pattern that represents a wider class of binding relations that can bind in alternative orders represented by permutation function π. It is not computationally efficient to generate the set of all possible alternatives π for binding orders, without context, and even in specific context without sufficient information. This is not also rational from general considerations, e.g., cognition, and how information should be presented and processed efficiently.

The formal theory L^{λ}_{ar} provides highly expressive computational utilities, including for representation of algorithmic semantics that is underspecified, while maintaining algorithmic structure that can be expanded and specified when more information is available. E.g., without context and sufficient information, the semantic information carried by a sentence like "Every professor gives some student two papers", does not need to be represented by the set of all alternatives, i.e., both scope distributions T_1, (4b)–(4e), and T_2, (6b)–(7e). It is more efficient and rational to render the common information that is carried by both of these specific interpretations, in an underspecified term U in (10a)–(10f). The L^{λ}_{ar}-term U is in canonical form, i.e., it represents algorithmic instructions for computing the denotations of U depending on context. The algorithmic instructions that are available in U contain available computational structure and facts, in their most basic forms, because U is in a canonical form. In a given context, with available information, an agent (which can be a computational system embedded in a device) can specify U, e.g., to the term U_{321} in (11a)–(11j) by instantiating the binding scope of the quantifiers. Furthermore, the agent can derive, from U_{321}, the more simple term S_{321}, (13a)–(13g).

Here, we briefly overview several areas of application of the computational technique introduced in this paper, which in the same time are subject of future work and developments.

Computational Semantics. A primary application is to computational semantics of human language. As we described and exemplified in Section 3, human language is abundant of ambiguities that present the major difficulty to computerized processing. Ambiguities and underspecification, typically can be resolved by context. Quantifiers in human language are among the major contributors of ambiguities. Expansion of multiple semantic representations have been avoid by the technique of semantic storage, e.g., see Loukanova [7]. While such techniques are successful, they involve meta-theoretic means and are specialized for quantifiers. The technique here has the superiority of using the facilities of the type theory of recursion L^{λ}_{ar} at its object level. In addition, it is applicable to more general relations.

The technique of Minimal Recursion Semantics (MRS), see Copestake et al. [2], has been useful for underspecified semantic representation of multiple semantic scopes. MRS has been implemented and used very successfully in large scale grammars, e.g., see [1] and [3]. MRS lacks strict logical formalization, and our work provides such via currying encoding of relations. Further work is due for direct, relational formalization, without currying, for semantic representation in large scale grammars, and in computational grammar in general.

Computational Syntax-Semantics Interface. Loukanova [8, 9] introduces a technique for syntax-semantics interface in computational grammar, which uses L^{λ}_{ar} for semantic representations, in compositional mode. While that work represents syntactic phrases that include NP quantifiers, quantifier scope ambiguities are not covered. Our upcoming work includes incorporation of the technique for underspecified semantic scopes, introduced in this paper, in computational syntax-semantics interface. The work by Loukanova and Jiménez-López [11] can be extended by the introduced technique for underspecified scopes.

Other Applications. We envisage that the formal theory introduced here has many potential applications, where covering semantic information that depends on context and information is important and includes relations that have scope binding. E.g.: (1) type-theoretic foundations of: a. semantics of programming languages b. formalization of algorithm specifications, e.g., by higher-order type theory of algorithms L_{ar}^{λ}, L_{r}^{λ}, or their extended, or adapted versions c. compilers and techniques for converting recursion into tail-recursion and iteration (2) information representation systems, e.g., in: a. data basis b. health and medical systems c. medical sciences d. legal systems e. administration.

Many of these areas include and depend on semantic processing of human language. Some of them include semantic data with quantifiers, or other relations having multiple scope binding. In particular, we consider that, for a better success, it is important to develop new approaches in the areas of Machine Learning and Information Retrieval that use techniques for integration of the quantitative methods (e.g., from mathematical statistics), which, typically, are used in these areas, with logic methods for semantic representations. We consider that L_{ar}^{λ} and its extended versions, by including the technique from this paper, can be very fruitful in such developments.

Mathematical Quantifiers. The technique introduced in this paper is used to represent not only quantifier relations, but also classes of relations that, similarly to quantifiers, have scope dependent arguments, where the scopes depend on order of binding the corresponding arguments. While we illustrate the formalization by examples from human language, it is useful for abstract, mathematical quantifier relations having n-arguments ($n \geq 2$), and for applications in areas with domains consisting of relations between sets of objects. Such applications are subject to future work.

Extending the Formalization. A more immediate future line of work is to provide details of the formalization of the constraints (10e)–(10f) for linking the quantifiers to the respective argument slots they bind.

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Towards Quantitative Networks of Polarized Evolutionary Processors: A Bio-Inspired Computational Model with Numerical Evaluations

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Abstract Networks of Polarized Evolutionary Processors is a highly parallel distributed computing model inspired and abstracted from the biological evolution. This model is computationally complete and able to efficiently solve NP complete problems. Although this model is inspired from biology, basically it has been investigated from the points of view of mathematical and computer science goals with a qualitative perspective. It is true that Networks of Polarized Evolutionary Processors incorporate a numerical evaluation over the data that it processes, but this is not used from a quantitative viewpoint. In this paper we propose to enhance Networks of Polarized Evolutionary Processors of a quantitative perspective through a novel number of formal components. In particular, these components are able to evaluate quantitative conditions inherent to biological phenomena preserving the same computational power of Networks of Polarized Evolutionary Processors. Moreover, as a proof of concept, we model and simulate a simple but expressive example: a discrete abstraction of the sodium-potassium pump that includes the components proposed. Finally, we suggest that this integration enhances Networks of Polarized Evolutionary Processors model to (a) be more expressive for the algorithm design and (b) use less resources (nodes, rules, strings and computation time). This resource

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reduction could become a clear advantage when we will deploy hardware/software solutions of these bio-inspired computational models on top of massively distributed computational platforms.

1 Introduction

Networks of Polarized Evolutionary Processors (NPEP) [1] is a highly parallel and distributed computing model inspired and abstracted from the biological evolution. In general, NPEP model consists of some very simple processors, called polarized evolutionary processors, each of which is placed in a node of a virtual graph. A polarized evolutionary processor is able to perform very simple operations, simulating point mutations in a DNA sequence (insertion, deletion or substitution of a pair of nucleotides). Each node processor is specialized exactly for one of these evolutionary operations which are applied on the local data (strings). Strings then become mobile agents which can navigate through the network following a protocol defined by a filtering strategy of polarization. This strategy is represented by an analogy to the electrical charge (positive, negative or neutral) which is applied to both strings and nodes. While the polarization of a node is previously defined and fixed for the whole computation process, the polarization of strings is dynamically computed by a valuation mapping which computes the polarity of a string depending on the values assigned to its symbols. Actually, the valuation mapping does not compute the exact value of a string, but just the sign of this value. Strings migration from one node to another depends both on their polarization and the node polarization.

It is natural to think that any bioinspired computational model and the biological reality that has been the source of inspiration can be closely related. However, NPEP has been used as a universal problem solver related to mathematical and computer science goals, while its bioinspired features have only been considered from a qualitative point of view. As long as quantitative aspects are essential to represent specific properties of a wide range of problems, it is necessary to consider a more flexible model able to represent these properties.

In this context, we propose to endow NPEP with a quantitative perspective through a novel number of formal components which both preserve its computational power and are able to model quantitative conditions inherent to biological phenomena. For this, they must allow to compute the exact value of a string by refining the NPEP polarization based communication protocol in order to resemble the transport of molecules between cell membranes through a solution gradient. In this way we consider that NPEP model could tackle the simulation of phenomena whose behavior is expressed by means of numerical conditions. To illustrate this, we present an abstraction of the sodium-potassium pump as well as a computational simulation using an ad hoc computational simulator for this abstraction. We suggest that this integration enhances the NPEP model to (a) be more expressive for the algorithm design and (b) use less resources.

The paper is organized as follows. In the next section, we introduce the formal definition of the NPEP. In section 3, we introduce the novel formal components proposed and explore their integration to the NPEP. In section 4, an abstraction of sodium-potassium pump using the proposed components, a computational simulation of this model and its results are presented. Lastly, we informally discuss the advantages of this integration focused in the reduction of the resources used. Finally, conclusions and some remarks for future research are presented.

2 Networks of Polarized Evolutionary Processors - NPEP

Networks of Polarized Evolutionary Processors (NPEP) [1] are the most recent model belonging to the family of highly parallel and distributed computing models inspired by and abstracted from the biological evolution denominated *Networks of Evolutionary Processors* (NEPs) [2]. NEP has been widely investigated from a theoretical point of view: many different works demonstrate their computational completeness and their ability to solve NP problems in linear time, and with a linear amount of resources [3]. In addition, the computational completeness of the NPEP model was recently demonstrated in [4].

In order to formally introduce the NPEP model we summarize some basic notations following [1]. An *alphabet* is a finite and non-empty set of symbols. Any sequence of symbols from an alphabet A is called a *word* over A. The set of all words over A is denoted by A^* and the empty word is denoted by ε. The set of evolutionary processors over A is denoted by EP_A.
A NPEP can be formally defined as a 7-tuple $\Gamma = (V, U, G, N, \varphi, x_I, x_O)$:

- V and U are the input and network alphabets respectively, such that $V \subseteq U$.
- $G = (X_G, E_G)$ is an undirected graph with vertices X_G and edges E_G.
- $N : X_G \to EP_U$ is a mapping that associates each node with the corresponding processor in a given NPEP. Each node $N(x)\ \forall\, x \in X_G$ contains:
  - M_x is a finite set of evolutionary rules (insertion, deletion, substitution).
  - α_x defines if the rules are be applied on the left, on the right or anywhere.
  - $\pi_x \in \{-, 0, +\}$ defines the polarization of the node.
- $\varphi : U^* \to \mathbb{Z}$ is the valuation function that reveals the polarity of a word.
- $x_I, x_O \in X_G$ are the *input* and the *output* nodes, respectively.

The dynamics of the NPEP model is determined by *evolutionary* and *communication* steps performed sequentially on the configuration of each network node. A node configuration can be understood as the set of words that are present in any node at a given moment. Firstly, the input word encoding the instance of the problem is injected to input node and the rest of the nodes are empty. Then, a sequence of evolutionary and communication steps (executed in distributed and parallel way by independent node processors) are performed until a *halt* condition is reached. In evolutionary steps, each node can apply its rules over received data. In communication steps, each node outputs a copy of every word not matching its polarity, and receive words matching it. The *halt* condition of a Γ computation is defined by one of the following events: 1) There exists a configuration in which the set of words contained in the output node is non-empty, and 2) no further change can be produced in the configuration of the output node. For more details about NPEP model we refer the reader to [1].

3 Enhancing NPEP with a Quantitative Perspective

The main motivation to enhance NPEP is to endow it with the ability to model quantitative features which represent specific properties of a wide range of problems. As first step to achieve this, we are interested in empowering the NPEP communication process in order to compute the exact value associated to strings instead of only computing the sign of this value as was introduced in [4]. Thus, the strings migration from one node to another might simulate the communication channel between the two cells through a solution gradient.

The main requirements to incorporate this capacity are:

- The string structure is not relevant. The valuation of any permutation of a given string is the same. Therefore, we consider a representation of the commutative closure of a string instead of the string itself like the Parikh mapping which is defined as follows. If $V = \{a_1, a_2, \ldots, a_n\}$ is an alphabet and $w \in V^*$, then the Parikh mapping ϖ associated with every word in V^*, is a vector of size n with nonnegative integers defined by $\varpi_V(w) = (|w|_{a_1}, |w|_{a_2}, \ldots, |w|_{a_n})$. We remark that for the sake of simplicity as one can see in the sequel, we prefer to work with strings.
- We require a more refined evaluation of the strings contained in the processors. This could be done by applying the evaluation mapping not to the whole string but to a projection of it over some predefined subsets of symbols associated with each processor. This suggests a similarity with the concentration of some chemical compounds in a cell.
- We also require to extend polarities of nodes as follows. In a NPEP, polarity is represented by $\{-, 0, +\}$. Now we need to represent this polarity as an interval: $(-\infty, 0)$, $\{0\}$, $(0, +\infty)$ of $\mathbb{Z}$. It is a generalization from the original simple polarization to a set of mutual disjoint intervals of $\mathbb{Z}$.

Formally, these requirements can be integrated in the NPEP model as follow:

1. *Projection of a string over subsets of symbols.*
   Let U be a finite alphabet and w be a word over U such that $w = a_1 a_2 \cdots a_k$, $a_i \in U$, $1 \le i \le k$. We define the projection function $\pi : U^* \times 2^U \longrightarrow U^*$ as

$$\pi(w, S) = a'_1 a'_2 \cdots a'_k \text{ where } a'_i = \begin{cases} a_i & \text{if } a_i \in S \\ \varepsilon & \text{otherwise} \end{cases}$$

This change implies also some modifications on the φ function introduced in [1]. Now, the extended version of function φ denoted by Φ it is applied to a subset of symbols of the string instead of to the whole string. Φ must be able to get numerical values looking at different symbols of the string. Let m be different subsets of symbols of w and $\Phi : U^* \rightarrow \mathbb{Z}^{2^m}$. Then,

$$\Phi(w) = ((\varphi \circ \pi)(w, S_1), (\varphi \circ \pi)(w, S_2), \ldots, (\varphi \circ \pi)(w, S_{2^m})).$$

For simplicity we could write $\Phi_X(w) = (\varphi \circ \pi)(w, S_k)$ where $X = S_k$.

2. *Extended polarities*: We redefine α as sets of mutually disjoint intervals of $\mathbb{Z}$. In addition, we define ρ as a mapping that associates each subset of U with an interval, possibly empty, of $\mathbb{Z}$.
3. *Dynamics of the model*: The integration of the previous components implies changes in the communication step, namely: those words from a node x whose valuation belongs to an interval associated with the polarization of x remain in x, otherwise they are expelled. In addition, each expelled word w from a node x that cannot enter into any other node connected to x is lost. Finally, a word w enters a node x when at least one of its values belongs to an interval of the polarity of x.

4 Simulating Problems with Numerical Evaluations Using Enhanced NPEP

In order to show that the components proposed in the previous section are able to evaluate quantitative conditions inherent to biological phenomena, we propose a discrete abstraction of the well-known biological phenomenon of the sodium-potassium pump. We highlight two important capabilities of our approach through this example: 1) their ability to use less resources than the NPEP model and 2) the power to express solutions to problems in a comfortable way.

Table 1 The Post−Albers cycle with occluded states.

$3Na^+_{int}$	$\rightleftharpoons$	$E_1 \cdot \text{ATP} \cdot 3Na^+$	Eq. 3.1
$E_1 \cdot \text{ATP} \cdot 3Na^+$	$\rightleftharpoons$	$E_1 \sim P \cdot (3Na^+) + \text{ADP}$	Eq. 3.2
$E_1 \sim P \cdot (3Na^+)$	$\rightleftharpoons$	$E_2 \sim P \cdot 2Na^+ + Na^+_{ext}$	Eq. 3.3
$E_2 \sim P \cdot 2Na^+$	$\rightleftharpoons$	$E_2 \sim P + 2Na^+_{ext}$	Eq. 3.4
$E_2 \sim P + 2K^+_{ext}$	$\rightleftharpoons$	$E_2 \sim P \cdot 2K^+$	Eq. 3.5
$E_2 \sim P \cdot 2K^+$	$\rightleftharpoons$	$E_2 \cdot (2K^+) + P_i$	Eq. 3.6
$E_2 \cdot (2K^+) + \text{ATP}$	$\rightleftharpoons$	$E_1 \cdot \text{ATP} \cdot 2K^+$	Eq. 3.7
$E_1 \cdot \text{ATP} \cdot 2K^+$	$\rightleftharpoons$	$E_1 \cdot \text{ATP} + 2K^+_{int}$	Eq. 3.8

4.1 A Discrete Abstraction of the $Na^+ - K^+$ Pump

Post-Albers cycle [5] is a detailed definition about the $Na^+ - K^+$ pump describing that, at some stage during their passage across the membrane, transported ions are occluded within the pump molecule. Therefore, they cannot escape to the surface unless a conformational or a chemical change occurs in the pump molecule. Following the notation introduced in [6], a formulation of the chemical reactions participating in this cycle is given in Table 1. According to it, the sodium-potassium pump has two mutually exclusive states in which the pump exposes ion binding sites alternatively on the cytoplasmic/intracellular (E_1) and extracellular (E_2) sides of the membrane. More detailed information about this cycle can be found in [6].

4.2 Extended NPEP $Na^+ - K^+$ Pump Model

The computational model for the $Na^+ - K^+$ pump that we present in this section, consists of one NPEP informally extended in the way previously described. This *informally-extended* NPEP is named Γ and includes two subnetworks. The first subnetwork models the detection of an membrane potential imbalanced and the second subnetwork starts the Post-Albers cycle. Now, we separately describe the NPEP structure and the new components needed to extend it.
Let $\Gamma_P = (V, U, G, R, \varphi, \underline{In}, \underline{Out})$ be a NPEP where:

- $V = \{s, S, p, P, v, V, A\}$ and $U = V \cup \{n, N, k, K, b, B, a, f, \bar{n}, q, r\}$ the input and network alphabet respectively. Additionally,
  $P = \{\{n\}, \{N\}, \{k\}, \{K\}, \{b\}, \{B\}, \{a\}, \{q\}, \{f\}, \{\bar{n}\}, V\}\{t, \bar{k}\}\}$
- G is an undirected graph containing the input and output nodes ($\underline{In}$, $\underline{Out}$ respectively) and two subnetworks denoted by X_1, X_2 which are communicated with each other.
- $R(\underline{In})$ and $R(\underline{Out})$ are defined in the Table 2 (note that $X_{1.\underline{In}}$, $X_{2.\underline{In}}$, $X_{1.\underline{Out}}$, and $X_{2.\underline{Out}}$ are the input and output nodes of the subnetworks X_1 and X_2 respectively).

Table 2 Parameters definition of the nodes in the subnetwork X_1

Node	M	α_x	S_x	Adjacent nodes
$\underline{In}$	∅	∅	∅	$X_{1.\underline{In}}, X_{2.\underline{In}}$
$\underline{Out}$	∅	∅	∅	$X_{1.\underline{Out}}, X_{2.\underline{Out}}$

The internal configuration of both X_1 and X_2 subnetworks are defined in the Table 3 and Table 4 respectively.

- The valuation mapping φ is defined as follows:

$$\varphi(n) = \varphi(N) = \varphi(k) = \varphi(K) = \varphi(q) = \varphi(\bar{n}) = \varphi(f) = \varphi(a) = 1$$
$$\varphi(b) = -90, \varphi(B) = -20, \ \varphi(r) = (\varphi(b) + \varphi(B)) * (-1)$$

– $\underline{In}, \underline{Out} \in X_G$ are the input and the output node of Γ_P, respectively.

In addition, we define the new component ρ introduced in section 3 as follows:

$$\rho(\{a\}) = \rho(\{f\}) = \rho(\{r\}) = (-\infty, 1) \cup (1, +\infty)$$
$$\rho(\{q\}) = (-\infty, 2) \cup (2, +\infty),\ \ \rho(\{\bar{n}\}) = (-\infty, 3) \cup (3, +\infty)$$
$$\rho(\{K\}) = \{5\},\ \ \rho(\{n\}) = (5, 15]$$
$$\rho(\{N\}) = \{145\},\ \ \rho(\{k\}) = \{140\}$$
$$\rho = (\{b\}) = [-120, -20], \rho(\{B\}) = (-20, 0)$$

Symbols s, p, S, P represent the sodium and potassium intracellular and sodium and potassium extracellular respectively; v, V are the internal and external potential for an ion respectively and A is the ATP enzyme. The network alphabet contains internal representation for each symbol in V in the same order: n is the internal representation for s, N for S and so on until $\bar{n}$ and q that represent the occluded version of sodium and potassium respectively. Particularly, in this model of $Na^+ - K^+$ pump, the words present in the configurations of Γ_P are considered like multisets of symbols, that is, the order in which each symbol is located within a word does not matter.

Table 3 Parameters definition of the nodes in the subnetwork X_1

Node	**M**	α_x	S_x	**Adjacent nodes**
$X_{1.\underline{In}}$	$s \to n, S \to N$	$(5, 15], \{140\}$	$\{n\}, \{N\}$	$\underline{In}, X_{1.2}, X_{2.\underline{Out}}$
$X_{1.2}$	$p \to k, P \to K$	$\{5\}, \{140\}$	$\{K\}, \{k\}$	$X_{1.\underline{In}}, X_{1.3}$
$X_{1.3}$	$v \to b, V \to B$	$[-120, -20], (-20, 0)$	$\{b\}, \{B\}$	$X_{1.2}, X_{1.4}$
$X_{1.4}$	$b \to v, B \to V$	$\emptyset$	$\emptyset$	$X_{1,3}, X_{1.\underline{Out}}$
$X_{1.\underline{Out}}$	$k \to p, K \to P, n \to s, N \to S$	$\emptyset$	$\emptyset$	$X_{1.4}, \underline{Out}, X_{2.\underline{In}}$

In the subnetwork X_1 (see Table 3) we define rules and intervals that allow the control of the steady-state values in the pump. We have assumed as standard steady-state values for ion concentration inside and outside in a typical mammalian cell, those values found in the literature. Subnetwork X_2 (see Table 4) follows the sequential Post-Albers cycle for implementing the equations of the Table 1. As can be observed, if a w word has reached the output node $X_{2.\underline{Out}}$, it is communicated to the initial node $X_{2.\underline{In}}$ and starts a new cycle representing the E_1 conformation state as well.

Table 4 Parameters definition of the nodes in the subnetwork X_2

Node	M_x	α_x	S_x	**Adjacent nodes**
$X_{2.\underline{In}}$	$s \to \bar{n}$	$(\infty, 0] \cup [1, 3) \cup (3, +\infty)$	$\{?\}$	$\underline{In}, X_{2.2}, X_{1.\underline{Out}}$
$X_{2.2}$	$A \to a$	$(-\infty, 0] \cup (1, +\infty)$	$\{a\}$	$X_{2.\underline{In}}, X_{2.3}$
$X_{2.3}$	$\varepsilon \to f, \varepsilon \to r$	$(-\infty, 0) \cup (1, +\infty)$	$\{f, r\}$	$X_{2.2}, X_{2.4}$
$X_{2.4}$	$\bar{n} \to S$	$\emptyset$	$\emptyset$	$X_{2.3}, X_{2.5}$
$X_{2.5}$	$P \to q$	$(-\infty, 1] \cup (2, +\infty)$	$\{q\}$	$X_{2.4}, X_{2.6}$
$X_{2.6}$	$f \to \varepsilon, r \to \varepsilon$	$\emptyset$	$\emptyset$	$X_{2.5}, X_{2.7}$
$X_{2.7}$	$q \to k$	$\emptyset$	$\emptyset$	$X_{2.6}, X_{2.\underline{Out}}$
$X_{2.\underline{Out}}$	$\emptyset$	$\emptyset$	$\emptyset$	$X_{2.7}, \underline{Out}, X_{1.\underline{In}}$

4.3 Computational Simulation of the Pump Model

In order to show the suitability of the proposed integration of components in the NPEP model, we have performed a series of computational simulations by means of an ad hoc home-made simulator. The experiments performed in these simulations prove scenarios in which the membrane potential is imbalanced.

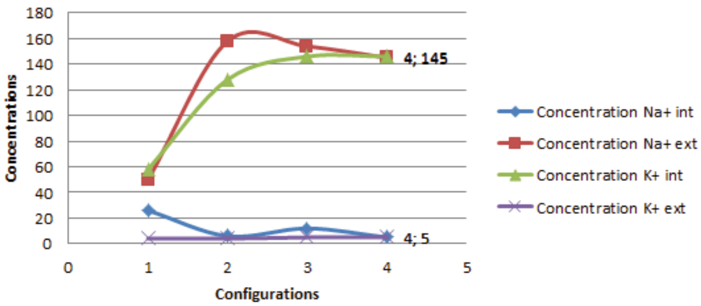

Fig. 1 Simulated experiments before steady-state values are reached.

Subsequently, the NPEP extended model of the pump tries to reestablish the right physiological conditions (numerical values belongs to the intervals defined by ρ function). Figure 1, shows the results of fifty different experiments. It can be observed that after 4 computations Γ_P recovers the steady-state values.

4.4 Short Discussion About Resource Usage

One of the main motivations for the enhancement of NPEP model is to test our hypothesis about the reduction on the resources (nodes, rules and evolutionary steps) needed to simulate phenomena with numerical evaluations. Clearly, the more efficient use of resources in any bio-inspired computational model is a key aspect when deploying instances of this model in big data platforms [7, 8].

In order to informally suggest the validity of this affirmation, we introduce the next example following the section 4.2. As it is observed in node $X_{1.in}$ in Table 3, we just used two rules to evaluate the concentration of n and N symbols. By the contrary, this exact situation with NPEPs requires to create two different subnetworks instead: the first one to test if the number of copies of symbol n is within the interval [5, 15] and the second to check if there are exactly 140 copies of symbol N. It is clear that each time we need to check similar conditions we will need subnetworks similar like these to represent it.

This fact suggests that our extended approach uses less resources than a pure NPEP that solves the same problem with a solution with a similar structure.

5 Conclusions and Future Work

We have proposed several novel components to be integrated into NPEP model in order to enhance it for modeling some quantitative conditions and features. We have modeled a discrete abstraction of $Na^{+} - K^{+}$ Pump which was simulated using our home-made simulator showing that our extended version of NPEPs seems to be a flexible and powerful tool that helps to fill the gap between the theoretical aspects of bio-inspired computing models. Our approach suggest that the integration of the proposed components enhances the NPEP model to (a) be more expressive for the algorithm design and (b) use less resources (nodes, rules, strings and computation time). This means a clear advantage when we will deploy enhanced NPEP on top of massively distributed computational platforms. A future work of interest in our view is to formally define this extension.

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Part VI
Special Sessions on Multi-Agent Systems and Ambient Intelligence (MASAI)

Using SPL to Develop AAL Systems Based on Self-adaptive Agents

Inmaculada Ayala, Mercedes Amor and Lidia Fuentes

Abstract One of the most important challenges of this decade is the Internet of Things (IoT) that pursues the integration of real-world objects in Internet. One of the key areas of the IoT is the Ambient Assisted Living (AAL) systems, which should be able to react to variable and continuous changes while ensuring their acceptance and adoption by users. This means that AAL systems need to work as self-adaptive systems. The autonomy property inherent to software agents, makes them a suitable choice for developing self-adaptive systems. However, agents lack the mechanisms to deal with the variability present in the IoT domain with regard to devices and network technologies. To overcome this limitation we have already proposed a Software Product Line (SPL) process for the development of self-adaptive agents in the IoT. Here we analyze the challenges that poses the development of self-adaptive AAL systems based on agents. To do so, we focus on the domain and application engineering of the self-adaptation concern of our SPL process. In addition, we provide a validation of our development process for AAL systems.

Keywords Agents · SPL · IoT · Variability modeling

1 Introduction

One of the most important challenges of this decade is to integrate real-world objects in Internet, called the Internet of Things (IoT)[1]. An IoT system is composed of various types of devices like sensors and home appliances, which are now connected to the Internet using different technologies. These devices can support various types of systems being the Ambient Assisted Living (AAL) one of its key areas. The goal

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of the AAL is to extend the time people can live in their preferred environment by increasing their autonomy and self-confidence[16].

The development of the AAL in the IoT is challenging since it requires to manage hardware and software technologies which are continuously evolving. From the user point of view, the application should consider factors that facilitate its acceptance and adoption, such as the perceived ease of use and usefulness [19]. This is not an easy task, since AAL systems have reached a level of complexity where the skills required by the user to keep the system running is high. A solution to this issue is to reduce the interaction between the user and the devices of the system. However, these devices are usually subject to changes that can affect their behavior, which could require user intervention. Also, system requirements could evolve at runtime, implying the addition of a new device by instance to be able to monitor a temporal disease. So, in our opinion, AAL systems should be self-adaptive [11], which implies to be able to adapt themselves autonomously to context changes resulting from device failure and the addition or loss of devices and services. In order to be self-adaptive, AAL systems should be endowed with self-adaptation capacities, which will be transparent to the final user.

The distributed nature of the IoT, autonomy, awareness and social behavior make software agents a suitable choice for the development of self-adaptive AAL systems. To implement an autonomous behavior for the nodes that compose an AAL system, agents must be embedded in these nodes. This is especially important with regard to the self-adaptation of the system. AAL systems can be composed of hundred of nodes that are distributed and interconnected using different means. So, traditional solutions for self-adaptation are centralized or are based on a fixed number of self-managers [11], which can result inadequate and non-viable for the variability of the IoT.

We have already proposed a Multi-Agent System (MAS) approach, called Self-StarMAS [2], where agents are embedded in IoT devices, also able to manage themselves. Using Self-StarMAS, we can develop the AAL application as a community of self-adaptive agents. Self-StarMAS has been previously applied to develop applications of the IoT [2]. However, since Self-StarMAS does not have a process to handle its variability, the implementation requires the development of different versions of these agents considering different devices, levels of cognitive capacity and degrees of self-adaptation. This process is important to guarantee that agent configurations meet application requirements, and the inter-operation between the different agents that compose the MAS is feasible.

In our opinion, current agent development processes are not adequate to develop AAL applications using IoT technology because they lack mechanisms to deal with the variability present in the IoT. An accepted solution to model variability is the Software Product Line (SPL) technology [6]. The benefits of SPLs are given by the reusability of the features common and variables, embodied in architectural elements during the development of a new product or configuration. This technology is being applied to the development of MASs. The integration of both technologies is known as MAS-PL (Multi-Agent System Product Lines) [17]. However, these MAS-PL approaches do not focus on solutions for the IoT.

To overcome these limitations, we have proposed an SPL process for the development of self-adaptive agents in the IoT [3]. Our starting point was Self-StarMAS, which was refactored to enable the development of MASs using an SPL. The process was defined using the Common Variability Language (CVL) [8], a domain-independent language for specifying and resolving variability. Here we analyze the challenges that poses the development of self-adaptive AAL systems based on agents. This analysis will be the starting point of the domain and application engineering of the self-adaptation concern of our SPL process. In addition, we provide a validation of our development process.

This paper is structured as follows: Section 2 presents our approach, Section 3 overviews CVL, Section 4 gives details of works related to our proposal, Sections 5 and 6 describes our SPL process, which is validated in Section 7. Our paper concludes with conclusions and future work.

2 Our Approach

This section reviews the specific challenges in the development of agent-based AAL systems. General challenges in the development of AAL can be found in different works [16].

The first challenge that we identify is **to manage the variability of agents for AAL systems (C1)**. Agents pose advantages for the development of AAL systems [10, 15, 21]. However, current solutions do not allow the development of heterogenous MAS, because they are restricted to a single agent platform and network technology [21], which makes difficult the integration of new technologies. A development process for agent-based AAL systems must manage this variability according to application requirements.

Our second challenge is **to manage software and hardware dependencies (C2)**. Until now, hardware and software dependencies were not important in the agent paradigm since MASs consists in the interaction of a population of homogeneous agents. When agents are embedded in devices that compose the AAL application, these dependencies must be taken into consideration (e.g. some network technologies are only available in specific devices). These dependencies usually go unnoticed by software architects until the implementation and deployment stages, but they should be considered and incorporated earlier in the development process to avoid incompatibilities.

The third challenge that we identify is **the support for different degrees of self-adaptation (C3)**. What can be adapted by the agent and how can be done depend on specific features and functions of the device where the agent is embedded. This leads us to consider different degrees of self-adaptation, which are influenced by the requirements of the AAL system and features of the device where the agent is embedded. The consideration of different degrees of self-adaptation must also be incorporated from the early stages of the process.

The combination of SPL and self-adaptive agents makes possible to address these challenges. Our development process (see Fig. 1) follows the two life cycles schema of SPL processes that separates domain (DomE) and application (AppE) engineering. The DomE of our process (defined in [3]) analyzes the SPL for MASs in the IoT as a whole to define and produce the commonality and the variability of the SPL (see 2). The second process, the AppE, involves creating and configuring the architecture of agents, which are built by reusing domain artifacts and exploiting SPL engineering. The use of SPL enables the management of the variability presented in the AAL domain. Additionally, SPLs provide specific mechanisms to manage the dependencies between the different concerns. Self-adaptation for AAL systems can be incorporated in SPL, so it can be considered from the early stages of the development process taking into account different degrees of it. In the following, we focus on the DomE of the self-adaptation concern of the agents and the AppE of a self-adaptive AAL system.

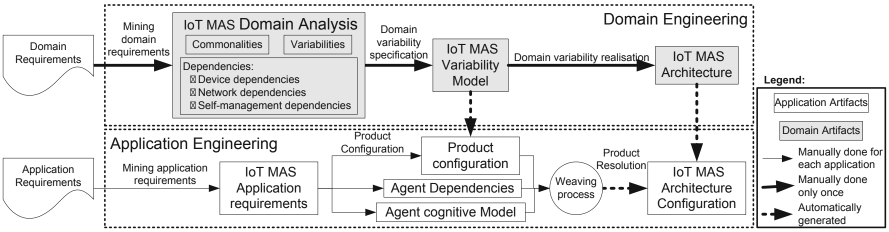

Fig. 1 SPL process for Self-StarMAS agents.

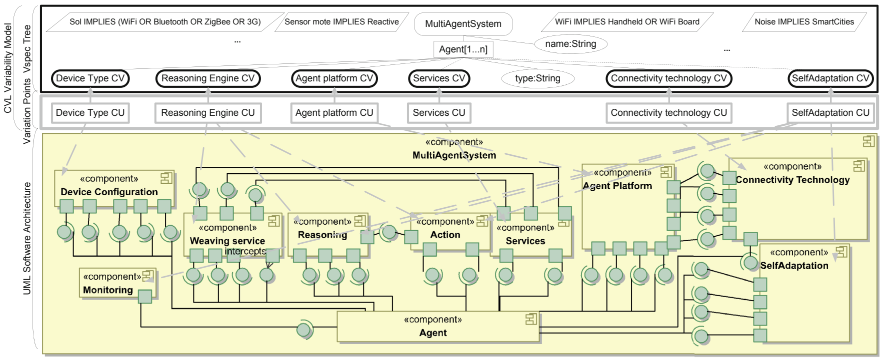

Fig. 2 Complete variability model of MAS for the IoT in CVL.

3 The Common Variability Language

CVL is a domain-independent language for specifying and resolving variability over any instance of any modeling language defined using a MOF-based metamodel [8]. The instance of the metamodel is referred to as the *base model* and CVL allows us to specify its *variability model*.

The *variability model* is a specification of the base model variabilities, and is divided into two parts. The first part, which is defined over the *base model*, marks its variation points. There are different types of variation points, in this contribution we use *existence*, to indicate the presence of an element in the base model, and *configurable units* that group a set of variation points.

The second part of the *variability model* is concerned with the definition of the relationships between the variation points. These are expressed by *variability specifications* (VSpec), which are organized using a hierarchical structure called a VSpec tree (see top of Fig. 2). The sub-tree under a VSpec means that the resolution of this VSpec imposes certain constraints on the resolutions of the VSpec in its sub-tree. These constraints will be explained in the following sections. Additionally, it is possible to specify *explicit constraints*, known as *crosstree constraints*. VSpecs are abstracts and they do not define which base model elements are involved nor how they are affected. The effect of the variability model on the base model is specified by *binding variation points*, which relates the base model and the VSpec tree.

Once the *base model* and the *variability model* have been defined, the *resolution model* is defined. This model results from selecting a set of VSpecs from the VSpec tree (i.e. the *variability model*). Then the CVL tool is executed to obtain the *resolved model*, a product model, which is a variation of the *base model* according to the choices that have been made in the *resolution model*.

4 Related Work

This section describes and discuses different approaches that are related to the presented work: development processes that use MAS-PL, self-adaptation for AAL systems and agent technology and AAL systems.

MAS-PLs have been applied to enhance the development of MAS in different ways. In [7] the Gaia methodology is modified to include SPL in the analysis and design phases of a MAS. The use of SPL allows to reduce by 48% the design documentation time at least in the case study presented, compared to the original Gaia. MaCMAS [18] is a methodology that uses formal methods and SPL to model autonomous and self-adaptation properties of MAS. It uses SPLs to model the evolution of the system taking into account the different products contained in the SPL. The work presented in [5] focuses on the AppE process by extending an existing product derivation tool for the MAS-PL domain. This proposal offers a complete SPL process with tool support to generate Jadex agents. These proposals are not suitable for the

AAL domain since they do not consider the generation of agents for IoT devices and only [18] considers self-adaptation.

Self-adaptation for AAL systems has been proposed in different works. The eWALL project [14] proposes a prefabricated wall that has attached all of the ICT technology needed to enable a number of services for seniors. The work of this wall is based on self-adaptive sensors. The goal of the work proposed in [12] is to care elderly people by providing to caregivers data collected from their homes. The system uses self-adaptation to self-configure when new technology or services are provided and to adapt the context of use. The work presented in [22] uses a metaphor based on human emotions to model the self-adaptation of sensors in AAL applications. A system to permit elderly with balance disorders to live independently at home is presented in [4]. The designed control system is self-adaptive, and it can be accommodated to conditions of users. These approaches demonstrate the benefits of endowing AAL systems with self-adaptation.

Agent technology and AAL systems are linked in several proposals. Due to limitations in space, here we mention just some of the most recent works. The paper [10] presents a context-aware MAS for care of the elderly that combines sensor technologies to detect falls and other health problems. In this case, agents are used to observe the elderly person from various points of view. An argumentative MAS is used in [15] to enable the reproduction and evaluation of inconsistent situations detected by AAL systems. They are part of an alarm management tool that supports carers to validate alarms raised by AAL systems. The goal of the system [20] is to help an elderly patient with his daily activities ensuring his security. The system uses Jade and Jason agents to implement a flexible architectural solution and reasoning about the patient condition. The work presented in [13] uses a MAS to control an AAL Flexible Interface. Agents adapt the interface based on the subject's requirements profile. The work [21] presents an environment of AAL created through the use of sensor networks and mobile agents. Agents are implemented using Jade and used for different purposes such as information retrieval. These are recent works that highlight the importance of the agent paradigm in the implementation of AAL systems and the relevance of a process that handles their development as we propose in here.

5 Domain Engineering of the Self-adaptation Concern

The DomE process (see Fig. 1) of our SPL process relies on the use of CVL and the Unified Modeling Language (UML) as MOF-based language. In [3] we defined the global variability model and architecture of the MAS for the IoT (see Fig. 2). Here we focus on the self-adaptation concern which is located in the VSpec *Self-Adaptation CV*, in the configurable unit *SelfAdaptation CU* and in the components *SelfAdaptation*, *Action*, *Reasoning* and *Monitoring*.

SelfAdaptation CV is a Composite VSpec (CVSpec), a type of VSpec that includes a VSpec tree inside. The root of the internal tree of this CVSpec (see Fig. 3) is

SelfAdaptation that has three VSpecs that represents the elements *Monitor*, *Analyze* and *Plan* of the MAPE loop of the self-adaptive systems [11]. For this concern we have opted for an approach that focuses on the computational resources of the device where the agent is embedded. Thus, the child nodes under the *Monitor* VSpec consider physical resources of devices (e.g. *Battery*). The children of the VSpec *Plan* represent plans for fixing problems that can occur in the functioning of the agent (e.g. *Recover the location service*). Crosstree constraints of the *SelfAdaptation CV* represent dependencies external and internal dependencies of the self-adaptation concern (e.g. according to the crosstree *Noise*, the appearance of the VSpec *Noise lectures* in a resolution model depends on the appearance of the VSpec *Noise* in the same model) By selecting different plans and monitoring services, we effectively model different degrees of the self-adaptation for the agent.

Self-adaptation is a complex activity that involves different components of the system. Depending on the resolution model this is represented by the *SelfAdjusting* or the *SelfAdaptation* component. The main difference between these components is that *SelfAdjusting* is intended for an agent with a cognitive reasoning engine, and generates goals to fix situations classified in states that requires self-adaptation (e.g. *Activity decrease state*). While *SelfAdaptation* is intended for an agent with a reactive reasoning engine, and executes pre-defined plans.

6 Application Engineering for AAL Systems

The AppE process (see Fig. 1) is intended to generate the final architecture of the AAL system. Here we propose an AAL system that performs tasks to make the life of the elderly more secure and comfortable. Among other services, it monitors his/her physical condition to detect injuries caused by falls or other problems. To ensure that the system works properly without requiring user intervention, self-adaptation tasks have been taken into consideration. This system is designed as a self-adaptive MAS composed of agents embedded in the different devices that comprise the application (i.e. sensing devices and personal devices of the user). This section focuses on the configuration of the agent embedded in the user personal device (named *UserAgent*), which collects data from the other agents in the system to assist the elderly user.

The first step in the AppE is to select the VSpecs that satisfies the application requirements. To generate a valid product configuration the software architect maps the application requirements to the VSpecs of the VSpec tree. For example, to fulfil the self-adaptation requirement, the VSpec *SelfAdaptation CV* (see Fig. 3) has to be selected, and the same procedure is followed for the VSpecs tree inside *SelfAdaptation CV*. After that, a tool qould generate the *resolution model* that includes the constraints of the VSpec tree. For instance, in our case study, self-adaptation is concerned with elongating the life of the system. So, when *UserAgent* detects a low battery level it decreases its activity by performing different tasks to save

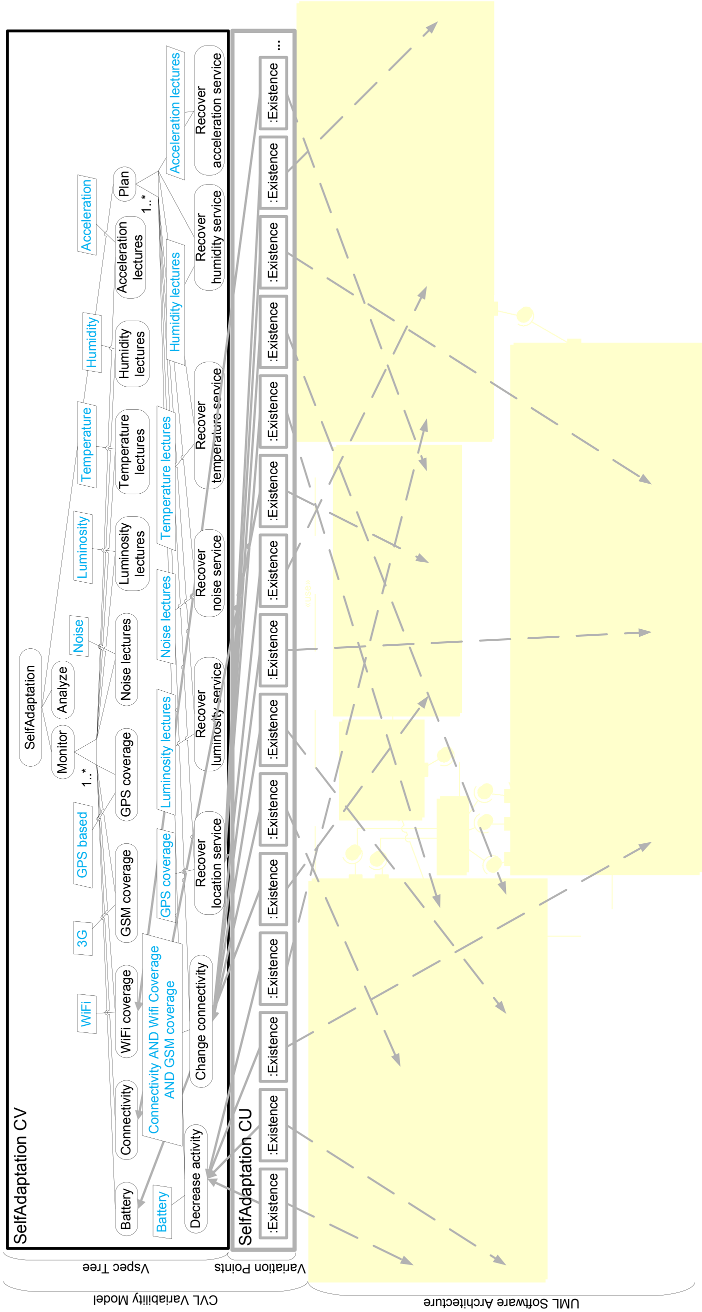

Fig. 3 Domain engineering of the Self-adaptation concern using CVL and UML.

battery. *Decrease Activity* requires *Battery* due to the crosstree constraint attached to *Decrease Activity* (see Fig. 3). The selection of both VSpecs also requires the selection of *SelfAdaptation*, *Monitor*, *Analyze* and *Plan* (because of parent-child relationships). Note that monitoring the battery level is not a requirement of the AAL system, but it is needed to obtain a valid configuration of the resolution model. So, this model not only contains VSpecs selected because of the application requirements, but it also includes VSpecs which are a result of crosstree constraints and parent-child dependencies.

Once the *resolution model* has been obtained, this is weaved with the *Agent cognitive Model* and the *Agent Dependencies* (see Fig. 1) using an ATL transformation [9]. The *Agent cognitive Model* includes goals, plans and knowledge specific to an application. The *Agent dependencies* model contains the dependencies between the *Agent cognitive Model* and the *IoT MAS Variability Model* (due to space limitations, a detailed description of these models is out of scope). Then the CVL tool uses the resultant model to generate the *resolved model*, which is a configuration of the system architecture with the set of components and connections that allow realizing the VSpecs present in the *resolution model*. This realization is derived from the Variation points, which are bound to elements in the VSpec tree and refer to elements of MAS for IoT architecture in *binding variation points*. For instance the variation point *:Existence* (see Fig. 3) bound to *Battery* indicates that if and only if this is selected in the resolution model, the *Battery* component will exist in the resolved model. The *resolved model* of *UserAgent* (see Fig. 4) includes the architectural components required to deal with two situations that require self-adaptation: to decrease the activity of the agent when the battery level is low and to recover the location service.

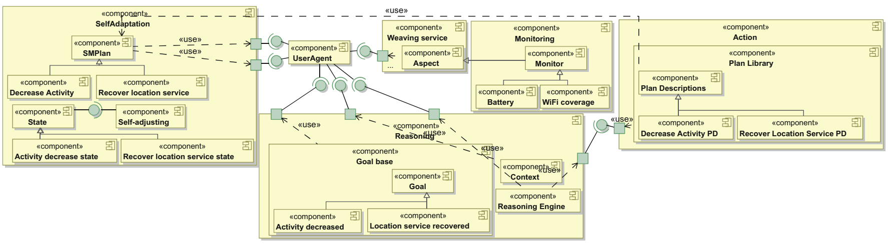

Fig. 4 UML diagram of the *UserAgent* architecture configuration.

7 Validation

In this section we analyze how our approach addresses the challenges raised in Section 2. To evaluate how well we address challenge C1, we calculate the degree of

Table 1 Degree of variability and dependency.

Concern	*Components*	*Choices*	*Valid resolutions*	*Degree of Variability*	*Intra-dependencies*	*Inter-dependencies*
Device Type	10	19	254	0.07	4	3
Reasoning	14	3	2	1.5	1	0
Agent platform	13	5	11	0.45	1	4
Services	10	14	2510	0.005	4	10
Connectivity	4	20	3423	0.005	11	8
Self-adaptation	43	22	35131	0.000626	10	8

variability of the concerns of our agents. This metric is the division between the number of choices and valid resolutions and shows the expressive power of a VSpec tree or a subtree (the lower the degree, the higher the expressiveness of the tree). To apply this metric we have counted for each concern the number of components that could be injected to realize it (*Component* column in Table 1), the number of choices the software architect has to select in the AppE phase (*Choice* column) and the number of valid resolutions that can be generated (*Valid resolutions* column). Results show that as the number of choices increases, the number of architecture configurations also increases exponentially. For example, the number of self-adaptation resolutions is 35131, which means that the software architect could obtain any of these configurations only considering 22 choices. However, notice that the software architect does not need to be aware of this high variability, they only have to focus on selecting those choices that fit application requirements.

In order to evaluate the expressive power of our VSpec tree, our model have been compared with other SPL models with similar number of features. Eighteen models (see Table 2) have been compared in terms of the number of products that can be generated and the degre of variability. These models have been extracted from the SPLOT (Software Product Line Online Tools) database[1], which has 717 models available to be analyzed. Specifically, we have selected models with a similar number of choices (between 70 and 100, see first comulm) and computed their number of valid configurations and degree of variability (provided in third and fourth column respectively). From the results we can conclude that our global SPL has a similar expressive power than other models with a similar number of choices, allowing to model a great variety of AAL systems from our VSpec tree.

To address challenge C2, we have included these dependencies in the VSpec tree using parent-children relationships and crosstree constraints. We evaluate the degree of dependency of our VSpec tree for the different concerns of our MAS counting these dependencies. We have distinguished between intra-dependencies (that occurs inside the same *CVSpec*, e.g. *Device Type*), and inter-dependencies (that occurs between different *CVSpecs*, e.g. between *Device Type* and *Reasoning Engine*). The modeling of dependencies eases the task of the software architect, since these dependencies

[1] SPLOT website: http://www.splot-research.org

Table 2 Comparison of SPL models in terms of number of valid configurations and degree of variability.

Model	*Number of Choices*	*Configurations*	*Variability Degree*
Database Tools	70	9,84E16	0,0083319
Video Player	71	4,5E+13	1,9061E-06
Reuso - UFRJ - Eclipse 1	72	226E+8	4,7758E-10
Car selection	72	3E+8	6,3626E-12
Toko	72	4,08E+11	8,6448E-09
Quality Attributes Functionalities	72	1,85E+11	3,9252E-09
Speech Recognition	75	652800	1,72779E-15
Photosharing	76	5,74E+12	7,5908E-09
J2EE web architecture	77	1,81E+10	1,2004E-11
Fish	80	2,25E+13	1,8582E-09
Webmail	81	4,49E+11	1,8581E-11
Self-StarMAS	**83**	**2.58E+7**	**1.6681E-7**
Frameworkprodemge	87	1,53E+11	9,8576E-14
Billing	88	3,87E+12	1,249E-12
Model Transformation	88	1,65E+13	5,3411E-12
Model Transformation	88	1,66E+13	5,3489E-12
Coche ecológico	94	2,32E+7	1,1725E-19
PGL_add	94	6,24E+8	3,1529E-18
UP Structural	97	1,48E+13	9,3455E-15

are included automatically. The identification of dependencies can be an error-prone and complex task because it requires an expert in different domains. In the case of the self-adaptation 18 dependencies are identified. Using our approach we can guarantee that dependencies are automatically considered, and all required components will be included.

Achieving challenge C3 is addressed by our VSpec tree and the associated SPL architecture. The first one includes different VSpecs to model typical self-adaptation tasks, like recovering specific services. In addition, our architecture includes two types of self-adaptation specific to agents with goal-oriented or reactive engines, and a predefined set of tasks for self-adaptation.

8 Conclusions

In this paper we have analyzed the challenges that poses the development of self-adaptive AAL systems based on agents in the IoT. In our opinion challenges that should be addressed by agent development processes are (i) the management of the variability of agents for AAL systems and (ii) the software and hardware dependencies, and (iii) the support for different degrees of self-adaptation. We have considered these issues to extend our SPL process for agents in the IoT. We have shown how to use our proposal to model and configure AAL systems and presented results that validate our proposal. As future work, we are working on the application of Dynamic SPL to enhance the self-adaptation of the agents and in the development of different tools to support the automatization of the resolution process.

Acknowledgments This work is supported by the project Magic P12-TIC1814 and by the project HADAS TIN2015-64841-R.

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Multi-agent-Based Framework for Prevention of Violence Against Women: Scenarios in Google Maps

Joaquin Losilla, Teresa Olivares and Antonio Fernández-Caballero

Abstract This paper proposes a multi-agent-based framework for the prevention of violence against women. A general description of the proposed service is presented. The service takes advantage of the Internet of Things that are/will be available in the context of Smart Cities and mobile technologies (such as smart phones). Lastly, some typical domestic violence scenarios are simulated by using Google Maps API and the results are shown.

Keywords Violence against women · Prevention · Simulation · Google Maps

1 Introduction

Domestic violence is a serious and complex social issue which is associated with significant health, economic and social costs to individuals and the wider community [1]. There are interesting review papers describing the domestic violence issues (e.g. [2]). Also, from the Council of Europe there are working groups to afford this terrible problem [3]. But this problem needs real solutions to eliminate it. We believe that Information and Communication Technologies (ICT) is mature enough to provide partial solutions to this burden.

This paper shows the first steps of a research at preventing family violence, with an important effort towards facing violence against women, through the deployment of cooperating sensor and actuator networks in the Smart City context [4]. The sensors deployed in the future cities as well as mobile sensors (such as smart phones) carried by humans can be easily incorporated into applications constructed with Google Maps Developer API [5]. For this aim, the design of a holistic and hierarchical multi-agent decision-making system is proposed in order to resolve the inherent

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problem of cooperation among fixed and mobile sensors and actuators (e.g. [6], [7], [8]). The new intelligent service proposed here will provide a very low ratio of false alarms through continuously updating the study/comprehension of the behavior of offender and victim.

2 General Description of the Framework

Our research work is aimed at creating family violence awareness at research and experimentation level. The expected ICT-based solution contributes to reducing the problem by supporting an innovative violence prevention service with quotidian smart objects. It is mandatory to insure that more people know and understand that family violence is not a private matter. It is a critical problem that affects the whole society - in every community, in every work place and in every school.

The proposed multi-agent-based abuse prevention service, aimed to address family violence scenarios, has a hierarchical structure, composed of the following three levels (see Fig. 1). At the first level the Internet of Things Agents (*IoT Agent*s) are located. These agents have to be understood as smart software agents that control the IoT network present in our current / future smart cities. In our proposal, *IoT Agent*s are constantly cooperating to ensure that victims and offenders do not meet. Fig. 1 does not show all the elements of the family violence prevention scenarios. Other IoT agents are mobile objects and/or persons such as the victim (*Victim Agent*), the offender (*Offender Agent*), the security identity (*Law Officer Agent*) - a policeman, for instance - and other mobile elements (mobile *IoT Agent*s), such as private cars, taxis, and so on, that can help the victim. All the *IoT Agent*s (be it fixed or mobile) have the capacity of taking smart elementary decisions at physical level starting from the interchange of low-level data.

On a second level, the *Gateway Agent*s are located. Each *Gateway Agent* is a software agent controlling physical gateways that are part of the smart city. The *Gateway Agent*s are responsible for interconnecting sensor clusters via the Internet.

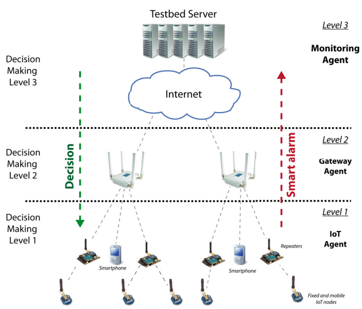

Fig. 1 The three levels of the agent-based service.

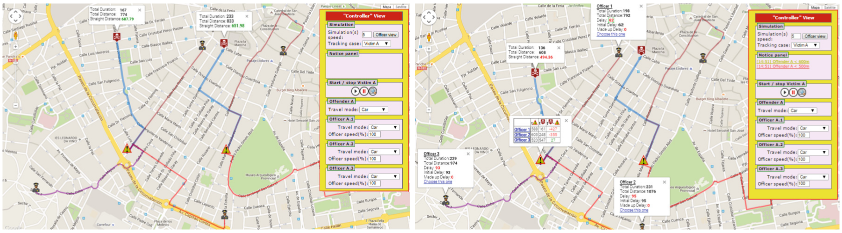

Fig. 2 Scenario 1. Left: Starting situation. Right: "Decision making" starts.

They are also responsible for establishing communication with the testbed server to update the geographic information on the monitored elements (victims, offenders, law enforcement, etc.). A *Gateway Agent* is able to take intelligent decisions at network level through cooperating with other close *Gateway Agent*s. A third level includes the *Monitoring Agent*. The *Monitoring Agent* is responsible for updating the relevant information of the monitored elements in the user interface. It is responsible for making global intelligent decisions to deal with alarms, as it has a complete vision of the overall multi-agent system.

Our first objective is to develop a fault-tolerant and real-time multi-agent based framework that models and implements all scenarios for an efficient prevention of family violence and abuse at different decision-making levels. This objective includes the establishment of new multi-agent coordination strategies to face up the different scenarios that can arise. The scenarios and strategies are modeled and implemented using well-known methods used in the agency [9]. The multi agent-based service proposes coordination strategies at different levels, making decisions at different levels with the aim of getting a fault-tolerant system [10].

3 Description of the Scenarios

A range of possible simulated scenarios has been analyzed. This study emphasizes on the decision-making aspects and the final results obtained. Notice that in this initial simulation stage only mobile IOT agents are simulated, namely, *Victim Agent*s, *Offender Agent*s and *Law Officer Agent*s. The *Gateway Agent*s are bypassed at this moment, and we use Google Maps as the *Monitoring Agent*.

3.1 *Scenario 1. Starting Situation and Motionless* Victim Agent

The first scenario starts with the situation shown in Fig. 2 (left). As can be seen, there are two tracking cases. This scenario focuses on the left hand side. There is

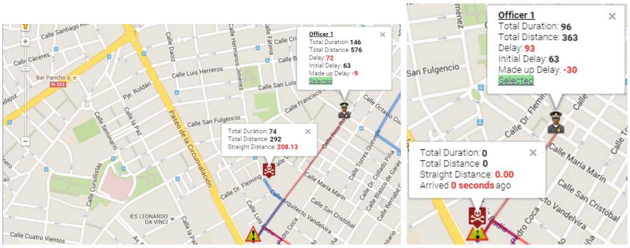

Fig. 3 Scenario 1. Starting situation. Left: Evolution of the delay. Right: Ending.

an *Offender Agent* 687.79 meters (more than 600 meters) away from the *Victim Agent* in a straight line. Accordingly, the distance indicator of the *Offender Agent* remains green, that is, this tracking case is not worthy of an alert. There are three *Law Officer Agent*s following the case and even though they are not on the alert, they have the route to the *Victim Agent* drawn just in case. Firstly, the simulation is started by pressing the "play button", the *Offender Agent* starts to walk towards the *Victim Agent*, he will go beyond the warning distance of 600 meters, and because of that a warning will be displayed in the "notice panel". When he crosses the violation distance of the restraining order (500 meters), a second alert will be displayed in the notice panel, this time marked in red, the "straight line distance" indicator of the *Offender Agent* will turn into red and the indicators for all *Law Officer Agent*s and the *Victim Agent* will be shown so that the controller *Law Officer Agent* can make a decision (see Fig. 2 (right)).

The first *Law Officer Agent* has a delay of 62 seconds in regard to the *Offender Agent*, the second *Law Officer Agent* has 95 seconds and the third *Law Officer Agent*, 93 seconds. The controller can make the decision to send the first *Law Officer Agent* to aid to the *Victim Agent* since it is the one with lower delay. For the time being, the *Victim Agent* won't be asked to move. "Play button" is pressed again, the InfoWindow of the *Law Officer Agent*s 2 and 3 will disappear and the chase will restart. It can be noticed that during the chase after the *Victim Agent*, there are little variations in the delay of the *Law Officer Agent*, as shown in Fig. 3 (left).

These variations are due to the fact that "Google Maps" objects provide, through their interface, time data for each "step" in the route, and many times inside a "step". "Google Maps" knows that it invests more time to cover a segment of the same length than other. But, unfortunately they do not expose this data trough the API. Nevertheless, these delay variations are not to be worried about because, in a real system, bigger variations over the estimation take place. These are due to traffic conditions, speed, type of driving, roadworks, mistakes, etc. All in all, the following will be gotten as depicted in Fig. 3 (right). In this scenario, it can be seen that the *Offender Agent* has arrived 93 seconds ahead of the *Law Officer Agent*, which is an unwanted situation, taking into account it was a not very adverse starting point with a *Law Officer Agent* 792 meters away from the *Victim Agent* when the *Law Officer Agent* was 500 meters away. Therefore, better choices to this intervention will be looked for.

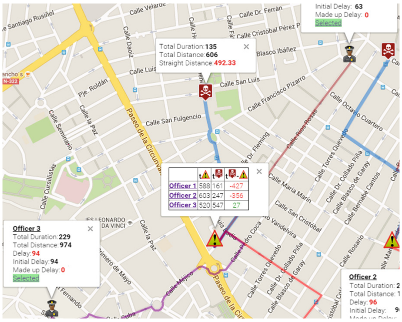

Fig. 4 Scenario 2. Sending the 3 *Law Officer Agent*s.

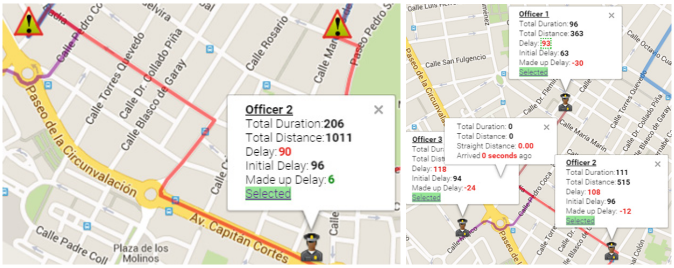

Fig. 5 Scenario 2. Sending the 3 *Law Officer Agent*s. Left: Occasional make up of the delay. Right: Final result.

3.2 Scenario 2. Sending the 3 **Law Officer Agents**

It starts from the same situation than scenario 1, when the *Offender Agent* has just crossed the violation distance (500m). A first try could be to send the three *Law Officer Agent*s to assist the *Victim Agent* (see Fig. 4). Although, any of the *Law Officer Agent*s might occasionally make up some time of the delay with regards to the *Offender Agent* (see Fig. 5 (left)). As could be expected, the strategy is not enough to avoid the disaster, and the result is quite similar to the scenario 1, with the first *Law Officer Agent* coming with a delay of 93 seconds with regards to the *Offender Agent* (see Fig. 5 (right)).

3.3 Scenario 3. Increase in **Law Officer Agent***'s Speed*

The possibility of increasing the speed of the *Law Officer Agent*s assisting the *Victim Agent* is studied in this scenario, considering that it is something which could be carried out in a real situation (in the event of an emergency situation, *Law Officer Agent*s could use sirens and they would have priority). This scenario starts making the "*Law Officer Agent* 1" 50% faster with regards to the "Google Maps" estimations.

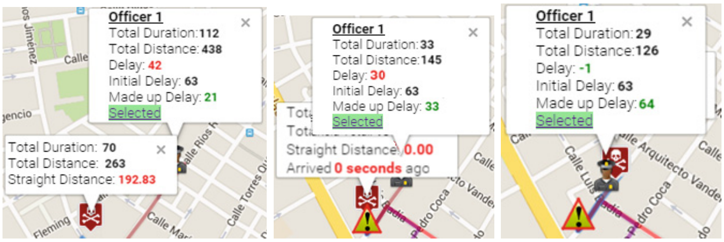

Fig. 6 Scenario 3. Increase in *Law Officer Agent*'s speed. Left: Amount of delay made up by making the *Law Officer Agent* 50% faster. Center: Offender arriving ahead by making the *Law Officer Agent* 50% faster. Right: Final result by making the *Law Officer Agent* 100% faster.

Fig. 7 Scenario 4. *Victim Agent* walking towards a *Law Officer Agent*. Decision making.

It can be noticed now how the estimated delay of the *Law Officer Agent* is getting smaller (i.e., in the image it is illustrated a reduction of 21 seconds in the delay) (see Fig. 6 (left)). However, it is still not enough as can be seen in the result of the simulation (see Fig. 6 (center)). A faster speed should have been used. Accordingly, the *Law Officer Agent* is made 100% faster than the *Offender Agent*. Finally, the goal of arriving with the *Law Officer Agent* ahead is achieved (see Fig. 6 (right)).

3.4 *Scenario 4.* Victim Agent *Walking Towards a* Law Officer Agent

Nevertheless, the strategy of making a *Law Officer Agent* 100% cent faster than the *Offender Agent* is not always feasible due to several problems (traffic conditions, high speed of the offender, and so on). Thus, a different approach will be tried. This approach is to ask the *Victim Agent* to walk towards a given *Law Officer Agent*. In this simulation, the speed of the *Law Officer Agents* would not be increased. This scenario starts with the same situation of the scenario 1 (see Fig. 7).

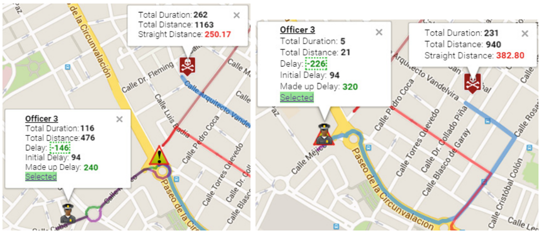

Fig. 8 Scenario 4. *Victim Agent* walking towards a *Law Officer Agent*. Left: Making up the delay. Right: Final result.

It can be seen how the "officer 1" has the lower delay. However, if the *Victim Agent*'s indicators are analyzed, it can be observed that it would take the *Victim Agent* 520 seconds and the *Offender Agent* 547 seconds to reach "officer 3" which produces a positive balance of 27 seconds compared to the times for the *Offender Agent* to reach the *Law Officer Agent*s. In addition to this, by sending both "officer 3" and *Victim Agent* to each other, they will increase the saved time over the *Offender Agent*. Thus, an appropriate decision of the controller in this situation would be to send the *Victim Agent* walking towards the "officer 3" (the walking route for the *Victim Agent* is drawn in green). Besides, the controller sends the "officer 3" towards the *Victim Agent*, instead of "officer 1". Note that, even though *Law Officer Agent*s and *Offender Agent*s travel by car, the *Victim Agent* will walk because normally their car would not be available at every moment. The simulation is started again (see Fig. 8 (left)).

In Fig. 8 (right), it is illustrated how the delay disappears, and now the *Law Officer Agent* is in a very advantageous situation. Despite the *Victim Agent* is walking, an amazing result it is achieved because the fact of approaching the agent causes, firstly the *Victim Agent* to move away from the *Offender Agent*, secondly by waking, the *Victim Agent* can go through non-accessible paths for the *Offender Agent* and sometimes it will force the *Offender Agent* to make a detour, and finally, the route of the agent will be simplified and shortened. As a re-sult of that, it can be seen that it started from an initial situation with the *Law Officer Agent* arriving 94 seconds late and finally a situation with the *Law Officer Agent* arriving 231 seconds ahead is reached. All in all, this strategy can be rated as highly effective (see Fig. 8 (right)).

3.5 *Scenario 5.* Victim Agent *Walking with 2* Law Officer Agent*s Assisting Her*

This scenario starts from the same situation than the previous one, with the *Victim Agent* walking towards the "officer 3", but now in addition to "officer 3", "officer 2" will go to assist the *Victim Agent* as well. This result will be achieved (see Fig. 9 (left)). It can be noticed how not only "officer 3" but "officer 2" gets a big advantage

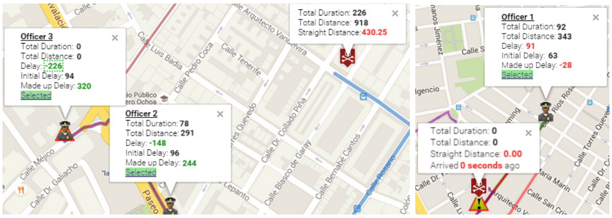

Fig. 9 Left: Scenario 5. *Victim Agent* walking with 2 *Law Officer Agent*s assisting her. Right: Scenario 6. *Victim Agent* walking to the wrong side.

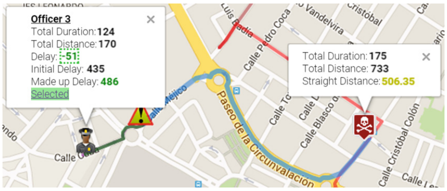

Fig. 10 Scenario 7. *Victim Agent* and *Law Officer Agent* walking.

over the *Offender Agent* (although to get more precise data, more casuistry should be analyzed since the initial position of the *Law Officer Agent* could have huge influence on the results).

3.6 Scenario 6. **Victim Agent** *Walking to the Wrong Side*

Obviously, if the controller makes a wrong decision with regards to where to send the *Victim Agent*, unwanted results will be obtained. For example, with the same starting situation of previous scenarios, if the controller sends the *Victim Agent* towards "officer 1" and "officer 1" go towards the *Victim Agent* (because she is the closer), a similar result to scenario 1 will be gotten (see Fig. 9 (right)).

3.7 Scenario 7. **Law Officer Agent** *3 Walking Instead of Travelling by Car*

In the last scenario, the *Offender Agent* will travel by car and "officer 3" and the *Victim Agent* will walk. The *Victim Agent* walks towards "officer 3" and "officer 3" assists the *Victim Agent*. Alt-hough it might seem a very advantageous situation for the *Offender Agent*, the simulation shows the opposite and the *Law Officer Agent* arrives ahead of the *Offender Agent* (see Fig. 10).

4 Conclusions

This paper has introduced a framework for the prevention of violence against women. Firstly, the proposed service and its advantages has been described. The proposed service has been modeled as a multi-agent system to inherit all the properties of intelligent distributed architectures. The service has been drawn to use any available smart cities' IoTs. Mobile technology in form of smart phones, used by the victims and officers (among others) or anti-violence bracelets carried by the offenders are key to this proposal. This paper has simulated some of the most common domestic violence scenarios by using Google Maps API. The results obtained so far seem promising to face the proposed project for combating violence against women.

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A Greedy Algorithm for Reproducing Crowds

Rafael Pax and Jorge J. Gómez-Sanz

Abstract The gathering of crowd traffic data either from videos or from visual observation has different uses. In the social simulation context, one of them is validating crowd behavior models and match the resulting traffic in control points with the real ones. When such models have been already validated, the immediate use can be aiding managers of facilities to infer, from real time data, what crowd behavior they should expect in their facilities. However, the transformation of those measurements into actual behavior patterns has not been satisfactorily addressed in the literature. In particular, most papers take into account a single measurement point. This paper contributes with an algorithm that produces possible populations that reproduces real traffic data obtained from multiple measurement locations. The algorithm has been validated against data obtained in a real field experiment.

Keywords Multi-agent based simulation · Crowd simulation · Inferring population composition · People tracking

1 Introduction

The simulation of large groups of people falls within the domain of crowd simulation. Literature gathers examples of theoretical models whose performance is compared with real data obtained from real world situations, such as [6] or [2]. In most cases, it is a validation activity what the researcher tries to achieve. However, there are cases where the problem consists in guessing what kind of population does fit into some observed data. Many populations can exhibit the expected behavior, but not all of them show a believable behavior. Here, believable stands for *satisfying the expectations*

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of the observer, e.g. an expert such as the social scientist. Generating believable populations is not trivial because the assistance of experts in human behavior must identify the criteria for distinguishing one from the other. Every iteration requires simulating, and then, observing the resulting behavior to decide if the simulation is satisfying. If not, a new population, selected with a different criteria, is needed.

In this open problem, a solution for quickly obtain populations is desirable. With the higher goal of reproducing the behavior of a large group of people, a first step constitutes *producing a traffic data over the control points close to the observed one*. This problem is relevant for replicating real life situations where the researcher does not have measurements of the whole facility where the measurement is performed, just a portion of this. Validation of the generated population can be made with the *take one out* technique used in machine learning. This technique consists in not using all of the data for training and keep some of it as oracle for assesing the goodness of the population.

This paper contributes with an algorithm for obtaining populations of actors that reproduce traffic data that includes number of people per minute in several zones of a facility. This algorithm is a first step towards creating more complex population that satisfy the criteria of experts in the behavior of large groups. Obtaining such population is not trivial, even if, initially, only traffic data is accounted. Simulated characters remain in the simulation for a long time, not only appear and disappear. Besides, there maybe obstacles, collisions, and wrong estimation of distances that can lead to deviations in the behavior of the population with respect to the observed data. The algorithm included in this paper has a root mean square error of 0.94510658 over observed data.

The structure of the paper is as follows. Section 2 introduces relevant work related to the algorithm introduced in this paper. Section 3 introduces the setup of the problem the algorithm addresses and justifies the complexity of the problem. Section 4 introduces the algorithm itself using pseudocde. Section 5 presents and discusses a sample experiment with a piece of a real field experiment where observations were made. Finally, section 6 contains the conclusions and future work.

2 Related Work

Due to their multiple applications, such as sociology, safety analysis, computer graphics or civil engineering simulations of virtual pedestrian crowds have gained increasing attention from industry and researchers. During the last years, the research on data-driven approaches for creating simulated pedestria crowds has been increased significantly, and multiple models have been proposed for solving this issue.

K.H. Lee et al. [3] developed a data-driven method of simulating a crowd of virtual humans, extracting trajectories of each individual from the video recordings of an aerial view of a crowd, and learning an agent model from the *state-action* trajectories acquired from visual tracking, having as a result a virtual crowd behaving in a similar way in the same area where the recordings were produced. Following the same paradigm, Lerner et al. [4] propose the creation of an example database for evaluating simulated crowds based on videos of real crowds. Bera et al. [1] also developed a behavior-learning algorithm for data-driven crowd simulation, capable of learn from mixed videos. Zong et al. [7] developed a framework for generating crowds for matching the patterns observed on video data,taking into consideration the behavior both at the microscopic level as at the macroscopic level. Yi Li et al. [5] developed a technique for populating large environments with virtual characters, cloning the trajectories of extracted crowd motion of real data sets to a large number of entities.

3 Overview

In this paper, we propose a way for recreating a crowd flow through a multi-agent simulation, where people are modeled as agents, which satisfies the data gathered during the experiment. That is, the people crossing the control zones during the simulation should match with the flow table provided. One of the characteristics of this problem is that the data gathered in the experiment does not contain the information about individual trajectories, only global numbers. This lack of information makes the problem challenging. As the information per person is not provided, the process consists of two phases: Individual path computation and simulation of the crowd flow in a realistic 3D environment.

3.1 Definitions

3.1.1 Control Zone

We define a *control zone* C as any zone in the environment where the crowd density has been measured over time. Normally, it is a room, a corridor, or an area around a door. Figure 2 illustrates a set of control points placed in an environment.

3.1.2 Time Record

The number of people that have entered a control zone C_i during a concrete time interval is represented by a *time record*, which consists on a triple $T_i = \{t, n, C_i\}$, where n is the number of people that have crossed the control zone in the time interval $t = [t_{start}, t_{end}]$. The value of t is expressed as an interval because depending on the people counting method, this data cannot be measured with exact precision (people counted by a human observer, for example).

Table 1 Example of a flow table

Time interval	FS_0	FS_1	FS_2	FS_3
[0, 60)	6	7	5	3
[60, 120)	5	3	1	5
[120, 180)	6	1	6	9
[180, 240)	1	0	2	1
[240, 300)	4	-	3	8
[300, 360)	4	-	1	6
[360, 420)	5	-	3	4
[420, 480)	6	-	5	3
[480, 540)	5	-	1	5
[540, 600)	6	-	6	9
[600, 660)	1	0	2	1
[660, 720)	4	0	3	8

3.1.3 Flow Set

All the time records belonging to a particular control zone C_i are grouped in a flow set $FS_i = \{T_{i_0}, T_{i_1}, \ldots, T_{i_n}\}$. The natural way for representing this data is arranging the time records in a table, (called *flow table*) being in the same row the ones having the time intervals in common. Table 1 illustrates how this arrangement is done. An entry containing a hyphen (-) instead of a number means that there is no data available for that time interval in the control zone (perhaps it was collected with different time intervals, or because the observation of the people flow was not performed during that time).

4 The Algorithm

Due to the lack of information about individual trajectories, different configurations for each agent should be generated in order to create a set of individual trajectories matching the data collected. As the recreation may involve many control zones, and large periods of time, we have developed a greedy approach in order to solve this problem. This approach creates trajectories passing through the control zones, taking into account the distances between them and the speed of each agent. It is assumed that there are no agents at the beginning of the simulation, that they come from outside of the environment via some specified *entrance points*, and that they exit the environment through another entrance point. The trajectories are computed in a reverse way: The first point added to the trajectory is the last one the agent will pass through. At each iteration, a set of reachable control zones is selected by a *selection function*, which takes into account the agent's speed and the the current control zone of the agent. Then, the number of people in the selected control zone is decreased by 1. The process is repeated until the first time interval is reached.

Listing 1. Main Algorithm

```
while Flow table is not empty do
    endLoc ← SELECTENTRANCE()
    tr ⟵ the time record with maximum time
    tr.n = tr.n − 1
    availableTime ← tr.t
    loc ← tr.c
    agentSpeed ← SPEEDSELECTION()
    availableTime ← availableTime − TRAVELTIME(endLocation, loc)
    trace ← GENERATETRACE(availableTime, loc, tr)
    traces ← traces + GENERATETRACE(availableTime, loc, tr, speed)
end while
    return traces
```

The algorithm ends when the flow table is empty: If the n value of all the time records is zero, there is no need to generate trajectories.

At the beginning, an *entrance point* is selected. It will be the location where the agent will *exit* from the environment (remember that the algorithm runs in a reverse way). After that, a non-empty time record (tr) with the highest time value is selected. The control zone corresponding to this time record will be the *last* control zone that the agent will cross before exiting the environment. If there are more than one available, can be chosen with a custom criteria.

Listing 2. Trace Generation

```
trace ← INITIALIZETRACE
while availableTime ≥ 0 do
    available ← AVAILABLETARGETS(availableTime, loc)
    if available is not empty then
        tr ← SELECTTARGET(available)
        availableTime ← availableTime − TRAVELTIME(c, loc, speed)
        loc ← LOCATIONOF(tr)
        tr.n = tr.n − 1
        ADDTOTRACE(loc)
    else
        if availableTime > 0 then
            ip = SELECTINTERMEDIARYPOINT()
            availableTime ← availableTime − TRAVELTIME(ip, loc, speed)
            ADDTOTRACE(loc)
        end if
        if availableTime ≤ 0 then
            go to the start point
            eP ← SELECTENTRANCE(B)
            ADDTOTRACE(loc, trace)
            availableTime ← availableTime − TRAVELTIME(eP, loc, speed)
        end if
    end if
end while
    return trace
```

The n value of the selected time record $(t.n)$ is decremented by 1. This is done because if n agents will be passing through that the corresponding control zone in the time interval $t.t$. Doing this operation n times for different agents (or the same agent, if the time interval is large enough), will satisfy the condition of the initial problem. After the initialization, the process of selecting time records is done iteratively, applying the same concept:

– An available time record is selected. A time record tr is "available" if the $tr.n > 0$ and the agent can reach it in the time interval $t.t$.
– If there is no time record available (There are too far from the agent's location, for example), an intermediary point in the environment is selected.
– Every time that a location is selected, the available time is decreased, taking into account the distance from the agent location and the agent's speed.
– When the *available time* is less or equal to zero, an entrance point is selected. This entrance point will be the *first one* that the agent will cross.

4.1 Example

For illustration purposes, let's consider a simple example with three control zones, C_0, C_1 and C_2. For an agent with an specific speed, the travel times in seconds between the control zones could be 200 ($C_0 \rightarrow C_1$), 100 ($C_0 \rightarrow C_2$) and 150 ($C_1 \rightarrow C_2$), as shown in Figure 1. The initial state of the flow table is shown in Table 2.

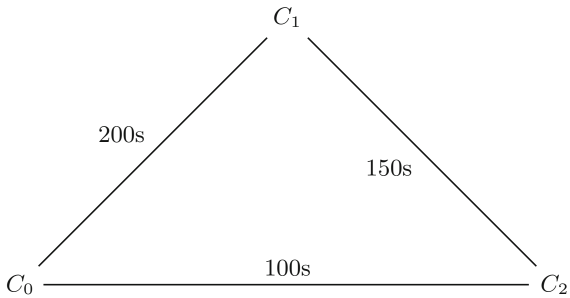

Fig. 1 Travel times from the different control zones of the example

When the algorithm starts, an non-empty record having the time interval with the highest value is chosen. In this example the chosen time record shown in table 2. The candidate time records are the ones highlighted, and the chosen time record ({[300, 360), 4, C_0}) is marked with an arrow (←). Once the time record is selected, its value is reduced by one, and the location of the agent is saved. The candidate time records after the first step are highlighted in table 3. The time intervals are [240, 300) and [120, 180), because traveling from C_0 to C_2 takes 100 seconds, and

Table 2 Initial state.

Time interval	FS_0	FS_1	FS_2
[0, 60)	6	7	5
[60, 120)	5	3	1
[120, 180)	6	1	6
[180, 240)	1	0	2
[240, 300)	4	5	3
[300, 360)	4 ←	0	1

Table 3 Second iteration.

Time interval	FS_0	FS_1	FS_2
[0, 60)	6	7	5
[60, 120)	5	3	1
[120, 180)	6	1	6
[180, 240)	1	0	2
[240, 300)	4	5	3 ←
[300, 360)	[3]	0	1

Table 4 Third iteration.

Time interval	FS_0	FS_1	FS_2
[0, 60)	6	7	5
[60, 120)	5	3 ←	1
[120, 180)	6	1	6
[180, 240)	1	0	2
[240, 300)	4	5	[2]
[300, 360)	3	0	1

Table 5 Last iteration

Time interval	FS_0	FS_1	FS_2
[0, 60)	6	7	5
[60, 120)	5	[2]	1
[120, 180)	6	1	6
[180, 240)	1	0	2
[240, 300)	4	5	2
[300, 360)	3	0	1

$359 - 100 = 259 \in [240, 300)$, being the other case analogous. In this step, the candidate time record that will be chosen will be $\{[240, 300), 3, C_2\}$, because its time interval is higher.

In the next iteration, the candidate time records are $\{[60, 120), 3, C_1\}$ and $\{[120, 180), 6, C_0\}$.

If we follow the same process that the one done in the previous step, the selected time record should be $\{[120, 180), 6, C_0\}$. But it is obvious that the trajectories of the agents would be awkward, moving forward and backwards every step. This restriction depends on how the control zone selection function is implemented.

The last step is shown in table 5. After this last step, a path from the control zone chosen (e.g., C_0 or C_2) to an entrance point should be computed.

5 Case Study

The case study considers the floor of a building,(see Figure 2), where control areas, painted in red, have been defined. Using this blueprint, samples of traffic data through red areas is used as input. The number of people crossing that control zones was annotated with a frequency of one minute.

The crowd behavior consists of entering the building through designed entrances and move along the floor in a way that traffic data through red areas matches input data. Data used for the experiment comes from a real human traffic observation in

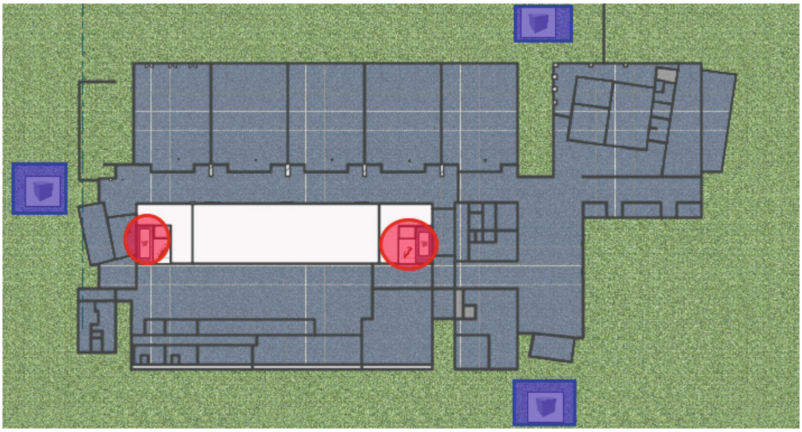

Fig. 2 Control zones of the case study.

a configuration similar to the one depicted in Figure 2, where the control zones are marked as red circles, and entrance points are marked as blue squares.

The traffic of the inhabitants during the simulation is represented in Figure 3. The characters move along different pathways automatically generated. These pathways are designed in a way that, assuming a constant speed, the characters cross the intended red areas at the designated times. The pathways may look unnatural because of this limitation. Hence, one can observe a character going to the middle of a room and just returning. One of the future work improvements consists in adding activities to perform along the pathways so that the simulation is more realistic. Despite this limitation, the obtaining traffic data from the simulation is close to the ideal.

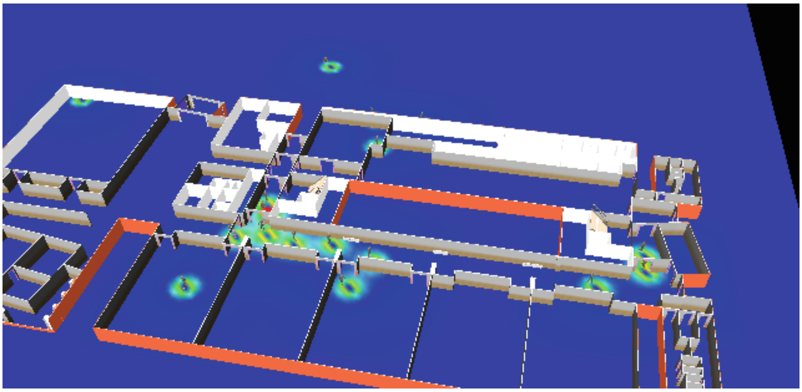

Fig. 3 Sample execution of the simulation over the blueprint from figure 2

Table 6 Control zone A density values

Time interval	Real	Simulated
0	4	10
60	1	4
120	4	9
180	7	9
240	2	6
300	8	14

Table 7 Control zone B density values

Time interval	Real	Simulated
0	10	14
60	1	2
120	6	9
180	1	5
240	5	12
300	2	3

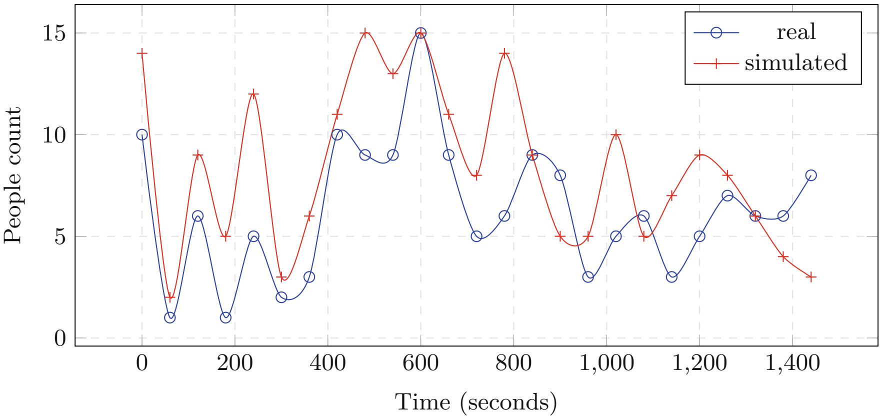

Fig. 4 Control zone crowd density values, real vs simulated.

Some of the observed results during one execution are presented in figure 4 and in tables 6 and 7. It can be observed a difference between the number of people that passed over the control zone in the real measurements and the simulated ones.

Two reasons may explain these results. First, the algorithm does not take into account (yet) the movements of other agents during its execution, the collision detection between agents and its resolution is done during the the simulation, not before. Second, that a trajectory may cross an undesired control zone, making the results slightly worse. The plot reported in Figure 4 shows how this issue alters the simulation results, increasing the number of people counted over one of the control points of the simulation.

6 Conclusion and Future Work

This paper has introduced an algorithm for creating populations of characters whose behavior produce a traffic data close to observed data. This population is made of characters that navigate through a facility which has obstacles and where characters can collide. The algorithm fails to give precise results so as to remain domain independent. Hence, there are differences in the navigation between the simple behavior assumed by the algorithm and the obtained behavior for the simulation. This difference is not high, but it may increase according to the complexity in the environment. Also, the algorithm does not account activities of the daily living of the characters beyond a navigation path going on for a long time and that goes through selected control points.

The relevance of the algorithm for research in crowd simulation is for creating specific populations that show specific traits in their behavior, such as traversing control points at precise times in a long simulation. Such populations can be used to validate theoretical models of crowd behavior. The number of populations that satisfy the constraints has not been studied. If only a few are possible, this may be an indirect way of determining the behavior of large groups when only a few observation points are available.

Future work will take into account the complexity of the environment as well as in the behavior of the characters in a way that the resulting behavior is closer to the observed behavior of large groups of people.

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ADELE: A Middleware for Supporting the Evolution of Multi-agents Systems Based on a Metaprogramming Approach

Pablo Pico-Valencia and Juan A. Holgado-Terriza

Abstract This paper presents a middleware based on an agent model for supporting reactive agents that can change their behavior in order to evolve with time based on the accomplish of active norm defined into a dynamic normative model. This middleware named Agent Dynamic EvoLutionary at runtimE (ADELE) was developed on a Java platform using the JADE framework. ADELE middleware allows developing dynamic multi-agent systems applicable to ubiquitous applications where environments are highly dynamic. Our approach includes metaprogramming mechanisms which enable agents to be able to evolve through a behavior injection (*on the fly*) at runtime, instead of killing agents which probably can be implicated in other processes and cannot be interrupted to prevent problems to the entire system.

Keywords Multi-agent · Behavior injection · JADE · Evolution · Metaprogramming

1 Introduction

Recent advances in mobile distributed systems demand new computing environments characterized by a high degree of dynamism [1]. Mainly these changes are related to the new requirements, resource availability, network connections, and

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new hardware specifications. Then, it becomes necessary to update dynamically the behavior of current systems at runtime without halting the system. To satisfy this need, agents may be one of the best options when ubiquitous applications are planned to be developed [2].

Multi-agent Systems (MASs) are an area of Distributed Artificial Intelligence and Distributed Software Development which have taken popularity recently in several domains. This is the reason why the agent paradigm and frameworks such as JADE (Java Agent DEvelopment Framework) have been widely used successfully for developing complex systems in Ambient Intelligence (AmI) [2], Robotic [3], Healthcare [4], Manufacturing [5], among others.

The evolution of agents is an important issue of MAS to be considered when highly dynamic systems are built using agents as occurs for example in ubiquitous environments. In these cases, agents must change continuously their behavior for adapting to the dynamic nature of the environment, satisfying at any time the requirements imposed to the system. The main reason is because these systems are characterized by the consumption of dynamic and heterogeneous resources which provide updated information of data and devices as well as its system environment conditions at any time. Then, they have to manage intelligently for using any device, at any location, in any format, in a transparent way to the user. Therefore, the "*agent evolution*" term is used in this paper to refer to the changes experienced by agents in their behavior, and not for characterizing agents that execute genetic algorithms to solve optimization problems.

The main approaches raised by the scientific community are essentially based on the evolutionary computation, on Belief-Desire-Intention (BDI) agents and also on reactive model. In Privošnik [6], the agent evolution is determined by the accomplishment of a state, which is achieved by means of an optimization process using genetic algorithms. In contrast, Nunes et al. [7] present an evolutionary mechanism which adapts continuously the BDI components to manage the agent evolution. However, in Li and Chi [8] the agent evolution is addressed by an event-based mechanism that triggers events when it detects new user requirements. The first two mechanisms required a more computational cost than third one.

However, our approach proposes the definition of a continuous evolution process adapting the behavior of active agents at runtime using norms, in an easy (activating and derogating norms) and low cost (introspection of methods using reflection) way. Similarly to Li and Chi [8], the agent evolution is managed by an event-based mechanism, but at the contrary events have been replaced by norms. Metaprogramming facilitated the agent evolution by mechanisms such as the reflection in meta-classes (meta-behavior and meta-agent) for injecting new behavior classes to agents according to active norms. In this way the MASs becomes more flexible and reconfigurable to change at runtime using a simple dynamic normative model that governs the evolution process of their active agents without the need of halting them.

The paper is organized as follows: Section 2 includes a background of this research and the evolutionary approach proposed by the ADELE middleware, in Section 3 we introduce some important aspects of ADELE and how the evolutionary process of active agents are managed by the behavior injection, Section 4 presents a formal description of ADELE elements required by an ADELE application for smart home automation. Section 5 presents the results obtained by ADELE on two scenarios, varying the agent number. Finally, we present our conclusions and future works in Section 6.

2 ADELE Approach

Software evolution is normally focused on the accomplishment of user requirements [8]. One of the helpful techniques for dynamic evolution at runtime is the metaprogramming approach, which serves important objectives of software engineering such as modularization and adaptability [9].

The metaprogramming is the ability of programs to write higher-level programs (metaprograms) to manipulate or create other programs. Even though this approach is widely used in software engineering, it is often misunderstood because it does not exist a standard taxonomy in the metaprogramming domain [10], and the syntax, semantic, capability and limitations of the tools differ (e.g., while Ruby uses mainly blocks for implementing anonymous functions, Python only supports lambdas).

Few programming languages like C++, Java, and other really dynamic as Ruby, Python, and Groovy, allow for developing programs that manipulate others ones or themselves, changing their behavior at runtime. This advantage has already been exploited in many systems such as middleware [1], concurrent systems [8], context-aware applications [9] and others. Thus, we have used the reflection integrated in Java code for writing reusable behavior classes that are independent of certain agent classes, and it allows us to add evolution mechanisms inside an agent platform.

To achieve the software evolution by means of agent approach, it has used actions to delete agents and later active new agents with new behaviors. However, it is not a good choice for ubiquitous applications because it is reasonable to have many dependent agents that explore at the same time the environment and accomplish their objectives using the hardware and software resources available in the ubiquitous space. A partial delete of an agent or a group of them could jeopardize the execution of the overall system. This is the reason why our approach does not sacrifice to existing agents, but it disables behaviors, modifies them, or adds new ones, for enabling agents to meet new needs that initially were not defined in the design or development phase. Therefore, agent objectives remain valid and any dependent agent can be benefited from their results at any time. Obviously, the new behaviors must satisfy the above behaviors.

Based on metaprogramming and normative theory, our approach uses the normative framework for Agent-Based Systems proposed by López et al. [11] to set norms in accordance to the system requirements. Only the active norms cause effects into the overall system when they are linked with specific behaviors. These behaviors are automatically injected at runtime to one or more agent entities, instantiated from an agent template, through a meta-agent and a meta-behavior. Furthermore this enables the addition of new agent templates and updates the initial hierarchy defined by the MAS.

Once the norms and behaviors are defined, ADELE does not guarantee the absence of contradictions between the defined norms. That is why the developers of ADELE applications have to act careful when they have to define the normative model to avoid possible inconsistencies that cause anomalous functionality after any evolutionary process is carried out. It may be considered as the most important limitation of ADELE.

In spite of the limitations previously specified, the proposed approach is helpful in controlled scenarios that require changes to support new user requirements. For example, in AmI the evolution of the system can include new scalable services to give smarter applications in home automating systems, while in Robotics can be a powerful mechanism to reconfigure the system when new sensors are added or removed. In both cases, the proposal can update the MAS policies to change its behavior and accomplishes the tasks for which it was created, or also adds new strategies that replace to others if any component of the physical infrastructure fails.

3 ADELE Middleware

A survey about agent languages, tools and platforms in Ivanovic and Budimac [12], shows that the most used frameworks currently for developing of MAS are JADE, ZEUS, RETSINA and MADKIT. Nonetheless, we have selected the JADE framework which provides an interoperable and runtime execution of P2P applications on reactive agent architecture useful in wired and wireless environment and fully compliant with the Foundation for Intelligent Physical Agents (FIPA) specifications.

Moreover, we have used some other functions already implemented in JADE such as platform, container, agent entity, and the static reactive model based in simple (one-shot and cyclic) and complex (sequential and parallel) behaviors. We have not limited to only one type of behavior since the applications have to act in a different way according to the complexity of the required actions for accomplishing a new requirement.

3.1 Architecture

In the agent oriented approach, it is possible creating agents based in three common architectures such as reactive, deliberative, or hybrid [13]. We have selected the reactive model considering its advantages such as simplicity, computational performance, computational low cost, robustness against failure, and easiness to modularize external behaviors [5]. Furthermore, we have applied the JADE framework as base of our approach because it provides reactive agents. However, we have included new concepts distributed in four layers, as shown in Fig. 1.

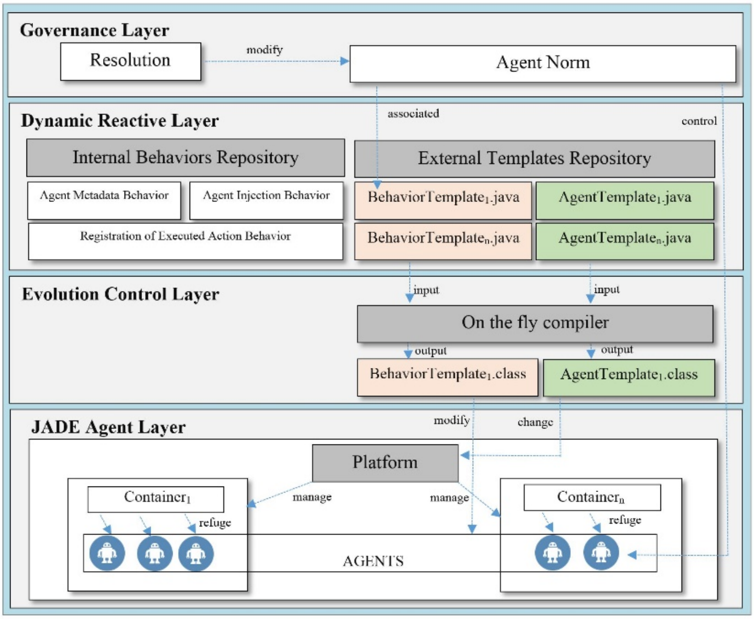

Fig. 1 ADELE middleware architecture.

The ADELE architecture has been developed for building dynamic MAS using a set of abstraction layers. The first layer "*Governance Layer*" defines the set of norms that control the agents through external behaviors. In addition the middleware uses the resolution concept to describe the changes that affect the state of a specific norm. Therefore norms and resolutions are the main components for evolution in ADELE.

The second layer, "*Dynamic Reactive Layer*" includes the internal and external behaviors which affect to agents. The internal behaviors are the default behaviors defined by the middleware to carry out the evolution process of agents, while the external behaviors are the behaviors associated to a norm created at runtime. *Agent Metadata Behavior* shows information about the agent itself such as its name or its parameters, *Agent Injection Behavior* uses the reflection paradigm for injecting external behaviors to agents according to their associated norms, and finally *Behavior for the Registration of Executed Action* saves in a log file the behaviors executed by each agent. In summary, this layer allows adding new external behaviors at runtime by using a local repository, where the behavior source code and their respective compiled java classes are stored, even allowing SOAP, RESTful, DPWS, DOHA[14] invoking services or other callable from Java if so requires.

The third layer “*Evolution Control Layer*” takes the source code of the classes for creating new agents (agent templates) and the classes for creating new external behaviors (behavior template) to add changes in agents at runtime using the “on the fly” compilation, instead of killing agents and create new ones with the new functionality.

Finally, the “*JADE Agent Layer*” includes the set of JADE agents that react to behaviors associated with previously defined norms.

3.2 ADELE Definitions

ADELE Norm: An ADELE norm is the description of a rule in the ADELE middleware which allows altering the agent functionality and consequently, change the global system. It is a tuple consisting of 3 elements as shown (1), where I_v is the norm identifier, Y is the norm type (norm or resolution), C_v is the norm category, and S_v is the norm state (active, derogate). N is the universal set of norms governing to an ADELE MAS.

$$ADELE_{Norm} = \langle I_v, Y, C_v, S_v \rangle \in N \quad (1)$$

ADELE External Behavior: An ADELE external behavior is an encapsulate functionality linked to a norm. Its concept extends of the formalization of JADE behavior included in the work of Bergenti et al. [15], but now it is a tuple consisting of 7 elements as shown in (2), where I_b is the identifier of external behavior, T_b is the template of the external behavior, my_{Agent} corresponds to an ADELE agent instance, $P_b = \{p_{b1}, p_{b2} \dots p_{bn}\}$ is a finite set of all possible parameters required by the behavior for processing the encapsulated functionalities, S_b = {block, action, done, onStart, onEnd} is a finite set with the JADE behavior states, N is the norm which triggers the behavior I_b, and E_k is the local repository directory where the behavior class it is stored. B is the universal set of all external behaviors in ADELE platform.

$$ADELE_{ExternalBehavior} = \langle I_b, T_b, my_{Agent}, P_b, S_b, N, E_k \rangle \in B \quad (2)$$

ADELE Agent: An ADELE agent also extends the formalization of the JADE agents [15], but now is a tuple consisting of 7 elements as shown equation (3), where I_a is the identifier of agent, T_a is the template of the agent class used for creating agent instances, $P_a = \{pa_1, pa_2 \dots pa_n\}$ is a finite set of all possible parameters known by an agent, S_a = {initiated, deleted, active, suspend, waiting} is a finite set of agent states supported by JADE, S_w = is the state of the environment, $L_b = \{\{L_{bint}\}, \{L_{bext}\}\}$ is the universal set of agent behaviors, including internal (default meta-behaviors of ADELE) and external behaviors (new injectable behaviors), $N = \{no_1, no_2 \dots no_n\}$ is a finite set with the norms which affect to the agent. A is the universal set of ADELE agents of the platform.

$$ADELE_{Agent} = \langle I_a, T_a, P_a, S_a, S_w, L_b, N \rangle \in A \tag{3}$$

An agent defines its own list of parameters when T_a is assigned the first time. If an agent requires the same T_a again, a subset of P_a is selected. L_{bint} = {metadata-agent-behavior, agent-injection-behavior, registration-of-executed-action-behavior} is a finite subset by default fixed behaviors and meta-behaviors that make possible the evolution of the agents, and $L_{bext} = \{B_{ext1}, B_{ext2} \ldots B_{extn}\}$ is a finite subset with the new external behaviors injected by the *Agent Injection Behavior* at runtime.

3.3 UML Model

Formal definitions previously described have been modeled based on the UML diagram of Fig. 2. The UML model describes the elements used by ADELE such as JADE platform and container to organize the habitat of dynamic agent instances created from agent templates, parameters for providing data to agents, and the normative model associated to the behavior model which allows controlling the evolution process.

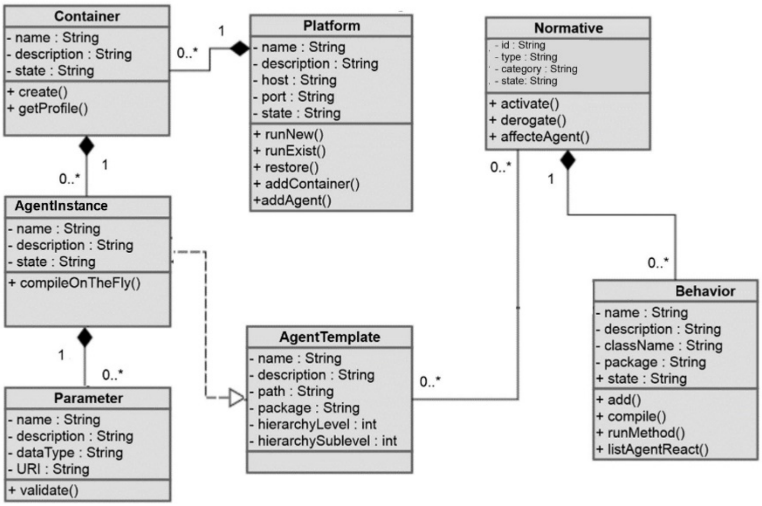

Fig. 2 UML diagram of ADELE middleware.

3.4 Evolution Process

It is important to differentiate the internal evolution process from the steps that the developers have to follow for updating the agent behaviors. Basically, the developers have to write declarations of metadata about norms, behaviors and associations between them, while the process performed by the middleware should compile the behavior classes, inspect these classes and create instances of these classes so that other objects can execute their methods.

Since MASs are addressed by a normative model, developers must implement the adequate elements and provide them to the ADELE middleware in a specific order for building and deploying of a MAS. The sequence of stages to follow are: a) creation of platforms, b) creation of containers, c) definition of agent parameters, d) instantiation of the agents, e) declaration of norms, f) programming the external behavior, and g) linking the behaviors to norms.

For creating platforms, container, agent parameters, agent instances and norms, only is required the definition of the metadata which describe these elements. However, the programmers play an important role because they have to write the code of the behavior templates and the agent templates that are stored later in the repository. Also, they have the responsibility of testing code before using it in an operative MAS.

On the other hand the evolution process is driven by ADELE middleware following two possible strategies. In the first one an agent injector uses a reflection process to inject new functionalities contained into a behavior class which is associated to an active norm, and can affect one or more agent instances. In contrast the second strategy used by ADELE, it also involves the addition of new agent templates which once compiled at run time, it allows the instantiation of new kind of agents that can incorporate a new behavior a posteriori using the first strategy. Next, we describe the main steps of each stage and the times required for performing each process.

Behavior Injection Process: The first strategy of the ADELE evolution is based on the behavior injection according with an active norm. It has two important steps (2 and 6) according to the sequence diagram shown in Fig. 3, and only if the execution of both steps is carried out in a successful way the changes affect the system.

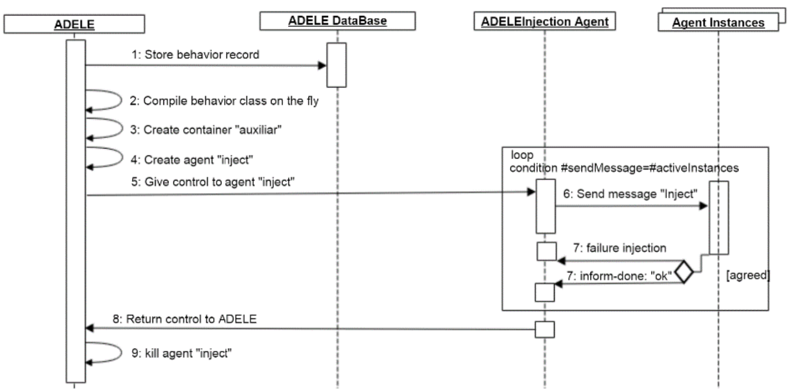

Fig. 3 Sequence diagram for injecting new external behavior.

Thereby, Time for Evolving by Behavior injection (TEB) corresponds to the sum of the Time for Compilation of Behavior class “on the fly” (TCB), plus the sum of the Time for Behavior Injecting (TBI) for each instance of any agent (n) created from the agent template involved by the norm associated with new external behavior, as is shown in (4). TCB is the time required by the system for compiling the new class with the encapsulation of behavior code while TBI corresponds to the required time for injecting the *action()* method for each active agent instance affected by the norm associated with that behavior.

$$\text{TEB} = \text{TCB} + \sum_{1}^{n} TBI;\ \text{n}>=0 \qquad (4)$$

Agent Template Adding: The second strategy used by ADELE for evolutionary process involves the addition of new agent templates and their “on the fly” compilation for creating new agent instances at runtime in order to change their initial behavior. According to the sequence diagram shown in Fig 4, the mechanism also has two steps (2 and 3), and both have to be executed to fully accomplish the evolution process. In this case, it is possible to update the hierarchy structure of MAS adding new agent types that can be assigned new responsibilities.

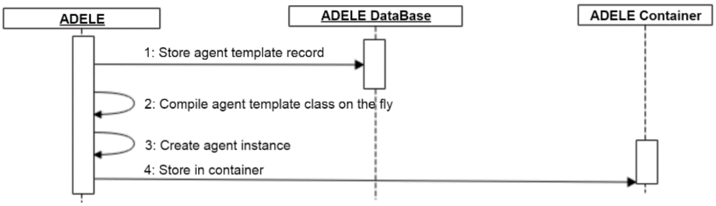

Fig. 4 Sequence diagram for adding new type of agent to the MAS hierarchy.

Regarding to the required time for the Hierarchical Evolution of ADELE (HEA). It corresponds to the sum of the Time for Agent Template Compilation “on the fly” (TATC), plus the Time of creating the Agent Instance (TAI), as is shown in (5), where TATC corresponds to the required time for compiling the class which encapsulates the new agent template code and TAI is the required time for creating the new instance using the template already compiled.

$$\text{HEA} = \text{TATC} + \text{TAI} \qquad (5)$$

The strategies commented previously described can be carried out in applications built with ADELE while they are executing without necessity to stop them. Nevertheless, the programmers should consider that normative changes are not retroactive, the norms cause effect only if it is linked to an externa behavior, and the behaviors are performed using a queue FIFO same to JADE.

4 ADELE Case Study

The ubiquitous scenario that we have selected is a smart home automation which we want to maintain the comfort to their inhabitants controlling the temperature and ambient light of a specific room of the house. To achieve that, the smart home has a set of sensors to monitor the temperature, outdoor and indoor ambient light, and a set of actuators to change ambient conditions such an air conditioning, a heating, and dimmers to change the light levels of the room.

4.1 Initial State Comfort System

The available *physical infrastructure* includes the room, temperature sensors, outdoor and indoor ambient light sensors, which allow measuring the following a*gent parameters:* temperature, and light levels inside and outside the room. Based on the definitions of section 3.2, in Table 1 we present the declaration of the main ADELE norms and their linked external behaviors (N_1-N_4), and the agent entities (A_1-A_3) to give basic comfort. For controlling the temperature we defined the norm N_1 with its corresponding external behavior, which is injected to the agent A_1 for measuring temperature on the smart home. Agent A_2 behaves in a similar way to A_1. But the agent A_3 performs actions for giving comfort using the N3 and N4 norm, and using data from agents A_1 and A_2.

Table 1 Norms-behaviors (N_i) and agents (A_j) tuples for basic comfort control.

Nº	ADELE components
N_1	Instantiated agents from TemperatureAgentTemplate have to control the temperature of the room. Norm<'NTemperatureControl', 'Norm', 'Function001', 'A'> Behavior<'TemperatureControl', 'TemperatureControl.class', 'myAgent', {AgentCTParameters}, {action, done}, 'NTemperatureControl', 'default'>
N_2	Agent's instantiated from LightingAgentTemplate have to control the light level inside the room. Norm<'NLightControl', 'Norm', 'Function002', 'A'> Behavior<'LightControl', 'LightControl.class', 'myAgent', {AgentCLParameters}, {action, done}, 'NLightControl', 'default'>
N_3	Agent's instantiated from MonitoringAgentTemplate have to assure the comfort of the room. Norm<'NComfortControl', 'Norm', 'Notify001', 'A'>: Behavior<'ComfortControl', 'ComfortControl.class', 'myAgent', {AgentMonitorParameters}, {action, done}, 'NComfortControl', 'default'>
N_4	The measurements obtained by the sensors have to be performed every fifteen minutes. Norm<'NTemporary', 'Norm', 'Config001', 'A'> Behavior<'ConfigureTemporary', 'ConfigureTemporary.class', 'myAgent', {'temporality'}, {action, done}, 'NTemporary', 'default'>
A_1	Agent for controlling temperature. Agent<'AgentCT', 'AgentCT.class', {'ListTemperatureSensors', 'latitud', 'longitud'}, {default}, 'homePlatform', {{default}, {'TemperatureControl', 'ConfigureTemporary'}}, {'NTemperatureControl', 'NTemporary'}>
A_2	Agent for controlling lighting. Agent<AgentCL, 'AgentCL.class', {'ListLightSensors', 'latitud', 'longitud'}, {default}, 'homePlatform', {{default}, {'LightControl', 'ConfigureTemporary'}}, {'NLightControl', 'NTemporary'}>
A_3	Agent for monitoring the comfort. Agent<AgentMonitor, 'AgentMonitor.class', {'AgentCTName', 'AgentCLName', 'TemperatureDesired', 'LightLevelDesired', 'Temporality'}, {default}, 'homePlatform', {{default}, {'ComfortControl', 'ConfigureTemporary'}}, {'NTemporary'}>

4.2 *Evolution Phase of Comfort System*

We started from the hypothesis that the previously described system must evolve to continue giving comfort, but now including energy saving policies. For achieving it, there were added shutter control actuators and a sensor for measuring the consumed energy. Table 2, shows the norms for system evolution (N'_1-N'_4). For controlling shutters we applied norm N'_1 and agent A'_1 in a similarly to the previous phase. We also have considered failures in temperature sensors, and the norm N'_2 add a new strategy that the agent A'_3 has to use when it happens. It is same to the light sensors but using another strategy. Finally, for the application of saving energy we have defined the norm N'_3 that reconfigure the system for sensors measures the comfort parameters every hour instead of a quarter. It was needed create a resolution that derogate the norm N_4 and active the norm N'_3, and also it was required create the agent A'_2 to monitor the energy efficiency based on N'_4.

Table 2 Norms-behaviors (N'_i) and agents (A'_j) tuples required for energy efficiency comfort.

Nº	ADELE components
N'_1	Agent's instantiated from ShutterAgentTemplate have to control the blinds of the room. Norm<'NShutterControl', 'Norm', 'Function003' , 'A'> Behavior<'ShutterControl', 'ShutterControl.class', 'myAgent', {AgentCSParameters}, {action, done}, 'NShutterControl', ''>
N'_2	Failures and removal of temperatures sensors will be replaced by weather meteorological data. Norm<'NTemperatureFailures', 'Norm', 'Function004', 'A'> Behavior<'TemperatureControlStrategy1', 'TemperatureControlStrategy1.class', 'myAgent', {null}, {action, done}, 'NTemperatureFailures', ''>
N'_3	The energy saving policies implies that measures will be gotten every hour. Norm<'NSaveEnergy', 'Norm', ' Config002', 'A'>, Norm<'Change001', 'Resolution', 'A'> (disable NTemporary') Behavior<'ModeEnergySave', 'EnergySave.class', 'myAgent', {null}, {action, done}, 'NSaveEnergy', ''>
N'_4	An agent instantiated from EnergyEfficiencyAgentTemplate, has to inform the saved energy. Norm<'NMonitorEnergyEfficiency', 'Norm', 'Notify002', 'A'> Behavior<'CalculateEnergySave', 'CalculateEnergySave.class', 'myAgent', {null}, {action, done}, ' NMonitorEnergyEfficiency', ''>
A'_1	Agent for controlling shutters. Agent<AgentCS, 'AgentCS.class', {'OutdoorLightLevel', 'IndoorLightLevel', 'latitud', 'longitud'}, { default waiting }, 'homePlatform', {{default }, {'ShutterControl', 'ConfigureTemporary'}}, {'NShutterControl', 'ModeEnergySave'}>
A'_2	Agent for monitoring energy efficiency. Agent<'AgentEnergyEfficiency', 'AgentEnergyEfficiency.class', {'Temporality'}, 'homePlatform', default}, {'CalculateEnergySave', 'ModeEnergySave'}}, {'NSaveEnergy'}>:
A'_3	Agent<AgentCT> ← Norm<' NTemperatureFailures', 'NSaveEnergy'>, Behavior<'TemperatureControlStrategy1', 'ModeEnergySave'>

5 ADELE Evaluation

The ADELE middleware was tested on a laptop with 2.3 GHz Intel Core i5 and 4 GB of RAM using two operating systems, Windows 8.1 64 bits, and Linux Ubuntu 14.04 32 bits. In both platforms we installed Java SE 1.8.0, JADE v4.3 and sqlite-jdbc-3.7.2.

5.1 *Evolution by Behavior Injection*

In order to test the evolutionary process of ADELE, we have defined a first scenario where exists a platform that includes a container with one agent instantiated from the agent template *genericAgent.class* with the capacity to show agent metadata. The required evolution process consisted on providing to the agent the functionality for showing its state and invoking a SOAP service. The results were obtained executing the evolution process 4 times, both on Windows and Linux, and with 1, 10, and 20 agents.

As shows Fig. 5, the evolution of one agent on Linux (729.75 ms) is slightly more efficient than the evolution of agents on Windows (947 ms). On the other hand, when a group of agents must evolve, it depends largely on the compilation process TCB because the time for injection TBI, is relatively short. Fig. 5 also illustrates that evolving time required by 10 and 20 ADELE agents does not grow enough compared with the evolution of only one agent instance. Therefore, ADELE can be a tool useful for developing evolutionary MASs because it allows the reconfiguration of agents at runtime without high computational cost neither long time for adapting to new user requirements, resources and smart devices.

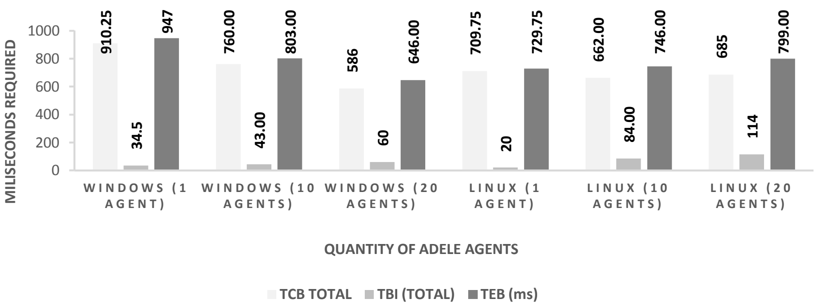

Fig. 5 Times for injecting external behaviors with 1, 10, and 20 agents.

5.2 Evolution by Agent Template Adding

The second scenario started with an agent instantiated from the agent template *GenericAgent.class.* In this case, a new kind of agent is instantiated rather than adding new behaviors to existing agent instances. The agent template has the ability to invoke the same SOAP service used in 5.1. The obtained results were similar to the previous experiment, and show that the required time for TATC compilation on Windows was 466 ms and 564 ms on Linux, while the time for instantiating TAI was 286.5 ms and 236 ms, respectively. Thus, the addition of new types of agent to the hierarchy of the MAS needed around 800 ms on Linux and 752.5 ms on Windows, but these times change because there is a direct dependency with the code encapsulated.

6 Conclusion and Future Works

A middleware for developing MAS, which evolves with time, based on the mechanisms of metaprogramming (Java reflection) have been presented in this work. Two alternative strategies are defined to achieve the system update in the base of the agent evolution addressed by a normative model. The obtained results evidence that agents can change their behavior relatively fast below a second when the system perceives a change in the active norms executed on the system. Thereby, both alternatives are quite good for the development of ubiquitous applications on highly dynamic systems where changes to the agent behaviors are a necessity. For future work, we are working for giving to ADELE the mechanisms to handle behaviors based on a priority level helpful in soft real time. Also, we are focusing efforts to include bylaws in the normative model for managing agent organizations. Finally, we want to extend the behaviors repository on a cloud giving the possibility to use agent behaviors as a service.

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Towards an Architecture for a Scalable and Collaborative AmI Environment

Cristina Roda, Arturo Rodríguez, Elena Navarro, Víctor López-Jaquero and Pascual González

Abstract In recent years, much research has focused its attention on *Ambient Intelligence* (AmI). Its potential applications to smart homes, hospitals, health monitoring or daily life assistance make this paradigm a very promising field of research that can have a great and positive impact in our lives. The combination of AmI environments and *Multi-Agent Systems* (MAS) has emerged as a perfect solution for the development of this kind of applications. However, there are many challenges to be addressed before such applications can be put into practice. In this paper, we propose an architecture based on MAS aimed to build rehabilitation systems for people with *Acquired Brain Injury* (ABI) and explain how this architecture has been applied for the development of Vi-SMARt: a system for defining and planning therapies for people with ABI, and to control and evaluate their rehabilitation process.

Keywords Acquired Brain Injury · Multi-Agent System · Ambient Intelligence · Event-Driven Architecture · SOA · Collaborative Rehabilitation Therapy

1 Introduction

For some time now, *Acquired Brain Injury* (ABI) has become an epidemic problem in our society with a growing impact every year. ABI has been even named as "the Silent Epidemic". Toronto ABI network [1] states that people with ABI have

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suffered "damage to the brain that occurs after birth and which is not related to congenital disorders, developmental disabilities, or processes that progressively damage the brain" but to different causes such as skull-brain trauma, degeneration of the blood vessels, meningitis, brain tumours, etc. People affected with ABI increasingly demand solutions that offer them with a relearning process in order to recover, not only their physical skills, but also their cognitive abilities. In this sense, the inherent characteristics of *Ambient Intelligence* (AmI), transparency and intelligence, have turned it into one of the best approaches to face up to the impairment derived from ABI.

AmI provides [2] digital environments that proactively, but sensibly, support people in their daily lives. In this context, as Ayala et al. state in [3], AmI systems offer *Ambient Assisted Living* (AAL) services in an imperceptible way, commonly embedded in daily devices, such as smartphones, or as sensor devices. As AmI focuses on the development of context-aware systems that integrate different devices to recognize the context and act accordingly, these systems can react rapidly and immediately to needs reflected by people with ABI, especially while they are performing their rehabilitation therapy.

For such people who have suffered a brain injury, *rehabilitation* is the process of regaining lost skills and abilities to respond to stimuli (visual, auditory and haptic), or developing coping mechanisms to replace those skills. In this context, we have developed a novel AmI system for the rehabilitation of persons with ABI, as part of the *Vi-SMARt* project (**Vi**rtual, **S**ocial, **M**ulti-sensorial and **A**daptive systems for the **R**ehabili**t**ation of people with ABI). This system allows therapists to design therapies that can be adapted to each specific patient and his/her abilities. In particular, these therapies not only stimulate the visual sense, but also include other sensory stimuli, mainly auditory and haptic ones. Thus, people with ABI can perform bespoke rehabilitation therapies and follow a suitable schedule according to their diagnostic. Furthermore, these therapies can be performed in different physical places since Vi-SMARt is composed of modules aimed to perform each type of rehabilitation therapy. Vi-SMARt is also intended to make possible a *collaborative rehabilitation therapy* because, as stated in [4], it facilitates the rehabilitation process. This feature implies an important challenge since the design of different interrelated rehabilitation modules must be addressed.

The usage of *Multi-Agent Systems* (MAS) in an AmI environment emerges as a natural and perfect combination because agents are reactive, proactive and exhibit an intelligent and autonomous behavior. For this reason, Vi-SMARt is intended to follow a Multi-Agent architecture, whose general overview was previously presented in [5]. Notice that the design of our MAS was initially planned for controlling and managing rehabilitation therapies carried out by older adults, but it has been modified to be used by people with ABI. This architecture makes Vi-SMARt *extensible*, since new types of ambient variables, devices and functionality can be added to the existing system; *adaptable* to consider the inter-personal and intra-personal variances of people with ABI; and *scalable*, so that the performance of the rehabilitation processes is not affected by the number of connected users.

In this paper, we present the different challenges that have emerged during the Vi-SMARt design and how its architecture has been designed to address them. This paper is structured as follows. First, in the next section, we give an overview of some systems that follow different architectural styles used in combination with MAS to support all features demanded by an AmI environment. Section 3 states several challenges that must be solved by Vi-SMARt and its architecture. Section 4 presents the software architecture of Vi-SMARt, describing the architectural styles it includes. Finally, in Section 5, some conclusions and future lines derived from this work are shown.

2 Related Work

If we take a glance at the literature, we can find many works, such as [6][7][8], that have proposed or studied different *rehabilitation* systems or approaches with the aim of treating people affected with ABI. The current trend regarding this kind of systems focuses on the use of AmI to support the rehabilitation process, taking into account different variables that can affect both the patient and the environment. In this sense, several studies have been published, such as the one presented in [9]. AmI approach turns rehabilitation systems into context-aware systems thanks to the integration of different devices to recognize the context and act accordingly. By doing so, they are able to rapidly react to the needs shown by people with ABI while they are carrying out their rehabilitation activities.

Furthermore, it has been reported that MAS are particularly good at modeling real-world and social systems, where problems are solved in a concurrent and cooperative way without the need of reaching optimal solutions. This is why the natural relationship between AmI and MAS is being widely exploited. For example, the work done by Gascueña et al. [10] shows how to implement AmI applications using the INGENIAS Development Kit (IDK) to develop them following the MAS approach. IDK supports both the specification of MAS models and a set of facilities for code generation. Another proposal that combines AmI and MAS is the one proposed by Corchado et al. [11]. They have developed an intelligent environment, called GerAmi that integrates MAS and other technologies, such as mobile devices, to facilitate the management of geriatric residences.

Other approaches, in addition to that of MAS, have been used in the development of AAL systems. Becker [12] identifies several ones, such as:

- Service-*Oriented Architecture* (SOA), whose main benefit is to support the separation between the contract and its implementation. In this context, applications in SOA are built on services, where a *service* is [13] an implementation of a well-defined functionality. Such services can then be consumed by clients in different applications or processes, facilitating the *reuse* of such services.

- *Peer-To-Peer* (P2P) [14] is a networking technology that has a serverless operation, enabling several systems to share resources and communicate directly with each other. This approach moves away from the conventional centralized server approaches, avoiding bottle necks and single points of failure. In this sense, a pure P2P system consists of equal peer nodes that lend the same functionality, acting as both clients and servers. Notice that, in heterogeneous systems made up of small sensor nodes up to powerful servers, this architectural style will not be applicable for the whole system but rather for groups of devices of the same type. Moreover, this approach solves a usual shortcoming of centralized approaches: *scalability*, as this is not limited by the features of the server.
- *Event-Driven Architecture* (EDA) follows the publish-subscribe pattern, so that some elements can promptly react to the notifications of events produced by other elements, being an *event* a significant change within our system. Note that, in EDA, the event producers are not aware of either the type or the number of event consumers, that is, a low coupling between them. This considerably contributes to both the *extensibility,* as new consumers can be easily developed, and *scalability* of the systems.

In this sense, there are some related works that follow some of these architectural trends, combined with Multi-Agent. The architectural style most frequently used together with the MAS approach is SOA. For example, in [15] it is presented FUSION@ with the aim of facilitating the development of AmI systems, exploiting the use of intelligent agents integrated into SOA platform, so that, most of the characteristics of the system are distributed into remote and local services. Similarly, another work presented in [16] proposes a methodology for integrating a FIPA[1]-compliant agent platform with the Open Services Gateway initiative (OSGi) service oriented framework. In [3], an Agent Platform (AP) called SolAgentPlatform is described, that enables the communication between agents running in Android-based devices and agents running in SunSPOT sensors. This architecture is extensible and partially supports the FIPA approach, making possible the integration of new types of sensors and other kinds of AAL devices in an easy way. Besides, this AP acts as a middleware that provides a set of services to the agents running on it. In [13], a MAS is presented aimed at improving healthcare and assistance to older or dependent people at their homes. A service-oriented platform, called PANGEA, has been created, where all services are implemented as Web services emulating a client-server architecture since this platform includes both a service provider agent and a service consumer one. In [17], Jade is presented, which is a FIPA-compliant implementation of a mobile agent platform able to dynamically add and configure services, implemented as Web services, as in the previous case. It supports the communication between Web services and agents thanks to WSAI (Web Services Agent Integration).

[1] Foundation for Intelligent Physical Agents.

Another work [18] presents a Model-Driven Development approach oriented to develop pervasive systems based on agents that follow a Service-Oriented architecture.

Additionally, EDA is also considered a good option when developing MAS. For instance, in [19], it is presented an agent framework that offers policy control for the insertion of plug-ins on-the-fly in a coordinated and proper way. Namely, the components of an agent communicate through an asynchronous event bus with traditional publish/subscribe semantics. Another example is the work presented in [20], a proposal for processing information to detect Activities of Daily Living (ADLs). This proposal is based on EARS (Event-driven Activity Recognition System), a multi-agent activity recognition framework which is in charge of detecting ADLs, following an event-triggered process.

Finally, as Becker states in [12], EDA is considered one of the best approaches to be applied in the development of AAL systems. However, he claims that SOA along with EDA will converge to develop an optimal solution in order to meet the different quality demands derived from AAL systems, i.e. an *Event-Driven Service-Oriented Architecture* (ED-SOA). Some works that follow an ED-SOA architecture for developing AAL environments can be found in the literature, such as [21][22][23].

Consequently, after analyzing the different approaches and proposals, we have detected that most of them focus on the ADL recognition and support, without considering the special needs of people with ABI. Although these proposals exhibit important benefits, they also present lacks when they are used in isolation. In the following section, we describe clearly the main challenges that an architecture must support for the development of Vi-SMARt: a rehabilitation AmI system for people with Acquired Brain Injury. Then, in Section 4, it is described how we have faced such challenges considering the current advances in the area.

3 Challenges to Be Solved by Vi-SMARt

The development of Vi-SMARt has posed important questions that have to be properly addressed to provide people with ABI with a proper solution. Before describing the architecture of Vi-SMARt, we are introducing in the following such challenges in order to understand the rationale underpinning such specification:

- *Collaboration*. The Vi-SMARt project is being developed in cooperation with several associations and hospitals that have a long experience in the rehabilitation of people with ABI. They have highlighted that one of the main problems these people have is isolation as they find difficult to engage their friends and family in their new life. For this reason, therapists working with ABI claim they need new solutions that turn the rehabilitation therapies into a social activity that enables people with ABI to communicate, collaborate and cooperate with their peers. This demand is also justified by different studies, such as [4], that show how other therapists have also highlighted the importance of collaboration with others as a facilitator of the rehabilitation.

For this aim, one of the main challenges to be faced is the definition of a solution that enables people with ABI to carry out their rehabilitation by means of virtual rooms where they can collaborate, cooperate and communicate for the achievement of both personal goals and group goals.

- *Adaptability*. One important issue that hampers the definition of a proper specification of the architecture of Vi-SMARt is the fact that the sensor configuration is specific for every deployment on the patients' side, depending on the sensors and communication devices deployed, the type of sensor data provided to monitor the therapy being carried out such as raw, fused, or already aggregated data. In addition, the evaluation of the therapy at hand is complicated by *inter-personal* variances so frequent among people with ABI, but also *intra-personal* along its treatment process, resulting in a diversity of needs and demands. Consequently, the proposed architecture has to ensure a high level of *adaptability* towards the patients' surrounding environment and the patients' needs and constraints.
- *Extensibility*. We just need to have a look at the market to see more and more devices that offer new monitoring facilities, the trendy *wearables*. These devices can be used by therapists to monitor users' heart rate, stress, etc., while people with ABI are performing their therapies in order to adapt them to people's capabilities and status. Moreover, it must be highlighted that, as the brain is the damaged area, people with ABI can suffer different long-term deficits that directly affect their daily lives. These deficits can be classified into four categories: (1) physical impairments related to inability to control part of the body, such as paralysis of one side of the body, motor in coordination, or balance problems; (2) cognitive impairments that directly affect intellectual performance, including attention or memory problems; (3) emotional impairments such as depression or adjustment problems; and (4) behavioral impairments related to interaction with their environment, such as irritability and restlessness. Due to both this variability and the new advances in technology, the architecture to be developed must facilitate its extension by adding new devices and therapies at runtime, in order to offer its evolution to changing demands over time.
- *Scalability*. As aforementioned, ABI is known as "the Silent Epidemic" because the number of people with ABI is growing every year, being one of the most extended problems nowadays. Just for instance, according to the Brain Injury Centre [24] Traumatic Brain Injury, one of the causes of ABI, is more common than breast cancer, spinal cord injury, HIV/AIDS, and multiple sclerosis (MS) combined. Just in the United Kingdom it is estimated that at least 1 million people live with long-term effects of brain injury [25]. According to such figures, the number of potential users can become extraordinarily high. Therefore, the architecture must be designed to scale as the number of users requests, so that the rehabilitation process is not affected by the number of users connected or any shortage of resources. Additionally, it must be also considered that not only individual therapies must be offered but also collaborative ones.

That is, different *virtual rehabilitation rooms* can run simultaneously where between two and four people with ABI can collaborate, cooperate or compete to carry out specific tasks of their treatment. Thus, the architecture must be designed to facilitate that connection problems with the server do not affect all this rehabilitation process.

As can be observed, the architecture of Vi-SMARt must be designed to address serious challenges that a traditional client/server approach cannot face. In the following section, a description of such design is presented justifying how it can help to face each one of the described dares.

4 Architectural Styles in Vi-SMARt

As aforementioned, important challenges had to be addressed in the development of Vi-SMARt. One of the first steps we have carried out has been the development of an architecture able to address them. As shown in Fig. 1, Vi-SMARt has been structured into three different systems:

- *Therapy Service*. This system has been defined as a data service where patients' data, preferences and results of their treatment are managed. Moreover, all the therapies designed by therapists, schedule, etc., are also managed by this service.
- *Therapy Design Environment*. This system has been identified to provide therapists with facilities to design new therapies, schedule the treatment of patients, monitor their evolution, etc.
- *Therapy Execution Environment*. This system has been defined to provide people with access to their treatment. It integrates different devices, such as, Kinect, Leap Motion, heart-rate sensors, etc., to facilitate the interaction and the monitoring during their treatment.

As can be observed in Fig. 1, the deployment of these systems is carried out by exploiting the following three approaches: *MAS*, *SOA* and *P2P*. In the following section, how the MAS approach has been used in the context of Vi-SMARt is presented.

The Therapy Service has been developed as a SOA service so that Therapy Execution Environments can use it to obtain the therapy to be done by the patient and then work in a disconnected way until he finishes his therapy. Then, the Therapy Execution Environment forwards the results of the execution for its analysis by the therapists. In this way, the *scalability* of the proposal improves as the connections are reduced.

Another important decision is related to the virtual rehabilitation rooms. As we have described in the previous section, one of the challenges to be addressed is to provide people with ABI with facilities for *collaboration* while they perform their treatment in order to improve, not only their cognitive and physical impairments, but also their behavioral ones. For this aim, we have used a P2P approach to provide Therapy Execution Environments with a serverless operation that enables people with ABI to communicate, collaborate and cooperate with their peers in order to achieve certain predefined goals while they can be supervised by a therapist. This alternative also improves the *scalability* of the architecture as the virtual rehabilitation rooms work in an isolated way one of each other, and only need to connect to the server just to download the therapy to be executed and the store the results of the execution.

Finally, the design of the Therapy Execution Environment follows an Event-Driven approach in order to address the expected *extensibility*. This architectural pattern has been selected in order to facilitate that not only new types of therapies can be easily integrated in Vi-SMARt, but also new devices or sensors.

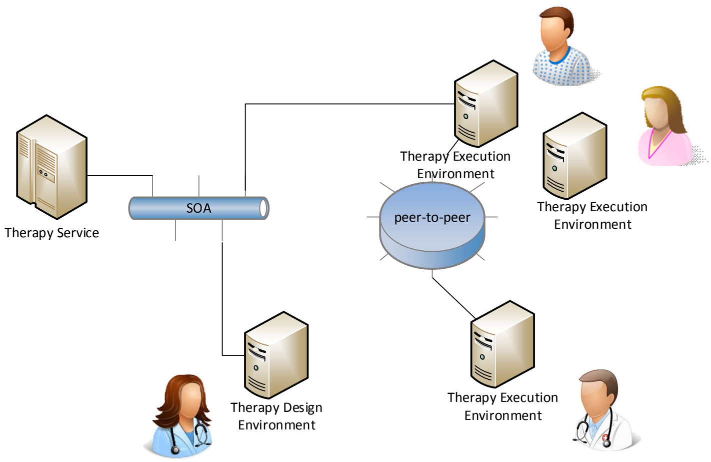

Fig. 1 Deployment of Vi-SMARt.

In the following section, the different MAS that made up Vi-SMARt and how they have been deployed following the previous infrastructure are described.

4.1 A MAS-Based Architecture for Vi-SMARt

The three systems that comprise Vi-SMARt architecture have been designed as MAS. To illustrate these MAS a general overview created with Prometheus Tool is used. This graphical notation includes the agents involved (in light brown color), the protocols including the messages they exchange (in magenta color), the actions each agent is responsible for (in light green color) and lastly, the percepts that represent the external information arriving to the MAS (in light red color) from the ambient.

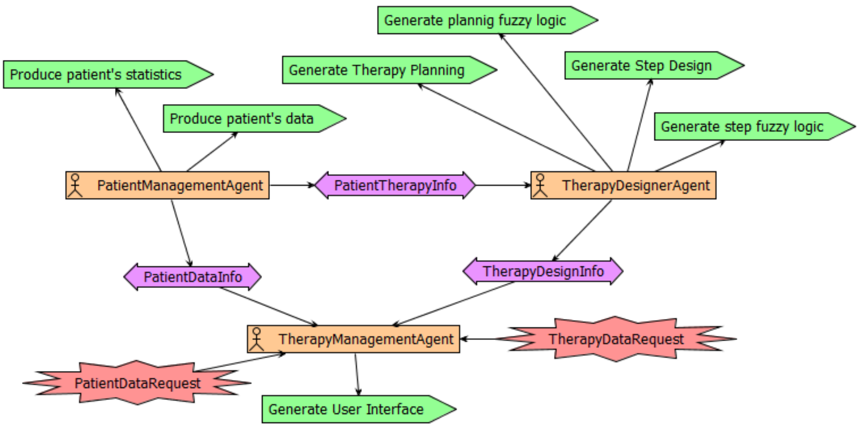

Fig. 2 Vi-SMARt: Therapy Design Environment MAS.

In Fig. 2, the multi-agent system architecture created for the Therapy Design Environment is depicted. The aim of this MAS is two folded. On the one hand, it supports the specialist in creating the therapies, and on the other hand it supports the therapist in managing the patient's information gathered during the execution of therapies. This MAS includes three agents. *PatientManagementAgent* is responsible for all the goals related to patient's data. It is in charge of producing statistics and drawing conclusions to help the specialist in understanding how the patient is evolving. This is very valuable information when it comes to design new therapies or when testing the effectiveness of the therapies designed. This agent also provides relevant data for therapy design to *TherapyDesignerAgent*.

TherapyDesignerAgent is responsible for supporting the specialist in the creation of therapies. This agent provides help to the specialist in designing the planning of the therapy, that is, in describing what activities should be made, the workflow of these activities and how this planning adapts to the patient's evolution [26]. This adaptation is specified in terms of a Fuzzy Inference System (FIS). The patient's information provided by *PatientManagementAgent* is also used to suggest potential features that can be used in the FIS to customize for the patient the therapies designed.

Lastly, *TherapyManagementAgent* serves as the interface of the MAS with other systems and with the user. This agent receives the requests from the user and returns a user interface for a therapy based on the patient's data, according to the data produced by both the *TherapyDesignerAgent* and the *PatientManagementAgent*. The user interface is generated in a similar way as in AB-HCI [27].

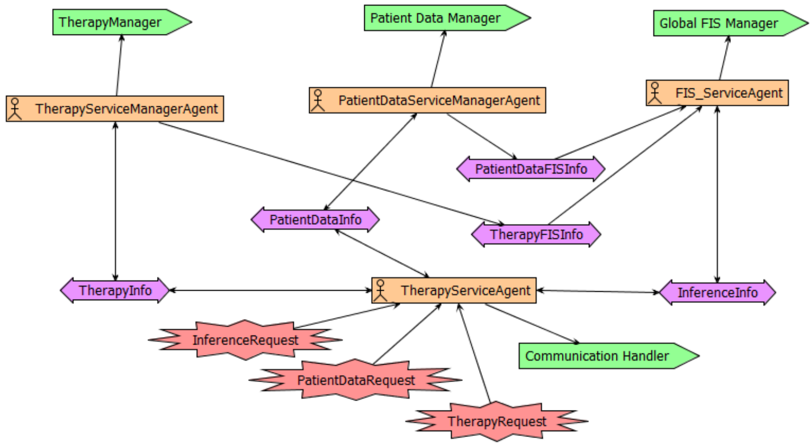

Fig. 3 Vi-SMARt: Therapy Service MAS.

The Therapy Service MAS (Fig. 3) provides the services required by both the Therapy Design Environment and the Therapy Execution Environment. This design allows for a centralized repository of those services required to design or start a therapy. All the services are made available through *TherapyServiceAgent*. This agent handles all the requests and communications, and offers a secured interface for the services. A secure interface is required in this case, since there is sensitive information about the patients stored.

Three agents are available to manage the three services provided. *TherapyServiceManagerAgent* is responsible for storing, organizing and providing the therapies and the steps these therapies require to be performed. *PatientDataServiceManagerAgent* stores, organizes and provides the patient's data required to perform a therapy or to design it. Some patient's data are needed to adapt the therapy to each patient, that is, to address the *adaptability* claimed in the previous section. This adaptation is achieved by means of the FIS. All the FISs designed for each therapy and step are managed by *FIS_ServiceAgent*. This agent has two main goals. On the one hand, it stores, organizes and provides the fuzzy sets designed for each therapy or step. On the other hand, it also makes those fuzzy inferences which are global.

Finally, the *Therapy Execution Environment* (Fig. 4) system provides the infrastructure for a therapy to be executed either individually or in the virtual rehabilitation room as a collaborative therapy. When a patient starts a therapy in the virtual rehabilitation room, this system will be instantiated. The instance will retrieve the therapy to be executed from the *Therapy Service*. To execute the therapy retrieved, the system will also retrieve the patient's data required together with the fuzzy sets defined for this therapy and its steps. All these communications are handled by the *CommunicationManagerAgent*. All the persons executing the collaborative therapy enter the P2P network for the therapy. The first client to enter the P2P network becomes the host for the P2P. All the others will be regular peers.

A host is required because some collaborative therapies include adaptation relying on information provided by all the peers, the so called collaborative adaptations. All the communication between the peers is made on the basis of an Event Driven approach. When the therapy arrives to *CommunicationManagerAgent*, it will forward this information to *TherapyControllerAgent* so the therapy can start. *CommunicationManagerAgent* sends also the Patient's data required for the therapy to *TherapyMonitoringAgent*. This information is enriched with the incoming information from the sensors that report about the ambient. One agent is devoted to each sensor to make the sensor network easily extensible. Before starting a therapy, it has to be adapted to the patients' characteristics. Therefore, the therapy is sent to *AdaptationManagerAgent* so it is adapted. This agent will produce an adapted therapy that will be started by *TherapyControllerAgent.* Whenever an adaptation is required, *AdaptationManagerAgent* will ask *SMARTManagerAgent* to infer what decisions to take.

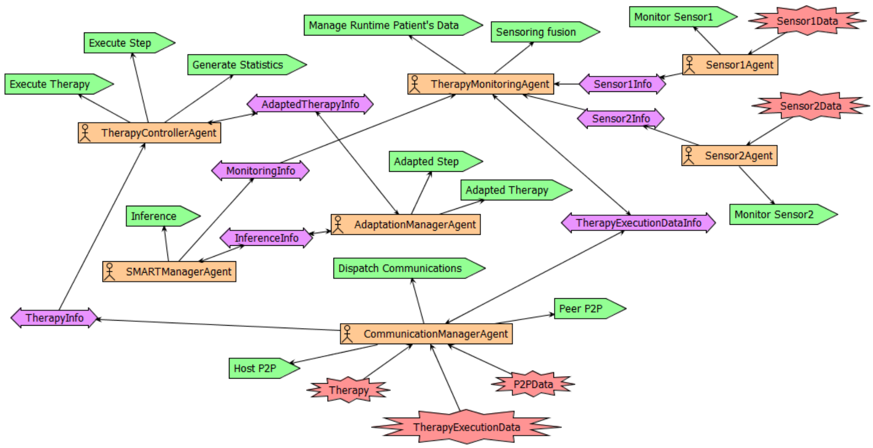

Fig. 4 Vi-SMARt: Therapy Execution Environment MAS.

5 Conclusions and Future Work

In this paper, we have presented a novel AmI system for the rehabilitation of people with ABI, as part of the Vi-SMARt project (**Vi**rtual, **S**ocial, **M**ulti-sensorial and **A**daptive systems for the **R**ehabili**t**ation of people with ABI). This system enables therapists to design therapies adapted to abilities and disabilities of each patient. These therapies can use different senses, such as visual, auditory or haptic ones, to rehabilitate some physical and/or cognitive capabilities of the patient. In addition, to manage the therapy execution process, the therapist can use different types of information. In particular, Vi-SMARt can control environmental information, physiological data of each patient, and other information gathered from the therapy execution. To manage all these features in our AmI system, the use of

Multi-Agent Systems has emerged as an adequate solution. However, as we have described in section 3, there are many challenges still to be solved before its application in a final and real system. Therefore, our proposal tries to address all these challenges offering an appropriate architecture that makes Vi-SMARt *extensible*, *adaptable*, *scalable* and *collaborative*. To achieve these goals, we include in our solution the MAS, SOA and P2P approaches to manage and establish the interrelationships between our three systems: *Therapy Service*, *Therapy Design Environment* and *Therapy Execution Environment*. The inclusion of SOA allows for working in a disconnected way during the therapy execution. In addition, P2P allows providing the communication between several patients that collaborate in the execution of a specific therapy. Finally, MAS supports the specialist in creating the therapies and in managing the patient's therapy execution and the information gathered during this process. Our next step is the evaluation of Vi-SMARt in a real environment. To do so, we count on the support of an association that assists people affected by Acquired Brain Injury.

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Part VII
Special Session on Web Mining and Recommender Systems (WebMiRes)

SemPMF: Semantic Inclusion by Probabilistic Matrix Factorization for Recommender System

Nidhi Kushwaha, Xudong Sun, O.P. Vyas and Artus Krohn-Grimberghe

Abstract We developed a novel approach for including metadata generated from Linked Open Data into Recommendation Systems by proposing a probabilistic view of Collective Matrix Factorization. The Linked Open Data cloud is being conceived and published to improve the usability and performance of various applications including Recommender Systems. While most previous works focus on exploiting Linked Open Data on content based Recommendation System, we include the semantic information into the collaborative filtering recommendation approach. With an unsupervised method, we generated different metadata representations for items from Linked Open Data and incorporated them into Probabilistic Matrix Factorization to get a double matrix factorization to boost the performance. Experiments showed that our proposed approach performs comparably well and in some scenarios generate significantly better results than Probabilistic Matrix Factorization methods when there is no semantic data inclusion.

Keywords Linked Open Data · DBpedia · Unsupervised feature generation · RDF · Recommender System · Matrix Factorization · Gradient descent method

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1 Introduction

In 2006, Tim Berners-Lee et al. [2] introduces Linked Open Data cloud (LOD), that utilizes various Semantic Web (SW) technologies for providing structured data instead of unstructured web pages. Moreover, the joint efforts of the project team of LOD crafted a big picture of leveraging the SW technology (Lorna 2010, Heiner et al. 2012) [3]. LOD has received great attention from the Recommender System (RS) community, to incorporate this semantic data as a side information for getting more accurate results. Traditional Recommender Systems utilized heuristic and model-based approaches, to predict the ratings for a user. Unfortunately, through literature survey, it is not clear that which approach is superior among them, in terms of prediction accuracy. Moreover, existing systems encountered the problems of cold start user, over-generalization, data sparsity and curse of high dimensionality. To improve the accuracy of the system in the above situations, a comprehensive framework is required to leverage the additional source of information related to the items. In our work, this additional source of information is fetched from metadata in an unsupervised feature generation manner. Here, unsupervised feature generation means, the same SPARQL query composition can work for movie, music, bibliographic and in other independent domains also. Furthermore, the main aim of the proposed algorithim is to, introduces a novel collaborative filtering recommendation approach for LOD based RS.

In the remainder of this paper, Section 2 formalizes recent works in the LOD enhanced recommendation systems and their shortcomings. Section 3 explains data acquisition and its processing with a brief discussion on our proposed methodology. Section 4 presents the performance of our algorithm and its comparison with non-semantic Probabilistic Matrix Factorization (PMF) approach. Section 5 concludes and proposes future directions of the proposed work.

2 Related Work

LOD based Recommender Systems generally utilize the information residing in it to generate the item-property matrix, having “1” for the presence and “0” for the absence of a particular property feature. Through rigorous study of the literature survey, it is clear that the first attempt to utilize LOD for recommendation had been made by passant et al. [10] in 2010 for music recommendation by exploiting DBpedia Resource Description Framework (RDF) database. It employs only binary item (artist) property matrix for distance measure among the artists and conveyed an idea to utilize a weighted item-property matrix, in the future. Later on, weighted item-property matrix has been exploited by Noia et al. [5] in 2012 for the movie recommendation through assigning weights for each feature. Furthermore, [5] used heuristic correlation method for predicting the ratings for target user while exploiting both item- property and user-item rating matrices. In continuation of [5], Noia et al. introduced model based approach [4] about MovieLens & DBpedia data, where items, its associated properties (semantic) and assigned rates by individual users are the input of the Support Vector Machine (SVM) algorithm and which yields a model for rate prediction. Recently, Noia et al. launched a workshop challenge on LOD based RS in 2014[1], for that he provided ratings & DBpedia mapping for each book. Authors in this paper briefly explain few important papers presented in that challenge. Maccatrozzo et al. [7] influenced by Passant [10] and proposed semantic pattern based approach. However, the approach is very simple and lightweight, it does not consider any information corresponding to user neighborhood and thus, suffers from the problem of overgeneralization. Another work was proposed by Ladislav et al. [12], which exploited Content Boosted Matrix factorization (CBMF) with both direct and derived features extracted from the DBpedia RDF database, in the book domain. They concluded to exploit, feature selection and reduction method in the future, to overcome from the problem of high dimensional and noisy data. Till now the discussed approaches are purely Content based (CB), as they utilized the contextual information of DBpedia for the recommendation. Next, the authors explore hybrid systems proposed specifically for the LOD based recommendation, in which the authors used both CB and Collaborative Filtering (CF) approaches. Meymandpour et al. [8] proposed LODifiy as a hybrid recommendation (HBR) method based on semantic similarity between concepts of two different encyclopedic datasets. Although, the authors considered many datasets, but they have concluded, that it didn't make any improvement in the results due to the problem of high dimensionality and sparsity. Another work in this direction was proposed by Moreno et. al. [9], for generating ratings in the cold-start situations. The authors have applied min-count sketches for CB and SVD++ for CF. The authors concluded that the approach mitigates the cold-start problem of new item by combination of content and collaborative methods. Basile et al. [1] proposed an ensemble approach by combining the results of different algorithms and exploited borda count method for it. The authors used more than two hundred thousand properties with normalized feature and concluded feature selection as their future work.

Most of the existing LOD based RS used supervised (manual) approach for feature generation for retrieving the information from LOD. Our work simply departs this, by efficiently incorporating semantic knowledge retrieved from LOD to user-item preference matrix by PMF approach. The proposed methodology is explained in the next section.

3 Proposed Methodology

3.1 Semantic Feature Extraction Methodology

As aforementioned, the proposed approach utilizes the semantic item-property matrix for the recommendation purpose. This section briefly explains the generation of

[1] http://2014.eswc-conferences.org/important-dates/call-RecSys.html

semantic features related to each item. In [11] Heiko et al. directed that only an URI can be expanded by feature generation of RDF datasets and for this, we need a mapping of semantic and non-semantic databases. This mapping provides an URI representation of the non-semantic concepts and thus, make them expandable. In our analysis, the authors have generated a mapping of DBpedia as a semantic and MovieLens 1M as a non-semantic datasets. DBpedia, of size 3.7 GB is an LOD dataset which has been utilized for unsupervised feature generation in this paper. A Java code[2] has been developed to interact with virtuoso local server and for generating semantic features using SPARQL 1.1 query language. Before SPARQL querying, this RDF database was stored in the Virtuoso RDF storage that provides efficient querying for RDF datasets. The SPARQL queries are utilized for unsupervised feature generation from DBpedia. Note that, unsupervised feature generation was initially proposed by Heiko et al. in [11] in 2011. The generated features are then converted into a weighted (TF-IDF) item-property matrix, for incorporation with user-item rating matrix. The method for conversion of RDF data into weighted item-property matrix instead of the simple binary matrix was proposed by Petar et al. [13] in 2014. Four different item-property files have been generated and analyzed to prove the worthiness of SemPMF approach. Table. 1 shows the statistics of this item-property files generated for MovieLens 1M dataset. It shows that all the files have different values of size, sparsity and dimensionality values.

Table 1 Statistics of item-property files we generated

Different Properties	# of Dimensions	Sparsity	Size (MB)
Direct (types)	10	0.992%	0.35
RelationIN&OUT	471	0.948%	7.97
Specefic1Hop	5006	0.998%	62.99
Specefic2Hop	10940	0.990%	141.51

3.2 Probabilistic Matrix Factorization with Semantic Item Features

This section explains a novel method (SemPMF) proposed by us for inclusion of semantic data by modifying the Probabilistic Matrix Factorization (PMF) approach [14]. In Fig. 1, we assume that the prior distribution of the latent variables are Gaussian with zero mean and variance σ_U^2, σ_V^2, σ_Z^2 and the likelihood of observing conditions on the latent variables also obey the Gaussian distribution with variance σ_Z^2, σ_{Im}^2. Thus the posterior distribution of all the rating and item-property is proportional to the joint distribution of

$$prob = P(U|\sigma_U)P(V|\sigma_V)P(R|U, V, \sigma_R)P(Z|\sigma_Z)P(Im|V, Z, \sigma_{Im}) \quad (1)$$

[2] https://github.com/nidhikush/SemPMF.

Taking the negative log likelihood of this, we get the objective function, shown below:

$$
\begin{aligned}
E =& \frac{1}{2\sigma_R^2} \sum\sum I_{i,j}^R (r_{i,j} - g(U_i V_j))^2 + \frac{1}{2\sigma_{Im}^2} \sum\sum I_{j,k}^{Im} (Im_{j,k} - g(V_j Z_k))^2 \\
&+ \frac{1}{2\sigma_U^2} \sum < U_i, U_i > + \frac{1}{2\sigma_V^2} \sum < V_j, V_j > + \frac{1}{2\sigma_Z^2} \sum < Z_k, Z_k > \quad (2)
\end{aligned}
$$

The regularized form of equation 2 is

$$
\begin{aligned}
E =& \frac{1}{2} \sum_i \sum_j I_{i,j}^R (r_{i,j} - g(U_i V_j))^2 + \frac{\lambda_{Im}}{2} \sum_i \sum_j I_{j,k}^{Im} (Im_{j,k} - g(V_j Z_k))^2 \\
&+ \frac{\lambda_u}{2} \sum_i < U_i, U_i > + \frac{\lambda_V}{2} \sum_j < V_j, V_j > + \frac{\lambda_Z}{2} \sum_k < Z_k, Z_k > \quad (3)
\end{aligned}
$$

Here, we have $\lambda_U = \frac{\sigma_R^2}{\sigma_U^2}$, the same for V and Z. $\lambda_Z = \frac{\sigma_R^2}{\sigma_Z^2}$,$\lambda_{Im} = \frac{\sigma_R^2}{\sigma_{Im}^2}$.

Note that in [17], the author proposed the Collective Matrix Factorization (CMF) technique with a Bregman divergence approach as a general loss function for recovering the user-item rating matrix, but in their case, they only considered binary relation between item and properties. However, in our contribution the property vector for each item is continuous, which allows more advanced feature engineering method for the item. For it, we endow a probabilistic view for CMF which could help us to extend our optimization approach in a Bayesian way. Compared to the Local Collective Embedding approach in [15], we used a modified Gradient Descent algorithm which is easier for implementation to conduct item cold start recommendation. Moreover, in comparison to the Joint Matrix Factorization approach in [16], our method naturally encodes the similarity matrix for items. In order to use Gradient Descent algorithm, we take the derivative of each component in equation 4 and get:

$$
\begin{aligned}
\frac{\partial E}{\partial U_i} =& \sum_{item:j} I_{i,j}^R (g(U_i V_j) - r_{i,j}) \frac{\partial g(U_i V_j)}{\partial U_i} + \lambda_u U_i \\
\frac{\partial E}{\partial V_j} =& \sum_{user:i} I_{i,j}^R (g(U_i V_j) - r_{i,j}) \frac{\partial g(U_i V_j)}{\partial V_j} + \\
& \lambda_{Im} \sum_{property:k} I_{j,k}^{Im} (g(V_j Z_k) - Im_{j,k}) \frac{\partial g(V_j Z_k)}{\partial V_j} + \lambda_V V_j \\
\frac{\partial E}{\partial Z_k} =& \lambda_{Im} \sum_{item:j} I_{j,k}^{Im} (g(V_j Z_k) - Im_{j,k}) \frac{\partial g(V_j Z_k)}{\partial Z_k} + \lambda_Z Z_k \quad (4)
\end{aligned}
$$

In order to reconstruct the user-item rating matrix, we only use U and V explicitly to compute the inner product, the latent factor Z act as a modifier to alternate the optimal position of U and V to satisfy the observation of Im.

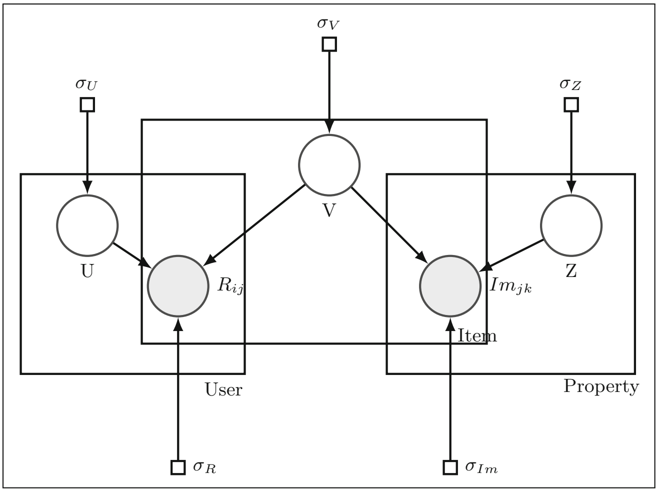
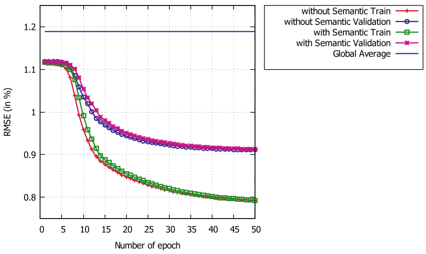
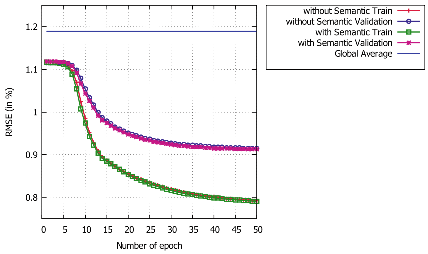


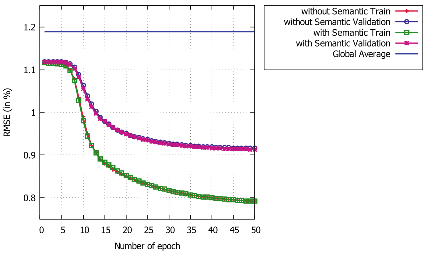
Fig. 1 Graphical model for SemPMF



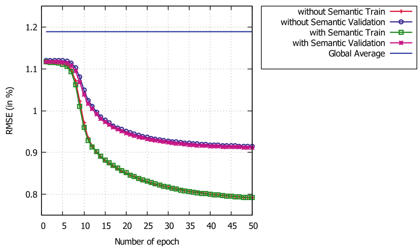
(a) Direct



(b) RelationIN&OUT



(c) Specefic1Hop



(d) Specefic2Hop

Fig. 2 Analysis of RMSE for different item-property files

4 Experimental Analysis

We have used Movielens 1M dataset(totally 6,040 users, providing 1M ratings to 3,952 movies) as user-item rating matrix. For item-feature matrix we have used an ontological information from the DBpedia dataset (version 3.9). For mapping from movie names to DBpedia URIs, we have written our own code and mitigate 175 flaws out of 3,277 mappings found in the mapping provided by Vito et al.[3] Thus, we obtained 3,274 corrected mappings[4]. These flaws are occurring mainly due to URI updates. The statistics of the semantic features used in the analysis have been explained with the Table 1. All the four item-property files have different sparsity and dimensionality values.

With Gradient Descent optimization, we compare the Root Mean Square Error (RMSE) of our algorithm against PMF and global average method for each epochs as shown in Fig. 2. The train and test split ratio is 80%-20%. All the results are drawn by taking an average of a 5 fold cross validation. In most cases, our algorithm achieved a comparable accuracy and in some cases, our algorithm outperforms PMF significantly. We conduct a grid search for all the hyper parameters (λ_{Im}, regularization parameter, latent dimension of U, V and Z, etc.) of our algorithm, and we found that a better RMSE could be gained through a hyperparameter tuning. In order to evaluate the effects of train-test split ratio, we also tried 60%-40% and 40%-60% train-test split scheme, and we found interestingly that when there are not enough training data, the improvement of our algorithm against PMF is usually more significant.

5 Conclusion and Future Work

In this paper, we have proposed a novel method (SemPMF) to incorporate semantic information of DBpedia with user-item rating through a probabilistic view of CMF. We have tested the proposed approach with four different semantic properties generated in an unsupervised manner from DBpedia. Through analysis of the experiments we showed that SemPMF approach provides as well, and in some scenarios significantly better results than the original PMF approach without semantic data inclusion. Currently, we have only tackled separate semantic property files for movies, in the future, we will explore more advanced feature reduction technique like Latent Dirichlet Allocation to reduce the dimension of item-property matrix and alleviate the sparsity and high dimensionality problem for the item-property matrix. We will also explore using a more complex loss function to increase the algorithm performance.

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[3] https://github.com/sisinflab/LODrecsys-datasets

[4] https://github.com/nidhikush/SemPMF.

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Framework for Retrieving Relevant Contents Related to Fashion from Online Social Network Data

Nhan Cach Dang, Fernando De la Prieta,
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Abstract Nowadays, online social networks such as Facebook and Twitter become increasingly popular. These social media channels allow people to create, share, and comment on information about anything related to their real-life. Such information is very useful for various application domains, e.g., decision support systems or online advertising.

In this paper, we propose a comprehensive framework for retrieving relevant contents from online social network data. Our approach is proposed on the basic of the Vector Space Model and Support Vector Machine to process and classify raw text data. Our experiments demonstrate the utility and accuracy of the framework in retrieving fashion related contents from Twitter and Facebook.

Keywords Text mining · TF-IDF · Vector Space Model · Support Vector Machine

1 Introduction

Fashion, especially to young people, is more and more interesting and widely shared in the form of user-generated contents on social media channels. Such data contain opinions of users, about some topics, fashion trends for the next season, such as fashion events and so on. Automatically collecting and analyzing that

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information is very helpful for recommender system, online advertising or for improving the quality of services and refining fashion designs. Typically, such information is obtained and analyzed manually through survey. This type of method exposes disadvantages such as high cost, low accuracy and especially not real-time update.

This paper presents a comprehensive framework for the purpose of automatically retrieving contents for a specific topic. Our approach is proposed on the basis of the Vector Space Model and Support Vector Machine (SVM) [1, 2] to process and classify raw text data. Although SVM has been studied for problems of text classification recently [3], applying it to retrieving and analyzing relevant content related to fashion from online social network data is still not much focused. Our experiments on two popular social networks, Facebook and Twitter, demonstrate the utility and accuracy of the framework in the extracted information on the fashion.

The rest of the paper is organized as follows. Section 2 introduces a background and related work of this trend. Section 3, presents the Framework for retrieving useful information related to fashion from online social network data. Section 4 provides some datasets for experiment this framework. Section 5 summarizes experiments and results, following by the conclusion in section 6.

2 Background and Related Work

2.1 Vector Space Model

Vector space model or term vector model [4] is an algebraic model for representing text documents as vectors of identifiers. The elements of this vector expresses the relevance ranking of words or some word frequency function as the appearance or absence of each word in the document.

This model presents text documents as points in n-dimensional Euclidean space. Each unique term in the document collection corresponds to a dimension in the space. Documents are viewed as points in a hyperspace whose axes are the terms used in the document vectors. The location of a document in the space is determined by the degree to which the terms are presented in a document. The similarity between two documents is defined as the distance between the points corresponding to them or the angle of the vectors. Show in Fig. 1.

The measure TF-IDF (Term Frequency - Inverse Document Frequency) is often used because of its effectiveness in the field of text mining. This is a common method to evaluate and rank the importance of a word in a document. Details of this measure are shown in the following sections.

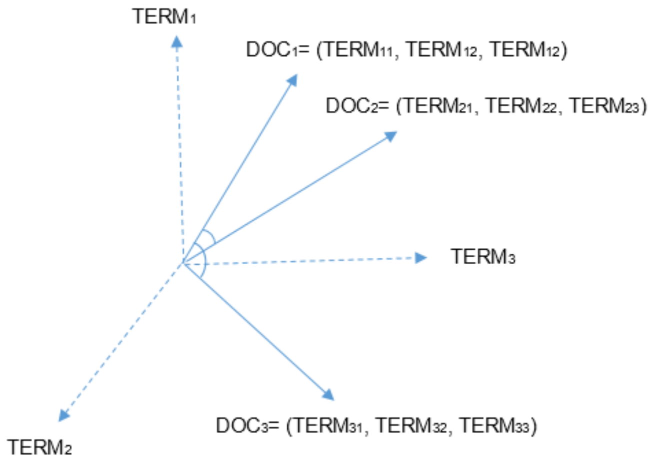

Fig. 1 Presentation vector space model.

2.2 TF-IDF Measure

TF-IDF, the short term of frequency–inverse document frequency, is a statistical measure reflecting how important a word is to a document in a collection or corpus [5]. Just like the name, TF–IDF is the product of two statistics, Term Frequency (TF) and Inverse Document Frequency (IDF).

TF (Term Frequency) – the number of times the words appears in the Document. It is measured which raw frequency divided by the maximum raw frequency of any term in the document:

$$tf(t,d) = \frac{f(t,d)}{\max\{f(w,d) : w \in d\}}$$

Where:

- f(t,d) is the frequency, that is ,the number of times the word t appears in the Document d,
- max {f(w,d):w∈d} is maximum raw frequency of any term in the document.

IDF (Inverse Document Frequency) is a reciprocal of the number of Documents in which the word occurs. The inverse document frequency is a measure of whether the term is common or rare across all documents. For example, in a corpus of fashion documents, the term "fashion" or "model" will appear all over the corpus. When it is already a popular term, it will not provide much information. IDF is calculated as:

$$idf(t,D) = \log\frac{|D|}{|\{d \in D : t \in d\}|}$$

Where:

- |D| : total number of documents in the corpus D,
- $|\{d \in D : t \in d\}|$:number of documents where the term t appear(it means $tf(t,d) \neq 0$).

If the term is not in the corpus, this will lead to a division-by-zero. It is therefore common to adjust the denominator to $1 + |\{d \in D : t \in d\}|$.

Mathematically, the base of the log function does not matter and constitutes a constant multiplicative factor towards the overall result. In other words, the change in the base of the log function will not change the ratio between IDF results.

$$tfidf(t,d,D) = tf(t,d) \times idf(f,D)$$

A high weight in TF-IDF is reached by a high term frequency (in the given document) and a low document frequency of the term in the whole collection of documents; the weights hence tend to filter out common terms, and keep the importance term (or keyword).

For the purpose of retrieving useful information related to fashion from online social network data, we use TF-IDF measure for transforming data to space vector model. However, we propose a technique that reduces the dimensional specifications of this Vector Space Model to train an SVM (Support Vector Machine) classifier.

2.3 Validation Measuring for Retrieved Documents

Precision, recall, and the F measure [6, 7] are set-based measures. They are computed by using unordered sets of documents. In a ranked retrieval context, appropriate sets of retrieved documents are naturally given by the top k retrieved documents. For each such set, precision and recall values can be plotted to give a precision-recall curve, such as the one shown in Fig. 2.

For classification tasks, the terms true positives, true negatives, false positives, and false negatives (see Fig. 3) compare the results of the classifier under test with trusted external judgments. The terms positive and negative refer to the classifier's prediction, and the terms true and false refer to whether that prediction corresponds to the external judgment. They are defined as an experiment from P positive instances and N negative instances for some conditions. The four outcomes can be formulated as showed in Fig. 3 in the form of a confusion matrix.

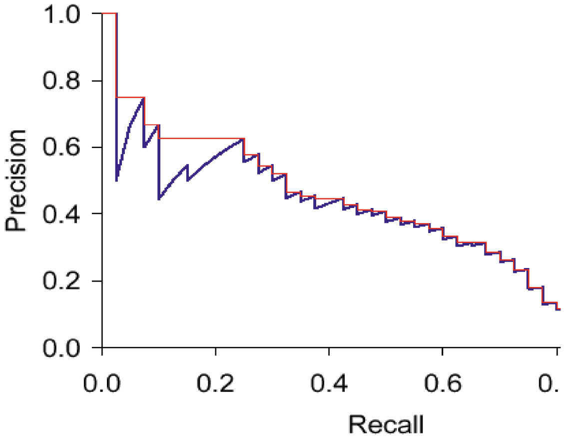

Fig. 2 Precision/Recall graph[1].

		True condition	
	Total population	Condition positive	Condition negative
Predicted condition	Predicted condition positive	True positive (tp)	False positive (fp)
	Predicted condition negative	False negative (fn)	True negative (tn)

Fig. 3 P positive instances and N negative instances for some condition.

Precision is the ratio of the number of relevant records retrieved to the total number of irrelevant and relevant records retrieved. It is usually expressed as a percentage.

$$precision = \frac{tp}{tp + fp}$$

Recall is the ratio of the number of relevant records retrieved to the total number of relevant records in the database. It is usually expressed as a percentage.

$$recall = \frac{tp}{tp + fn}$$

---

[1] http://nlp.stanford.edu/IR-book

Accuracy is the proximity of measurement results to the true value.

$$Accuracy = \frac{tp + tn}{(tp + tn + fp + fn)}$$

F measure is a measure that combines precision and recall is the harmonic mean of precision and recall, the traditional F-measure or balanced F-score is the harmonic mean of precision and recall:

$$F = \frac{recall \times precision}{(recall + precision)/2}$$

Commonly used evaluation measures including Recall, Precision, F-Measure and Rand Accuracy are applied due to their origin in Information Retrieval. In fact, sometimes we can not directly use these measures to compare two lists of ordered documents returned because of independence of the internal order of the documents [8]. To measure the quality of an ordered list of documents, the average precision of all the relevant documents in the ordered list can be calculated.

2.4 Text Classification

Text (or Document) classification [3, 9-11] is a problem belonging to data mining, but focus on unstructured or semi-structured data [12]. The problem of text classification can be found in applications in a wide variety of domains in text mining. Some examples of domains in which text classification is commonly used are: news filtering and organization (text filtering); document organization and retrieval [13]; opinion mining (sentiment); email classification and spam filtering.

Simply, text classification process includes some steps: (1) data preprocessing; (2) model machine learning; (3) classification processing in training model and (4) result interpretation and reporting. Data pre-processing is an important step in the data mining process. Data pre-processing includes cleaning, normalization, transformation, feature extraction, selection and transforming the text data into space vector model. Machine learning focuses on prediction, based on known properties learned from the training data. Some key methods which are commonly used for machine learning are decision trees; pattern (rule)-based classifiers; support vector machine (SVM) classifiers; neural network classifiers; Bayesian classifiers. Some of the techniques have been converted into software that can be used such as BOW toolkit [14], Mallot [15], WEKA[2], and LingPipe[3]. In this research, we use support vector machines for model training because of advantages [2].

The prediction process is used through the training model in the new text data and a label to unclassified instances is assigned. Finally, the results are interpreted

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2 http://www.cs.wailato.ac.nz/ml/weka

3 http://alias-i.com/lingpipe

and reported. Based on this general process, we propose a comprehensive framework for retrieving useful information related to fashion from online social network data. It will be discussed in further details in the next session.

3 Framework for Retrieving Information from Social Network

Process of our framework is as follow, we use a measure to determine the importance of a word in the text, called TF-IDF [4] (Term Frequency – Inverse Document Frequency) as described in session 2.2 Based on the TF-IDF measure, we transform the document text of information into Vector Space Model (VSM) [1, 4]. This model allows the text to be represented by the vector in n-dimensional space, each dimension corresponding to the index. In this space, each component of the text vector represents weighted measure of the index corresponding in that text. First, based on the vectors representation in the document, text classification model is built from a training set by means of a Support Vector Machine algorithm. To build the training sample, we use the common account that provides

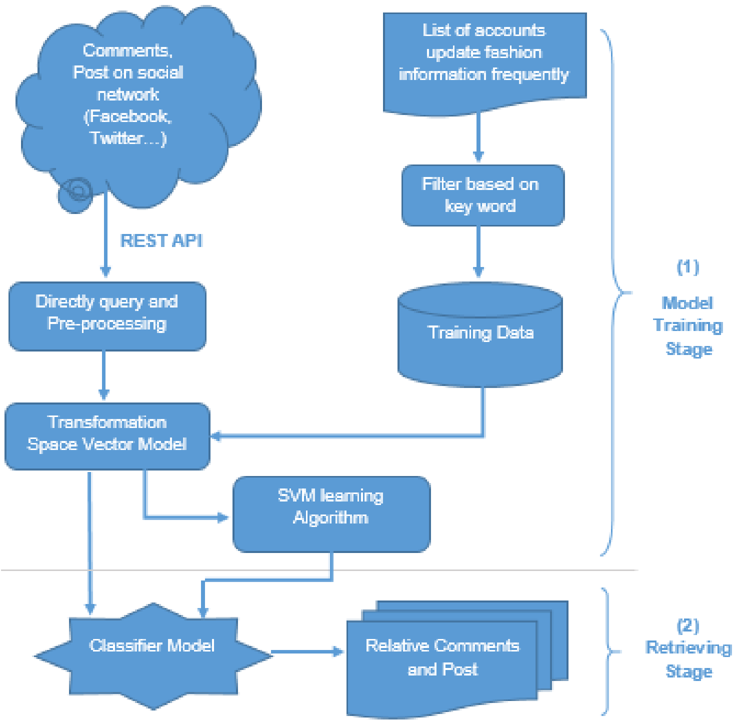

Fig. 4 Framework for model training and retrieving fashion data

updates about fashion (Ex accounts of www.Fashionista.com andwww.elle.com in Twitter and Facebook). Experiments on two popular social networks Facebook and Twitter, have been chosen to see the efficiency and accuracy of the model in the extracted information about fashion.

Fig. 4 presents our framework that automatically trains a model for retrieving fashion data from Facebook and Twitter. Basically, there are two stages for retrieving information in this framework (1) model training and (2) retrieving fashion contents using the induced classification model.

In the stage of model training, social network data (comments, post…) are real-time collected by using REST and Graph protocol (as REST APIs in Twitter and Graph API in Facebook). Some popular accounts or fan pages providing status of fashion (Ex accounts of www.Fashionista.com and www.elle.com on Twitter and Facebook) are used to train a SVM model. Text data are transformed into Space Vector Model by using IF-IDF measure. Using the model trained from training data, new information from social network is classified and related fashion information is retrieved and saved. In the next stage, we also collect data from account in Facebook and Twitter that are not related to fashion such as: economic; weather; traffic; technology...These data are merged with related fashion data to test the accuracy of the SVM model. In the next session, we present in a more detailed way the data used in the experiments carried out to test and evaluate the effectiveness of this framework.

4 Data Model Scenario

To perform the experiments on the proposed framework, we use real-time text data of two popular social networks including Twitter and Facebook. The data are accessed through the APIs provided, that is, REST APIs in Twitter and Graph API in Facebook. Per time launch framework to test, the framework collects 1000 posts or comments from Twitter and Facebook in the real-time.

Training data are built based on data related to fashion provider. That is, we use comments and posts from account on Facebook and Twitter of website www.Fashionista.com and www.elle.com. In addition, we use some other accounts which are not related to fashion. Such as economic data[4]; weather data[5]; traffic data[6]; technology data[7]. Then, we merge them to evaluate the trained model. We use both accounts on Facebook and Twitter of those websites for this task.

Fig. 5 and Fig. 7 present important keywords for two datasets related to fashion and related to traffic as discussed above. We can see the related keywords in Fig. 5 such as fashion, style new… Otherwise, some words as: accident, roadway, lane… appear in the Fig. 7, which it is reasonable.

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4 http://www.cnbc.com/economy/

5 http://www.weather.com/

6 https://tfl.gov.uk/traffic/status/?cid=trafficnews

7 http://techcrunch.com/

Fig. 5 Visualization of fashion related data retrieved from Facebook account "Fashionista_com". The more important a word is the larger its size is [8].

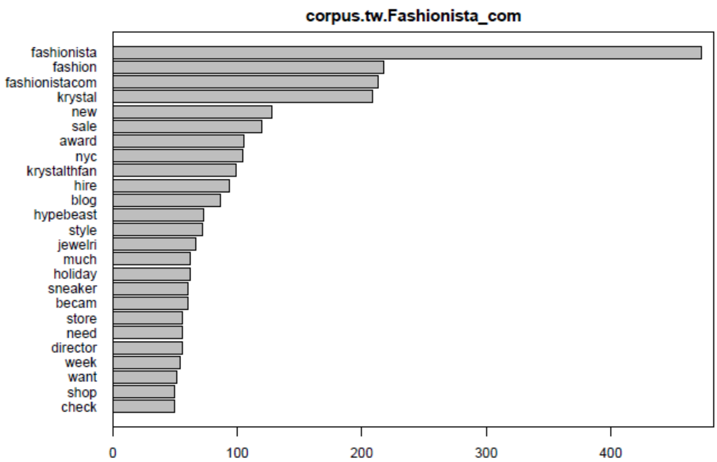

Fig. 6 Frequency of 1000 twitters sample get from "Fashionista_com" account

8 Using Wordcloud library in R language

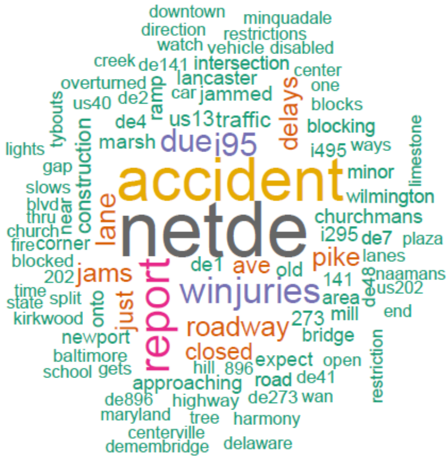

Fig. 7 Visualization traffic related data retrieved from Facebook account "traffic". The more important a word is, the larger the text size.

5 Experimental Results

With the data source described in the previous section, we perform several experiments to test the effectiveness and accuracy of the proposed framework. From each source (Facebook and Twitter), we extract 6 datasets (2 datasets related to fashion and 4 datasets not related to fashion). We use both Accuracy and F measure to evaluate the accuracy of filtering. Because F measure is derived from Recall and Precision, we also show the two measures for reference purpose.

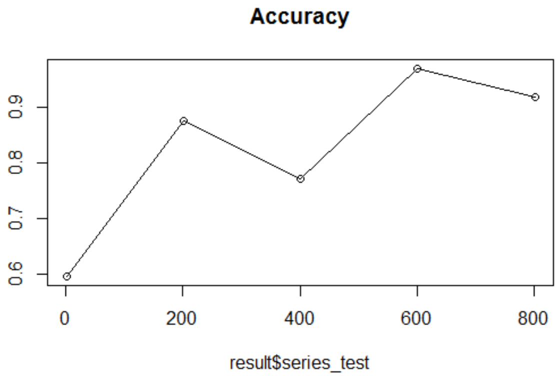

Fig. 8 Experiments with the parameter minfreq to reduce data dimensionality. The highest accuracy was achieved for the value 600.

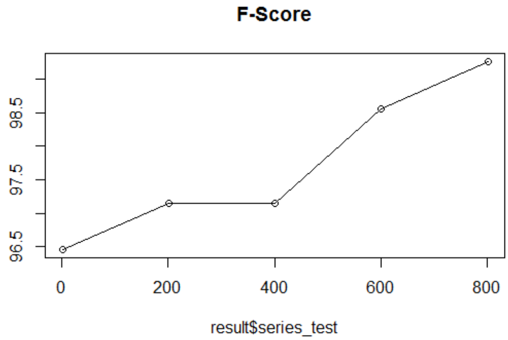

Fig. 9 Experiments with the parameter series_test to reduce data dimensionality. The highest accuracy was achieved for the value 800.

For each run, we need two datasets, one for fashion-related and another one for fashion-unrelated contents. Each dataset contains 1000 posts (comments) obtained from Twitter (Facebook). Then we merge them for training and testing. After that, we transform the text into Vector Space Model based on the TF-IDF measure and reduce the dimensionality of data collection. That can be done by analyzing the frequency of terms that appear in the datasets. To prevent bias, we create several sub dataset from original. That is, each original dataset is partitioned into 5 sub dataset, each one contains 200 posts. Then we train and test with these types of data. Fig. 7 and Fig. 8 show that the highest accuracy was achieved for words appearing more than 500 times in the dataset using as vocabulary.

The experimental results that show our filters have high accuracy (> 91%) in the experimental cases. More detailed reference in Table 1 and Table 3.

Table 1 Experimental result based on data retrieved from Twitter with 5 sub-datasets identified by indices:

Test	Index	Recall	Precision	F measure	Accuracy
1	1	100.00	55.28	**55.28**	**0.59**
2	201	100.00	80.00	**80.00**	**0.87**
3	401	100.00	68.69	**68.69**	**0.77**
4	601	98.53	95.71	**95.71**	**0.97**
5	801	98.53	87.01	**87.01**	**0.92**

Table 2 Experimental result based on data retrieved from Facebook with 5 sub-datasets identified by indices:

Test	Index	Recall	Precision	F measure	Accuracy
1	1	100.00	93.15	**96.45**	**0.96**
2	201	100.00	94.44	**97.14**	**0.97**
3	401	100.00	94.44	**97.14**	**0.97**
4	601	100.00	97.14	**98.55**	**0.98**
5	801	100.00	98.55	**99.27**	**0.99**

The chart in the Fig. 10 shows experimental result with 6 datasets. For each run, we use two datasets. One is related to fashion and the other is not. The F measure in this chart is computed from tests performed on Twitter datasets.

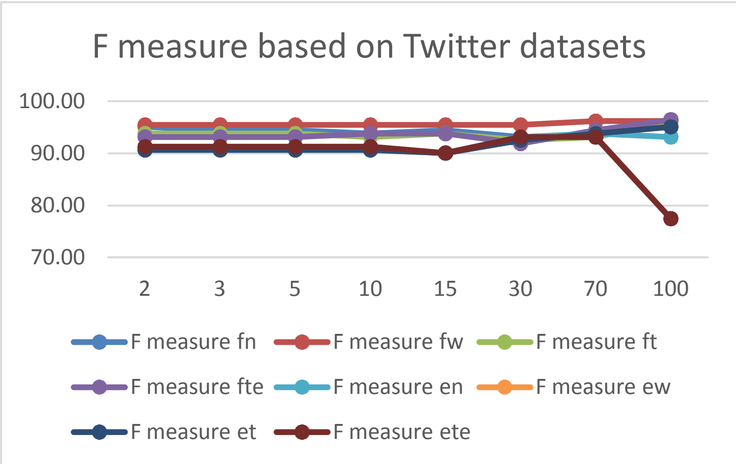

Fig. 10 F measure with 8 times running base series_test<- c (2, 3, 5, 10, 15, 30, 70, 100) partitioned into 8 subdatasets.

6 Conclusion

In this research, we develop a framework to automatically retrieve relevant contents related to fashion from online social network data. We employ machine learning, which automatically train the model to classify fashion contents. The framework tested with datasets from Facebook and Twitter, shows a good performance.

The information about fashion is very useful for various application domain, e.g., decision support systems; automatic surveillance systems; creating suggestion and recommendation systems. The future work for this approach research that uses data retrieving for useful related applications can be the prediction of fashion opinion of users in the social network. We also intend to extend the framework with the use of more reliable data mining based techniques.

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Twitter User Clustering Based on Their Preferences and the Louvain Algorithm

Daniel López Sánchez, Jorge Revuelta, Fernando De la Prieta, Ana B. Gil-González and Cach Dang

Abstract In this paper, a novel agent-based platform for Twitter user clustering is proposed. We describe how our system tracks the activity for a given topic in the social network and how to detect communities of users with similar political preferences by means of the Louvain Modularity. The quality of this clustering method is evaluated against a subset of human-labeled user profiles. Finally, we propose combining community detection with a force-directed graph algorithm to produce a visual representation of the political communities.

Keywords Clustering · Data mining · Community detection · Visualization

1 Introduction

During the last years, the number of users in social networks has grown exponentially. Many individuals from all around the world share publicly their opinions, likes, dislikes and interests. In this context, the technological challenge consists of designing and deploying new information systems that enable us to mine the massive amount of information available to successfully extract knowledge from it.

In addition to mining the information that the users provide in the social media, it is also interesting to analyze the way users aggregate and form communities.

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For instance, if it is designing a political strategy it might be of interest to analyze the different communities of users that support and detract a specific topic. It could be possible to track their activity independently to design specific actuations.

In this article, it is proposed a novel agent-based platform to identify communities of users with the same opinion alignment in Twitter. Section 2 explains the state of the art about information retrieval. In section 4, we present the summary of the platform and the approach that it is used to detect communities in this network. Section 4 presents the results of the experiment we conducted to determine the degree of political aggregation of the users. Finally, in section 5 we explain how to integrate the results of the Louvain algorithm with a force-directed graph algorithm to produce a consistent visualization of the communities in a 2D surface.

2 Data Extraction, State of the Art

The tremendous growth and development of the Web produce a collapse of information to any user interested in access to quality information [12]. Additionally, another difficulty is the necessity to automatically extract information from different and heterogeneous sources [3]. To cope with this challenges, there are research oriented studies and application specially oriented to retrieve and organize information, especially nowadays in social networks [11][13].

The vast amount of content available on the Internet, provokes that the end-users can not exploit all its usefulness if they do not have the adequate tools to retrieve and display useful information organized. Much of the needs of Web information recovery for users is solved with the usage of search engines [8]. However, there are still open challenges on the organization of information in quantities priori impossible to handle for users [6].

Formally, the term information retrieval usually refers to the query and data mining both structured and unstructured data. The solutions developed by search engines or conventional web browsers are very effective to recover the visible contents of the Web. They make use of web crawlers or spiders [10]. These spiders crawl websites and recursively follow hyperlinks in the documents. The data extracted by the spiders are treated differently by the various search engines. The difficulty that exists in dealing with all the huge amount of information stored on the web is the homogeneity of the sources, which terribly difficult their harvesting. Virtually every website has its own way of representing information: i.e. social networks like Facebook or Twitter have their own APIs for accessing data, blogs and online newspapers have the most diverse information structures and navigation, etc.

At the end, crude extraction of the contents of the web and social networks is all stages of analysis which is more developed and involves the least of the problems web content. The difficulty increases when we talk about the treatment of the information obtained to get useful information. To deal with this challenge, specially in social networks, this article presents a novel agent-based platform to harvest information and analyze it.

3 Agent-Based Platform

The proposed architecture is based on organizational aspects and, therefore, it is necessary to identify the organizational structure to be used. For this reason, the first step has been to identify its components, which allows for the interaction model based on the analysis of the needs of potential users of the system. Subsequently, from this analysis it has been possible to deduce the roles of users and components involved in the system and how they will exchange information. Fig. 1. show the platform obtained from this approach including organizations and agents.

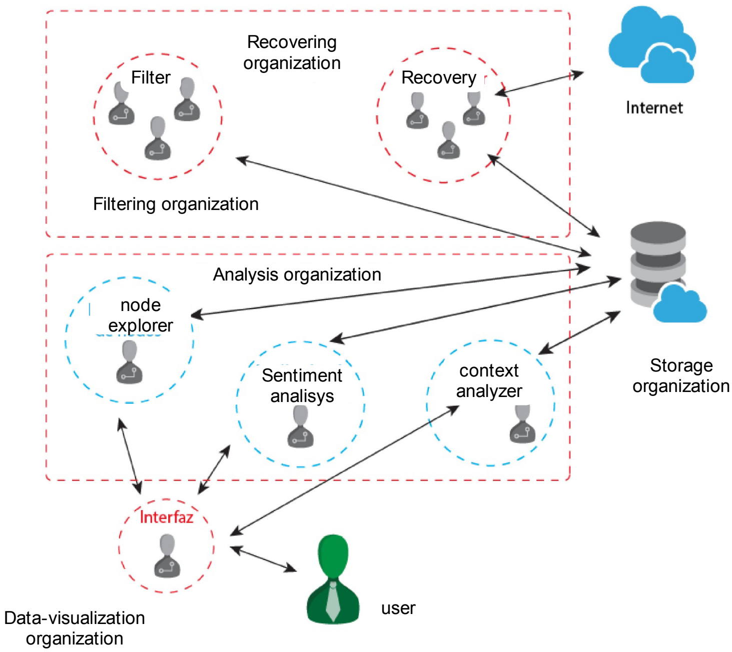

Fig. 1 Agent-based platform

Recovery agents use the stream API of Twitter to extract all the tweets published in Spanish that contain a specific list of keywords; for each recovered tweet, they perform a request to the REST API of Twitter to obtain information concerning the user who published the tweet (e.g. followers, retweets, followings…).

Filter agents keep the extracted information up to date: as several attributes of social users may vary over time, it is necessary to keep polling Twitter periodically to update fields like the followers and followings of social users.

The agents of the Analysis organization perform the different data mining algorithms described in the following sections. Although our platform is capable of performing automatic sentiment analysis (via the sentiment analysis agent) this feature is not applied to the case study of this paper.

The main objective of this article is not to describe the proposed architecture, more details about it, can be read in [14]. Following sections describe the tasks performed by agents of the analysis organization.

3.1 Louvain Modularity for User Clustering

The Louvain Modularity [1] is one of the most widely used methods to extract communities from networks of any kind. It is especially interesting when other methods for community extraction are not applicable due to the size of the network, both in terms of the number of nodes and links. The computational complexity of the algorithm is not known, but it has been shown empirically that it can be computed over a network with n nodes at the cost of time $O(n \log(n))$.

The method follows a greedy optimization strategy, trying to optimize the modularity of a partition of the network. The modularity [7] is a metric that takes values inside the interval [-1, 1]; it measures the density of links inside communities compared to links between communities.

The modularity is optimized by means of two phases or steps that are repeated iteratively:

1. each node of the network is assigned to its own community and the modularity is optimized locally.
2. nodes in the same community are grouped and a new network is build where nodes are communities from the previous step.

The links between nodes of the same community are represented with a self-loop on the community node of the new network and links between nodes in different communities are represented as weighted links between community nodes. Figure 2 shows a sample iteration of the algorithm.

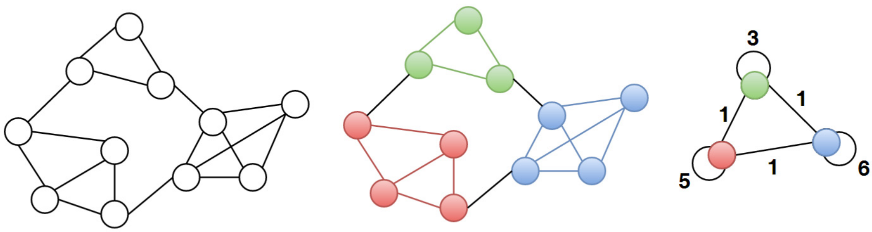

Fig. 2 First iteration of the Louvain algorithm on a simple network

The proposed system, uses the Louvain method to detect communities based on the information extracted from twitter. Note that, the Louvain method does not consider the direction of links within the network to detect communities. In the other hand, the relations between twitter users have a semantical direction: if one user *follows* another one, not necessary the second user follows the fist.
We defined two manners of transforming twitter *following* relations to links in the network that will be segmented in communities by means of the Louvain method. In the first approach, we settle a link between two users (i.e. nodes of the network) if and only if they follow each other, we call this a *hard link*. In the second approach, we place a link between two users if one of them follows the other, or when both of them follow each other; we call this a *soft link*.

4 Community Purity Evaluation

Our goal is to obtain a split of the extracted network such that the preference of the users is homogeneous inside communities. This is possible since many social networks exhibit similar properties [5] (i.e. users prefer to connect to those more like themselves). To evaluate the proposed system, it is used a small set of users whose political alignment (i.e. left or right alignment) has been labeled manually by a human expert. Then we apply the purity metric to evaluate how well our community detection matches that gold standard.

Purity is an external criteria of clustering evaluation. It is computed by assigning to each community the class or label that is most frequent in that community. Then the number of correctly assigned nodes is counted and divided by the total number of nodes in the network. Formally:

$$Purity = \frac{\sum_{i} max_j \, n_{ij}}{\sum_{ij} n_{ij}} \tag{1}$$

Where i is the index for communities, j is the index for ground truth labels and n_{ij} is the number of nodes with label j assigned to community i. An example of this can be seen in figure Fig. 3.

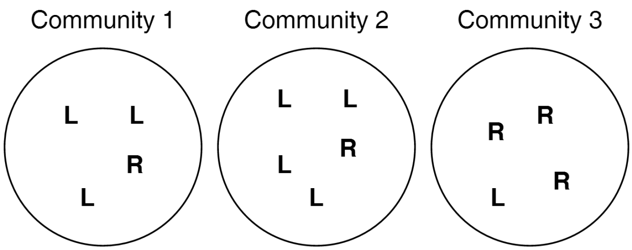

Fig. 3 Most frequent label and number of nodes of the most frequent label for the three communities are: L, 3 (community 1); L, 4 (community 2); R, 3 (community 3). Purity is $(1/13) \cdot (3 + 4 + 3) \approx 0.76$

To evaluate whether if using *hard links* or *soft links* produces a better community detection the following experiment was conducted. The activity concerning a current controversial topic on Twitter is tracked, i.e. the political situation of Catalonia (Spain). A total of 1575 users tweeted about the topic during a period of two days, it was extracted a total of 8448 *hard links* between those users. A human expert evaluated a number of user profiles, labelling then as left-aligned, right-aligned or ambiguous; this yield a total of one hundred non-ambiguous user profiles. This expert based knowledge was used as a gold standard and computed the purity of clustering this one hundred manually-labelled users according to de communities detected by our system in the complete network with 1575 users. Using the *hard link* approach lead to a purity of 0.95 whereas using the *soft link* criteria the purity was of 0.98.

This evidences that the *soft link* approach produces a community detection where users are more accurately grouped by their political alignment.

4.1 Visual Representation: Force-Directed Graph

It is very useful to generate a visual representation of the communities detected by the Louvain algorithm. For this purpose we used a force-directed graph layout as implemented by D3 library [2].

Force-directed graph algorithms are a family of algorithms designed to create graph visual representations in an aesthetically pleasing way. They perform a physical simulation to decide the final location of each node in a 2D surface; an attractive force is simulated for each pair of linked nodes, as well as a repulsive force between nodes. The attractive force is often simulated according to Hooke's law, while repulsive force considers nodes as infinitesimal points with equal charge and mass and thus the repulsion is computed according to Coulomb's law. Additionally, D3 implements a pseudo-gravity force that keeps nodes centered in the visible area and avoids expulsion of disconnected subgraphs.

Simulating such an n-body system would have a computational complexity of $O(n^2)$, to overcome this problem D3 uses the Barnes–Hut [9] approximation algorithm. In this, a quadtree is applied to accelerate the charge interactions between the particles, reducing the computational complexity to $O(n \log(n))$.

To ensure that the nodes belonging to the same community are drawn together and that the communities do not overlap in the representation, we modified the force-directed graph algorithm. In our version, a link existing between nodes of the same community (as detected by the Louvain algorithm) produces an attractive force ten times stronger that those links between nodes in different communities.

Figures 4 and 5 show an example community detection, specifically the one used in the previous section for our experiments. The images show that the communities detected when considering *soft links* are more fine-grained, which explains why the purity was higher in that case.

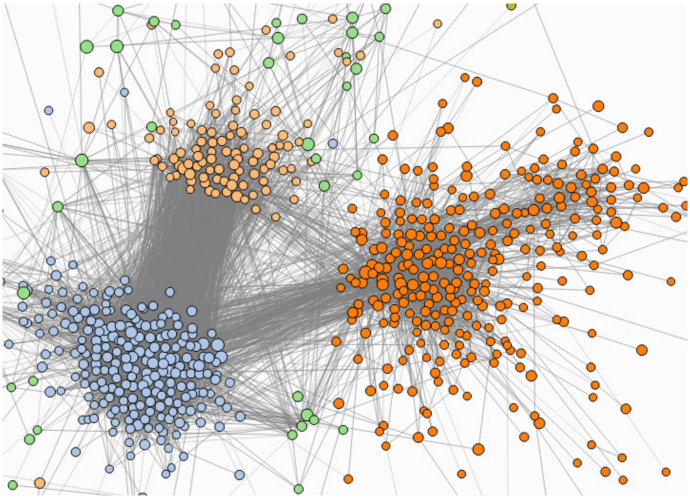

Fig. 4 Community visualization (*hard links*)

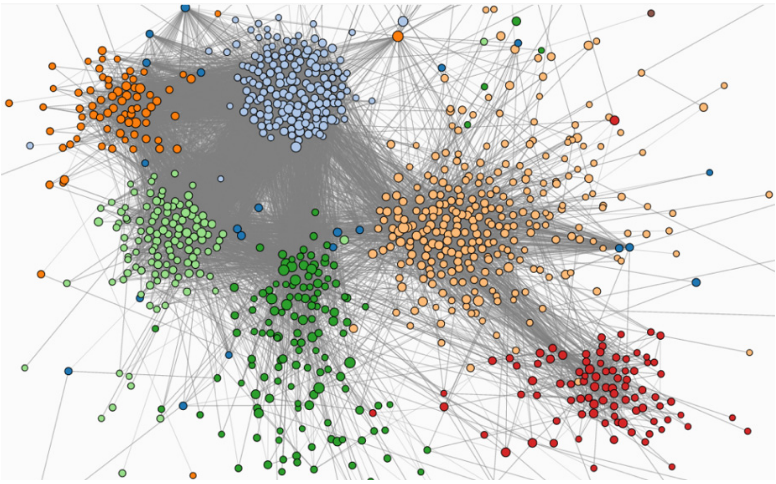

Fig. 5 Community visualization (*soft links*)

5 Discussion and Future Work

In this paper, a novel framework for twitter user clustering was proposed. The empirical results presented in section 4 suggest that *soft links* (i.e. unidirectional following relations) are more suited for political community detection than *hard links*. This technique can be applied to detect, analyze and visualize communities of users with the same political preferences.

The proposed setup could be modified to be used as a simple classifier that could predict the political alignment of a given user. If a few nodes from each community are manually labelled by a human expert, then the resulting community map can be used as a multiclass classifier where each new user is assigned to the community (and therefore class) that contains most of the users he is following. It would be also interesting to perform a similar study considering the political party that users support, and not only their political alignment (left or right winged). This could be also applied to cybersecurity; detecting communities of users with extremist ideologies could help security forces to anticipate riots and other violent events. The recent advances in automatic sentiment analysis [4] could be integrated in the system to automatize the task of conflictive community vigilance.

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Part VIII
A Proposal to Combine Depth Information from LIDAR and RGB-D Sensors in an Assistant Personal Robot

A Proposal to Combine Depth Information from LIDAR and RGB-D Sensors in an Assistant Personal Robot

Eduard Clotet, Dani Martínez, Javier Moreno, Marcel Tresanchez and Jordi Palacín

Abstract This paper proposes a methodology to combine the depth information obtained from LIDAR and RGB-D sensors in order to generate enhanced 2D navigation maps which will be used by an Assistant Personal Robot. The objective of this procedure is to locate the mobile robot and to avoid collisions while performing movements in any direction.

Keywords Navigation · LIDAR · 3D camera · Mobile robot

1 Introduction

The use of high resolution RGB-D cameras in modern robotics is a low-cost alternative for 3-D mapping and object tracking [1] with mobile robots. This paper proposes the combined use of a 2D LIDAR sensors and RGB-D cameras with a limited depth range for its application in an Assistant Personal Robot [2] with high mobility capabilities which requires a system to enhance the localization and the obstacle detection procedures and to guarantee the safety of the robot and its environment.

2 Proposed Methodology

The proposal is to combine the long-range depth information provided by 2D LIDAR sensors with the short-range depth information provided by 3D RGB-D

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sensors by generating accurate 3D representation of the environment around a mobile robot. This information is used to locate close obstacles which are not properly detected by the 2D LIDAR sensor due to the plane limitation of the 2D measurement. The proposal is the development of a Simultaneous Localization and Mapping (SLAM) procedure based on a Hokuyo UTM LIDAR while creating a 3D representation of the environment with a Crative Senz 3D camera which was initially planned for gesture recognition [3]. The combination of the spatial information obtained will have other applications such as detecting area changes and unsupervised luggage or objects, people tracking and monitoring, and collision avoidance with moving objects.

3 Current Results

Figure 1 (left) shows the 3D model generated from the combination of the raw data obtained with a LIDAR sensor and four RGB-D cameras. Figure 1 (right) shows the interpretation of the 2D and 3D data and the 2D projection of the relevant depth points used for SLAM and mobile robot navigation.

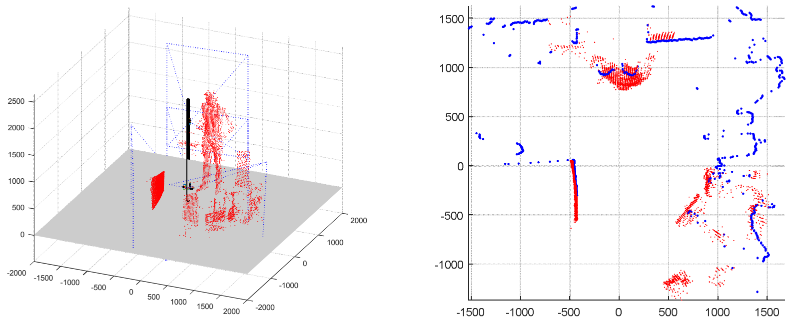

Fig. 1 (left) 3D APR representation with four RGB-D cameras. (right) Enhanced 2D map combining the LIDAR data (blue dots) with the 3D data (red dots) of the cameras.

4 Conclusions

The combination of 2D LIDAR sensors with multiple RGB-D depth cameras can generate enhanced 2D navigation maps. In one hand, the LIDAR sensor provides long range data required for the SLAM procedure, and in the other hand, the 3D cameras provide accurate information over near obstacles.

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A Distributed Algorithm for Topology Discovery in Software-Defined Networks

Leonardo Ochoa-Aday, Cristina Cervelló-Pastor and Adriana Fernández-Fernández

Abstract To ensure a proficient topology discovery service in Software-Defined Networks (SDN), we propose a simple agents-based mechanism to improve the efficiency of the topology discovery process. In this work, an algorithm for a novel Topology Discovery Protocol (SD-TDP) is designed. This protocol will be implemented in each switch through an agent. Thus, this approach will provide a distributed solution to solve the problem of network topology discovery in a more simple and efficient way.

Keywords SDN · Agents · Topology discovery · Distributed protocol

1 Introduction

The need for maintaining a comprehensive view of network topology generates a large amount of state information from the physical plane [1]. This would represent a tremendous pressure for the central controller (CRL) and, as a consequence, scalability issues might appear [2]. To solve this problem our research aims to design a simple and efficient protocol for discovering the link layer in SDN. This solution use a distributed algorithm and switches with SD-TDP based agents for minimizing the time required to obtain the network graph.

Efficient procedures for topology discovery in SDN have been already researched in [3][4]. Contrary to these related works, our approach is not based on the CRL previous knowledge about network nodes obtained through the establishment of an initial connection. In [5], a mechanism for network topology discovery is designed. Even though this model discovers the network topology, it needs a previous layer

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3 configuration. This method also requires that the CRL has a previous knowledge about network nodes.

Discovering the physical topology requires to divide the big discovery problem into smaller processes. In that way and without incurring in scalability issues, we could obtain the network graph as quick as possible. Our research hypothesis is that an efficient and simple mechanism for topology discovery in large scale SDN could be achieved through careful design of an algorithm which divides the whole process in phases and distributes hierarchically the discovery functions between network nodes.

2 Distributed Algorithm for Topology Discovery in SDN

To improve the overall efficiency of the topology discovery service, our proposal divides the problem into two phases, where each switch should run our distributed protocol through an agent. In the end, only selected switches will provide topology data to the CRL.

The first phase is initialized by the CRL sending a multicast message, called *TDP-Request*, through all the active interfaces. This stage lasts during the propagation of the message through the network. The node identifier used in the packets will be the MAC address. The agents within the switches change from the initial state (*Standby*) to the corresponding one according to the state machine of Fig. 1. As a result, the distributed algorithm defines a hierarchical delay-constrained shortest path tree rooted at the controller and, simultaneously, sets which switches will send the topology data to the CRL. In addition, each node will know the MAC address of its CRL.

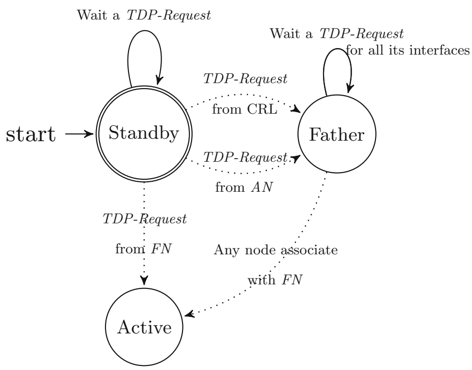

Fig. 1 State machine of a switch with SD-TDP based agent

In the second phase, selected switches (*Father nodes, FN*) aggregate topology data from their neighbors (*Active nodes, AN*) and asynchronously send it to the

CRL through the hierarchical tree. Each *FN* sends the topology data when it has the information from all the *AN* associated to it. Moreover, each *AN* has only one *FN*, at which it will send its topology information.

Each node in the network, after receiving a *TDP-Request* message has to reply this request to the sender node and then forwards the *TDP-Request* through its other interfaces. Based on this mechanism, each node can determine the delay to its neighbours. Furthermore, each *AN* has to send a *TDP-ACK* message to indicate its association with its *FN*.

2.1 Protocol Complexity

To derive the overall complexity of our protocol, we compute the complexity in terms of time and number of messages sent. Considering N the number of nodes in the network, and V_n the number of neighbours of a node $n \in N$, we can express the running time (T) as $T = N \sum_{n \in N} V_n$. Similarly, the number of messages sent (M) is determined by the expression $M = N \sum_{n \in N} V_n + N$. Due to V_n reaches his maximum value in fully connected networks, the asymptotic overall complexity can be considered of $\mathcal{O}(N^2)$.

2.2 Preliminary Results

To evaluate the performance of SD-TDP, a number of simulations with real topologies from the Internet Topology Zoo [6] were carried out. In order to validate the feasibility of the distributed protocol, we developed a heuristic algorithm using the programming language Python and the NetworkX library [7].

Some metrics of running the SD-TDP protocol on GÉANT topology are shown in Fig. 2. The figure below reveals the time for discovering all nodes and the number of *FN* that send topology data. Each point in Fig. 2 represents a simulation taking one node of the topology as network CRL. SD-TDP shows better performance with Germany as CRL, it is also worth nothing that these results coincide with the controller placement obtained using the minimum K-center algorithm [8].

Running SD-TDP on GÉANT has shown that the distributed protocol converges and discovers all nodes in 29.9 ms, with Germany as CRL. Moreover, the algorithm reveals that only 8 *FN* of 40 total nodes had to send topology data to the CRL, needing in total 162 packets to achieve a global view of the network. In addition, results of Fig. 2 show the minimum convergence time of the entire process. This times are equal to the Round Trip Time (RTT) from the CRL to the farthest node, achieved through the hierarchical tree formed in the first phase.

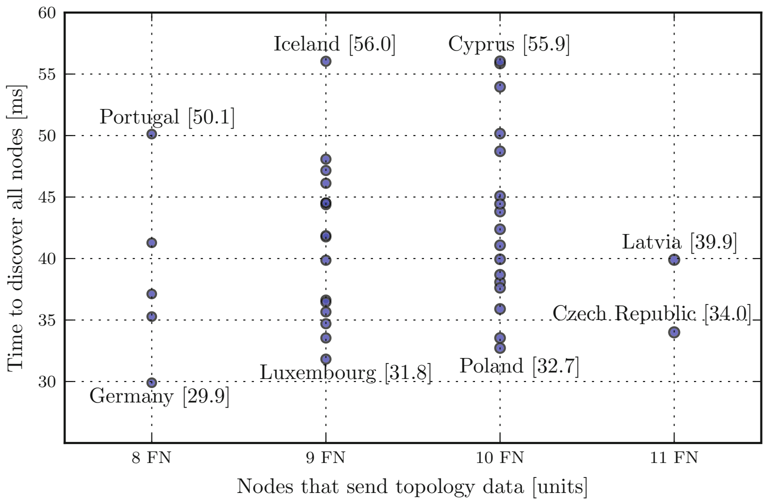

Fig. 2 Parameters of running SD-TDP on GÉANT topology

3 Reflections

A distributed algorithm for the discovery of layer 2 topologies in large SDN using an agents-based mechanism was accomplished. The results after running the algorithm on GÉANT show that the convergence time of our proposal is upper bounded by $\mathcal{O}(N^2)$, with a simple and efficient scheme.

Our future efforts will be directed to extend the protocol to a model with several controllers. Also, we pretend to incorporate resilience mechanisms in order to achieve a robust protocol against changes in the network. And last but not least, a mathematical formulation to model the protocol behavior will be developed.

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A Distributed Energy-Aware Routing Algorithm in Software-Defined Networks

Adriana Fernández-Fernández, Cristina Cervelló-Pastor and Leonardo Ochoa-Aday

Abstract In this paper we address the issue of designing a novel distributed routing algorithm that optimizes the power consumption in large scale software-defined networks (SDN) with multiple domains. The solution proposed, called DEAR (distributed energy-aware routing), tackles the problem of minimizing the number of links that can be used to satisfy a given traffic demand under performance constraints such as control traffic delay and link utilization.

Keywords Distributed routing algorithm · SDN · Energy-aware routing

1 Introduction

The high energy consumption generated by network elements and the expansion of Internet, have brought power consumption of data networks to the forefront as a major optimization concern [1]. For this problem, the emerging paradigm of software-defined networks (SDN) can be seen as an attractive solution.

In SDN, control functions are decoupled from forwarding devices and are logically centralized in a new entity called controller. The controller has a global network view and can manage network tasks without the need of additional software in each of the switching elements. Meanwhile, the network devices only forward traffic according to the rules set by the controller. In this paper we address the problem of optimizing the power consumption in software defined networks.

The idea of saving energy by turning off unused networks elements was first considered in [1]. Zhang et al. [2] formulate the exact optimization problem of maximizing the total power saving under maximum link utilization and network

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delay constraints in traditional networks. The use of OpenFlow for this purpose has already been included in other research papers [3][4], however these related works consider a centralized approach. In practice, the logically centralized control in SDN could be implemented with multiple distributed physical controllers, which is the scenario considered in this work.

The hypothesis of our research is that in these scenarios, an effective optimization of power consumption could be achieved with a distributed energy-aware routing algorithm.

2 Distributed Energy-Aware Routing Algorithm

The distributed approach of our proposal consist of a MIQCP (Mixed Integer Quadratically Constrained Program) with two steps of optimization. In the first step, each controller-instantiated agent individually computes the routing paths in its domain that minimize the number of links used. In this phase, performance constraints (e.g., control traffic delay and link utilization) could be included.

After completing this computation, distributed control plane agents exchange some information (i.e., a comparison criteria of performance, e.g., Maximum Link Utilization (MLU), and the identifier of selected border nodes) that allows a proper and coherent rerouting of interdomain data traffic demands. In the second step, the agent of the domain with the best performance (less MLU, for instance) recomputes its routing paths using now, for each interdomain data traffic demand, the border nodes preselected by its neighbor domains.

2.1 Network Model

We assume that each controller has a total knowledge of its domain topology and a partial knowledge of the global network topology, i.e., it has identified border nodes that it shares with each other domain. Interdomain traffic demands are routed in each domain using these nodes. It is also worth noting that we consider a network model with intradomain in-band control.

Each controller domain is represented by a directed graph $G = (V, E)$, where V and E denote the set of nodes and links, respectively. Each link $e \in E$ has associated its capacity, denoted by c_e. The set $B = \{b_1, \ldots, b_{|B|}\} \subset V$ contains the border nodes. D_v and D_w denote the set of intradomain demands for the data and control plane communications, respectively. D_u denote the set of interdomain data traffic demands.

For each $k \in D_\text{v}$, let d_k denote the demand bandwidth and P_k be the set of paths that can route this demand. $P_c^k \subset P_k$ denote the set of paths that pass through the controller for each $k \in D_\text{v}$. Let $P_e^k \subset P_k$ be the set of paths that use link $e \in E$ for each $k \in D_\text{v}$. Similarly, it holds for D_w and D_u demands.

Table 1 Notation of Binary Variables

Variable Name	Description
x_e	Indicates whether link e is active
λ_b^k	Indicates whether border node b is selected to route demand $k \in D_{\mathrm{u}}$
$l_{b,p}^k$	Indicates whether path p is selected to route demand $k \in D_{\mathrm{u}}$ through border node b
r_p^k	Indicates whether path p is selected to route demand $k \in D_{\mathrm{v}}$
q_p^k	Indicates whether path p is selected to route demand $k \in D_{\mathrm{w}}$

2.2 Optimization Problem Formulation

Considering the notation of binary variables shown in Table 1, the optimization model of the first phase can be formulated as:

$$
\begin{aligned}
\text{minimize} \quad & \textstyle\sum_{e\in E} x_e && && (1)\\
\text{subject to} \quad & \textstyle\sum_{b\in B} \lambda_b^k = 1, && \forall k \in D_{\mathrm{u}} && (2)\\
& \textstyle\sum_{p\in P_k} l_{b,p}^k = \lambda_b^k, && \forall k \in D_{\mathrm{u}}, b \in B && (3)\\
& \textstyle\sum_{p\in P_k} r_p^k = 1, && \forall k \in D_{\mathrm{v}} && (4)\\
& \textstyle\sum_{p\in P_k} q_p^k = 1, && \forall k \in D_{\mathrm{w}} && (5)\\
& r_p^k = 0, && \forall k \in D_{\mathrm{v}}, p \in P_c^k && (6)\\
& l_{b,p}^k = 0, && \forall k \in D_{\mathrm{u}}, b \in B, p \in P_c^k && (7)\\
& \textstyle\sum_{k\in D_{\mathrm{u}}} \sum_{p\in P_e^k} \sum_{b\in B} l_{b,p}^k d_k \; + \\
& \textstyle\sum_{k\in D_{\mathrm{v}}} \sum_{p\in P_e^k} r_p^k d_k \; + \\
& \textstyle\sum_{k\in D_{\mathrm{w}}} \sum_{p\in P_e^k} q_p^k d_k \; \le \; c_e x_e, && \forall e \in E && (8)
\end{aligned}
$$

The objective function (1) minimizes the number of active links. Equation (2) ensures that exactly one border node is selected for every interdomain demand. Equation (3) guarantees that exactly one path is used to route every interdomain demand through the border node selected. Equations (4) and (5) ensure that exactly one path is used to route every intradomain demand for the data and control plane communications, respectively. Equations (6) and (7) ensure that paths passing through the controller can not be used to route data plane communications. Equation (8) forces that the total traffic in each active link $e \in E$ is less that its capacity c_e.

As we previously mentioned, after completing this computation, distributed control plane agents exchange its λ_b^k as identifier of selected border nodes for each $k \in D_{\mathrm{u}}$. The corresponding problem for the second step of optimization could be formulated using these received identifiers in (3) of the model above.

3 Preliminary Results

The evaluation of DEAR in Abilene topology (11 nodes, 28 links) is shown in Fig. 1 against two other versions of the algorithm with additional constraints. We used the subset of online available traffic matrices measured on September 5th 2004 [5]. The controllers placement is obtained using the well known minimum k-median model [6]. Due to space limitations, we only show the case of having two controllers. We conducted our simulations in the solver Gurobi Optimizer [7].

Results show that DEAR could save until near to 40% of energy consumption when traffic is low. More restricted constraints will be paid with less energy saving, so it will be a trade-off to consider in accordance with the main objectives in each implementation.

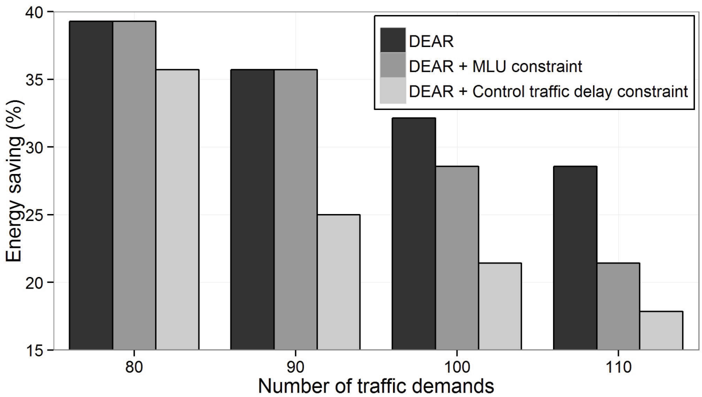

Fig. 1 Percentage of shutdown links in the Abilene topology with two controllers

4 Reflections

Using an agent-based approach, DEAR could be implemented as a software agent in each one of the distributed controllers in different SDN domains. In this way, an energy-aware control plane could be achieved. DEAR allows to attain optimal solutions for the power consumption problem in multi-domains SDN. Developing an heuristic algorithm to use this model in topologies with a bigger number of nodes in each domain, will be an important task as future work.

We also plan to extend this work to consider an energy-aware model for controller-switches association. This will outperform the energy savings since it will determine the best distribution of nodes between control domains in terms of power consumption efficiency.

Acknowledgments This work has been supported by the Ministerio de Economía y Competitividad of the Spanish Government under project TEC2013-47960-C4-1-P and through a predoctoral FPI scholarship.

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Development of a Scheduler for Heterogeneous Telescope Networks with Different Decision Algorithms

Carmen López-Casado, Carlos Pérez-del-Pulgar and Víctor F. Muñoz

Abstract This paper proposes the design and development of a telescope network scheduler to maximize the overall observation acceptance rate. A key module of this scheduler is the telescope decision algorithm which objective is to avoid serving an observation to a telescope that cannot execute it.

Keywords Astronomy · Telescope network · Scheduler · Software

1 Problem Statement and Related Work

The extended used of robotic telescopes contributed to start the GLORIA project which aim is the creation of a world-wide network of robotic telescopes. The project [1] includes telescopes which operative time is shared between the network and the telescope owner or institution. This fact makes the GLORIA network to be different from other telescope networks [2,3], where telescopes are exclusively used by the network. Another important difference is the telescope control software; while other telescope networks have all the telescopes with the same control software; the GLORIA network includes telescopes that use different control software to manage them (RTS2, ACP, etc.).

Moreover, the telescope usage has to be shared between the owners and the GLORIA network, what makes mandatory the interaction with the own third-party local scheduler of the telescopes. In this way, the GLORIA central scheduler will send observation requests to the telescope local scheduler. This difference in architecture and use makes the scheduler main goal to be different from the one of

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current telescope networks. The maximization of completed observations is mandatory to attract amateur astronomers to use the network. Meanwhile, in classical robotic telescope networks, minimize the time per observation is crucial to maximize the telescope usage. To achieve this main goal, the telescope decision algorithm is a key factor in the scheduler development to avoid offering an observation to a telescope that cannot execute it and then making the overall process longer.

The scheduler architecture of these networks can be distributed or fully centralized. The first one [3] usually includes a central node that decide the telescope and local nodes that schedule the observations. On the other hand, centralized systems [2] schedule all the telescope observations in the central node, acting the telescope just as a sequencer.

However, not all these telescope networks includes a telescope decision algorithm [2] as required in GLORIA network. In some of them it is the previous step to schedule [3] and in others, it belongs to the scheduler process itself [4].

2 Work Plan Proposal and Methodology

The main objective of this dissertation is the development of a network scheduler for a heterogeneous telescope network, where the overall completed observed plans should be maximized. The specific contributions, as well as the methodology to achieve them, are detailed next:

- Design, implementation and deployment of a network scheduler for a heterogeneous telescope network. The heterogeneity of the network is twofold, different telescope features and different telescope control software. The deployment and test will be carried out in the GLORIA telescope network.
  To achieve it, a study of the scheduler of current telescope networks will be carried out, focusing on the architecture model. Also, all the scheduler use cases will be analyzed in order to identify the data use and flow. Finally, the scheduler will be implemented in a modular way.
- Definition of several telescope decision algorithms for the scheduler. As a key module in the architecture, different kind of algorithms based on fuzzy logic and machine learning will be defined.
  Fuzzy logic and machine learning techniques will be studied, then the different possibilities of each algorithm will be tested to decide the final configuration of each algorithm.
- Simulation of the decision algorithm. Taking advantage of the real data of the network scheduler, previously deployed, a model of the telescopes and the network itself will be created. Once the whole network is modeled, different decision algorithms will be tested and compared.
  Previous step to the network model creation is the analysis of the data provided by the GLORIA network once the scheduler has been deployed. Next, the models will be made and simulated in SimEvents, the discrete-event simulation engine of Simulink. The whole network model will be verified with the network real data and finally the decision algorithm will be tested and compared.

3 Preliminary Results

The first step was the design and development of the GLORIA scheduler [5] as part of the whole GLORIA network [1]. This scheduler, based on a hybrid distributed-centralized architecture, included a decision algorithm based on the weather forecast of the telescope location. The scheduler architecture is based on 3 layers (Fig. 1): a central node that control all the user requests, makes an initial analysis, and then establishes communication with the local nodes in order to resolve which telescopes can manage the observation. Then, the central node decides, through the telescope decision algorithm, the telescope to offer the observation. The offered observation is then included in the night plan of the telescope third-party scheduler.

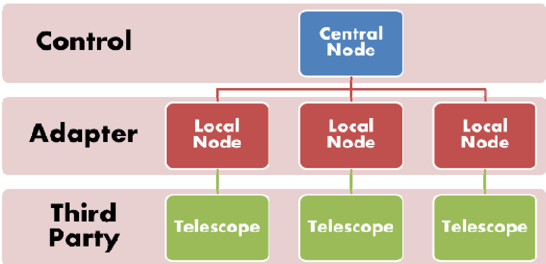

Fig. 1 Scheduler architecture

Next, the decision algorithm was change to one based on fuzzy logic that includes information about astronomical weather, target quality observation and telescope network feedback [6]. It was deployed and tested in the network, improving the telescope acceptance rate compared to the use of the previous algorithm. As it can be seen in fig. 2, the percentage of completed observation is higher when using the fuzzy algorithm, only 3% of the requests were finally rejected; in contrast to the 14% of no completed observations when only forecast information was relevant.

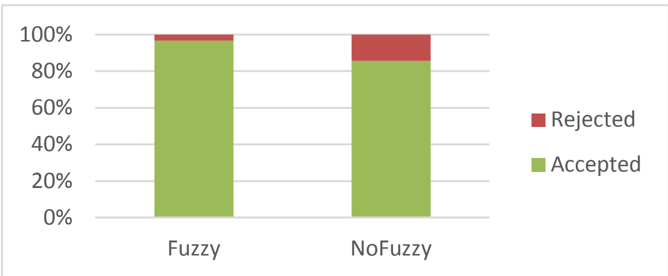

Fig. 2 Acceptance rate comparative

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On Verifying Information Extractors

Daniel Ayala Hernández

1 Problem Statement

Currently, the Web provides many different information sources with valuable information that is available in human friendly formats only. This makes it difficult for software agent to sift through them to extract relevant information to feed automated business processes. Information extractors are software components that help in this task.

Unfortunately, information extractors may easily fail to extract the correct information when the structure of the web documents to which they are applied changes, be it because the web site changes or because a new document with a structure that has not been seen previously is found.

This motivates the need for verifiers, which are components that analyse the information that is returned by an information extractor and raise an alarm if it deviates significantly from the information that is known to be correct.

2 Related Work

Rapture [1] uses a set of numeric features to compute the similarity between an extractor's output and pre-verified outputs. Normal distributions are used as heuristics. Feature values are used to estimate the distribution parameters of each feature. These are used to derive the overall probability that an output is correct. If it is below a user-defined threshold, an alarm is raised.

DataProG [2] computes a means vector from numeric features of pre-verified outputs obtained from a set of queries to a Web source. During the verification phase,

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new outputs are obtained using the same set of queries and a new means vector is computed. If it is not statistically equivalent to the original one, an alarm is raised.

Maveric [3] improves on Rapture by normalising the distributions used as heuristics and taking negative information into account. (That information is obtained by using so-called perturbations on correct information). The weight of each feature on the final decision is computed using the Winnow algorithm.

We have identified the following problems regarding these proposals:

– Alarms are associated to entire datasets, instead of specific erroneous attributes.
– Rapture and DataProG train with positive examples only. Maveric uses negative examples, but they are synthetic, which means that they might well not be representative enough of actual negative examples. Furthermore, the perturbations have to be handcrafted.
– Rapture and DataProG do not give features different weights representing their relevance, and all are considered equally important. Maveric gives weights to features, but they are global.

3 Hypothesis

We hypothesise that we can improve on the existing verifiers by training binary classifiers that classify information as belonging or not to a certain class.

4 Proposal

Our proposal, Sydney, uses extracted attributes from pre-verified datasets to train binary classifiers. One classifier is created per information class, e.g., book, title or price. If an attribute belongs to the information class associated to a classifier it is used as a positive example, otherwise, it is used as a negative one.

When a dataset must be verified, its attributes are classified using every binary classifier. If the results are not consistent with the supposed class (its classifier gives a negative result or any other classifier gives a positive one), an alarm is raised. This alarm is associated to the inconsistent attribute. The confidence of each classifier is taken into account, so that more precise classifiers are given more importance.

Further verification is performed at dataset level using global features with positive examples only, since negative dataset examples are not available during training.

Unlike existing proposals, ours is trained with real examples of what are and what are not instances of each information class. Existing proposals only do the former or use artificial perturbations. This allows us to use a wider range of existing classification techniques.

5 Evaluation Plan

We intend to evaluate our verifier using results from existing information extractors. These will be verified and classified as well extracted or potentially erroneous. Erroneous extractions shall be used as negative examples.

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Kizomba: An Unsupervised Heuristic-Based Web Information Extractor

Juan C. Roldán

1 Problem Statement

The Web is an ever growing repository of valuable information. That information lacks semantics since it is buried into web documents that are represented using HTML. Information extractors are software components that help software engineers in the task of extracting structured information from web documents. The problem that we face is how to devise information extractors that can extract information from current web sites with high precision and recall. Our proposal is unsupervised and heuristic-based, which makes it appropriate for the Web.

2 Related Work

There are many proposals in the literature. They can be classified as rule-based or heuristic-based. Rule-based information extractors require the user to provide information extraction rules that can be handcrafted, learnt supervisedly or unsupervisedly. Heuristic-based information extractors have built-in heuristics that allow them to extract information without any user intervention. We think that the most appropriate approaches nowadays are rule-based proposals whose rules are learnt unsupervisedly or heuristic-based proposals since they require little or no user intervention, which makes them appropriate to extract information from the Web. Current proposals in this category include RoadRunner [1], ExAlg [3], FiVaTech [2], and Trinity [4].

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RoadRunner works on a collection of documents which are compared to infer union-free regular expressions to describe the input template. ExAlg works in two stages: it first computes large and frequently occurring equivalence classes of tokens and then learns a regular expression and a data schema from them. FiVaTech first identifies nodes in the input DOM trees that have a similar structure and then aligns their children and mines repetitive and optional patterns to create the extraction rule. Trinity, partitions the input documents into a trinary tree, which is traversed to build a regular expression with capturing groups.

The previous proposals have some problems regarding extracted rules. None of them is able to deal with all the particularities of typical web documents, namely: nested attributes, multi-valued attributes, attribute permutations, and unique data records. Furthermore, their complexity has not been analysed in most cases.

3 Hypothesis

The Web is the biggest repository of information, and that information lacks semantics. The existing unsupervised proposals cannot extract information from complex current web sites with high precision and recall. Thus, the extractors need to be improved to integrate web information into automated processes.

4 Proposal

In this PhD, I am going to develop a new heuristic-based web information extractor that is based on a pipeline of heuristics, which are rules that can modify both the documents and the extracted information. The heuristics can be classified into three categories: pre-processing, extraction, and post-processing heuristics. Pre-processing heuristics modify the content of the documents. Extraction heuristics identify common web structures, extract the underlying information, and remove that structures from the documents. Post-processing heuristics apply corrections to the extracted information.

In summary, this is a novel proposal that addresses the problems that we have identified in the literature and is expected to be scalable to the Web.

5 Evaluation Plan

Classic evaluation methods shall be adapted to measure hierarchical records both from a golden rule and an extracted record, handling overlap, tree matching and unused data. This is a challenge that have not been addressed in the literature so far. Therefore, evaluation will require additional research work to devise an appropriate method to measure precision and recall.

6 Reflections

We think that this proposal may be a quantum leap in web extraction.

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Organizational Metamodel for Large-Scale Multi-Agent Systems

Bogdan Okreša Đurić

Abstract The main objective of this research is to ease organizational design of large-scale multi-agent systems (LSMAS) development. Methods including ontology engineering, metamodeling and code generation are proposed to achieve the set goal. The resulting modeling tool is expected to aid in development of LSMAS for numerous application domains.

1 Introduction

The function of an organization is to overcome various limitations of individual agents [6], and utilize agent cooperation and diversity in order to achieve organizational goals. Therefore, organizational modeling of large-scale multi-agent systems (LSMAS) that comprise software agents (as characterized by [3, p. 34]), is a problem worth researching. Proposing an upgrade of recent research on LSMAS organization, the planned research and the proposed organizational metamodel are based on the seven perspectives of organizational modeling [4]: organizational structure, organizational culture, strategy, processes, individual agents, organizational dynamics, as well as context and inter-organizational aspects.

2 Research Proposal

The planned research will build upon already established results presented in [1, 4, 6], based on three identified objectives:

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– O1: To define a comprehensive ontology that will combine concepts of organizational modeling and concepts of large-scale multi-agent systems.
– O2: To create an extensive organizational metamodel based on the developed ontology.
– O3: To develop a modeling tool to generate a basis (i.e. skeleton) of a large-scale multi-agent system, consistent with the defined principles of organizational modeling.

Several research questions have been identified, based on the proposed objectives:

– RQ1: Which organizational concepts are meaningful and suitable for organizational modeling of the large-scale multi-agent systems domain? Which of those should be included in the ontology or the metamodel being developed?
– RQ2: What real-life large-scale multi-agent system scenarios shall be targeted using the developed modeling tool?
– RQ3: How do large-scale multi-agent systems modeled according to various organizational models contained in the defined metamodel perform compared to each other and to real-life agents?

The stated driving elements of this research will serve as evaluation basis for the identified research hypothesis expressed as follows:

*Research hypothesis (**H1**): Based on the holistic organization ontology, it is possible to build a metamodel to be used for modeling complex large-scale multi-agent systems.*

It is assumed that an organizational metamodel can be built based on the developed holistic organization ontology. The presented hypothesis H1 will be evaluated using test-bed scenarios that will be developed within a massively multiplayer online role-playing game (MMORPG) as a suitable example of LSMAS application domain.

2.1 Preliminary Research

Preliminary research has been conducted within the ModelMMORPG[1] project: performance of real-life agents has been measured, a work in progress autonomous agent is being developed, and an ontology of organizational terms is being defined. Furthermore, initial multi-agent modeling methods for multiplayer on-line games (MMOGs) have been identified.

[1] Large-scale Multi-Agent Modelling of Massively Multi-player On-line Role-Playing Games, for more information visit ai.foi.hr/modelmmorpg

2.2 Future Research Plans

Focused on answering the identified research questions, the following stages are planned:

1. The comprehensive LSMAS organizational modeling ontology will be defined (building on [5]) using an ontology engineering methodology (e.g. METHONTOLOGY).
2. An extensive organizational metamodel for LSMAS will be constructed.
3. A modeling tool for generating LSMAS skeleton will be developed based on the metamodel.
4. The implemented modeling tool will be put to use on a number of test-bed scenarios to be identified, possibly including the Internet of Everything (IoE), smart cities, and especially MMOGs.

2.3 Methodology

Proposed methodology for achieving the set research goals depends heavily on ontology engineering, since the proposed organizational metamodel will be based on the ontology being developed. One of the considered ontology engineering methodologies is METHONTOLOGY [2].

The metamodeling process based on the developed ontology will yield an organizational metamodel. Symbols of the metamodel should be suitable for use with a modeling tool, yet descriptive enough for organizational models of LSMAS. Similar modeling languages will be considered in the process, and the defined metamodel may be compared for disadvantages and advantages to a popular modeling language (e.g. UML). Once developed, the metamodel will be tested using test-bed scenarios.

3 Reflections

Having performed analysis of related LSMAS research, the author is not aware of an attempt to build a comprehensive ontology that combines concepts of organizational modeling and concepts of LSMAS in the way proposed in this research. The most distinguishable novelty of the proposed holistic ontology lies in its comprehensiveness, since it comprises several perspectives of organizational modeling, as opposed to classically observed organizational structure perspective only.

Interdisciplinary nature of the subject area is most enticing, since it encompasses both a social (organization theory) and computer science (ontology engineering, metamodeling, software development) approach. It is hoped that the results of the proposed research will provide us with new and unseen possibilities of software engineering of LSMAS, especially in the areas of the IoE, smart cities and MMOGs.

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On Link Discovery Using Link Specifications with Context-Information

Andrea Cimmino

1 Problem Statement

A link discovery task is performed to automatically link instances from different datasets that describe the same real-world concept by means of owl:sameAs. The link discovery relies on a link specification [3, 5] which is an equality criteria between instances from different datasets. The link specification defines a set of restrictions over the inner attributes of two instances, each pair of inner attributes is measured by means of a string distance function and the obtained score has to be higher than a given threshold. For example, we can consider a dblp:Author instance and a nsf:Researcher instance the same if they have similar names, Jaro higher than 0.9. However, to improve the effectiveness of results we aim to take the context of these instances into account, e.g, dblp:Author and nsf:Researcher instances are the same if they have publications in common, dblp:Article and nsf:Paper instances linked by means of another link specification.

2 Related Work

Over the last years, several link specification techniques have been developed to address the link discovery task [1, 2, 3, 4, 5]. However, since all of them rely on the definition of link specification [3, 5], to the best of our knowledge, none of them are able to exploit the context.

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3 Hypothesis

In recent years, we have witnessed an increasing interest in the publication of datasets. Due to this growth, integrate those datasets or refine the already existing links has becoming an appealing problem to solve.

4 Proposal

We aim to extend the definition used by current techniques [3, 5] and add restrictions over the instances of both contexts. To achieve this, we introduce the concept of overlap degree which using a link specification as equality criteria allow us to calculate the intersection degree between contexts. The overlap degree is a function that takes as input the contexts of two instances and returns a value, full, if all the instances from both contexts are linked with at least another one, or partial, if it is not full and at least one instance from both context is linked. In this way, we are able to define restrictions over the degree of overlapping between the contexts.

Our technique generates a context-aware link specification, which is defined for two sets of rdf:types and relates as many overlap degree as link specifications are defined. We perform the linking taking instances from both contexts into account.

5 Preliminary Results

We have developed a research prototype with these preliminary ideas using two real-word scenarios in which we study the effectiveness obtained using regular link specifications and context-aware link specifications [6]. Both were built from real data, using researchers that have published in PVLDB, extracted from DBLP, and then looking for them, using their names, in the NSF portal. Former scenario has data of DBLP and data from the NSF, the latter is made by DBLP authors and their aliases.

We improve the effectiveness regarding a well-known technique from the literature, GenLink [5]. In the former we improved the precision by 0.24, in the latter we improved the recall by 0.58.

6 Reflections

The experiments results are promising, however, we still have to work on several features: refine the concept of overlap degree and bound the amount of context required.

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Torii: A Novel Attribute-Based Polarity Analysis

Fernando O. Gallego

1 Introduction

In recent years, companies are demanding finer market analysis in order to increase their revenues, improve their products or services, and carry out better marketing campaigns. Most current proposals perform polarity analysis on a message level, that is, they cannot analyse the opinion regarding the different attributes that are referenced in a message. An attribute is a feature, an aspect, or a component of the entity to which a message refers. Attribute-based polarity analysis computes the polarity of a message regarding each of the attributes that are referenced in that message.

Current approaches focuses on using ontologies to give more importance to an attribute respect to the domain [1]. Other proposals explore the neighbours of a message in order to enrich them with sentiment and semantic distance distributions using an unsupervised lexicon-based method [2].

In this paper, we introduce a novel attribute-based polarity analysis proposal that explores conditions. Our model is based on semantic skeletons that carry the information that our proposal extracts from the messages, including attributes, their values and conditions. Our hypothesis is that semantic skeletons and the opinion about them can be extracted from actual messages using syntactic patterns, which are regular expressions that use the part-of-speech tags.

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2 Research Proposal

Our method focuses on extracting so-called semantic skeletons from messages that are gathered from social media. We assume that every message is related to a so-called item, which refers to a product or a service on which a user is commenting. Semantic skeletons are represented as tuples of the following form: (d, c, a, v), here d is a describable, that is, an item or a component of an item, c is a condition, a is an attribute, and v is a value.

Our method consists of the following steps: preprocessing, intended to clean the messages so as to facilitate performing the following steps; extracting; summarising, in order to create cluster to facilitate the understanding of what the people are saying about the item; and analysing, to compute whether the polarity of a summarised cluster of semantic skeletons is positive, neutral or negative using a lexicon-based implementation provided by Opileak [3].

The extracting step extracts semantic skeletons from messages using a set of rules. A rule to extract semantic skeletons is represented as a tuple of the following form: (p, t), where p is a standard Java regular expression to which we refer to as the syntactic pattern and t is a replacement template to which we refer to as the semantic skeleton template. In addiction to attributes, we need to extract conditions and the item. We think that we might also extract the conditions using syntactic patterns, but we did not validate this hypothesis yet. We are planning on exploring Conditional Random Fields to discover the boundaries of conditional sentences [5].

We have to design an evaluation plan to the whole proposal, that is, given a set of messages that refers to an item, evaluate, using performance measures from confusion matrix, the polarity calculated over each cluster of semantic skeleton. For now, we focus on evaluation of semantic skeletons extraction, that consist on building a set of syntactic pattern using an own tool developed for this purpose [4]. We perform the dataset creation on a set of reviews (more than 450 000 messages) from different web sites like Ciao, Amazon, or Dooyoo. We use a subdataset of 10 413 messages that have any matches with a set of experimental syntactic patterns and a test set of labelled messages. These patterns have a precision of 0.70.

3 Conclusions

In this paper, we have presented a new method for attribute-based polarity analysis that has the novel of extracting conditions. This method exploits the POS-tagging information in order to make easy the extraction via syntactic patterns that we use to define the templates of the extracted information. This information is summarised in order to group similar semantic skeletons and finally, we calculate the polarity with a lexicon-based algorithm. Now we are in the phase of building the set of syntactic patterns that give us the best results.

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