On data-driven systems analyzing, supporting and enhancing users' interaction and experience

Ph.D. Thesis

Candidate

Juan Cruz Benito

Supervisors

Roberto Therón Sánchez, Ph.D.

Francisco José García Peñalvo, Ph.D.

Sept 03, 2018

Outline

Outline (1/4)

- **Introduction**
  - Initial considerations
  - Context
  - Research questions and goals
  - Methodology
  - Framework
- **State-of-the-art in systems/software architectures supporting Human-Computer Interaction**
  - Introduction
  - Methodology
  - Systematic Literature Mapping Results
  - Systematic Literature Review Results
  - Conclusions

Outline (2/4)

- **Experimental research (1/2)**
  - Improving virtual worlds users' experience and giving feedback on their interaction to different stakeholders
    - Context & Goals
    - Materials and methods
    - Results
    - Discussion
- Analyzing MOOCs users' interaction to get insights about their learning processes
  - Context & Goals
  - Materials and methods
  - Results
  - Discussion

Outline (3/4)

- **Experimental research (2/2)**
  - Analyzing and improving users' experience and performance in web forms
    - Context & Goals
    - Materials and methods
    - Results
    - Discussion
  - Aiding programmers in Quantum programming
    - Context & Goals
    - Materials and methods
    - Results
    - Discussion

Outline (4/4)

- **Overall discussion**
  - Answering the research sub-questions
  - Answering the primary research questions
  - Final reflections
- **Conclusions & further work**
- **Outcomes & merits achieved**
  - Publications
  - Software released
  - Official records on intellectual property
  - Predoctoral research stay
  - Awards
  - Grants received

Introduction

Initial considerations

Introduction

“the Software Architecture of a system is the set of structures needed to reason about the system, which comprises the software elements, relations among them, and properties of both”

(Bass, Clements and Kazman, 2013)

“the Human-Computer Interaction is the study of the way in which computer technology influences human work and activities”

(Dix, 2009)

“one of the common communication breakdowns between software engineers and usability professionals is the lack of strategies to inform the early design of software architectures with usability principles, which helps avoid late (and expensive) architectural changes to accommodate user experience requirements”

(Seffah, Gulliksen and Desmarais, 2005)

“the architectural design of interactive systems is the object of many pieces of research since the eighties”

(Tran, Ezzedine and Kolski, 2008)

“the users are components of the ecosystem, they establish information flows with other components, and they are affected if the ecosystem evolves”

(García-Holgado and García-Peñalvo, 2016)

It can be considered that the users' interaction with software components in the system are as much significant as the interaction between the software components.

It may result in considering the HCI process/ characteristics to be at the same level as the other components or parts of the (eco)system when designing or developing a system.

“the software architecture should not only define the technical issues needed to develop and implement functionality, but also to manage and facilitate the interaction between the users and the system”

Thesis’ motto

Context

Introduction

Since many years ago, one of the most relevant challenges in computer science and areas-alike is dealing with large, complex, or unstructured data

The information surrounds us, but working with data is a difficult task: it presents issues related on how to save information (in a physical mode), structure the information, adequately analyze the data, extract knowledge from data, make decisions, etc.

Despite these issues, information is one of the most relevant aspects and source of power in the society

“the information kept within a system is an opportunity to extract knowledge about the system itself, its components, the software included, the users or the interaction that occurs inside”

(Holzinger, 2013)

Introduction: context

- Extending the thesis' motto, this research is about these kinds of challenges:
  - How approaches like data-driven software architectures can help to improve the users' interaction with a system.
  - Specifically, the thesis deals with how to improve the interaction of different kinds of stakeholders with software systems to improve different aspects like the user experience, the easiness to accomplish a specific task, etc.

But… how to distill knowledge from information?

The Knowledge Discovery in Databases (KDD) can be defined as “an automatic, exploratory analysis and modeling of large data repositories and the organized process of identifying valid, novel, useful and understandable patterns from large and complex data sets”

(Zyt, Klosgen and Zytkow, 2002)

The KDD field is now broader than ever: it includes the knowledge discovery in almost any kind of information saving system (and not only in databases) as well as it covers more methods of knowledge discovery beyond the query of databases or the Data Mining, as areas like the Machine Learning or the Artificial Intelligence are assumed as fields that could involve KDD

(Domingos, 2015)
(Piatetsky-Shapiro, 2000)

Introduction: context

- HCI has experimented a significant evolution in recent years. Part of this growth is due to new HCI paradigms:
    - the use of new design systems
    - the consideration of the users as the center of the systems and the evaluation of their interaction
    - the consideration of elements of human life such as culture, emotion, experience or psychological aspects
    - the changes in use context (mobility, ubiquity, etc.), the multiplicity of interaction in conventional systems
    - the broader application types in technical systems, the normalization of computing as a daily resource to use,
    - the tailorability or adaptability of systems to users, etc.

“a synergistic combination of methodologies, methods and approaches of two areas [KDD and HCI] offer ideal conditions for addressing these challenges: HCI, with its emphasis on human intelligence, and KDD, dealing with computational intelligence —with the goal of supporting human intelligence with machine intelligence— to discover new, previously unknown insights within the flood of data”

(Holzinger, 2013)

Is the combination of KDD and HCI needed?

The benefits of joining humans and computers were summarized by the following old proverb:

- Computers are incredibly fast, accurate, and stupid.
- Human beings are incredibly slow, inaccurate, and brilliant.
- Together they are powerful beyond imagination.

~~**(Einstein, ???)**~~
(Cherne, 1968)

In a world where the data are flooding all kinds of systems, and the users' interfaces have evolved to be ubiquitous and present many different shapes, the application of knowledge discovery can help systems to evolve, be adaptive and respond better to the users' needs, desires and behaviors.

The KDD principles and procedures, the current data science approaches and the advantages of data-driven environments can be a golden opportunity for the HCI field and sub-areas to tackle the current challenges in the area.

Research questions & goals

Introduction

Introduction: research questions

1. Is it beneficial to follow a data-driven/KDD approach in a system to support, analyze or improve the users' interaction and experience and tackle the HCI-related challenges to these aspects that the interactive systems present?

2. How should a software environment evolve to respond to the users' needs and improve or support the users' interaction and experience?

3. How is it possible to do that in a more automated way?

Introduction: research sub-questions

1. What kind of software artifacts does a system require to respond to the users' needs or to be adaptive to users?

2. What features should these kinds of systems have?

3. What kind of software behaviors related to those features should be the common ones?

4. What kind of strategies should these systems include to provide valuable feedback to the users?

5. Could an intelligent system be capable of improving the UX in a significant manner? Would it be adequate to include intelligent features in a system to pursue such UX improvement?

Introduction: goals

- This academic work is not intended to respond the research questions with a simple answer like ‘yes’, ‘no’ or even with heavy-weight words like “it is true because it is statistically significant”.

- The plan is to dig into the central questions, to later respond more specifically to the different sub-questions and build up, using these responses, a broad answer to the primary questions and discuss them.

Introduction: goals

- To answer these previous questions, it is planned to explore the different related issues by researching using different (and incremental) scenarios.

- These scenarios are selected following two primary considerations: they are available to the author (research based on the accessibility to the scenarios), and they present relevant human-computer-interaction-related challenges.

Promote the Development of Environments of Use	*Support Communities of Users*	*Extend User-Centered Design to Support New Virtualities*	*Establish Suitable Accompanying Measures*
Determine desirable properties of environments of use (e.g., augmented capabilities on user's demand, multimodality, cooperativity, intelligence, adaptation, etc.)	Develop individual and collective intelligence and community knowledge management	Develop suitable foundations for design, by applying, integrating, and extending existing user-centered design methods to facilitate the design of new virtual spaces	Articulate demand for design for all
Develop novel architectures for interactive systems for managing collective experiences of users and nonusers	Develop methodologies for collecting and analyzing requirements and understanding virtual communities	Develop metrics for important quality attributes (e.g., usability, accessibility, adaptation, intelligence, etc.)	Support of the industry
Design architectures for multiple metaphor environments	Provide means to access communitywide information resources	Provide computation support for usability engineering (e.g., computer-supported usability platforms)	Create awareness and knowledge dissemination
Develop multiagent systems and components to support cooperation and collaboration	Develop models to support social interaction among members of online communities	Extend existing requirements for engineering methods to facilitate elicitation of requirements in novel contexts of use and different user groups	Extend technology transfer
Support individualization and user interface adaptation (e.g., adaptability and adaptivity) of environments of use		Promote user involvement and develop protocols for effective user participation in design activities	
		Investigate and provide design recommendations for alternative interaction modalities and their combinations	

Proposed R&D Road Map for HCI

(Stephanidis *et al.*, 1999)

Introduction: goals

Prototypical scenarios interesting for research based on (Stephanidis *et al.*, 1999):

1. Highly interactive scenarios where the users should develop individual activities or tasks based only on their interaction without human aid.

2. Systems including a high number of users collaborating or using concurrently the same resources to solve the same tasks. In this scenario, other stakeholders evaluate the users' performance in solving their tasks.

3. Information-intensive applications where the users could need aid and be engaged in solving the proposed challenges appropriately (with challenge referring to the need for solving a task).

4. Complex systems where the user could not have enough previous knowledge to solve a task efficiently.

Introduction: goals per research scenario

1. Scenario 1

    1. Primary objective: Collect and analyze individual users' interaction from a highly interactive environment to extract knowledge and evaluate users' performance solving tasks.

    2. Secondary objective: test how to take advantage of the knowledge gained, from a software perspective, to provide feedback to the users and improve their results.

2. Scenario 2.

    1. Primary objective: understand how users collaborate in a large environment to solve (individually) a task shared by all users.

    2. Secondary objective: integrate a software solution in a massive environment to automatize the analysis performed in the primary objective.

Introduction: goals per research scenario

3. Scenario 3.

    1. Primary goal: improve the user experience (and engagement) in a complex environment that involves a high amount of information and introduces a high level of friction for users when solving a task. This enhancement of UX seeks to improve the users' performance in the proposed task by reducing the friction.

    2. Secondary goal: define an automated data-driven pipeline to analyze the users' interaction and improve the user experience.

4. Scenario 4.

    1. Primary goal: study and propose a way to aid users in solving a complex task, even when they do not have enough knowledge to solve it.

    2. Secondary goal: create software that helps users and could be integrated into different environments related to the problem.

Methodology

Introduction

Introduction: methodology

- Quantitative perspective

  - A quantitative methodology is oriented to the development of knowledge. It focuses on the development of the theories through approaching the objectives, hypotheses, and questions. In this case, if a researcher wants to test the general hypothesis, designs smaller hypotheses and uses the corresponding data to confirm or refute them

- All the different experiments performed during the Thesis follow the quantitative approach

Introduction: methodology

- Besides using a quantitative approach, this thesis follows a formal process called hypothetic-deductive model

    - Using the theory from the knowledge area, the author plans an inductive process (from the particular to the general) to be validated by a deductive process (from a general premise to the particular outcomes).

- About the knowledge level to achieve in each research scenario, most part of the research can be framed as descriptive or exploratory.

Introduction: methodology

- Considering the researcher's role in the research process, all the experiments performed in this thesis follow a non-experimental design.

    - The researcher has not designed previously controlled groups of people when experimenting with the users involved in each research scenario, and there is no control of variables prior to the experiment. It is true that during the experiments the author has controlled somehow groups of users, experimental conditions, and so on, but from the research theory, this cannot be considered experimental or quasi-experimental research designs.

Introduction: methodology

- The orientation of this thesis is to produce conclusions-oriented research. Using the quantitative framework adopted, the author tried to find some responses to the research questions and hypotheses previously presented.

- Regarding the source of the knowledge in the research, this thesis employs two kinds of research: bibliographic and empirical.

Framework

Introduction

Introduction: framework

- This thesis is, in part, a result of the combination of the work done in multiple projects where the author has been involved during the last five years, as well as the collaborations with people around the world, and author's experiences and personal interests.
    - Interest in data science & HCI developed during the Master in Intelligent Systems @ USAL
    - Work & research for the GRIAL Research Group @USAL. Involvement in many national and international R&D projects
    - Collaboration with the USALPHARMA innovation teaching group on using Educational Virtual Worlds
    - Work for the Spanish Observatory for University Employability and Employment (OEEU)
    - Grant received from the Junta de Castilla y León in collaboration with the European Social Fund.
    - The experience as a teaching assistant in the Human-Computer Interaction subject @ USAL
    - The predoctoral research stay @ IBM Research's T. J. Watson Research Center (NY) within the IBM Research AI & Q division.

State-of-the-art

in systems/software architectures supporting Human-Computer Interaction

State-of-the-art

STOA: Introduction

- Workflow: Systematic Literature Review (SLR) and Mapping as proposed by Kitchenham and other authors (Kitchenham, Brereton, Budgen, Turner, Bailey and Linkman, 2009)

- Main questions to answer:

- Is the combination of software architectures and HCI/HMI processes: how can software architectures support HCI/HMI processes?

- How could software architectures help, improve, analyze, intervene or contribute to HCI/HMI processes?

STOA: Methodology

- This review is organized using the main activities proposed by Kitchenham:
  - planning
  - conducting
  - reporting

STOA: Methodology

- Mapping questions:
  - MQ1. How many studies were published over the years?
  - MQ2. Who are the most active authors in the area?
  - MQ3. Which publication vehicles are the main targets for research production in the area? (Journal, conferences, etc.)
  - MQ4. In which domains has it been applied? (e.g. Computer Sciences, Education, Medicine, Business)
  - MQ5. Which kinds of devices have been involved in software architectures supporting or analyzing HCI / HMI processes (e.g. computers, wearables, smartphones, cameras, etc.)?
  - MQ6. What kind of support has been provided by the software architectures to the HMI / HCI processes?

STOA: Methodology

- Research questions:
  - RQ1: What are the trends in software architectures that support or analyze Human-Computer Interaction?
  - RQ2: What are the trends in software architectures that support or analyze Human-Machine Interaction?
  - RQ3. Are there significant differences in the trends of software architectures that support or analyze HCI to those applied to HMI?
  - RQ4: What kind of software architectures have been proposed to support or analyze Human-Computer Interaction?
  - RQ5: What kind of software architectures have been proposed to support or analyze Human-Machine Interaction?
  - RQ6: Are there significant differences in the software architectures proposed to support or analyze HCI to those applied to HMI?

STOA: Methodology

- Review scope — PICOC method— (Petticrew and Roberts, 2008):
  - Population (P): The target group for the investigation. In this study: Software architectures
  - Intervention (I): specifies the investigation aspects or issues of interest for the researchers. In this case, those aspects or issues that provide support or analyze HCI / HMI processes.
  - Comparison (C): the aspect of the investigation with which the intervention is being compared to. No comparison intervention has been planned in the study.
  - Outcomes (O): the effect of the intervention. The goal is to seek for Software Architectures proposals and real-world experiences.
  - Context (C): the setting or environment of the investigation. In this case, they are those environments related to HCI / HMI (in the industry, academia, etc.).

STOA: Methodology

- Inclusion Criteria (the Exclusion Criteria are the negative form of these):
  - IC1: The papers had a software architecture-based solution AND
  - IC2: The presented solution was applied to HCI OR HMI fields AND
  - IC3: The presented solution supported OR analyzed HCI OR HMI processes AND
  - IC4: The papers were written in English AND
  - IC5: The papers were published in peer-reviewed Journals, Books, Conferences or Workshops

STOA: Methodology

- Databases where the search was performed (attending to quality criteria):
  - Web of Science
  - Scopus
  - IEEE Xplore
  - ACM Digital Library
  - Springer Link

STOA: Methodology

- Query string:

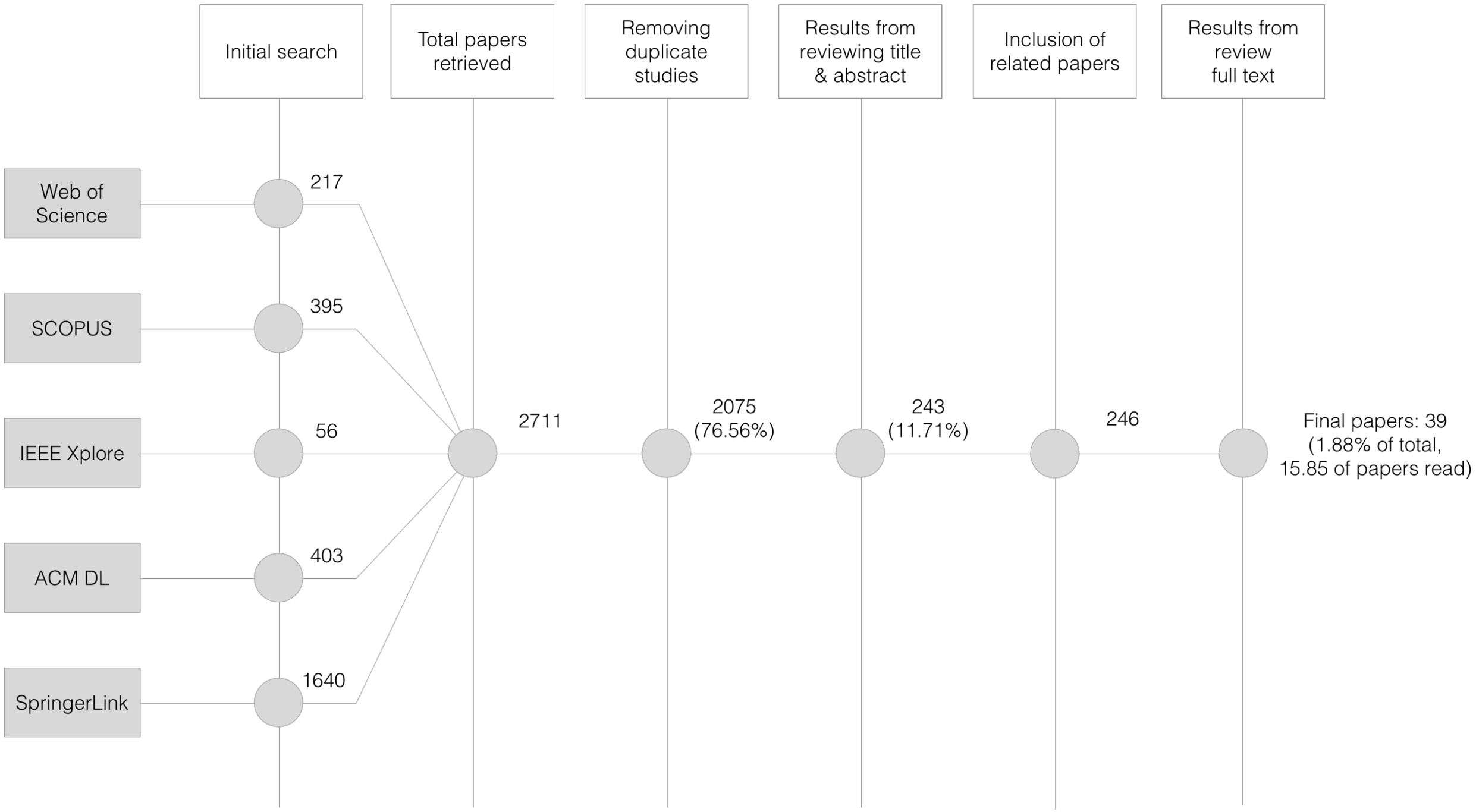
("software architectur" AND ((HCI OR "Human-Computer Interaction" OR "Human Computer Interaction") OR (HMI OR "Human-Machine Interaction" OR "Human Machine Interaction")))*

STOA: Methodology

- Review and mapping process: all the steps are available in public GIT repositories and spreadsheets to provide traceability to the process

  - G Spreadsheet: https://docs.google.com/spreadsheets/d/1msTveEyKp-IHVVQfsSpNjJquzKmvfUj5J6wloXoYME0/edit#gid=1992634926

- GitHub repo: https://github.com/cbjuan/slr-softwareArchitectures-HCI-HMI



Overview of the process

Reported similarly to the PRISMA Statement (Moher, Liberati, Tetzlaff, Altman and The Prisma Group, 2009)

STOA: Methodology

- Process:
    - Execution of the query string in the databases: 2711 papers retrieved (217 from Web of Science, 395 from SCOPUS, 56 from IEEE Xplore, 403 from ACM Digital Library, 1640 from Springer Link).
    - Remove duplicate studies: 2075 (including those that the author did not remove due to the appearance of doubts regarding duplicity).
    - 3.a) Selected papers after reviewing titles and abstracts: 243 (11.71% of the unique papers retrieved). 3.b) Inclusion and review of papers after reviewing the primary paper references: 3
    - Papers selected after reading the full text: 39 (1.88% of the total papers considered, 15.85% of the papers read).

STOA: systematic literature mapping results

- The selected papers were published between 1995-2017
- Include 151 different authors. Only 3 of them authored more than one paper.
- Most papers (22) were published in conference proceedings, while 15 were published in journals and 2 other as book chapters.
- The main source names and the relevance of the conferences, journals, and books where the papers were published are very diverse.
- The application field the selected papers highly varied: aeronautics, (2,56%), BCI systems (5,12%), cognitive systems (2,56%), collaboration systems (2,56%), context-aware systems (7,7%), eyewear computing (2,56%), healthcare systems (10,25%), industrial machines (5,12%), mobile systems (7,7%), multimodal (17,95%), robotics (15,38%), smart environments (2,56%), software engineering aspects (8,16%), ubiquitous environments (2,56%), vehicle systems (2,56%) or eLearning systems (2,56%).
- The main trends regarding design and implementation are related to modular software architectures, layered architectures or architectures based on software agents to conduct the software behavior, features or methods.
- Regarding the interfaces analyzed, the most common ones are those related to GUIs and multimodal and natural interfaces.

STOA: systematic literature review results

- In the papers exist many different implementations and proposals to deal with HCI/HMI from the software architectures, but there is a lack of formal proposals and standardization: most of the papers present custom and ad-hoc solutions to different problems (data transmission, interconnection, patterns, etc.).

- Regarding the methods to conduct or evaluate interaction, there are not common methods, but different common algorithms or heuristic rules adapted to these problems.

- There is a lack of adaptive systems or systems that analyze user interaction based on current trends like artificial intelligence, etc.

- As a result, we believe that more studies focused on the interaction itself and how we can benefit it from the systems and their software should be developed, emphasizing the standardization of techniques and approaches.

STOA: conclusions

- Despite the work done in the past, there is room for new advances and research
- The combination of both areas is active in the community of researchers
- New research should focus on avoiding ad-hoc or use standard solutions
- There are exciting research opportunities in adaptivity, tailorability, users' interaction analysis, etc.
- A paper about this SLR is under review in JCR's Q1 journal

Experimental Research

Overview of the scenarios

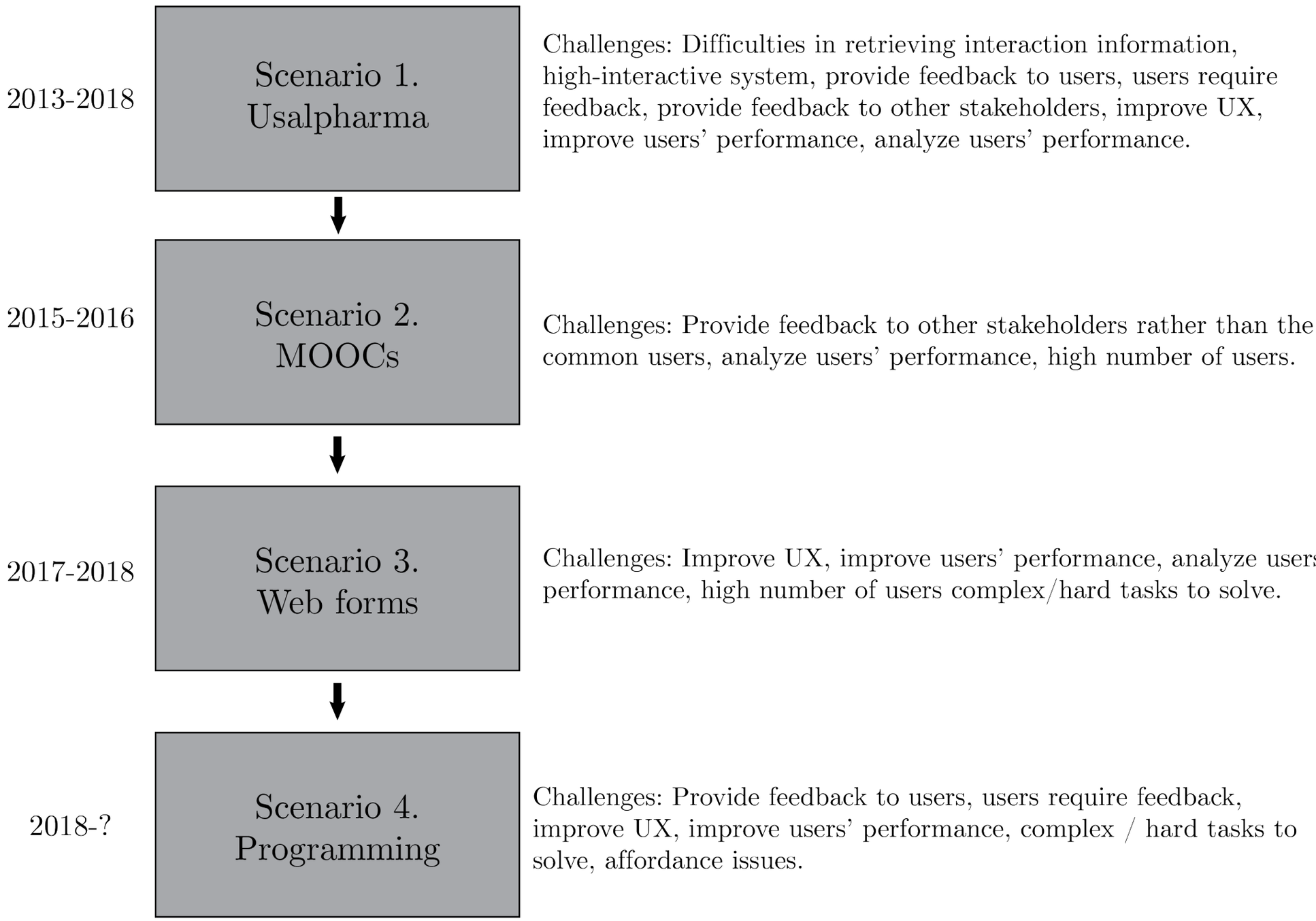
Experimental Research

Experimental research: scenarios

- Scenario 1: Highly interactive scenarios where the users should develop individual activities or tasks based only on their interaction without human aid.
    - The case study selected for this scenario is an educational environment in a virtual world. In this case, the environment is the Usalpharma island hosted in Second Life. This island is designed and built to serve as an educational facility to teach and train students in Pharmacy.
- Scenario 2: Systems including a large number of users collaborating or using concurrently the same resources to solve similar tasks. In this scenario, other stakeholders evaluate the users' performance in solving their tasks.
    - The case study selected is a MOOC (Massive Open Online Course) that includes users' interaction with learning contents and conversations among them in a web platform and social networks.

Experimental research: scenarios

- Scenario 3: Information-intensive applications where the users could need aid and be engaged in solving appropriately the challenges proposed (with challenge understood as the need for solving a task).
    - The selected case study is an extensive web form (consisting of between 30-90 questions) owned by the Spanish Observatory for University Employability and Employment. The study pursues to gain knowledge on how to improve the users' experience and engage them and improving their performance in completing the form.
- Scenario 4: Complex systems where the user might not have enough previous knowledge to solve a task efficiently.
    - The case study selected for this scenario is devoted to understanding how to aid programmers when they develop code in a challenging and new context as quantum programming. In this case, the research was developed by the author during his predoctoral research stay (and is still in progress) in collaboration with the IBM Research AI & Q team.



Planification of the experiments carried out during the thesis and challenges present in each scenario.

Challenge	Scenario 1: Usalpharma	Scenario 2: MOOCs	Scenario 3: Large forms	Scenario 4: Programming QC
Difficulties in retrieving interaction information	X			
High-interactive system	X			
Provide feedback to users	X			X
Users require feedback	X			X
Provide feedback to other stakeholders beyond than the common users	X	X		
Improve UX	X		X	X
Improve users' performance	X		X	X
Analyze users' performance	X	X	X	
A large number of users		X	X	
Complex/hard tasks to solve			X	X
Affordance issues				X

Differences and similarities between the different study cases

Improving virtual worlds users' experience and giving feedback on their interaction to different stakeholders

Experimental Research

ER: Virtual Worlds - Context

- Since the beginning of the use of Virtual Worlds in educational contexts, several authors have pointed out the problems related to knowing what is happening within the 3D environment about users' behavior, the usage of the virtual world features, etc.

- Among the goals of this knowledge of what happens in virtual worlds, highlights the possibility of evaluating offline (outside the Virtual World) what happens online (inside the Virtual World).

- Achieving this goal, teachers related to Educational Virtual Worlds could know completely the learning process that takes place within it so that they could measure the learners' evolution, interest, contents learned, results they get, or even predict abnormal behavior, drop out of students, etc.

ER: Virtual Worlds - Context

- From students point of view, the data retrieved from their usage of a virtual world could help to improve their learning process.

- For example, if there is a system integrated with a virtual world that guides students to achieve learning goals discovering new training process, warning them if they fail, scoring their progress and achievements in educational activities, etc. like a virtual master who helps them improve.

ER: Virtual Worlds - Goals

- Collect and analyze individual users' interaction from a highly interactive environment to extract knowledge and evaluate users' performance solving tasks.

- Test how to take advantage of the knowledge gained, from a software perspective to feedback users and improve their results.

ER: Virtual Worlds - Specific Goals

- Create a system that collects users' interaction from Virtual Worlds.

- Analyze the users' interaction collected using this tool and determine what kind of users' behaviors and performance indicators can be discovered using the data gathered.

- Offer feedback related to the interaction to the students that use Usalpharma facilities to learn about Pharmacy.

- Offer feedback related to the interaction to the teachers that use Usalpharma facilities to teach about Pharmacy.

ER: Virtual Worlds - Materials and Methods

- Second Life Virtual World: Usalpharma island and laboratory, a property of the Department of Pharmacy and Pharmaceutical Technology from the University of Salamanca (to research on improving students' learning process)

- OpenSim Virtual World: an open source virtual world developed by the University of Salamanca (to analyze users' behavior and engagement)

- ~50 users in Second Life

- ~75 users in OpenSim

- +30000 users' interaction pieces of evidence

- +100 hours of interaction analyzed

- Direct data gathering and observation in the case of Second Life Island

- A panel of experts + data analysis in the case of OpenSim

ER: Virtual Worlds - Results

- Results on detecting users' engagement and behavior
  - 5 heuristic rules related users' interaction were discovered and validated with the experts from observing OpenSim logs.
  - From these heuristic rules can be distilled knowledge like taxonomies of users, engagement indicators, patterns of resource usage, etc.
  - Full results published and available in Cruz-Benito, J., Therón, R., García-Peñalvo, F. J., & Lucas, E. P. (2015). Discovering usage behaviors and engagement in an Educational Virtual World. *Computers in Human Behavior*, *47*, 18-25.

ER: Virtual Worlds - Results

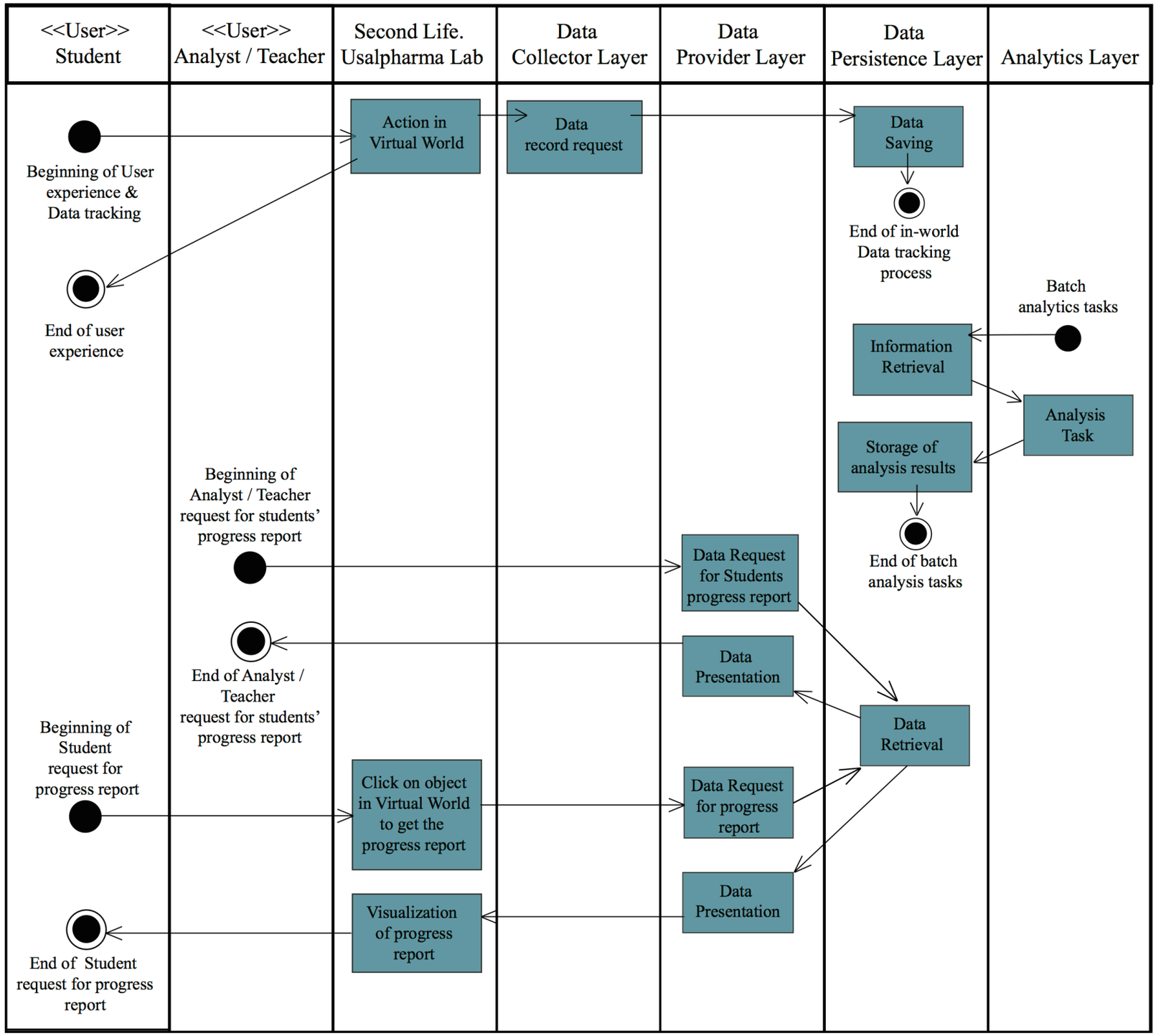
- Results on retrieving information about users' interaction and giving feedback to them in Second Life

  - A technical solution to extract data from Second Life was achieved: client + server schema.

  - Server-based on Python + Django

  - Clients implemented for web and Second Life

  - Use of protocols, methods, and technologies like HTTP, Resource Description Framework (RDF), NoSQL databases, etc.

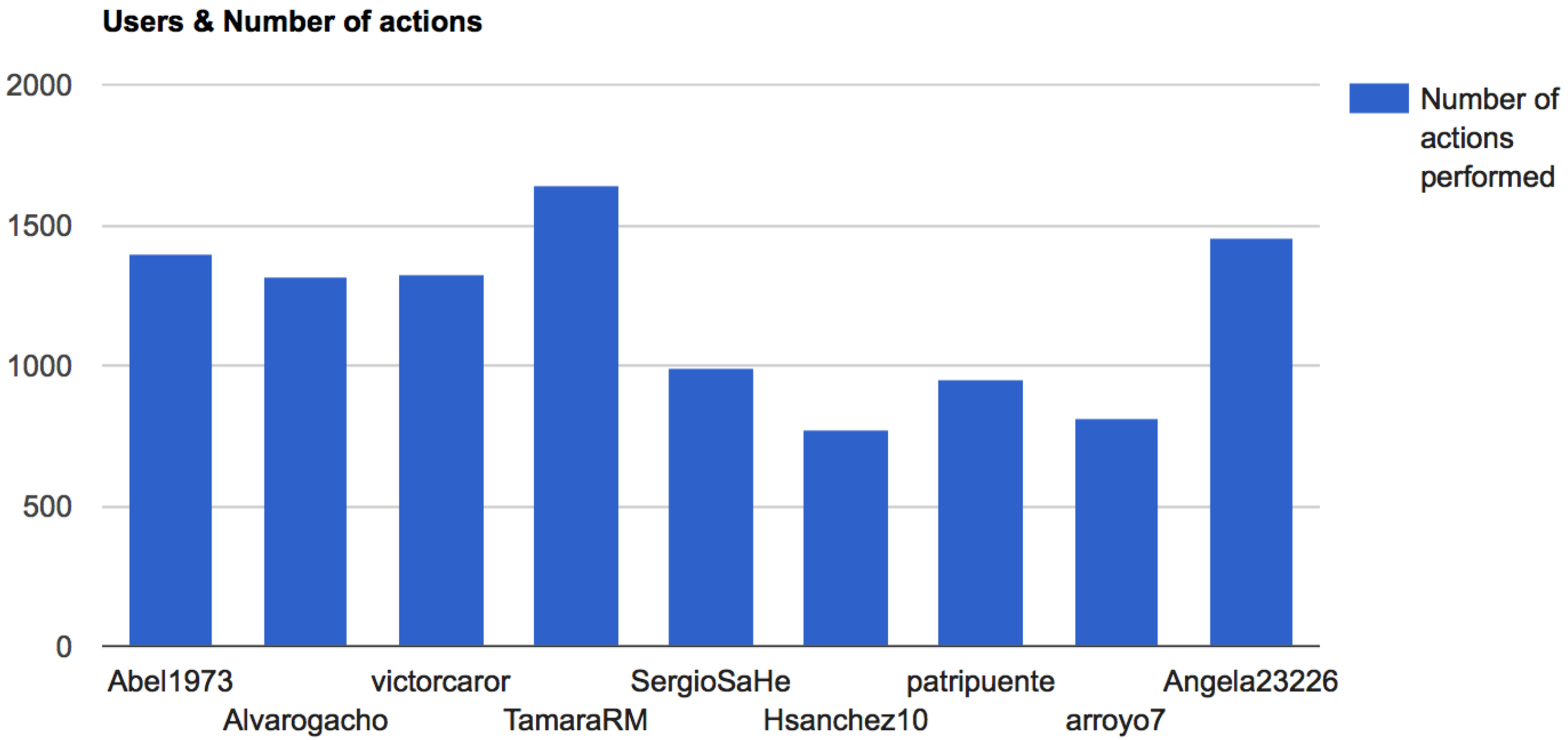


Activity diagram among users, Virtual World, and system.

(*Cruz-Benito, et al., 2017*)

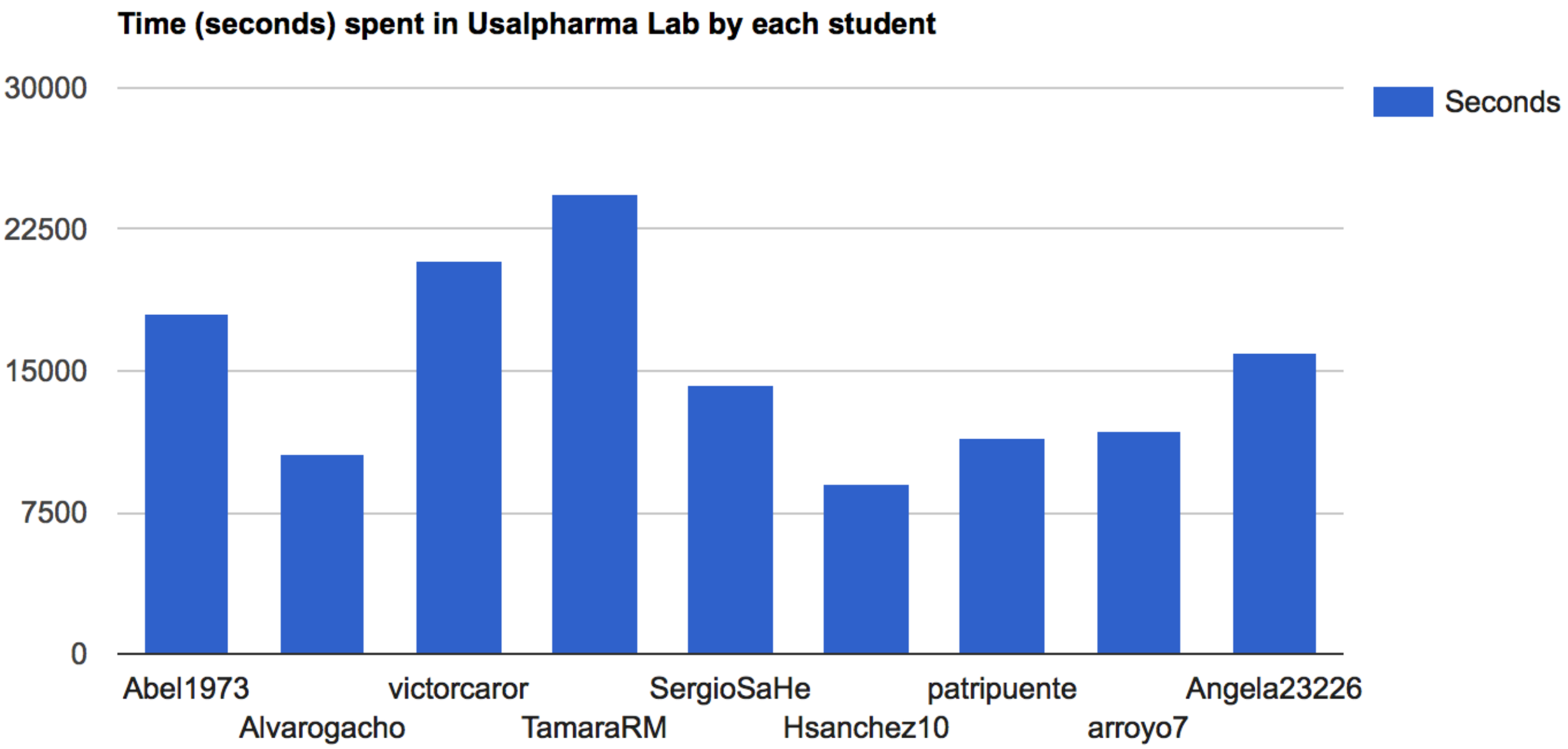
ER: Virtual Worlds - Results

- Using the system developed, teachers and managers from Usalpharma could:
    - Analyze users interaction with objects within the virtual world
    - Feedback students about their progress on learning tasks.



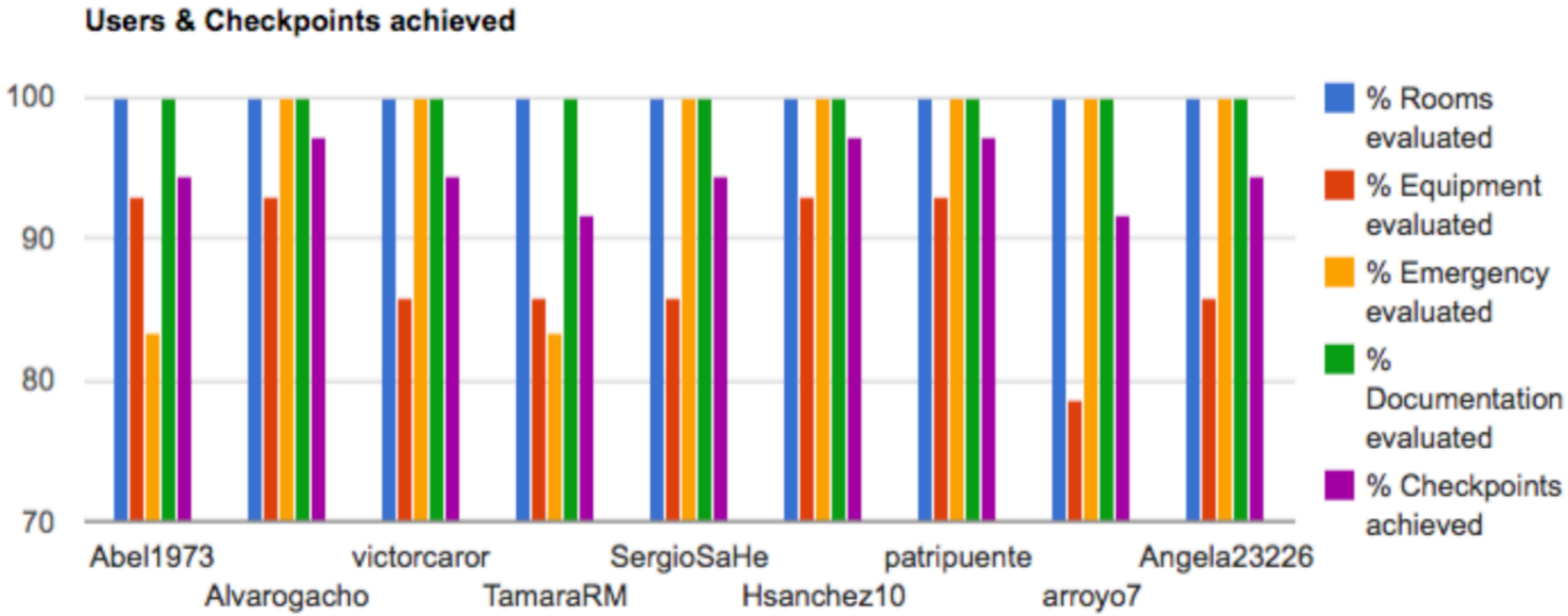
Users and count of their actions within the virtual laboratory

(*Cruz-Benito, et al., 2017*)



Time spent by each student inside the Usalpharma Lab

(*Cruz-Benito, et al., 2017*)



Users and checkpoints achieved in the learning tasks at the lab

(*Cruz-Benito, et al., 2017*)

Feedback to users within the virtual world

(*Cruz-Benito, et al., 2017*)

Despite we cannot establish a causal relation, since the integration of the system to analyze and feedback students, the average mark of them in the practical tasks performed in the virtual world were increased in more than 1 point (1/10, +10% performance)

(Cruz-Benito, et. al., 2017)

Course	Number of students	Average mark obtained (0 to 10)	Standard deviation
2011-2012	14	7.28	1.38
2012-2013	16	7.5	1.27
2013-2014	9	7.81	0.7
2014-2015	9	8.54	0.56

Progression of average mark obtained by each student (system in production since 2013)

(*Cruz-Benito, et al., 2017*)

ER: Virtual Worlds - Results

- The principal results achieved using the system to analyze users' interaction and profile feedback have been published in:

  - García-Peñalvo, F. J., Cruz-Benito, J., Maderuelo, C., Pérez-Blanco, J. S., & Martín-Suárez, A. (2014). Usalpharma: A cloud-based architecture to support Quality Assurance training processes in health area using Virtual Worlds. The Scientific World Journal, 2014.

  - Cruz-Benito, J., Therón, R., García-Peñalvo, F. J., Maderuelo, C., Pérez-Blanco, J. S., Zazo, H., & Martín-Suárez, A. (2014, June). Monitoring and feedback of Learning Processes in Virtual Worlds through analytics architectures: A real case. In Information Systems and Technologies (CISTI), 2014 9th Iberian Conference on (pp. 1-6). IEEE.

  - Cruz-Benito, J., Maderuelo, C., García-Peñalvo, F. J., Therón, R., Pérez-Blanco, J. S., Gómez, H. Z., & Martín-Suárez, A. (2016). Usalpharma: a software architecture to support learning in virtual worlds. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, 11(3), 194-204.

ER: Virtual Worlds - Discussion

- This kind of system is novel in the field of educational virtual worlds (Griebel et al. 2015)

- In the case used, the system was beneficial and useful. In other cases, the researchers must evaluate the need for a solution like this

- For analyzing users and retrieve knowledge from their interaction, the obvious conclusion is that this kind of system is worth.

- For the improvement of users' performance on solving tasks (to learn or not), it is observed an increment of the average mark but without empirical causality validation.

Analyzing MOOCs users' interaction to get insights about their learning processes

Experimental Research

ER: MOOCs - Context

- MOOCs: learning environments which make available to many users (thousands in many cases) virtual classes as knowledge containers that provide open learning resources for all users enrolled in the course, as well as methods and systems to reinforce that knowledge acquisition from different perspectives

- Sometimes MOOCs are combined with social networks and other online tools to improve and upgrade the learning experience.

ER: MOOCs - Goals

- Understand how users collaborate in a large environment to solve (individually) a task shared by all users.

- Integrate a software solution in a massive environment to automatize the analysis performed in the primary objective.

ER: MOOCs - Specific goals

- Design and develop a modular software architecture to allow teachers and managers of a MOOC retrieve knowledge about how users enrolled in a MOOC course utilize some tools external to the MOOC platform.

- Discover how is performed the knowledge acquisition by users when interacting with other peers in environments non-designed for Learning like the social networks.

- Study users' conversations and interactions with MOOC content or related on social networks like Google+ or Twitter and how users use tagging resources on such networks (hashtags).

- Determine if there are patterns or coincidences between the use of social networks and the advance in the MOOC courses by the users.

- Evaluate if it is possible to use the users' usage of MOOCs and social networks to establish parallelism between both and to determine the types of learning that are given in these environments.

ER: MOOCs - Materials and Methods

- iMOOC: a MOOC platform developed by the Technical University of Madrid, the University of Zaragoza and the University of Salamanca. Based on Moodle

- Course “Social Networks and Teaching”, a special version of the course “Application of social networks to teaching” previously developed in the platform MiriadaX (https://goo.gl/EG1sEF).

- Social networks to enhance the course: Facebook, Twitter, Google+

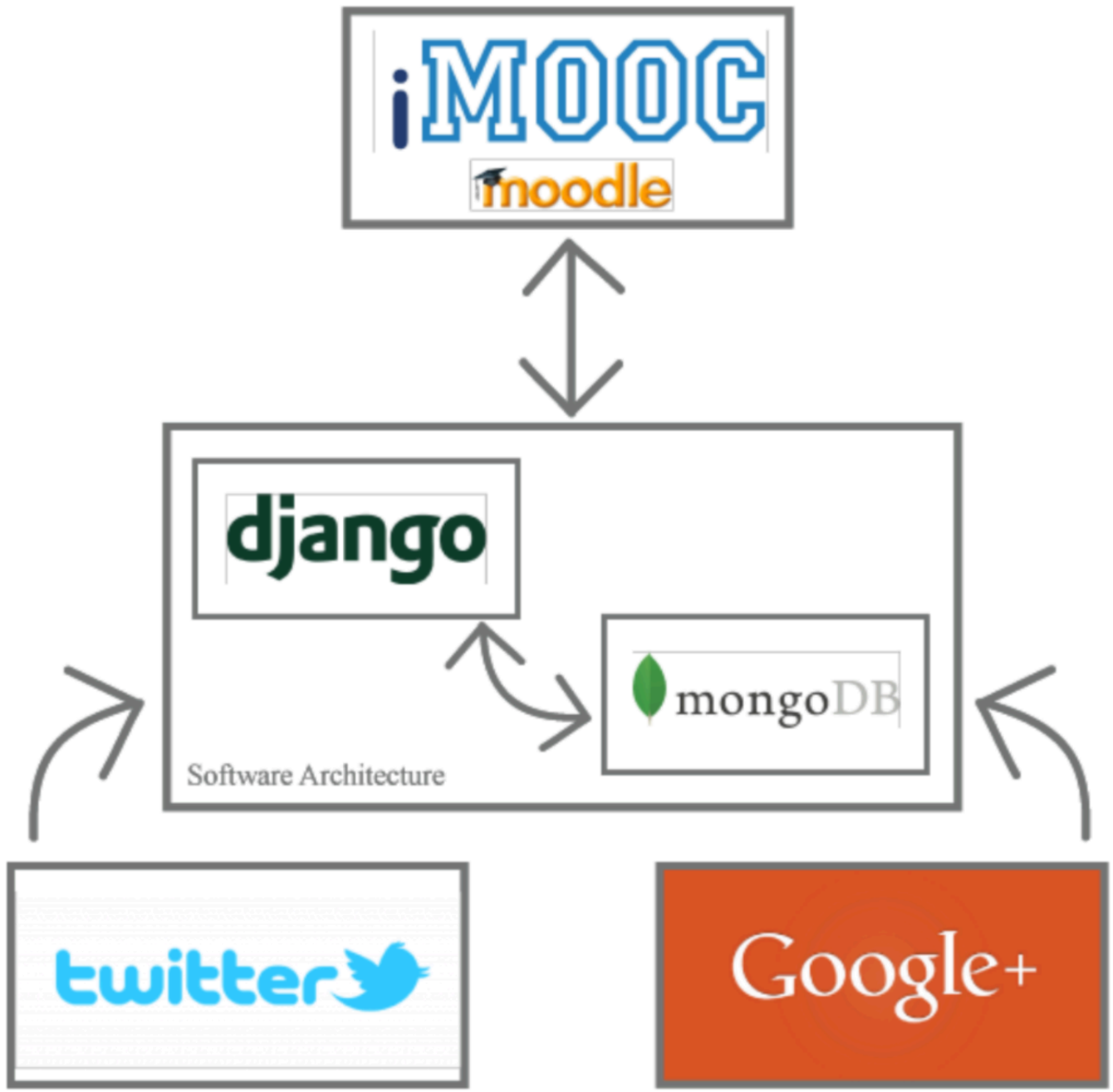
- 793 users enrolled in the course

- Questionnaire to ask users about their use of social networks and MOOC capabilities

- Data gathered about users and their interactions in MOOC and social networks

ER: MOOCs - Results

- Created a system to extend MOOC platform's capabilities and interconnect with other platforms. Based on:
  - REST APIs to communicate with the Moodle platform which is the base for the iMOOC platform
  - Crawlers to get information from social networks
  - GILCA (Google Analytics Informal Learning Communities). This application collects data from Google+ communities through the email notifications sent by the social network
  - Server built on top of Django (Python) + MongoDB



Overview of the software architecture proposal for the experiment related to MOOCs.

(*Cruz-Benito, et al., 2015*)

ER: MOOCs - Results

- It was possible to classify the users on different categories, from the questionnaire answered by users,

- It was observed that many users (depending their experience using digital tools and age) have problems to use comments, tags/hashtags, and other tools to discuss and expand their non-formal learning related to the MOOC course

- It was detected which social network empowers better the collaboration between users in the learning process and to what type of learning (formal, non-formal, informal) are related to each type of comment and social activity

Google +

Publication

Category	Type	Amount	+1s	Comments	*Reshares*	Type of learning
Debates	Proposed throughout the course	1	83	17	14	Non formal (proposed by teachers)
	Use of social networks	4				Informal (proposed by students)
	About learning	3				
	About digital identity	2				
	About digital identity	1				
	About Facebook	1				
	About *badges*	1				
Total posts in the discussion category = 11						
Activities and exercises	Examples of social networks	31	309	41	20	Non formal (proposed by teachers)
	Exercises on bad practices in social networks	25				
	Exercises about Facebook	28				
	About influence (Klout)	22				
	Uses of Twitter in teaching	3				
	Others	2				
Total publications on activities and exercises = 111						
Resources		150	552	66	93	Informal (proposed by the students)

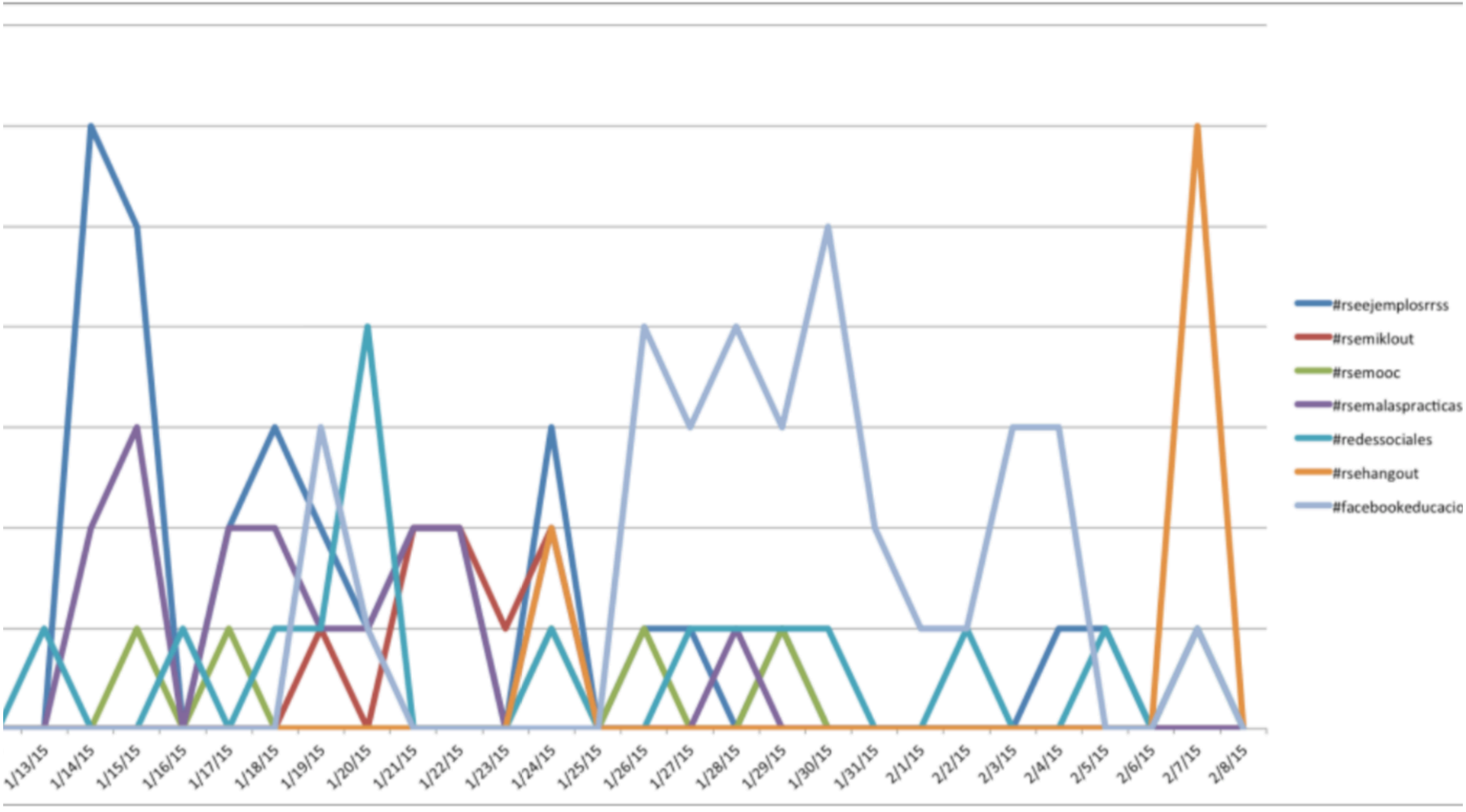
Twitter

Publication

Type	Hashtag	Tweets	Responses	Retweets	Favorites	Type of Learning
General	#RSEMOOC	9	2	5	5	Non formal
	#RSEHANGOUT	19	4	16	15	(proposed by teachers)
	#Modulo1RSE	1	0	1	1	
	#Modulo2RSE	1	0	1	1	
	#Modulo3RSE	1	0	1	1	
Activities and exercises	#RSEEjemplosRRSS	4	1	0	0	
	#RSEMalasPracticas	5	0	1	2	
	#RSEmiKlout	8	1	5	6	
	#RSEMoodleTwitter	59	9	9	11	
	#ActividadesRSE	1	0	3	3	
Total tweets = 107						

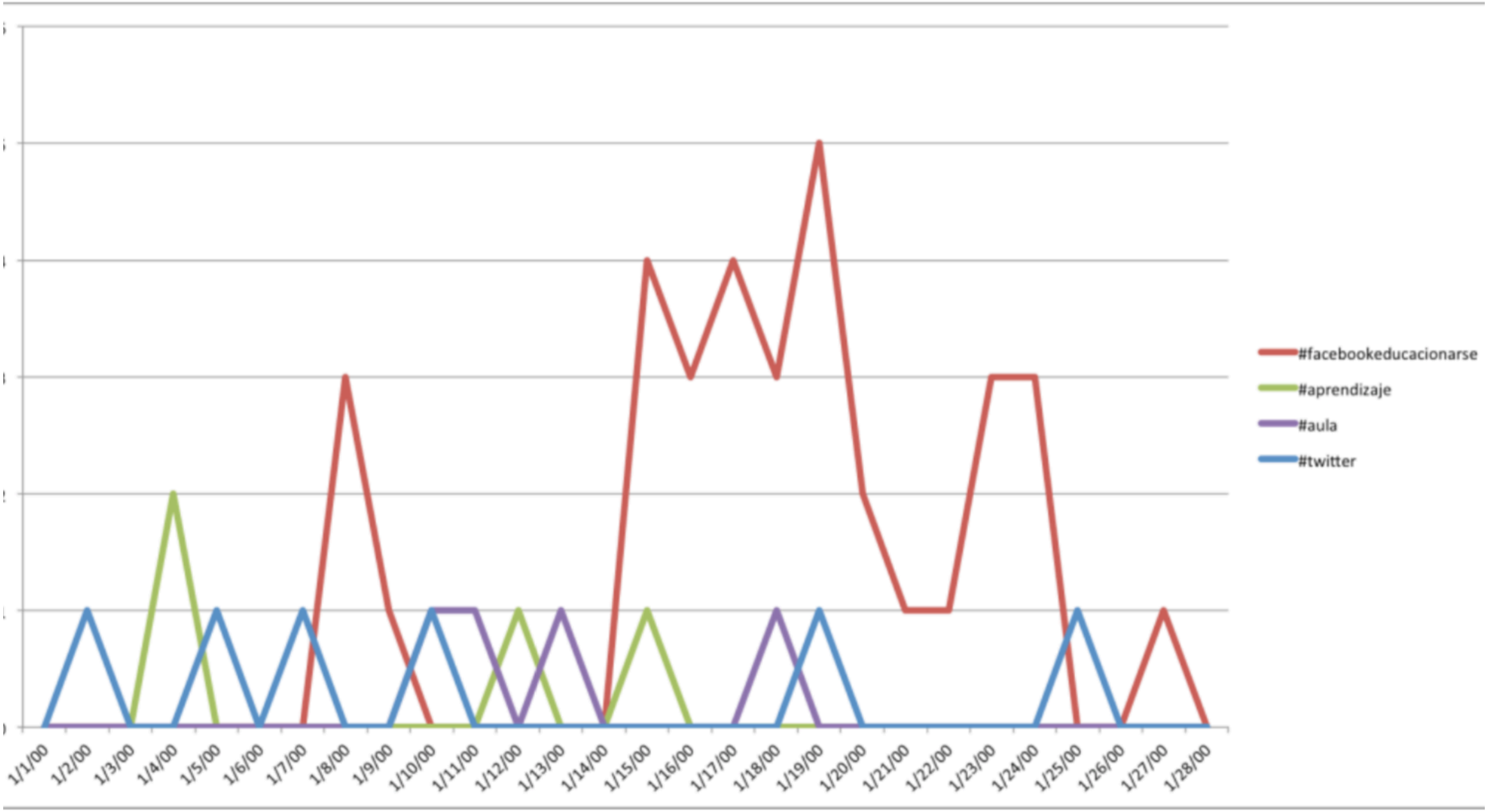
Distribution of interactions on Google+ and Twitter by type of content and learning.

(*Cruz-Benito, et al., 2017*)



Evolution of the use of non-formal hashtags on Twitter throughout the course

(*Cruz-Benito, et al., 2017*)



Evolution of the use of informal hashtags on Twitter throughout the course

(*Cruz-Benito, et al., 2017*)

ER: MOOCs - Results

- Full results published in:

  - Cruz-Benito, J., Borras-Gene, O., Garcia-Penalvo, F. J., Blanco, Á. F., & Theron, R. (2017). Learning communities in social networks and their relationship with the MOOCs. IEEE Revista Iberoamericana de Tecnologias del Aprendizaje, 12(1), 24-36.

  - García-Peñalvo, F. J., Cruz-Benito, J., Borrás-Gené, O., & Blanco, Á. F. (2015). Evolution of the Conversation and Knowledge Acquisition in Social Networks related to a MOOC Course. In Learning and collaboration technologies (pp. 470-481). Springer, Cham.

  - Cruz-Benito, J., Borrás-Gené, O., García-Peñalvo, F. J., Blanco, Á. F., & Therón, R. (2015, September). Extending MOOC ecosystems using web services and software architectures. In Proceedings of the XVI international conference on Human Computer Interaction (p. 52). ACM.

ER: MOOCs - Discussion

- The main drawback of retrieving labeled knowledge (i.e., from social networks), as can be observed in the results, is the lack of digital skills on the part of the participants in this learning communities.

- People of age 50+ use less the digital resources than younger people.

- Digital natives do not necessarily use the digital tools more or better than others.

- Advancing on the analysis could help to classify better the users or predict learning-related aspects.

Analyzing and improving users' experience and performance in web forms

Experimental Research

ER: UX forms - Context

- Analyzing users' interactions or their opinion about what they use makes it possible to ascertain the system's strengths or weaknesses regarding users' experience to improve the system based on evidence

- By knowing user profiles and identifying users' behavior and desires, the system could adapt its components to match users' expectations and likings better, and (probably) boost user performance and satisfaction

- Using this idea, software engineers could develop versions of the system in which different version are shown to each user/ kind of user.

ER: UX forms - Context

- The research has been conducted using a system that belongs to the Spanish Observatory for University Employability and Employment (OEEU)

- This observatory gathers data about employment and employability parameters among the Spanish graduates to analyze the information they provide and understand which are the employment trends and most crucial employability factors for this population

- To do that, the Observatory uses digital tools to retrieve data from universities and graduates

ER: UX forms - Context

- One of these tools generates custom web forms and questionnaires that are to be completed by the graduates after they leave the university. Problem: typically include between 30 and 90 questions.

- This web form was previously used in a gathering process in 2015

- This research was to improve the UX of the questionnaire in 2017 and improve the users' performance in completing it.

ER: UX forms - Goals

- Improve the UX (and engagement) in a complex environment that involves a high amount of information and introduces a high level of friction for users when solving a task.
    - This enhancement of UX seeks to improve the users' performance in the task proposed by reducing the friction.
- Define an automated data-driven pipeline to analyze the users' interaction and improve the user experience.

ER: UX forms - Specific Goals

- Design and validate different changes in the context of an extensive questionnaire regarding users' trust, user experience, usability and engagement with the final goal of improving the users' completion/success ratios.

- These possible improvements should be compared to the questionnaire developed previously by the Observatory for the same topics and context.

ER: UX forms - Specific Goals

- Present a new approach for enabling adaptability in web-based systems using A/B testing methods, user-tracking and machine-learning algorithms that could lead to improving user performance in completing a (large) web form, validating the obtained results through statistical tests.

- Produce all machine learning processes in a white-box way, using algorithms and techniques that allow researchers to understand what is happening in every moment.

- Moreover, to allow readers and other researchers to follow or reproduce the entire process was provided all the code used in the analysis process in Jupyter notebooks available publicly in Github.

ER: UX forms - Materials and Methods

- A literature review (+650 papers) was conducted to determine what kind of changes should be made in different versions of a web questionnaire to improve the users' experience.

- After that, there was a design phase for the different versions of the questionnaire

- The changes proposed were evaluated by experts and changed accordingly to their evaluation

- Later the experiment was carried out with:

  - 7349 total users enrolled in the questionnaire

  - 5768 considered for the experiment

  - 3456 used finally on the analysis and A/B enriched with Machine Learning

ER: UX forms - Materials and Methods

- *Paradata.* To know more about users were used ~50 variables (extracted from the OEEU's information system and a custom data collector)

- Part of the information was taken from the records provided by the university about the student that answers the questionnaire

- Another part was taken directly from the student (clicks, the device used, scrolls performed, etc.).

- The operations/calculations were made using Python + Pandas + Scikit-learn (for ML) and other libraries.

“show different variations of your website to different people and measure which variation is the most effective at turning them into customers (or people that complete successfully a task in the website, like in this experiment). If each visitor to your website is randomly shown one of these variations and you do this over the same period, then you have created a controlled experiment known as an A/B test”

What is A/B testing? (Dixon, Enos and Brodmerkle, 2011)

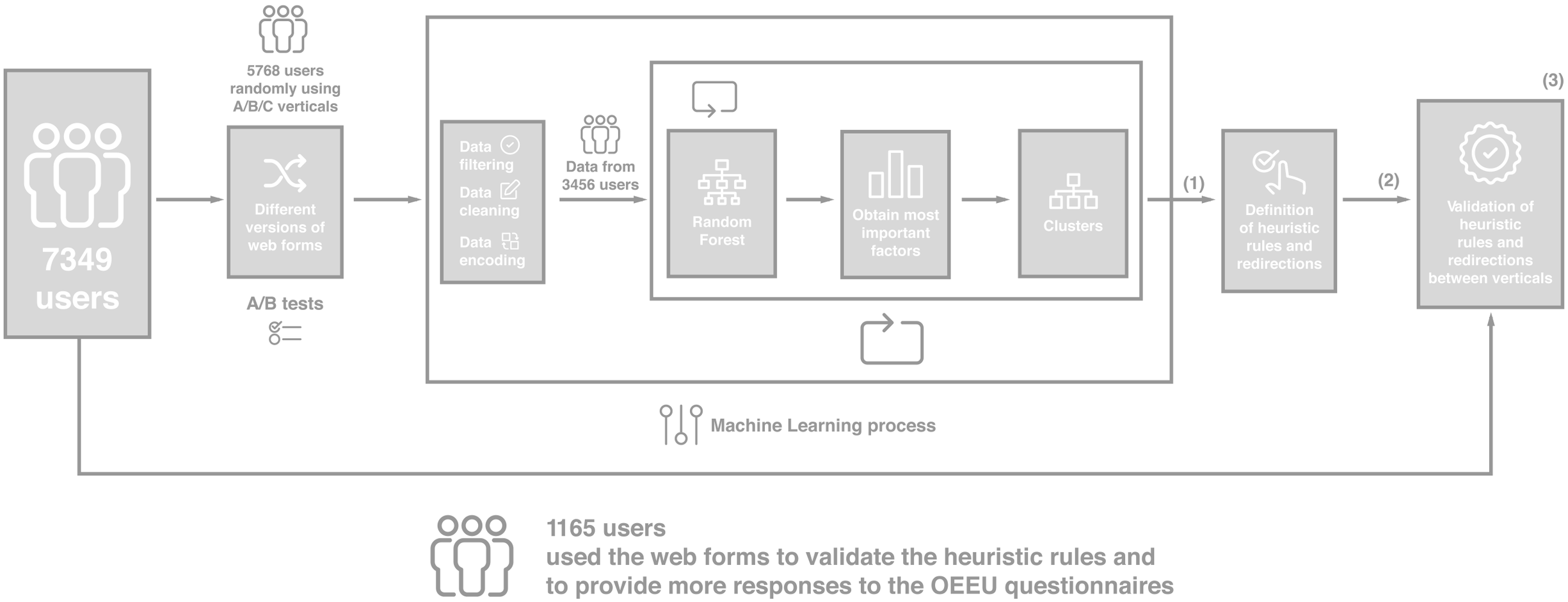
ER: UX forms - Results

- From the literature review, were obtained 11 changes to improve UX in a questionnaire.

- The changes were validated by 5 experts and were improved based on their evaluation before the implementation.

- In collaboration with the other members of the OEEU project, were developed 3 versions of the same questionnaire. Each one implemented different changes from those extracted from the literature.

and the main experiment was conducted



Overview of the process followed to enable adaptability in web forms

(Cruz-Benito, et al., 2018)

ER: UX forms - Results

- First of all, were randomly assigned to the questionnaire 5768 users
- Their performance and information were analyzed, modeling via Random Forest to create a predictive model on what user will finalize the questionnaire what the main factors that affect the users' completion or not the questionnaire are
- Also, using the analysis outcomes were discarded one of the verticals since it performed poorly than the others and there were no differences concerning the parameters for the adaptivity
- In the second round of data gathering, 1165 were used to test our adaptive system based on the parameters detected via ML
- All the code used to generate to adapt each version to the users is available in https://github.com/cbjuan/paper-ieeeAccess-2017

	precision	recall	f1-score	support
False	0.92	0.35	0.51	69
True	0.85	0.99	0.92	263
avg / total	0.87	0.86	0.83	332

	precision	recall	f1-score	support
False	0.92	0.37	0.52	161
True	0.74	0.98	0.85	301
avg / total	0.81	0.77	0.73	462

	precision	recall	f1-score	support
False	0.89	0.37	0.52	132
True	0.74	0.97	0.84	238
avg / total	0.79	0.76	0.73	370

Precision of the predictive model per each vertical

(Cruz-Benito, et al., 2018)

ER: UX forms - Results

- Using the adaptive system, the users' performance was increased: 69.34% previously, 71.59% after the reinforcement with the redirection with adaptivity.

- This improvement on the performance was significative according to the statistical tests performed.

- There are some data about users' feelings to the questionnaire that still have been not analyzed.

ER: UX forms - Results

- Full results have been published in:

  - Cruz-Benito, J., Vázquez-Ingelmo, A., Sánchez-Prieto, J. C., Therón, R., García-Peñalvo, F. J., & Martín-González, M. (2018). Enabling adaptability in web forms based on user characteristics detection through A/B testing and machine learning. IEEE Access, 6, 2251-2265.

  - Cruz-Benito, J., Sánchez-Prieto, J. C., Vázquez-Ingelmo, A., Therón, R., García-Peñalvo, F. J., & Martín-González, M. (2018, March). How different versions of layout and complexity of web forms affect users after they start it? A pilot experience. In World Conference on Information Systems and Technologies (pp. 971-979). Springer, Cham.

  - García-Peñalvo, F. J., Cruz-Benito, J., Martín-González, M., Vázquez-Ingelmo, A., Sánchez-Prieto, J. C., & Therón, R. (2018). Proposing a machine learning approach to analyze and predict employment and its factors. International Journal of Interactive Multimedia and Artificial Intelligence, (In Press).

ER: UX forms - Discussion

- It is worth to comment, first of all, that the A/B testing approach used for this research is not a pure application of such methodology. While A/B tests are commonly based on singular changes between the different experimentation groups (or verticals), in the presented approach the author grouped different changes into the same verticals.

- The white-box ML workflow created can be used in other research (García-Peñalvo, 2018) and it is interpretable by humans.

- The most relevant factors for the adaptivity where not personal ones, but those related to the devices, screen ratio, and size, etc.

- The heuristic rules were generated manually. A future research line could be to generate it using other kind of AI.

Aiding programmers in Quantum programming

Experimental Research

ER: Quantum Programming - Context

- Quantum computing (QC) programming is not currently an easy task.

- New languages like Open QASM and SDKs like Qiskit open new horizons for the research and development within the new paradigm of quantum computing.

- Aiding programmers by enabling recommenders, assistants or other intelligent agents can make this learning curve smoother and help to popularize quantum computing, at least regarding code development.

ER: Quantum Programming - Goals

- Study and propose a way to aid users in solving a complex task, even when they do not have enough knowledge to solve it.

- Secondary goal: create software that helps to aid users and could be integrated into different environments related to the problem.

ER: Quantum Programming - Specific Goals

- Offer help to quantum computing programmers by recommending different code sequences, logical steps or even small pieces of code. The recommendations should be based on the code typed previously by the programmer.

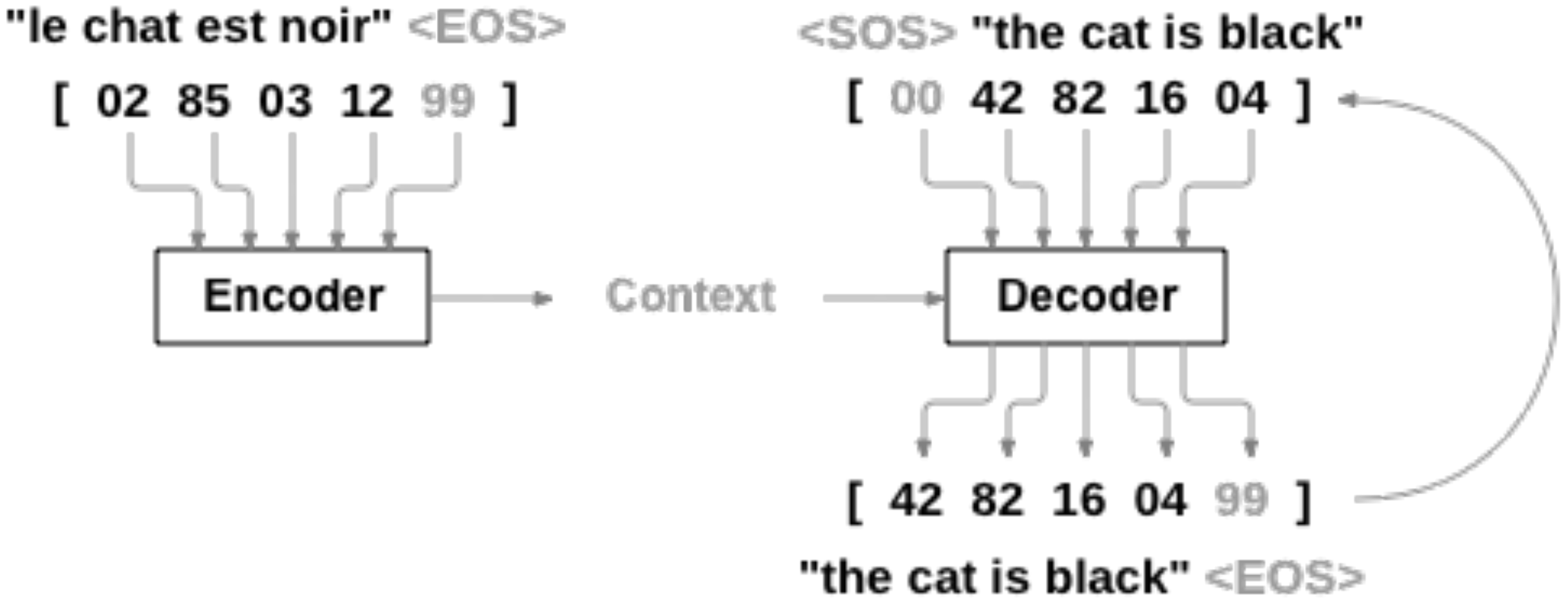
- Implement an intelligent system based on a deep learning approach that learns how people to code using the Open QASM language to recommend code to programmers as described in the previous goal.

ER: Quantum Programming - Materials and Methods

- Natural Language Processing (NLP): sequence-2-sequence neural —*seq2seq*— network model (Deep Learning approach).

- This model consists of two RNN's: "one RNN encodes a sequence of symbols into a fixed-length vector representation, and the other decodes the representation into another sequence of symbols. The encoder and decoder of the proposed model are jointly trained to maximize the conditional probability of a target sequence given a source sequence".

- The RNN is trained with users' code to predict new code blocks.



Overview of a sequence to sequence network using different networks as encoders and decoders.

Taken from (Robertson, 2017)

ER: Quantum Programming - Materials and Methods

- PyTorch framework https://pytorch.org/
- IBM's *seq2seq* library https://github.com/IBM/pytorch-seq2seq
- More than half a million QASM source codes from IBM Quantum systems to train the neural networks involved taken.

ER: Quantum Programming - Results

- A functional implementation of the RNN-*seq2seq* model
- A prediction accuracy of QASM code sentences based on the users' code input of 88-92%
- A REST API to deploy the neural model to be tested with real users (*deep learning as a service* approach)
- For now, the outcomes have been validated by experts from IBM Research. Need testing from real users

ER: Quantum Programming - Results

- The full results have been published in:

  - Cruz-Benito, J., Faro, I., Martín-Fernández, F., Therón, R., & García-Peñalvo, F. J. (2018, July). A Deep-Learning-Based Proposal to Aid Users in Quantum Computing Programming. In International Conference on Learning and Collaboration Technologies (pp. 421-430). Springer, Cham.

ER: Quantum Programming - Next steps

- To complete the experiment, the RNN should be trained with more data (we know we can use more than 4 millions of pieces of code).

- Test the results with real users and gather UX metrics to review the real effect of the solution to the programming challenge.

Overal discussion

Answering research questions

Overal discussion

OD: Answering the research sub-questions

- RSQ1: *What kind of software artifacts does a system require to respond to the users' needs or to be adaptive to users?*

  - A system to gather information from the users and their interactions.

  - A system to analyze the information retrieved

  - A system to provide feedback to different stakeholders and components based on the analysis.

“have a set of tools that collect information about users’ interaction empower the system and administrators to know users and use the knowledge to change the environment to face up users’ needs and behaviors”

OD: Answering the research sub-questions

- RSQ2: *what features should have these kinds of systems?*

  - Transparent data collection.

  - Ethical data collection and exploitation (avoiding dark patterns, etc.).

  - A well-designed data environment.

  - Proper effectors to deal appropriately with HCI challenges.

OD: Answering the research sub-questions

- RSQ3: *what kind of software behaviors related to those features should be the common ones?*
    - The systems should be reactive according to the Reactive Manifesto
        - Responsive
        - Resilient
        - Elastic
        - Message-driven

OD: Answering the research sub-questions

- RSQ4: *what kind of strategies should these systems include to provide valuable feedback to the users?*

    - Gauzy feedback: evident feedback to the users like in the Usalpharma Lab or the quantum programming helper

    - Stealth feedback: hidden feedback, like the redirection between different web verticals

OD: Answering the research sub-questions

- RSQ5: could an intelligent system be capable of improving the UX in a significant manner? Would it be adequate to include intelligent features in a system to pursue such UX improvement?

  - According to the different literature reviews performed during the thesis, the use of AI-related techniques has not been the typical approaches in the field of HCI.

  - As seen in the last two experiments (conducted in 2017 and 2018) the answer is YES, an intelligent system could be capable of helping with the UX improvement of a system

  - The adequacy depends on the goals pursued, the methods utilized (white-box/black-box, etc.) and the data available.

OD: Answering the primary questions

- RPQ1: is it beneficial to follow a data-driven/KDD approach in a system to support, analyze or improve the users' interaction and experience and tackle the HCI-related challenges to these aspects that the interactive systems present?

- The software environments should embrace KDD principles and methodologies to respond properly to the users' needs and improve or support the HCI processes, tackling the typical issues presented in systems that involve users' interaction.

- After developing 4 different research scenarios involving more than 6000 users, this approach has been proved to be a valid one

OD: Answering the primary questions

- RPQ2: How should a software environment evolve to respond to the users' needs and improve or support the users' interaction and experience? How is it possible to do that in a more automated way?

- To embrace the data-driven or KDD approach, software environments need to extend their software architectures to cover also the issues related to Human-Computer Interaction.

- In the sub-questions have been presented the different minimal software components required, the different types of feedback to provide and reinforce the users' interaction and experience.

OD: Answering the primary questions

- RPQ2: How a software environment should evolve to respond to the users' needs and improve or support the users' interaction and experience? How is it possible to do that in a more automated way?
  - Since many years ago, the HCI community has been seeking for new ways of automatizing the evaluation of users' interaction, adapt systems automatically to the users, retrieve information to extract knowledge, etc.
- The work done in this thesis does not solve the problem but shows some exciting approaches to deal with the problem from the software perspective to influence what users feel and perceive.
- Some of the solutions presented are ad-hoc, but many other can establish the foundations to be applied similarly in other challenges and contexts.

OD: Final reflections

- Albeit I have worked with more than 6000 users, the final valid data for the different scenarios came from only ~1500 users (after data cleaning, validation, etc.)

- The most exciting experiment and experience carried out during the thesis is the 3rd scenario (adaptivity on web forms):

  - Several kinds of results: a traceable machine learning workflow, the application of different algorithms that could be interpretable by researchers, the improvement of users' performance, as well as to be the most valuable demonstration achieved on how AI techniques can be applied to face HCI challenges.

OD: Final reflections

- The least exciting experiment was the related to MOOCs.
  - This case was planned in the beginning as an excellent opportunity to experiment with a high amount of users and with new kind of systems that usually need the extension of their features using new software components.
  - In this case, the software components designed and the overall software architecture could be the most exciting result.
- Regarding the users, some issues reduced the interest of the possible results: first of all, the users enrolled in the MOOC course were not as many as expected (there were some MOOCs organized in the same platform that involved more than 5000 users).
- Also, the conversations and interactions between users in the different social networks analyzed were not as meaningful as expected.

Conclusions & further work

About literature reviews

Conclusions

Conclusions

- The primary outcomes of the research undertaken for this thesis were the literature review and mapping of software architectures affecting Human-Computer Interaction and the development of different software solutions in different scenarios to analyze, support and enhance the users' interaction and experience.

- Many authors have been working over the years in the definition, development, and testing of software solutions based on software architectures to deal with the analysis and enhance of users' interaction with computers.

- Despite this effort, the literature shows that there are many applications based on ad-hoc solutions and a lack of formal proposals and standardization.

Conclusions

- In the review, a lack of intelligent software that could enable new ways of interaction analysis, feedback to users, etc., was also observed.

- It is clear that the advance in the integration of new trends like data-driven environments, artificial intelligence or reproducible workflows for analysis and feedback of users can lead to a significant improvement in the research area.

Conclusions

- There is a need for conducting research focused on the definition of standardized techniques and novel approaches to deal with the analysis, support, and enhancement of the users' interaction and experience using software environments.

- I have been detected a significant number of publications outside the academic papers that deal with similar goals than those specified in this thesis.

Is the academia missing a good opportunity to establish the foundations for new ways to extract knowledge from users' interactions and experience?

About experimental research

Conclusions

Conclusions

- The research and development of software solutions to analyze, support and enhance the users' interaction and experience carried out in the different case studies has been conducted following the recommendations that are given in the literature and considering the different needs and possible improvements detected in the reviewed literature.

Conclusions

- In this sense, in the empirical research performed, the following aspects have been validated as positive:

  - Define data-driven software systems.

  - Develop clear information workflows (using KDD principles) to help different stakeholders with the issues related to the users' interaction and experience.

  - Employ novel techniques to analyze the available data and provide feedback consequently the users.

Conclusions

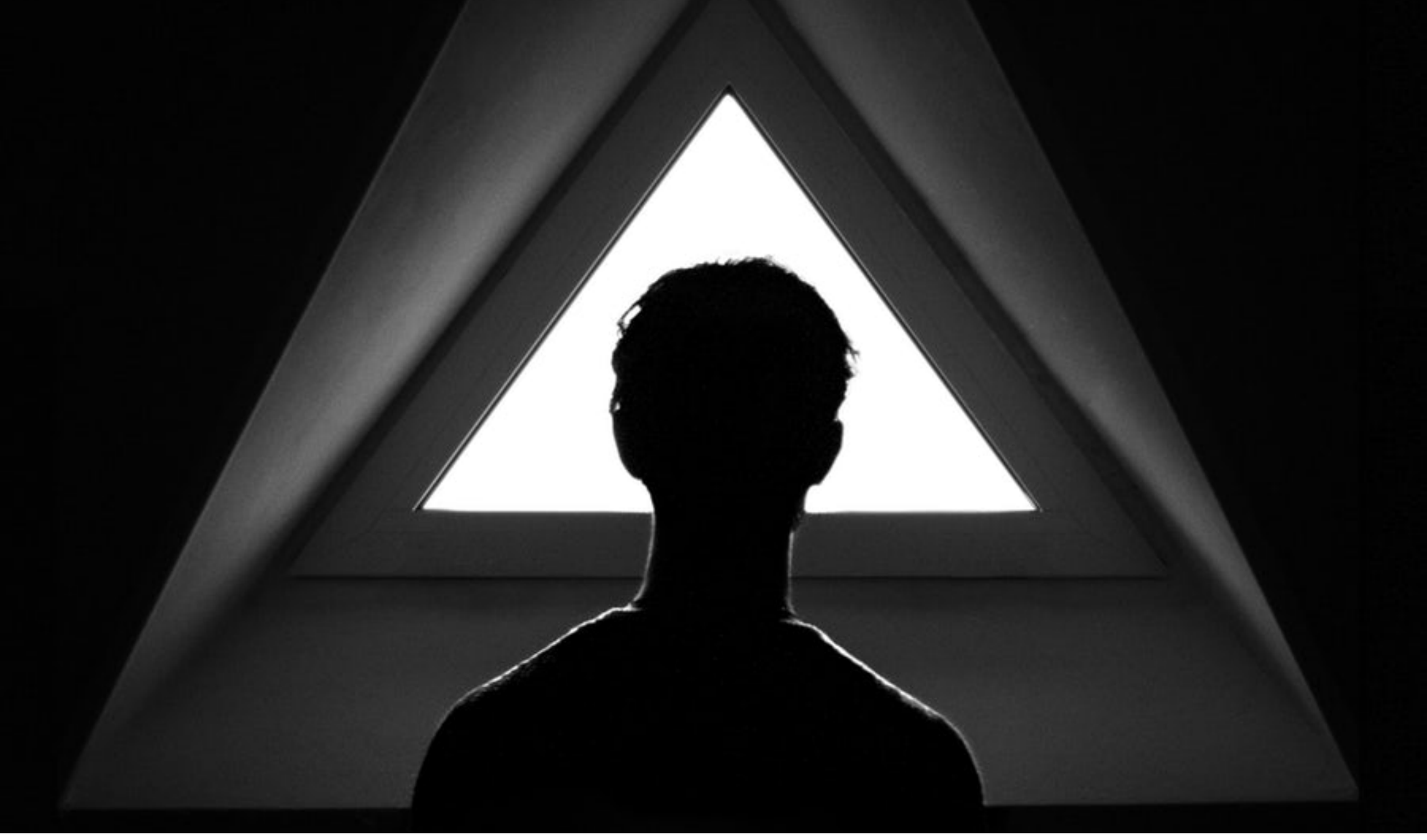
- On the need of extracting knowledge, during the experimental part of this thesis it has been demonstrated that many different kinds of stakeholders (humans and software ones) can take advantage of the knowledge raised by the human-computer-interaction-related information.

- A deeper understanding on this information could help these stakeholders to evaluate users' interaction, to detect users' behavior, to extract performance patterns, to engage users in different tasks, or to help them to solve a difficult task.

Conclusions

- Concerning the different techniques used to analyze data and extract knowledge, those that present a significant novelty and the most promising results are the AI-related techniques and its subareas (machine learning, deep learning).

- The analysis techniques to be applied in each case depend on the problem to solve, but using artificial intelligence and approaches like supervised learning, unsupervised learning or natural language processing can be adequate to automate part of the knowledge extraction tasks and build workflows to tackle some common challenges in analyzing, support and enhance the users' experience and interaction.



Further work

Further work

- The first topic to research could be the analysis of other different applications of AI techniques to evaluate the users' interaction and experience and try to detect which of them are suitable to automate the improvement of users' experience.

- The second one could be a study on what kind of AI techniques could help researchers and software engineers to create adaptive HCI-related systems.

Further work

- Expand this research in the definition of a catalog of white-box algorithms and analytics workflows to extract knowledge from data and to explain the results in the area of analyzing users' interaction.

- It would be very valuable to define a catalog of relevant metrics to be included in any system that aims to analyze, support or improve HCI processes.

Further work

- Within the software engineering knowledge area, the standardization (through software patterns, meta-models, etc.) of the ideas related to software architectures is challenging research, in order to create a general framework and contribute to the development of new HCI-centered systems.

- Also, it would be very significant to develop software frameworks that could be pluggable to other software environments or technological ecosystems to extend them using the results of the standardization outlined above.

Further work

- Similarly, in the HCI knowledge area, a further research line is to continue the work performed in the case study of large forms to analyze the effect of each proposed change in the form on the users' performance, trust, and experience.

- Another research line that could be relevant is to propose better methodological models to support the experimentation with users in systems that evolve to support or improve HCI processes.

- Moreover, of course, test all of the ideas and knowledge from this Thesis in other research scenarios and systems.

Outcomes & merits achieved

Publications

- 11 papers published in journals
  - 2 JCR - Q1.
  - 7 Scopus.
  - 2 in other minor indexes.
- 21 papers published/presented at international conferences.
- 2 book chapters.
- 2 books.
- 2 technical reports.

Software released

- 3 software repositories
    - 2 with the full AI/ML workflows used in the different experiments: http://doi.org/10.5281/zenodo.1009618 and https://doi.org/10.5281/zenodo.1040464
    - 1 including all the information and data from the systematic literature review (ensuring the traceability and reproducibility of the research): http://doi.org/10.5281/zenodo.1101169

Official records on intellectual property

- 2 accepted by the Spanish Government and the regional government (Junta de Castilla y León
- Another 3 under review

Predoctoral research stay

- IBM T.J. Watson Research Center (NY, USA)
  - Department: IBM Research AI & Q
  - Supervisor: Ismael Faro Sertage
  - Period: 20/09/2017 – 22/12/2017
  - Topics: Human-Computer Interaction, Software Engineering, Artificial Intelligence

Awards

- Best paper award (jointly with other colleagues) in the track International Workshop on Software Engineering for E-Learning (ISELEAR'17) within the International Conference Technological Ecosystems for Enhancing Multiculturality (TEEM) 2017.

Grants received

- 4 different grants
    - 3 awarded by the University of Salamanca to fund my publications and assistance to conferences
    - 1 grant awarded to contract me as research staff during my thesis, co-funded by the Junta of Castilla y León and the European Social Fund (EDU/310/2015)

Acknowledgments

Questions?

On data-driven systems analyzing, supporting and enhancing users' interaction and experience

Ph.D. Thesis

Candidate

Juan Cruz Benito

Supervisors

Roberto Therón Sánchez, Ph.D.

Francisco José García Peñalvo, Ph.D.

Sept 03, 2018