Tecnologías y Aprendizaje:

Investigación y Práctica

Manuel E. Prieto-Méndez, Silvia J. Pech-Campos y Agustín Francesa-Alfaro

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Índice

Identificación de Elementos Clave en el Estudio de Casos Clínicos para su Gamificación

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Resumen. La gamificación es un proceso modificador de rutinas que sirve para mejorar la condición humana creando experiencias agradables en contextos que son ajenos a lo lúdico, beneficiando así aspectos como la motivación y el aprendizaje. En la actualidad existe un interés por el desarrollo y la aplicación de guías prácticas, tanto para la prevención, como para la atención de diversas situaciones en el contexto clínico de la salud. El objetivo de este estudio es generar un modelo mediante teoría fundamentada, en el que se identifique cómo los médicos estudian y definen casos clínicos, para posteriormente añadir elementos de gamificación. Los resultados obtenidos revelaron elementos clave de casos clínicos y su relación para crear una experiencia gamificada. El modelo propuesto resulta en un punto de partida para transformar el estudio de casos clínicos de la literatura médica a un contexto lúdico e interactivo mediante el desarrollo de herramientas tecnológicas.

Palabras Clave: Gamificación, Casos Clínicos, Simulación, Teoría Fundamentada.

1 Introducción

Un juego es una actividad recreativa en la que se compiten bajo un conjunto de reglas y en la que se ejercita alguna capacidad o destreza. Los juegos están por todas partes, sencillamente con la finalidad de crear experiencias [1]. Históricamente se ha defendido el uso del juego para mejorar la condición humana de forma que la unión de distintas tecnologías como la web, modelos empresariales digitales y juegos en línea basados en localización dio lugar a la manifestación reciente de esta idea [2].

La gamificación es el proceso de cambiar un conjunto de operaciones tradicionales a una atractiva experiencia de juego para el usuario [1]. Además se convierte en una tendencia que se centra en la aplicación de la mecánica del juego a contextos ajenos, con el fin de involucrar al público e inyectar diversión en las actividades mundanas, capaz de generar beneficios motivacionales y cognitivos [3].

La aplicación de la gamificación sobresale como una herramienta que modifica rutinas tanto a nivel individual, como organizacional. La gamificación habilita también el desarrollo de juegos inmersivos en ambientes virtuales en los cuales se motiva a los usuarios a realizar acciones deseadas, mediante aplicaciones en el ámbito académico

Intelligent Data Centric Systems

Series Editor Fatos Xhafa

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CHAPTER

1 CHARTING THE PAST, PRESENT, AND FUTURE IN MOBILE SENSING RESEARCH AND DEVELOPMENT

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1.1 INTRODUCTION

With the advent of smartphones and mobile technologies capable of sensing the environment at reasonable costs, an emerging area has been helping researchers capture data from large groups of populations scattered across large regions. This area, dubbed mobile sensing, has been gaining traction as research relying on mobile technologies has been increasingly carried out in the wild, yielding better results with ecological validity. Mobile sensing allows researchers to collect data at precise times and locations, and these sensors are stored in remote repositories for detailed scrutiny. For instance, data can be collected through sensors (e.g., GPS, accelerometer, and microphone) used by older adults to infer their functional status (e.g., frailty syndrome, mobility, and physical activity) and compared to data obtained by physicians during assessment interviews. However, utilizing mobile phones for research purposes does not bind the findings just to an individual's affairs, but allows the scope of research to extend far beyond the immediate proximity of the phone or sensor, into the surrounding environment, whether physical or societal. For example, mobile phones can be used to map social behavior that can be linked to reported levels of wellbeing within a city.

The field of mobile sensing will be instrumental in several areas of research and development. In particular, research in health care is poised to be infused with mobile sensors derived from the precision medicine initiative (PMI) [1]. In this medicine model, medical treatments are tailored based on a personalized approach, taking into account individual differences (e.g., genetic, contextual, environmental, and behavioral). In this approach, intelligent datacentric computerized systems can be useful for defining better medical treatment and health outcomes.

The use of mobile technologies for wellness—mobile phones in particular—has been increasing over the last few years. This is particularly true for mobile phone applications that aim at increasing a person's wellness, such as calorie counter, physical activity, and socialization apps. This also holds true for the development of commercial sensors such as Fitbit (http://www.fitbit.com) or much more specialized brands such as Polar (http://www.polar.com), which are usually accompanied by mobile phone applications to notify findings.

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In this chapter, we present an analysis of the pervasive trends in the mobile sensing field. We first identify relevant studies by following a research procedure for conducting scoping reviews, which includes a search strategy to identify published studies, defining an inclusion and exclusion criteria, papers selection, abstracting and charting relevant data, and summarizing and reporting the results. A scoping review is defined as "a type of literature that identifies and maps the available research on a broad topic" [2], which can be used for varied purposes [3]. Then, we analyze the selected studies to identify how technology has provided a large range of types of sensors and how researchers use them. Other papers have reported similar studies [4–17], but to the best of our knowledge, this is the first work aimed at presenting such analysis in the area of health care and wellness. We have focused our analysis on understanding what types of studies have been carried out using mobile sensing that have an impact on health care and wellness.

In particular, we reviewed the methodological design of each paper to identify data that enabled us to determine the type of contribution and to assess the quality of the evidence provided. With this information, we proceeded to classify each paper according to a set of criteria defined by the authors of this paper, such as the sensing paradigm utilized, the subject area of the publication, the types of sensors used in the study, and the application domain to which the studies were applied, mainly health care and wellness.

As a result, we characterize the evolution of the area mainly in terms of the types of sensors used in mobile sensing studies (see Section 1.2). Since 2003, this research area has been gradually developing and can be split into three major research interests that have been gaining attention as the area unfolds: (1) the construction of custom sensing devices, (2) the use of on-device built-in sensors, and (3) the use of commercial sensors. As shown in the Results section, most studies follow the opportunistic sensing paradigm rather than the participatory sensing paradigm. In terms of sensors, researchers have been increasingly using external sensors, as many of them are available off-the-shelf and provide reliable data. Also, during the first years, much of the efforts in the field of mobile sensing were aimed at constructing new sensors. Lately, researchers have been concerned with making sense of the data collected.

In terms of health care and wellness, we found that extensive research has been carried out in engineering areas. Although some studies have included researchers from the field of medicine, they represent only a small proportion of the total number of papers.

To present this review, we organize the book chapter as follows: (i) we first introduce the three main research interests in mobile sensing development; (ii) then, the methodology used for searching the studies analyzed in this work is described; (iii) next, the aggregated results are described; and (iv) finally, we discuss the future of the field of mobile sensing.

1.1.1 RESEARCH AND DEVELOPMENT IN MOBILE SENSING

Mobile phone sensing is a relatively new area of research that has come into existence in part due to the development of tiny, cheap sensors that can be incorporated into mobile devices. This research area, as such, has been gradually developing during the last 15 years and can be split into three different focuses of attention that have been gaining momentum as the area unfolds: (1) the use of custom sensing devices, (2) the use of on-device built-in sensors, and (3) the use of commercial sensors. These three research divisions speak for the development of sensors in particular and the manner in which this development has been influencing the area. As shown in this paper, the development of sensors for mobile sensing was initially led by researchers in academia and later by those in industry.

1.1.1.1 The use of custom sensing devices

The first major research focus in mobile sensing used several devices that were built to meet a particular research need. These sensing devices were mainly crafted after the technology was mature enough to combine sensors that would fit in a box that subjects could carry with them in an unobtrusive way. In some studies, sensing devices with storage mechanisms were used and researchers analyzed the information after downloading it from these devices [18–20]. An early example of a custom sensing device is the Sociometer [20], a shoulder-mounted device with an embedded accelerometer, an infrared (IR) sensor, and a microphone.

As the capabilities of mobile phones increased, they were often used along with custom sensing devices. Advanced feature phones could store a considerable amount of information and communicate with external sensors and remote servers, and also had acceptable processing power. While the custom-made device sensed the environment (or the subject), the phone usually communicated with this device via Bluetooth to collect and save the data in its storage or send it through the network to remote servers for analysis. Also, advanced feature phones enabled researchers to inform subjects of their status as well as correct bad sensor readings. One such example can be found in Ref. [21], where the user received feedback on her physical activities with a glance at the screen of the phone.

Nowadays, modern mobile phones or smartphones include several kinds of sensors. In addition, many specialized sensors are on the market. However, many of those sensors are not suitable for all types of studies. Researchers will always find new variables to measure using different means, so custom-built sensing devices will still be needed, for the time being. As sensors become more manageable and smaller, they could be easily concealed (see Ref. [22]) or embedded.

This first research focus of mobile sensing, although limited, was important as it introduced new ways to sample the outer world, introducing different techniques for observation and data collection.

1.1.1.2 The use of built-in sensors

The second field that gained momentum in mobile sensing research started with the emergence of smartphones. By 2007, mobile phones began to embed sensors for a better user experience (e.g., accelerometers and gyroscopes) and for novel types of services that involved knowing the user's location and orientation (e.g., GPS and compass). With these augmented mobile devices, researchers began to exploit the advantages of their ubiquity and pervasiveness, in addition to their increased capabilities of perceiving and measuring the outer world and their ever-increasing storage, processing, and communication capabilities.

Recent papers have shown that researchers are able to infer several aspects of subjects, like the quality of their sleep [23,24], their level of stress [25], their wellbeing [24], their surroundings [26,27], and even personality traits [28,29]. The usefulness of mobile phones with built-in sensors does not end at the personal level; they also have contributed at the social level, where researchers look for ways to infer social behavior and interaction patterns [30–33], or at the community level, where they help map and identify urban situations and tendencies, like identifying noise pollution in a city [34], mapping potholes, bumps, and chaotic places in a city [35], or predicting bus arrival [36].

Even though the development of built-in sensors in mobile phones and other wearable devices is improving, being able to infer information on situations in the outer world is still an open problem. This is mainly due to the changing nature of the context being inferred, apart from the fact that sensor readings are often noisy. Some real-world situations exacerbate that problem: for instance, carrying a mobile phone in the pocket or purse.

As new sensors are embedded in mobile phones, the number of ways to measure the outer world will increase. At the same time, finding alternate means of using certain sensors will also unfold. For instance, utilizing Bluetooth or microphones as social sensors has become very useful when working with groups of people.

While this research focus area has certainly gained momentum, and mobile phones indeed have many capabilities, certain studies demand on-body sensors placed at particular locations for increased accuracy. For instance, a heart rate monitor at the wrist can enable continuous readings rather than the sparse, often clumsy, readings obtained from a similar sensor on a mobile phone.

1.1.1.3 The use of commercial sensors

As sensors became embeddable and the market matured, devices were created to measure several variables. Health-related gadgets that include sensors such as Baumanometers, heart-rate monitors, pedometers, or calorie counters have been on the market for some years. With the arrival of smartphones and standards for personal area networks, a broad set of applications for these devices began to arise.

Commercial sensors not only help users in their daily lives, but they have also been adopted by the research community for different purposes. In the literature, two main uses for commercial sensors along with mobile phones were found: (1) as a tool to get the ground truth (i.e., they are used to compare with the results of a study using an alternate method), and (2) as a companion to the mobile phone. To illustrate the former, in Ref. [23] they developed an algorithm that uses built-in mobile phone sensors to infer when a person is sleeping and the amount of time they slept. Then, they compared the results with commercial gadgets that compute that information: Jawbone's UP that uses a wrist band, and the Zeo Sleep Manager Pro that uses a head band. To illustrate the latter, in Ref. [37] researchers used the Emotiv Epoc Electroencephalography (EEG) headset to control the address book dialing app of the smartphone with the mind of the subject.

Generally, the usage of external commercial sensors seems to be influenced by the limits of technological development in mobile phones. That is, the device placement and sensors available make the mobile phone suitable for some studies but very limited for others. However, often in these types of studies mobile phones are used to store, process, and send data to remote servers as well as to offer feedback to users.

1.2 METHODS

The scoping review was conducted by the authors of this paper, who have expertise in the development of platforms for carrying out sensing campaigns and in the development of medical informatics technologies. The authors worked in pairs to conduct the search, selection, data abstraction, and analysis of three randomly assigned groups of papers. Thus, each pair read a subset of all the studies (title and abstract for screening, and full text for final selection) independently. To increase reliability they discussed ambiguities of inclusion criteria until consensus was reached. At the end of each methodology phase, results were presented to the overall team to be discussed.

1.2.1 SEARCH AND SELECTION PROCESS

To identify high-quality literature to be included in this paper, we conducted the following search process:

1. Search on Google Scholar. We used the search phrase "mobile sensing" and retrieved the references from the first five results pages. Our search was conducted in December 2016.

2. “Snowballing” [37]. We scanned the reference lists from the full text papers that matched the inclusion criteria, and selected the ones that included the following keywords: mobile, phone, smartphone and sensing in their title, or a composite phrase using two or more of those words. The selected references were looked up on Google Scholar to filter out the ones that were not relevant for the aim of this review.

We used the following criteria to select relevant studies:

- Papers published in journals, conferences, and book chapters.
- Papers written in English.
- Papers reporting results that contribute to the development of the mobile sensing area and/or that apply mobile sensing technologies to study a research problem, e.g., a health-care domain problem.

These criteria were used in a peer-review manner by each subteam. A first selection stage was based on screening and binary rating of abstracts (0: exclude; 1: consider for inclusion). To facilitate the management of study references, they were uploaded to Mendeley reference managing software, which was also used to discard duplicate papers. Afterwards, a review and assessment were carried out on full papers to extract data from the research reported.

1.2.2 DATA ABSTRACTION

Each paper was assigned to two reviewers (authors of this paper), who completed an online form with each paper’s descriptive information such as publication year and type (journal, conference, or book chapter). Additionally, reviewers agreed on how to categorize papers based on a taxonomy of study characteristics that was defined to determine the addressed issues, open challenges, and limitations and opportunities for future research.

1.2.2.1 Reviewed papers’ contribution

We reviewed the methodological design of each paper to extract data that enabled us to determine the type of contribution and to assess the quality of the evidence provided:

- *Study type*: We identified the main contribution of each paper:
  - o A survey/review to map the relevant literature on mobile sensing.
  - o A framework or toolkit designed for addressing challenges associated with the development of sensing campaigns.
  - o A sensing study conducted to understand the behavior of some variables, which includes identifying which variables are correlated, e.g., finding a link between mobility and depression; or for making inferences, e.g., using machine-learning techniques to infer physical activities from accelerometer data.
- *Ground truth*: An important aspect of sensing studies to consider is the inclusion of a reference to measure the performance of the classification or inference process. This reference, known as ground truth, could be objective, when it consists of data collected through an already validated/reliable technological instrument (e.g., a GPS), or clinical instruments (e.g., using the mini-mental state examination (MMSE)). Ground truth could also be subjective, when it is obtained through participants’ self-report.

1.2.2.2 Data collection techniques

This set of characteristics was extracted to identify trends in the techniques, including the types of mobile technologies used for data collection. They help us determine what, how, and when the data collection was conducted.

- *Sensing scope*: This is related to the main focus of a sensing study (i.e., situations about the subject or about the surroundings of the subject): it can be person-centric or environment-centric. Person-centric focuses on situations about the person carrying the phone or mobile technology, by monitoring or sharing information that the person considers is sensitive [10]: for instance, location, daily life patterns, physical activities, health condition (e.g., heart rate and glucose level). In environment-centric sensing, the data collected relates to the person's surroundings, and could be shared with everyone for the public good. It involves sensing environmental data (e.g., noise, air pollution) or fine-grained traffic information (e.g., free parking slots, traffic jam information) [10].
- *Sensing paradigm*: This refers to the way the user intervenes in the study. This classification is not new, as it has been mentioned in Refs. [10,11]. There are two types of sensing paradigms: participatory sensing and opportunistic sensing. Participatory sensing means that the user actively partakes in collecting data. Users can decide when, what, and how to capture data. It can also be the case that the study suggests to users when to collect data as a call to action, so users are directly involved in the process of collection. In the opportunistic sensing paradigm, users are only the device bearers and they are not explicitly participating in data collection. The sensing system by itself makes all of the decisions according to a schedule or an event, and does not require active user participation.
- *Types of mobile sensors*: It includes mobile phone's built-in sensors (e.g. accelerometer, GPS, microphone, etc.). However, as of today no smartphone has incorporated all the sensors available in the market. In terms of space, it would be very difficult to fit them all; also, in terms of energy, it would be challenging to power them all. Indeed, there are many sensors that can communicate with smartphones via personal area networks communications protocols (e.g., Bluetooth). Therefore, we also identified external sensors custom-made to gather information about specific conditions (e.g., pollution, cycling cadence), and commercial sensors (e.g., Fitbit). Additionally, we identified if the phone was used as a hub for storing/processing/uploading data collected from external or commercial sensors.

1.2.2.3 Multidisciplinary research

- *Research areas*: Reveals the different research and domain application areas that were involved. We identified whether clinical and social sciences areas were involved in each research study, to either assess and/or conduct it. This involvement was evident through the papers' coauthoring information (i.e., researchers/practitioners from clinical areas appeared as coauthors), or if they report that an institutional review board (IRB) was formally designated to assure that the study protocol included appropriate steps to protect the rights and safety of the participants.
- *Subject area*: Additionally, each paper was classified according to the subject areas as provided by the journal [38] and conferences [39] rankings. Alternatively, for those not appearing in these rankings, we reviewed their call for papers to determine the area to which they contributed. Thus, we classified paper contributions as Computer Science/Engineering (Cs/Eng), Medical and Biological area (Med/Bio), and Social Sciences and Humanities.

1.2.2.4 Health care application domain

Finally, we also identified which papers reported studies addressing medical conditions and/or wellness issues, and classified them by using the following criteria:

- *Dimensions of wellness*: Wellness is defined as a positive outcome that is meaningful for people. It helps to know how people perceive that their lives are going well [40]. This category includes papers measuring indicators of specific living conditions (such as the quality of their relationships, stress, and environmental noise level), and/or using the collected data to make participants aware of a well-being condition. The wellness conditions were categorized in seven dimensions [41]: social wellness, physical wellness, emotional wellness, career wellness, intellectual wellness, and environmental wellness.
- *Type of disease*: Studies addressing a medical condition were classified as Communicable disease, which is caused by infectious agents such as influenza, hepatitis or HIV/AIDS; and as noncommunicable disease, which is noninfectious or nontransmissible, such as depression, obesity, cancer, or diabetes [42].

1.3 RESULTS

We identified 77 papers that fit the inclusion criteria: 14 of them reported a literature review or survey, and the remaining 63 were included in this review. All selected papers were published from 2003 to 2016. Eighteen papers refer to studies published in journals, 44 in conference proceedings, and 1 in a book chapter. Table 1.1 summarizes the data abstracted from the papers. Papers suitable for inclusion were counted for each category. Some categories were not mutually exclusive, such as type of mobile sensors, as some papers included more than one type (e.g., built-in sensors, external sensors). Thus, this means that some papers were considered in two or more categories: i.e., some papers were counted more than once.

1.3.1 SENSING SCOPE AND PARADIGM

Fig. 1.1 shows that, during the reported years, there was more opportunistic than participatory sensing. We found that 57 papers used an opportunistic approach (as opposed to 20 papers in which participatory sensing was used). However, it is important to consider that several studies, 14 to be precise, combine these two sensing paradigms, such as [21,27,29,43–53]. As seen, not many papers were published prior to 2007, when the first smartphone became available. There seems to be a valley between 2011 and 2014, which could have been the result of the search terms used. The trend in the number of papers published, however, seems to be steadily increasing. We found more studies that are person-centric (PC = 49) than environment-centric (EC = 17), with the opportunistic and person-centric combination the most used (44 papers).

1.3.2 STUDY AIMS AND CONTRIBUTIONS

There are 34 papers reporting the use of an objective ground truth to compare and assess their results, which is more than twice the use of subjective ground truth (14 papers). From the 20 papers categorized as not using any ground truth, 13 present a framework or toolkit, while the remaining 7 report sensing studies by using reliable commercial sensors or mobile phone built-in sensors to study the users'

Table 1.1 Characteristics of Papers Analyzed

Sensing Paradigm O: Opportunistic P: Participatory B: Both	Ground Truth O: Objective S: Subjective N: Not used			Type of Mobile Sensors B: Built-in E: External C: Commercial			Sensing Scope P: Person E: Environment		Subject Area C: Cs/Eng M: Med/Bio B: Both			Application Domain W: Wellness D: Disease O: Others			Multidisciplinary Y: Yes N: No	
	O	**S**	**N**	**B**	**E**	**C**	**P**	**E**	**C**	**M**	**B**	**W**	**D**	**O**	**Y**	**N**
O (43)	26	8	11	34	13	1	31	13	40	1	2	18	4	23	5	38
P (6)	3	0	3	4	2	1	5	1	6	0	0	4	2	1	2	4
B (14)	5	6	6	13	1	0	13	3	11	3	0	9	2	5	6	8
Total (63)	34	14	20	51	16	2	49	17	57	4	2	31	8	29	13	50

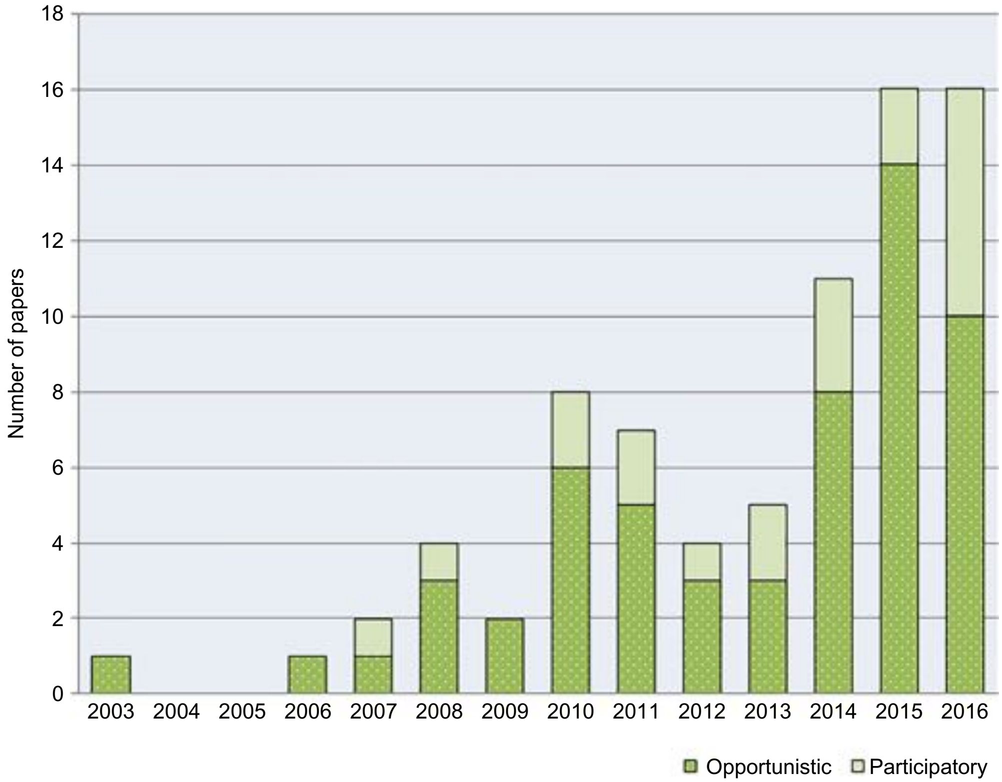

FIG. 1.1

Number of papers for opportunistic and participatory sensing paradigms.

attitudes or behavior related to a wellness condition. For instance, in Ref. [54], they use the mobile phone's GPS and body sensors to monitor the heart rate and body postures to map a cycling experience.

Also, following Fig. 1.2, it can be seen that there has been an increase of papers employing predictive models (e.g., machine learning) rather than more descriptive ones (i.e., based on statistical correlations). Perhaps not very surprising is the fact that the first papers describing a toolkit or framework for carrying out sensing studies were published in 2007, which corresponds to the year in which the IPhone was presented. The iOS, despite its popularity due to the way it handles background processes, has not been the platform of choice for developing those toolkits or frameworks. Table 1.2 presents the references to the papers reporting frameworks and/or sensing studies, categorized by the sensing paradigm that they followed.

1.3.3 HEALTH CARE APPLICATION DOMAINS

We identified 34 papers addressing a wellness and/or disease condition, while 29 pertain to other application domains, such as transportation and activity modeling. As presented in Table 1.3, 31 out of the 34 papers report sensing studies trying to infer a wellness condition, e.g., monitoring a person's stress level [25,52] or sleep [23]; and 8 papers address diseases like common cold and

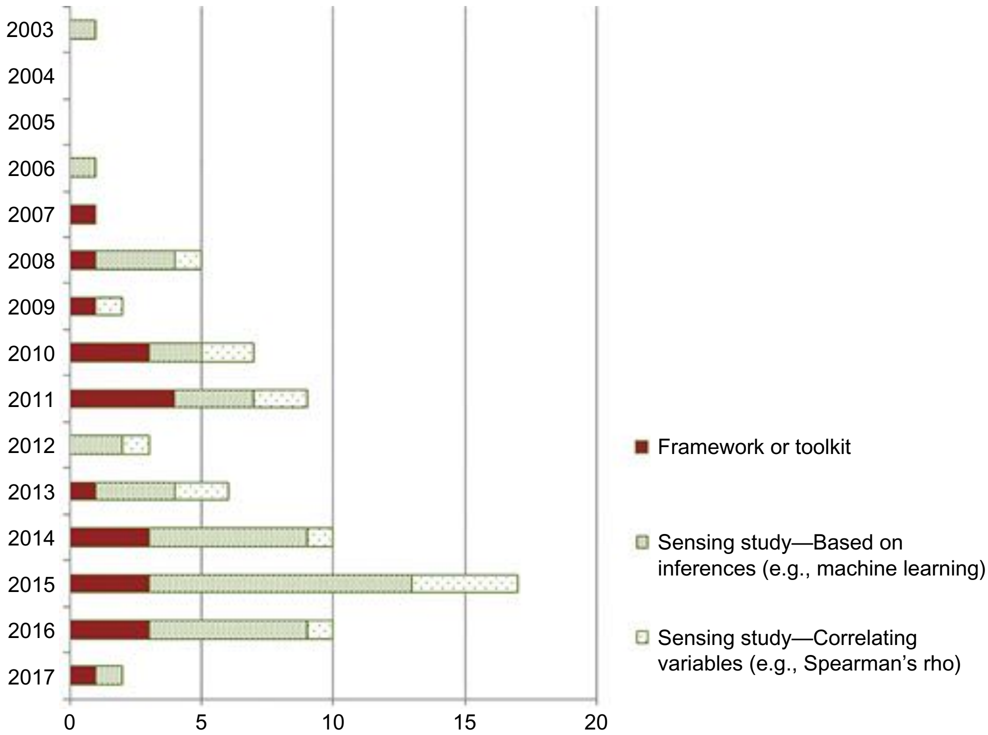

FIG. 1.2

Number of studies by *study type*.

Table 1.2 References to the 63 Papers Categorized by *Study Type* and *Sensing Paradigm* Characteristics

Study Type	Participatory	Opportunistic	Both
14 Frameworks	[55–58]	[59–65]	[43,47,48,51]
42 Sensing studies	[66,67]	[19,20,23,25,26,28,31,32,34–36,54,57,68–86]	[29,44–46,49,50,52,53]
7 Frameworks + sensing studies	[87]	[22,24,30,33]	[21,27]

influenza [50], schizophrenia [86], and dementia [57]. As seen, most of the studies on wellness focus on 4 of the 7 wellness dimensions that we used: the physical (13 papers), emotional (9 papers), environmental (6 papers), and social (5 papers).

1.3.4 MOBILE SENSORS

For the papers reported, different types of sensors were used, mainly from three sources: (a) 51 out of the 63 papers used the smartphone itself (built-in sensors), (b) 16 used custom external devices or sensors, and (c) 2 commercial external devices. Generally, the sensors that fit into these three sources are

Table 1.3 References to the 34 Papers Addressing Wellness or Disease Conditions Categorized by *Sensing Scope* and *Sensing Paradigm*

Refs.	Wellness				Disease		Sensing Scope		Sensing Paradigm	
	So	Ph	Em	Env	C	NC	PC	EC	O	P
[54]		✓					✓		✓	
[68]				✓				✓	✓	
[73]		✓					✓		✓	
[53]		✓					✓		✓	✓
[57]						✓	✓		✓	
[85]			✓			✓	✓		✓	
[86]						✓	✓		✓	
[66]				✓				✓		✓
[60]		✓					✓		✓	
[55]		✓					✓			✓
[59]				✓				✓	✓	
[46]			✓				✓		✓	✓
[76]				✓				✓	✓	
[56]						✓	✓			✓
[78]				✓				✓	✓	
[67]		✓				✓	✓			✓
[45]			✓				✓		✓	✓
[21]		✓					✓		✓	✓
[23]		✓					✓		✓	
[24]	✓	✓					✓		✓	
[25]		✓					✓		✓	
[26]			✓			✓	✓		✓	✓
[30]	✓						✓		✓	
[31]	✓						✓		✓	
[32]	✓						✓		✓	
[33]			✓				✓		✓	
[34]				✓				✓	✓	
[52]			✓				✓		✓	✓
[75]		✓				✓	✓		✓	
[79]		✓					✓		✓	
[44]		✓					✓		✓	✓
[87]			✓				✓			✓
[50]	✓		✓		✓		✓		✓	✓
[49]			✓				✓		✓	✓

So, *social;* Ph, *physical;* Em, *emotional;* Env, *environmental;* C, *communicable;* NC, *noncommunicable;* PC, *person centric;* EC, *env. centric;* O, *opportunistic;* P, *participatory.*

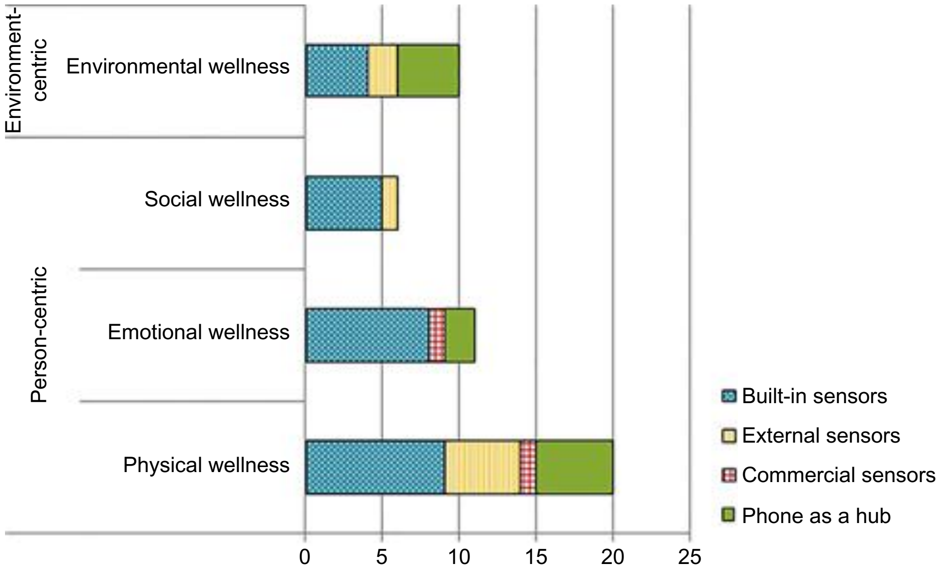

FIG. 1.3

Number of papers using different *types of sensors* in wellness-related studies by *sensing scope*.

called hard sensors, as their purpose is to measure the real world and they generally are based on the use of hardware (e.g., microchips). However, there is another type of sensor based on software: logs about the use of the mobile phone (e.g., call logs, SMS logs, internet usage logs, calendar logs, social network logs) [28,49–51,61,88]. These "sensors" virtually exist in almost every mobile phone. Usually, these sensors have been used to infer social or personality traits of the user. According to Félix et al. [6], most studies prior to 2016 used hard sensing (e.g., accelerometer, GPS, Bluetooth and microphone), since on-device hard sensors are the most accessible and less obtrusive. These statements are reinforced in this review as illustrated in the graph of Fig. 1.3, which presents how many papers, addressing a wellness condition, report using each of the types of mobile sensors. For instance, from the 6 studies on environmental wellness, 4 papers report using built-in sensors, while 2 out of 6 used external sensors, and, finally, 4 used the phone as a hub for processing data. Thus, this graph provides an appreciation of the focus of most studies. While a few of them have focused on studying environmental issues through mobile sensing, the vast majority have focused on the individual, studying aspects related to wellness such as physical, emotional, or social.

1.3.5 MULTIDISCIPLINARY RESEARCH

Even though it is evident how mobile sensing is being applied or used to study research health care issues, there are more studies published in venues or forums related to computer science and engineering [Cs/Eng = 57] than in medical and biological [Med/Bio = 4]; and only 2 papers were classified as both Cs/Eng and Med/Bio. This is associated with the fact that most of the papers do not report collaboration with health care researchers or practitioners, or include an IRB from this area.

In Fig. 1.4 it can be seen that, whereas the sensing scope was mainly person-centric, engineering-only areas tended to be more diverse in that they mainly addressed issues that go beyond the individual.

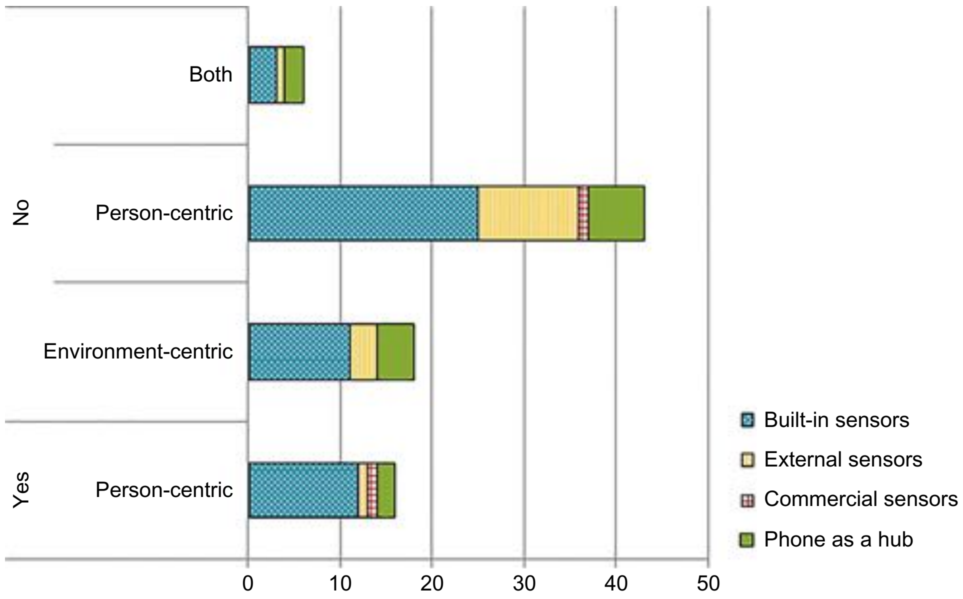

FIG. 1.4

Number of papers using different *types of sensors* in a particular *sensing scope* by studies that include clinical departments or health care researchers (yes = including clinical areas; no = only engineering areas).

As expected, the involvement of clinical areas focused mainly on the individual, i.e., person-centric sensing scope. Also, as opposed to what one might think, most studies that also include health care researchers rely on sensors that are embedded in mobile phones rather than on commercial sensors or external ones.

1.4 CONCLUSIONS

Mobile sensing is increasingly becoming a part of everyday life due to the rapid evolution of sensing platforms. Diverse applications such as social networks, health care, environmental monitoring, transportation safety, and social business can vastly benefit from the contributions of mobile sensing. This chapter discusses the current state of the art in the emerging field of mobile sensing. We have analyzed a large amount of research works and sensing applications and have summarized the observed trends in those research works.

Mobile phone built-in sensors are by far the most used types of hard sensors. This is expected, as they are now readily available in modern mobile phones. In addition, more recent papers seem to have favored the development of studies that include external sensors such as wireless electrocardiograms (ECGs) [87], electroencephalography (EEG) headsets [37] to control mobile phones, or out-of-voice-band microphones [76] used for identifying nonspeech body sounds, such as sounds of food intake, breath, or laughter. This is mainly due to new devices that allow wireless connection between the mobile phones and those devices, mainly via Bluetooth.

Most of the research on mobile sensing that studies medical and wellness conditions is being published in venues pertaining to the engineering and computer science areas; however, some multidisciplinary work is being conducted (barely). This is expected to change in the years to come due to the aforementioned precision medicine initiative, in which medical areas will be using mobile-sensing technologies to monitor patients or create much more precise characterizations of health-related conditions. Also, many of the efforts in wellness are related to either physical or emotional wellness, which makes sense, as most published papers have been person-centric studies.

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Intelligent Data Centric Systems

Intelligent Data Sensing and Processing for Health and Well-being Applications

Edited by Miguel Wister, Pablo Pancardo, Francisco Acosta, and José Adán Hernández

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Intelligent Data Sensing and Processing for Health and Well-being Applications uniquely combines full exploration of the latest technologies for sensor-collected intelligence with detailed coverage of real-case applications for healthcare and well-being at home and the workplace. Forward-thinking in its approach, the book presents concepts and technologies needed for the implementation of today's mobile, pervasive, and ubiquitous systems and tomorrow's IoT and cyber-physical systems.

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- Features analysis of security, privacy, and ethical issues in smart sensor health and well-being applications.
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Innovations, Algorithms, and Applications in Cognitive Informatics and Natural Intelligence

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Chapter 16
Modulation Scheme for Biasing the Emotional Process of Autonomous Agents:
A Component-Based Approach

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ABSTRACT

Autonomous agents (AAs) are capable of evaluating their environment from an emotional perspective by implementing computational models of emotions (CMEs) in their architecture. A major challenge for CMEs is to integrate the cognitive information projected from the components included in the AA's architecture. In this chapter, a scheme for modulating emotional stimuli using appraisal dimensions is proposed. In particular, the proposed scheme models the influence of cognition on appraisal dimensions by modifying the limits of fuzzy membership functions associated with each dimension. The computational scheme is designed to facilitate, through input and output interfaces, the development of CMEs capable of interacting with cognitive components implemented in a given cognitive architecture of AAs. A proof of concept based on real-world data to provide empirical evidence that indicates that the proposed mechanism can properly modulate the emotional process is carried out.

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INTRODUCTION

Autonomous Agents (AAs) are software entities that carry out tasks on behalf of users or other programs with a certain degree of independence and autonomy. In doing so, AAs make use of knowledge about the environment and representations of desires and goals (Chiriacescu, Soh, & Shell, 2013). This type of intelligent system has been crucial for the advance of fields such as software engineering, human-computer interaction, and artificial intelligence. In these fields, AAs have been designed to carry out tasks that require the imitation of human cognitive functions, including decision making, planning, and reasoning, to name a few (Ligeza, 1995; Maes, 1995; Sun, 2009).

Develop components inspired by human cognitive functions allows AAs to perform more complex tasks minimizing human intervention. That is why researchers in artificial intelligence (AI), human computer interaction (HCI) and software engineering focus on improving the problem solving, reasoning and communication skills of AAs. On the one hand, the research community in the AI field has devoted efforts to create human-like systems for communication and reasoning as well as to reproduce in computer environments the brain processes that perform them (Gubbi, Buyya, Marusic, & Palaniswami, 2013). On the other hand, in the HCI field some interfaces and mechanisms that improve the interaction of these systems with other agents (computational or human agents) have been developed (Martínez-Miranda & Aldea, 2005; Perlovsky & Kuvich, 2013).

According to literature (Ben Ammar, Neji, Alimi, & Gouardères, 2010; Pérez, Cerezo, Serón, & Rodríguez, 2016), it is notable the importance of AAs having the abilities for agent-to-agent and human-to agent communication, coordination, negotiation in order to achieve its objectives. Using components inspired by cognitive aspects of the human brain has allowed creating systems whose behavior is similar to humans. Nowadays, the use of the effect as another cognitive component has become popular in these types of systems, because emotions are immersed in all expressions of human behavior and intelligence. (Brackett & Salovey, 2006).

Researchers in psychology argues, that human emotions can be seen as a process that involves a subjective appraisal of significant events as well as the preparation of the organism for dealing with such events (LeDoux & Hofmann, 2018; Rukavina et al., 2016a). Evidence shows that emotions influence cognitive functions (Ayesh, Arevalillo-Herráez, & Ferri, 2016; Phelps, 2006) modifying the normal operation of processes such as attention, perception, and learning. Psychologically, emotions alter attention, trigger certain behaviors, and activate relevant associative networks in memory. According to Phelps (2006), emotions are necessary to establish long-term memories. In addition, they provide opportunities for learning, from simple reinforcement learning to complex and conscious planning (LeDoux, 2000; Novak & Gowin, 1985).

As mentioned earlier a key objective of artificial intelligence is the development of software systems capable of doing complex tasks that produce intelligent responses (Perlovsky & Kuvich, 2013), systems that act and reason like humans. In this context, the literature reports an increasing interest in the development of AAs with abilities to evaluate and respond to emotional stimuli, (Brown et al., 2015; Dias, Mascarenhas, & Paiva, 2014; Rukavina et al., 2016b; Wang et al., 2012). Recent works have proposed the incorporation of affective processing in AAs by designing computational models of emotions (CMEs), which are software systems designed to imitate the mechanisms of the human emotional process (emotional evaluation of perceived stimuli, elicitation of emotions, and generation of emotion-driven behaviors) in computing environments (L.-F. Rodríguez, Ramos, Rodriguez, & Ramos, 2014; Luis-Felipe Rodríguez & Ramos, 2015).

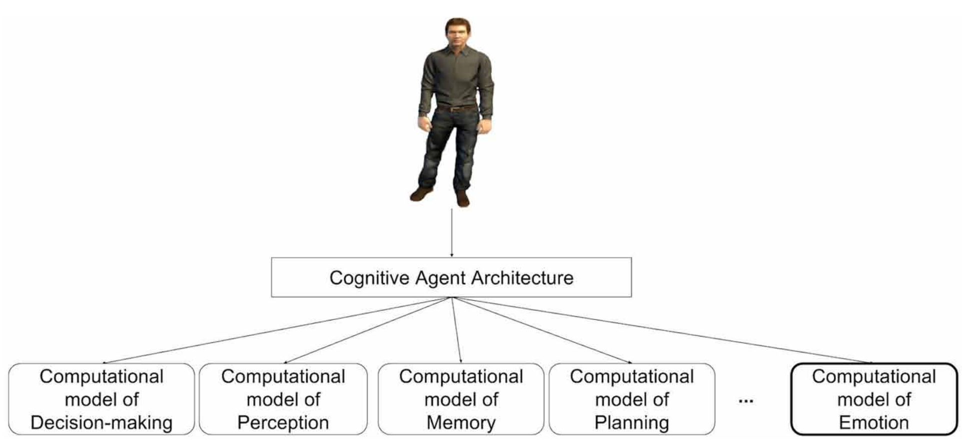
These CMEs are designed to be included in cognitive agent architectures to provide AAs with mechanisms for the processing of affective information, generation of synthetic emotions, and generation of emotional behaviors (see Figure 1). However, adding an affective component (a CME) in AAs architectures brings with a series of complex challenges. On the one hand, those related to the development of MCEs according to Ojha & Williams (2017) are:

- Low replicability. Most CMEs describe their components only conceptually.
- Domain dependency. The model is only applicable in one or more predefined scenarios or domains. CMEs model emotions according to specific implementation needs. Depending on the problem, the emotional process is modeled by selecting one or two aspects of the complete cognitive-affective process (Ortony, 2003; Paiva Ana, Parada Rui, 2007).
- Poor scalability and integration. It is hard to add new components to CMEs because their design is domain-specific.

And on the other hand, those challenges to be addressed to modeling in cognitive agent architectures the close relationship between mechanisms associated with cognitive and emotional functions. The following are some of such challenges addressed in this work:

- A cognitive agent architecture may include a variable number of cognitive components. As it was discussed above, there are many cognitive processes involved in the emotional process so it is not possible or recommendable to implement them all. The domain in which the agent operates determines which components to implement.
- Each cognitive component in a cognitive agent architecture projects very particular information using different structure and formatting. Each cognitive component is complex by itself and its mechanisms are not standardized. In many cases they are not even implemented and each researcher proposes solutions from his perspective and for specific objectives. This result in different models that make it difficult their integration, due to, for example, these would hardly share the same format.

Figure 1. Representative cognitive agent architecture



- The information provided by cognitive components changes frequently depending on the type of cognitive function these components implement. For example, the physical context changes very frequently but information regarding the agent's culture and personality change very slowly.
- The emotion component must weight differently the influence of each cognitive process on the emotion process. It refers to the fact that the same cognitive information does not produce the same answer. Mainly because if the same stimulus persists more than once, the agent learns how to deal with it and is already prepared and knows how to deal with it. It is possible that the result is very similar but the intensity should vary.

The main problem that is addressed in this work is to answer the question: What elements should have a computational model of emotions to facilitate the integration of new cognitive components and that their influence is reflected in the processes of evaluation, elicitation and generation of emotional behavior in autonomous agents?

In this sense, the authors present a conceptual box-model in which all necessary components for a CMEs be able to emotionally evaluate and label the stimuli perceived by the agent, also includes an interface that allows the addition of new cognitive components that help and substantially improve the evaluation and labeling process. Emphasizing the generation of rules for the elicitation of emotions

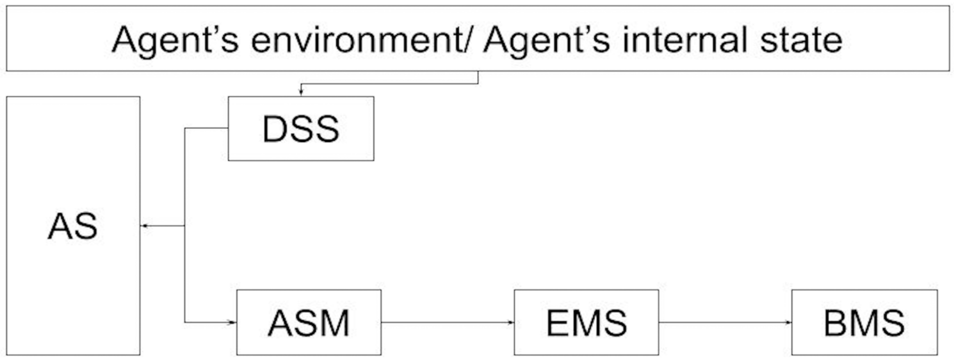
Our proposal promotes the design of CMEs capable of modeling in a gradual manner the complex emotional evaluation process as occurs in humans. In doing so, our proposal generates synthetic emotions in AAs according to their individuality (i.e., their specific personality, culture, motivations, gender, age, etc.). The paper is structured as follows. In Section 2, related work and discuss evidence about internal and external factors that influence the emotional evaluation of stimuli in humans are presented. In Section 3, the authors introduce the proposed mechanism and in Section 4, is developed a proof of concept to explore the extent to which the mechanism allows the modulation of configurable appraisal dimensions, which ultimately leads to the elicitation of emotions. Finally, the authors provide some concluding remarks in Section 5.

RELATED WORK

Literature reports a variety of CMEs that consider diverse cognitive information in their evaluation phase. In this section, some contemporaries CMEs are analyzed in order to understand the role of cognitive information in their evaluation process and how researches incorporate them. There are different efforts that aim to provide AAs with emotional components. Next, some of the strategies used in different CMEs are reviewed. The authors then provide a detailed description of the role of motivations, internal impulses, personality and learning in some CMEs to analyze their influence on AA.

Components in non-integrative models form a closed system that does not allow including new components (at least not in a simple way). Non-integrative models or agents are developed for a specific purpose and context. They include one or two emotional aspects in their emotional process, which in many cases is sufficient to obtain a functional system. DPSEDH (Daknou, Zgaya, Hammadi, & Hubert, 2010) y EECA (Ben Ammar et al., 2010) are examples of agents whose use of cognitive components improves their interaction with other agents in order to improve their quality of service. Both are multi-agent systems; however, their cognitive components vary. On the one hand, DPSEDH has a planning component that allows better management of resources in a hospital in case of emergency. While EECA

Figure 2. Framework FeelMe



is a conversational agent that acts as a tutor, which, through an emotional model adapts its teaching strategies depending on the student's mood. The previous multi-agent systems are just a couple of examples, however there are similar applications in the literature such as emergency simulators (Pan et al., 2006; Tsai et al., 2011; Zoumpoulaki et al., 2010), virtual environments that require extensive interaction between AAs and human users such as intelligent tutoring systems (Mao & Li, 2010; Ammar 15 et al., 2010), personalized virtual assistants (Eyben et al., 2010; Chen et al., 2018), and robots for health care (Kirby et al., 2010; Broadbent et al., 2009) to mention a few others.

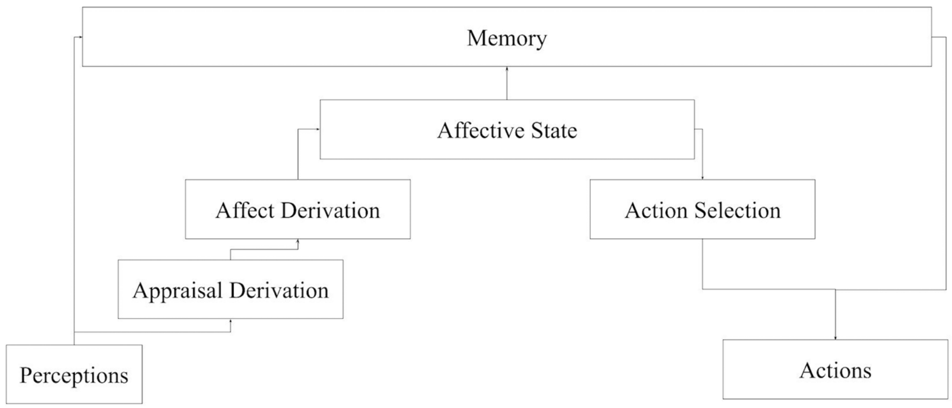
EMA (Marsella, Gratch, & Petta 2010), a computational model of emotions designed to integrate the emotional component in a cognitive-emotional agent architecture is another example. EMA is based on the psychological theory of evaluation, which consists of establishing emotional processing as a series of relationships between individuals and their environment. Another example is Flame (El-Nasr, Yen, & Ioerger, 2000), which is a computational model that uses fuzzy logic to link emotional states to certain events, in this way considers factors such as past experiences and memory to influence decision making.

In contemporary CMEs, a variety of cognitive factors that influence the emotional process are usually taken into account. For instance, to assess the emotional significance of an event, it is necessary to take into account information about agents' current intentions and goals and some other factors such as personality, culture, and motivations which, usually are not seen as indispensable during the design of the computational mechanisms underlying to emotional evaluation. For instance, FAtiMA (Dias et al., 2014) is a CMEs which take into account personality as an important factor that influences the mechanism underlying the emotion process implemented in the CME. In addition, although some CMEs take into account this type of factors, the design of most CMEs hardly allows a modification in their architectures without considerable efforts.

FeelMe (Broekens & Degroot, 2004), is a framework designed to address the problem of scalability in computational models of emotions for agent architectures. It is implemented in a modular and extensible way so that it becomes feasible to add characteristics to the emotional model to make it more complete. It is based on the psychological theories of appraisal, which characterize emotion as the result of a process of valuation of events that occurs differently in each individual, usually taking into account aspects such as their goals, plans, among others.

FeelMe is proposed with a modular scheme, in which the emotional process is separated into five steps (see Figure 2):

Figure 3. Fatima Architecture



1. Decision Support System (DSS). It converts the environment information into viable objects to be evaluated.
2. Assessment System (AS). It evaluates the objects generated in step 1 continuously and interprets them in terms of dimensions (variables) of evaluation, whose number and type are configurable. It generates continuously a vector of size n, where n is the number of dimensions (variables) with the values resulting from the evaluation process.
3. Assessment Signal Modulator (ASM). It adjusts the results (vectors) obtained in the previous step, amplifying them, reducing them or correlating them.
4. Emotion Maintenance System (EMS). It integrates the results to form a vector of values of integrated dimensions, which conforms in the emotional state of the agent.
5. Behavior Modification System (BMS). It selects, controls, and expresses the emotional behavior of the agent based on its emotional state.

Modular FATIMA (FearNot Affective Mind Architecture) (Dias, 2014) is an architecture for autonomous agents, which uses personality and emotions to generate an influence on agent behavior. This architecture proposes a modular scheme to provide the scalability feature. Figure 3 shows the operation of FATIMA. First it perceives information of the environment with which the internal state is updated (memory of the agent) and begins the process of evaluation, which is divided into 2 phases. The result of this latter process is stored in the affective state and is used to influence the action to be performed, which generates an agent response to the change in the environment. The evaluation process is divided into two parts, appraisal derivation and affection derivation according to the structural theories of appraisal of (Reisenzein, 2001).

There are also more recent CMEs, dealing with the problem of complexity in emotional appraisal from another perspective, not as part of a CME intended for a specific application or relationship between cognitive and affective components, but as a more complete and varying representation of the process. These models focus on the complexity of the complete emotional process through scalability-oriented mechanisms and are considered as integrative models.

An example is the computational emotion model (EMIA) (Jain & Asawa, 2015), a multi-layer architecture these layers are responsible, first to deals with the external environment. then the domain-specific

Table 1. Cognitive processes involved in the emotion process in some CMEs.

Model	*Cognitive Processes*
EMA	Provides support for cognitive, perceptual, and motor operators. However, the model does not implement such processes directly (Armony, 2010).
Kismet	Perception and attention processes, learning mechanisms, behavior and expressive systems, and motor functions (Breazeal, 2003).
Flame	Decision-making process, memory and experiential systems, and learning and adaptability processes (El-Nasr et al., 2000).
Mamid	Perceptual and attentional processes, memory systems, expectation and goal managers, and decision-making processes (Hudlicka, 2005).
Alma	Dialog generation processes, decision-making and motivation functions, and behavior and expression generation systems (Gebhard, 2005).
Cathexis	Perceptual processes, memory systems, behavior systems, and motor processes (Velásquez, 1996).
WASABI	Perception and reasoning processes, memory systems, and processes for the generation of expressions and voluntary and non-voluntary behaviors (Becker-Asano & Wachsmuth, 2009).

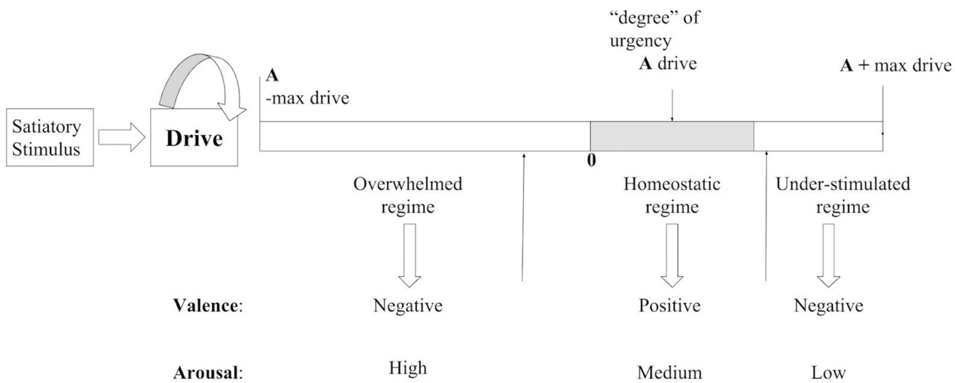
knowledge / data is encoded and decoded into domain-independent information to perform an action against the event and finally, the last layer is responsible for processing domain-independent data and eliciting emotions. EMIA, implements some cognitive components during the processing of their layers such as memory and Learning. EMIA applies various types of memories used in the model to allow learning at different phases. Memory is used to perform intermediate computation and stores the result temporarily and long-term as experience.

Kismet (Breazeal, 2003) and Mamid (Hudlicka, 2005), which are two CMEs that have proven useful in several application domains. Moreover, in table 1, the authors present a summary of the role of cognitive functions in the emotion process of some CMEs reported in the literature.

Motivations and Internal Drives. Motivations refer to an internal phenomenon that results from the interpretation of the agent's internal and external condition (Breazeal, 2003). They regulate the agent's behavior in order to attain a certain state of affairs. Particular instances of motivations are drives, a factor that is often considered as participating in the processing of emotions in CMEs. In Kismet, a social robot designed to learn from humans by interacting with them, a motivational system is designed to carry out the processing of drives and its influence on emotions. The drives implemented in Kismet are social drive, stimulation drive, and fatigue drive. They represent the robot's basic needs and always have an intensity level associated. The levels of intensity tend to increase in the absence of stimuli, and decrease when appropriate stimuli are being perceived. Furthermore, there is a bounded range called the "homeostatic regime," which establishes a desirable status for each drive as shown in Figure 4.

When the intensity of a particular drive is out of this range, the drive is into one of the following two states: under-stimulated (increased intensity) or overwhelmed (decreased intensity). In Kismet, drives influence the dynamics of emotions by contributing to their level of valence and arousal. As shown in figure 2, when the intensity of a drive is within the overwhelmed regime, the valence of emotions becomes negative and their arousal high; when the drive is within the homeostatic regime, the valence is positive and arousal medium; and when the drive is within the under-stimulated regime, the valence is negative and the arousal low (Cynthia Breazeal, 2003). In this manner, the intensity of emotions in Kismet depends on the status of its drives.

Figure 4. The model of internal drives in Kismet (Breazeal, 2003).

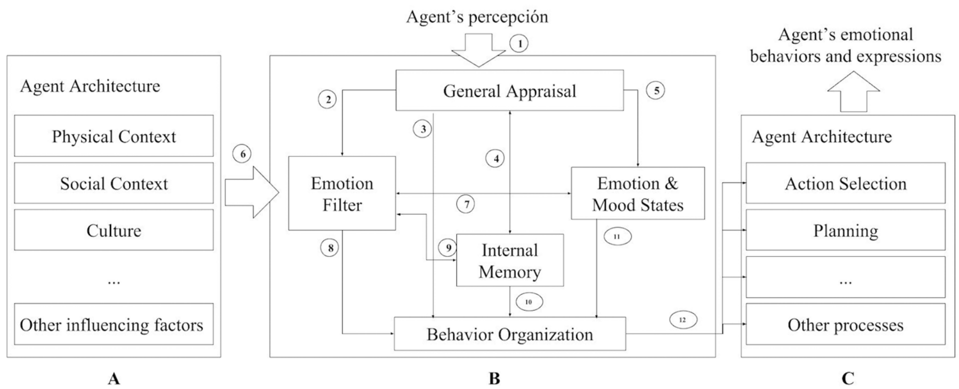


Personality. This term is seen in the domain of CMEs as the set of individual traits in which people differ from each other (Rukavina et al., 2016b). These traits are considered consistent patterns of behavior that provide support to individual differences. In MAMID (Hudlicka, 2005), a model that includes a methodology for modeling the effects of individual differences in cognitive affective architectures, personality traits influence the agent's cognition and behavior. The personality traits modeled are extraversion, introversion, aggressiveness, and conscientiousness. They combine to form personality profiles which are characterized in terms of parameters that control the processing (e.g., speed), structure (e.g., long term memories), and content (e.g., beliefs) of architectural components. In particular, in the affect appraiser module, responsible for deriving the agent's affective state, personality contributes to the elicitation of emotions. For example, high neuroticism and low extroversion makes the agent susceptible to negative valanced emotions as well as negative and anxiety affect.

Learning. FLAME (Fuzzy Logic Adaptive Model of Emotions) is a CME that focuses on memory systems and learning processes to improve the dynamics of emotions. This model implements decision-making processes, memory systems based on experience, and processes of learning and adaptation to elicit a coherent emotion and different for each agent since the experiences contribute a degree of individuality to the agent which helps to elicit emotions different for the same stimulus thanks to the bias that is made from the past experiences.

As seen in Table 1, and the analyzed models, cognitive information plays a key role in the emotion process. In particular, cognitive functions are highly involved in the process of evaluating stimuli from an emotional perspective in CMEs. Nevertheless, the complexity of such evaluation process has led to the design of CMEs whose architecture takes into account very specific types of cognitive information projected from components of cognitive agent architecture. For example, Kismet (Cynthia Breazeal, 2003) considers only Motivations and Internal Drives whereas Mamid (Hudlicka, 2005) considers the influence of personality on the evaluation process. In this sense, most CMEs are not designed to take into account other type of cognitive information that may be available in a given cognitive agent architecture. This type of computational model is usually developed to work on very specific applications. In contrast, the complexity of the emotion process in humans involves an extensive interaction between cognitive and emotional components. The consistency of the emotional evaluation process in CMEs depends on projections from several cognitive processes. Therefore, CMEs should be designed considering that the

Figure 5. Design of the integrative framework. It shows the relationships of a CME (part 'B') with cognitive agent architectures (part 'A' and 'C'). Note that numbers on the arrows are only for explanation purposes within the text, these do not explain the temporal relationships between the model's data flows.



more cognitive information considered in the emotion process, the more consistency and accuracy in the agent's affective states and emotional behaviors.

INTEGRATIVE FRAMEWORK

The Integrative Framework (InFra) proposed by Rodríguez (2016) follows the idea that instead of developing a CME that tries to unify cognitive and affective information in order to generate consistent emotional signals that allow AAs to implement believable behaviors, it is importan approach this problem by creating a framework that enable the development of CMEs whose architectures provide a convenient environment for the unification of cognitive and affective information. A basic assumption in the design of such InFra is that CMEs should comprise in their design only those mechanisms related to affective processing, leaving aside other mechanisms associated with cognitive processes and psychological constructs such as perception, action selection, motor action, culture, and personality. The design of the InFra considers that these latter processes are fundamental elements of cognitive agent architectures and that therefore these should be implemented there (see Figure 1). Nevertheless, this assumption does not mean that the internal processing and appropriate behaviors of CMEs are independent of those cognitive processes and psychological constructs. Instead, what the InFra suggests is that the design of a CME should be focused on two major aspects: (1) the modeling of mechanisms underlying affective processes such as emotions and mood states, and (2) the incorporation of input and output interfaces that facilitate the exchange of data between affective processes implemented in CMEs and cognitive processes implemented in agent architectures (see Figure 5).

Based on this assumption, two main characteristics were considered for the InFra's design:

1) The framework should enable CMEs to take as input all information available from agent architectures in order to accurately evaluate the emotional stimuli perceived by an agent and to generate more consistent emotional states and emotional behaviors.

Table 2. Components of the InFra.

Component	*Abbr.*	*Description*
General Appraisal	GA	Determines the emotional value of the stimuli perceived by the agent.
Emotional Filter	EF	Amplifies, attenuates, or maintains the emotional significance of the stimuli perceived by the agent.
Behavior Orgnization	BO	Decides the type of emotional behavior that the agent should implement in order to deal with the emotional stimuli presented.
Emotion & Mood States	EMS	Maintains the agent's current emotional and mood states.
Internal Memory	IM	Provides knowledge to most components in the model and is highly involved in associative learning.

2) The framework should enable CMEs to deliver appropriate emotional signals to those components in a cognitive agent architecture that are involved in the control of the agent's behaviors and expressions in order to exert an emotional bias.

In this context, among the requirements underlying the InFra's design, there are three related to this assumption, which recognize the need for more integrative designs in CMEs that facilitate the interactions between cognitive and emotional processes in cognitive agent architectures:

1) Adaptable input interface: the model should incorporate an input interface to handle all data that a cognitive agent architecture can communicate to contribute to the proper functioning of the CME.
2) Reasoning with variable information: the system should be able to reason about available information to generate coherent emotional signals. This information is received from the CME and components of cognitive agent architecture.
3) Compatible output signals: the model should be able to deliver appropriate emotional signals to all components of cognitive agent architecture that are involved in the control of the agent's emotional behavior.

In this paper, the proposed computational scheme is designed to address the first and second requirement: Adaptable input interface and Reasoning with variable information. In the InFra, these requirements involve the components of the called indirect route (see Figure 3). This indirect route starts in the General Appraisal (GA) module, goes through the Emotion Filter (EF) module, and ends in the Behavior Organization (BO) module.

In general, this indirect route comprises processes that allow a CME to assign accurate emotional values (according to the agent's current internal and external condition) to the stimuli perceived by the agent and enable the agent to appropriately deal with social and emotional situations (see Table 3). In particular, there are two assessment phases in this route, one taking place in the GA and the other in the EF component. The main purpose of the evaluations performed by the GA is to determine the inherent emotional significance of incoming stimuli. The EF component conducts a second assessment of perceived stimuli. The main purpose of this evaluation is to re-appraise the initial emotional significance assigned by the GA. This evaluation process takes into account more information than that stored in the IM component (which provides the emotional significance of stimuli previously perceived and acquired by experience). Particularly, the operating cycle implemented by the EF is influenced by cognitive signals

Table 3. Interactions among the InFra's components (numbers in the first column correspond to the numbers in Figure 3).

	Description
1	Stimuli perceived by the agent.
2	Emotional significances of perceived stimuli.
3	Information about stimuli identified as highly emotional.
4	Information about the stimuli received and evaluated by the GA is sent to the IM component. Information about the emotional significance of incoming stimuli is sent from the IM to the GA component.
5	Initial emotional values determined for perceived stimuli.
6	Data projected by components of the agent's architecture.
7	Updated emotional significances of perceived stimuli are sent from the EF to the EMS component. In the opposite direction, the EMS sends to the EF information about the current agent's emotional and mood states.
8	Updated emotional significances of perceived stimuli.
9	Updated emotional significances of perceived stimuli are sent from the EF to the IM component. Information about the emotional significance of incoming stimuli is sent from the IM to the EF component.
10	Behavior tendencies associated with the stimuli perceived.
11	Current agent's emotional and mood states.
12	Emotional signals are sent from the BO component to various components in the agent's cognitive architecture.

received from components in the agent architecture that are mainly involved in determining the agent's internal condition and interpreting its external environment (these signals are supposed to be crucial for the processing of emotional stimuli in humans).

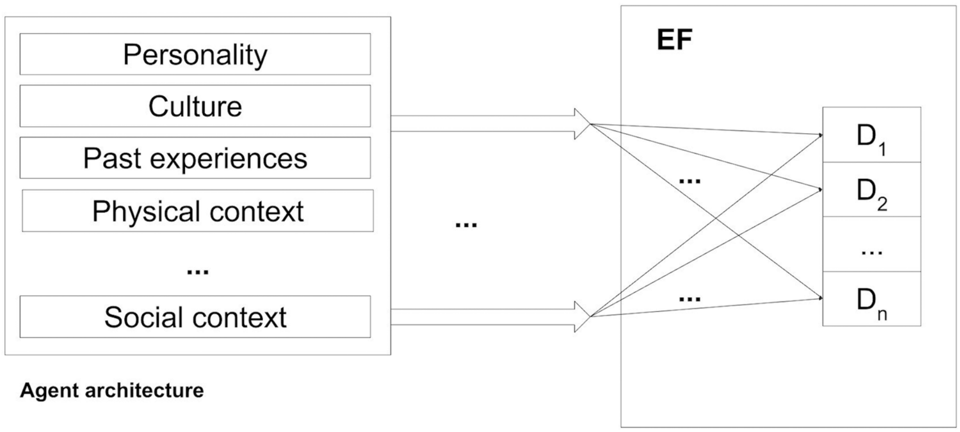
As mentioned above, the presented computational scheme is focused on addressing the first and second requirement of the InFra (Adaptable input interface and Reasoning with variable information), leaving aside any other process involved in the operating cycle and architecture of the InFra. In particular, the computational scheme is designed to provide mechanisms for the cognitive modulation of appraisal variables used in the emotion evaluation process of autonomous agents.

SCHEME FOR MODULATING APPRAISAL VARIABLES

This approach does not allow MCEs to take into account other aspects (i.e., a factor of influence in the evaluation process such as personality or culture) for those that were not designed at first. A novel approach promotes the development of CMEs whose architecture facilitates the addition of new components that influence the evaluation process, which are called influencing factors. Thus, the proposed scheme integrates cognitive information in the emotional process. This involves designing scalable CMEs capable of considering information projected from cognitive components of agent architectures even when a CME was not initially designed to consider a particular type of cognitive information. In doing so our proposed computational scheme addresses some of the design requirements of the integrative framework proposed by Rodríguez (2016).

In InFra the evaluation of emotional stimuli takes place in the Emotional Filter component (see Figure 3). This process of evaluating stimuli from an emotional perspective is based on the Appraisal

Figure 6. Influence of cognitive components in agent architectures on appraisal



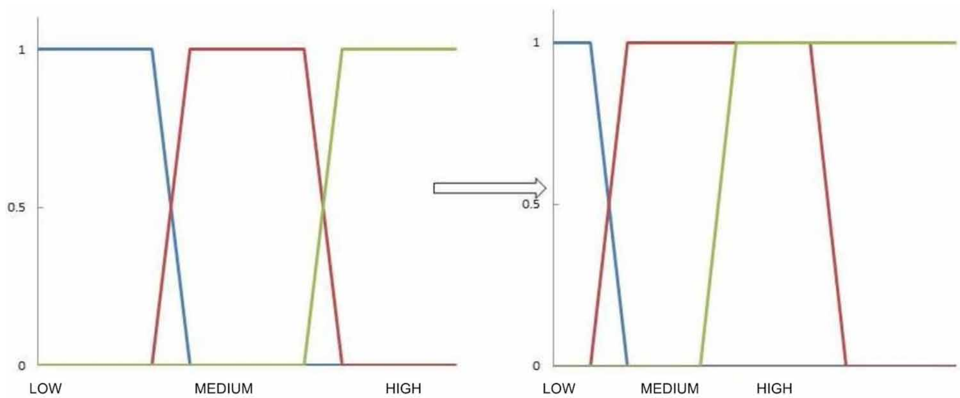
Theory, a psychological theory that explains the elicitation of emotions based on the relationship between individuals and their environment (Marinier, Laird, & Lewis, 2009; Ojha & Williams, 2017; Scherer, 2001). This evaluation of the individual-environment relationship is carried out using a series of appraisal dimensions such as pleasantness, goal conduciveness, suddenness, and controllability to name a few. In this context, in the proposed model, emotions are characterized in terms of a set of values corresponding to appraisal dimensions. Moreover, cognitive components of agent architectures are assumed to send information that should be considered when evaluating such appraisal dimensions. In this sense, it is necessary to define a scheme to determine the level of influence of cognitive information on each appraisal dimension as shown in Figure 6.

Our computational schema involves three main challenges: 1) considering that cognitive components vary in terms of the information they project, it is necessary to define the particular degree of influence that a cognitive component exerts on each appraisal dimension, 2) the information projected from the influencing factors should be translated into values that bias the emotional state, 3) Map the appraisal variables with an emotional label. Once the evaluation process is completed, a value is established for each appraisal variable considered during the evaluation. Together, these values form a vector that represents an emotion and its intensity. The problem with this is that there is no formal way to relate such values to an emotional label.

The proposed scheme is divided as follows:

- Appraisal phase. Consists in evaluating agents' perceived stimuli using appraisal dimensions assigning a numerical value (one for each evaluation dimension) within the continuous range [0, 1]. this phase occurs in the InFra's General Appraisal module. Each appraisal variable is represented by a fuzzy logic scheme (see Figure. 8).
- Factor influence calculation phase. Consists of computing, by means of influencing models (mathematical functions), the relationship between each influencing factor and each appraisal dimension. Based on this relationship value (e.g., a correlation coefficient between an influencing factor and an appraisal dimension), the influencing model determines to what extent the fuzzy logic scheme should be adjusted see Table 4.

Figure 7. A possible effect of the agent's personality on the membership functions associated to the novelty dimension.



Each of the appraisal variables has different levels of intensity whose initial value is predefined, for example the variable novelty can take values of "Low novel", "Medium novel" or "High novel" which is associated with the following three membership functions:

$$\mu LOW = \{1, si\ x \leq 0\ \frac{0.4 - x}{0.4 - 0.3},\ si\ 0.3 \langle y \leq 0.40,\ si\ x \rangle 0.4\ .$$

$$\mu MEDIUM = \{0,\ si\ y \leq 0.3\ \frac{y - 0.3}{0.4 - 0.3};\ 1,\ si\ 0.3 < y \leq 0.4;$$

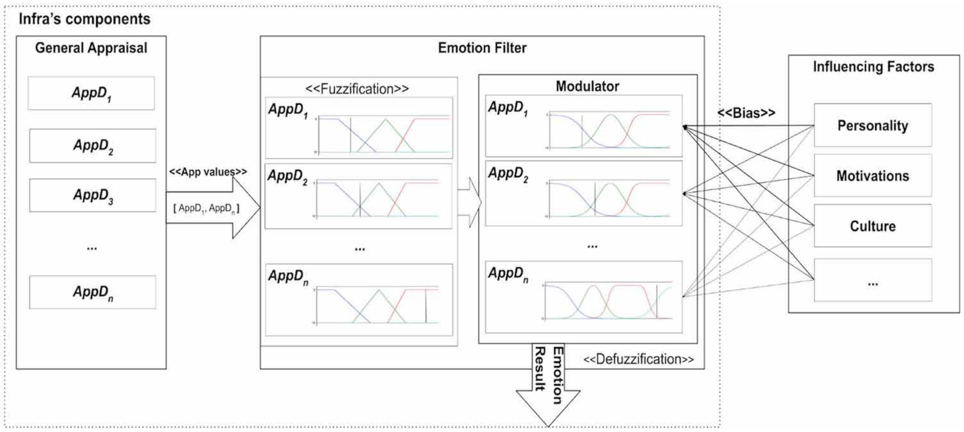
$$1,\ si\ 0.4 < y \leq 0.7\ \frac{1 - y}{1 - 0.7},\ si\ 0.7 \langle y \leq 0.1\ \ 0,\ si\ y \rangle 1$$

$$\mu HIGH = \{0,\ si\ z \leq 0.6\ \frac{z - 0.6}{0.1},\ si\ 0.6 \langle z \leq 0.7\ \ 1,\ si\ z \rangle 0.7$$

These functions are initially predefined and are then adjusted according to the cognitive modulator. Let's assume that the literature reports that the personality and other factors such as the physical context influences the emotion evaluation. The resulting emotion is different for the same stimulus since its physical context and the agent's personality is different. In this case, such influence is represented by the modification of the membership function limits. For example, a neurotic or euphoric personality increases the probability for the agent to perceive and assess an event as novel. In this context, the limits of the membership function LOW would be reduced, the limits of the membership function HIGH will be increased, and possibly, the limits of the membership function MEDIUM will increase in one side (see Figure 7).

- System adjustment phase, consists in modifying the Infra's fuzzy logic scheme based on the relationship value between appraisal dimensions and the influencing factors. The authors propose two

Figure 8. Model of appraisal dimensions modulation.



possible actions to modify the fuzzy logic scheme i) changing the membership function types (for instance, from triangular to trapezoidal) and/or ii) changing the limits of currently used membership functions. The system adjustment phase is carried out by the Infra's emotion filter component. The output of the adjustment phase is a set of adjusted appraisal dimensions.

It is important to mention that for each cognitive component influencing agents' emotional evaluation there should be a corresponding influencing model, which determines the adjustment for each configurable appraisal dimension. An influencing model, defines the relationship between a given cognitive component and each configurable appraisal dimension utilized in the emotional evaluation phase. An influencing model interprets such relationship in terms of fuzzy adjustments. In doing so, they translate an influencing factor into a fuzzy parameter that can be integrated into the Infra's fuzzy logic scheme.

- Fuzzy calculation phase, consists in (de) fuzzifying the values of each appraisal dimension and carrying out the fuzzy logic inference, which determines the resulting emotion, using the adjusted appraisal dimensions. The fuzzy calculation phase is executed by the Infra's emotion filter component. It should be noted that the fuzzy inference system should be provided with a set of fuzzy rules to establish the relationship between appraisal dimensions and emotions.

The modulation of these values is then determined according to what theories and models explain about the influence of cognition on the emotion process in humans. Although these theories and models are still scarce and limited, this information helps to define tendencies on the relationship between cognitive functions and appraisal dimensions. For example, Han & Northoff (2008) a study concludes that individuals' culture (characterized as collectivist and individualist) influence the situation assessment. The study indicates that in collectivist individuals occurs a more intense assessment of negative situations (based on the goals and objectives of the individual) but a more tenuous assessment of positive situations. Considering this type of evidence from human studies, in the proposed schema logical relationships are defined to model the influence of cognitive information and psychological constructs (e.g., personality and culture) on appraisal dimensions.

SCHEME VALIDATION: PROOF OF CONCEPT

In this section, is carry out a proof of concept of the modulation scheme proposed in the previous section. In particular, to clarify, it describes how the four phases of the scheme were carried out. For the proof of concept, an influence factor (gender), twenty-five appreciation variables (described below) that carry out the evaluation process is taken into account, it is described how the gender modulator was defined, that is, the function that relates gender with each variable of appreciation, it is described how the rules were obtained to relate the appraisal vector with an emotion.

For this proof of concept, the authors used data extracted from a study reported by Meuleman & Scherer (2013); Scherer (1993). This study involved 9,102 participants from different countries where each participant was requested to report an emotionally significant event and to label it with at most two dominant emotions and were requested to characterize the event using appraisal dimensions with the aim of establishing a relationship between appraisal variables and emotions.

Defining an Influencing Factor and Its Modulator

With the above information, the researches try to find patterns that suggest some kind of influence on emotion, such as the culture, language or physical context of each participant, to use as an influencing factor. However, the data was not reliable enough to determine whether there is a correlation between these criteria and the appreciation variables, mainly because the experiment was not directed in this regard. Except gender, the researchers used the field gender of each participant as the influence factor to be implemented in the proof of concept, due to data suggest a correlation between gender and the appraisal variables. Additionally, the literature shows that gender influences the way an agent perceives its environment. Particularly, gender may influence the appraisal of aspects associated with the emotional evaluation of stimuli such as personal control in social contexts. For example, males have been found to be more responsive to positive stimuli whereas females to negative stimuli (Rukavina et al., 2016a).

The available emotions were shame, guilt, sadness, despair, fear, rage, irritation, contempt, anxiety, disgust, joy, pride, and pleasure. In this case, they utilized two out of the thirteen emotions considered in the study: sadness and joy. The authors select these emotions because they were the most commonly reported emotions in the study presented in (Meuleman & Scherer, 2013; Scherer, 1993). The correlation values obtained are shown in the following table (Table 4). As mentioned above, gender was selected as the influencing factor because i) gender has been found to influence the emotional evaluation of stimuli (Brebner, 2003; Fischer, Rodriguez Mosquera, Van Vianen, & Manstead, 2004; Plant, Hyde, Keltner, & Devine, 2000) and ii) Data on emotionally significant events and the gender of the participants describing the events were available. The influencing model designed to determine to what extent gender may modulate the emotional evaluation of stimuli was based on computing correlation coefficients between the values of emotion intensity and the appraisal dimensions grouped by emotion and gender. The correlation coefficients ranged from -0.1368 to 0.3376 (see Table 5). This suggests that there is no a strong linear relationship between a single appraisal dimension and the intensity of an emotion, however, the relationship exists as reported in (Chaplin, 2015) and as indicated by the nonzero correlation coefficients. For this reason, to exemplify the effects of gender as an influencing factor, so the correlation coefficients were normalized with respect to the maximum correlation coefficient.

From the correlation obtained, A set of ranges was formed to classify the influencing degrees as follows: high negative (from -1.00 to -0.75), medium negative (from -0.75 to -0.25), low negative (from

Table 4. Appraisal dimension and its correlation index, divided by emotion and then by gender.

Appraisal Variables	Emotion: Joy		Emotion: Sadness	
	Gender A	Gender B	Gender A	Gender B
Adjustment	0.142	0.260	-0.318	-0.362
Caused by chance	0.240	0.319	0.410	0.125
Caused by other	0.317	0.132	0.075	0.072
Caused by myself	0.355	0.077	-0.053	-0.045
Conduciveness	0.651	0.462	0.067	-0.233
Consequences expected	-0.011	0.009	-0.135	-0.119
Consequences far future	-0.005	0.038	-0.021	0.033
Consequences felt	-0.118	0.091	0.290	-0.078
Consequences near future	-0.171	0.189	-0.117	-0.182
Familiarity	-0.339	-0.230	-0.405	-0.265
Intentional-other	0.248	0.086	-0.051	0.088
Intentional-self	0.479	0.008	-0.365	-0.139
Modifiability	0.005	-0.295	0.069	-0.119
Moral acceptability	0.146	0.117	-0.215	-0.383
Norm violation	-0.296	-0.179	-0.204	0.071
Obstructiveness	-0.269	-0.239	0.694	0.509
Pleasantness	1.000	0.408	-0.144	-0.354
Predictability	0.111	0.120	-0.126	-0.144
Relevance	0.640	0.556	0.697	0.639
Self-image compatibility	0.361	0.079	-0.096	-0.166
Suddenness	0.239	0.275	0.301	0.511
Unfairness	-0.270	-0.399	0.409	0.343
Unpleasantness	-0.356	0.079	0.865	0.667
Urgency	0.270	0.290	0.353	0.357

-0.25 to -0.1), low positive (from 0.1to 0.25), medium positive (from 0.25 to 0.75), and high positive (from 0.75 to 1.00). The gender modulator takes into account the set of ranges and applies them during the system adjustment phase of the proposed model to modify the diffuse scheme of each appraisal variable. Then, a set of fuzzy rules to determine the relationship between particular appraisal vectors (representing the assessment of perceived stimuli) and the two emotions (i.e., sadness and joy) was defined. In particular, this set of fuzzy rules was created using the Predictive Apriori algorithm (Scheffer, 2005). This algorithm mines association rules from data based on how frequently a set of items are connected with a certain class.

Table 5 shows the results produced by the Predictive Apriori algorithm. By emotion, the rule column shows those appraisal variables that are related to the emotion while in the next column the accuracy with which the prediction was made. The values that accompany each appreciation variable range from

Table 5. Extract of resulting rules using the a priori algorithm.

Emotion: Joy		Emotion: Sadness	
Rule	**Accuracy**	**Rule**	**Accuracy**
Pleasantness=5 ConsequencesExpected=4	0.99448	Relevance=5 ConsequencesFarFuture=3	0.9945
MoralAcceptability=5 SelfImageCompatibility=4	0.99448	Pleasantness=1 Unpleasantness=4	0.99449
Unpleasantness=1 ConsequencesFelt=4	0.99447	Pleasantness=1 MoralAcceptability=4	0.99449
Familiarity=3 NormViolation=1	0.99447	Predictability=3 Intentional-Self=1	0.99449
Suddeness=3 Unfairness=1	0.99446	CauseChance=2	0.99449
Unpleasantness=1 Intentional-Other=4	0.99371	Intentional-Self=2	0.99365
Urgency=2	0.99369	Unpleasantness=5 Cause-Self=5	0.99365
Pleasantness=5 Intentional-Other=1	0.99368	Unpleasantness=5 Modifiability=4 208	0.99365
Avoidability=4	0.99365	Relevance=5 ConsequencesFarFuture=4	0.99365
CauseChance=4	0.9936	Unpleasantness=5 SelfImageCompatibility=4	0.99361

0 to 5 and indicate the intensity, 0 being a disposable value, 1 very low, 3 medium and 5 very high. From the 100 results obtained and only show the first and last 5 rows.

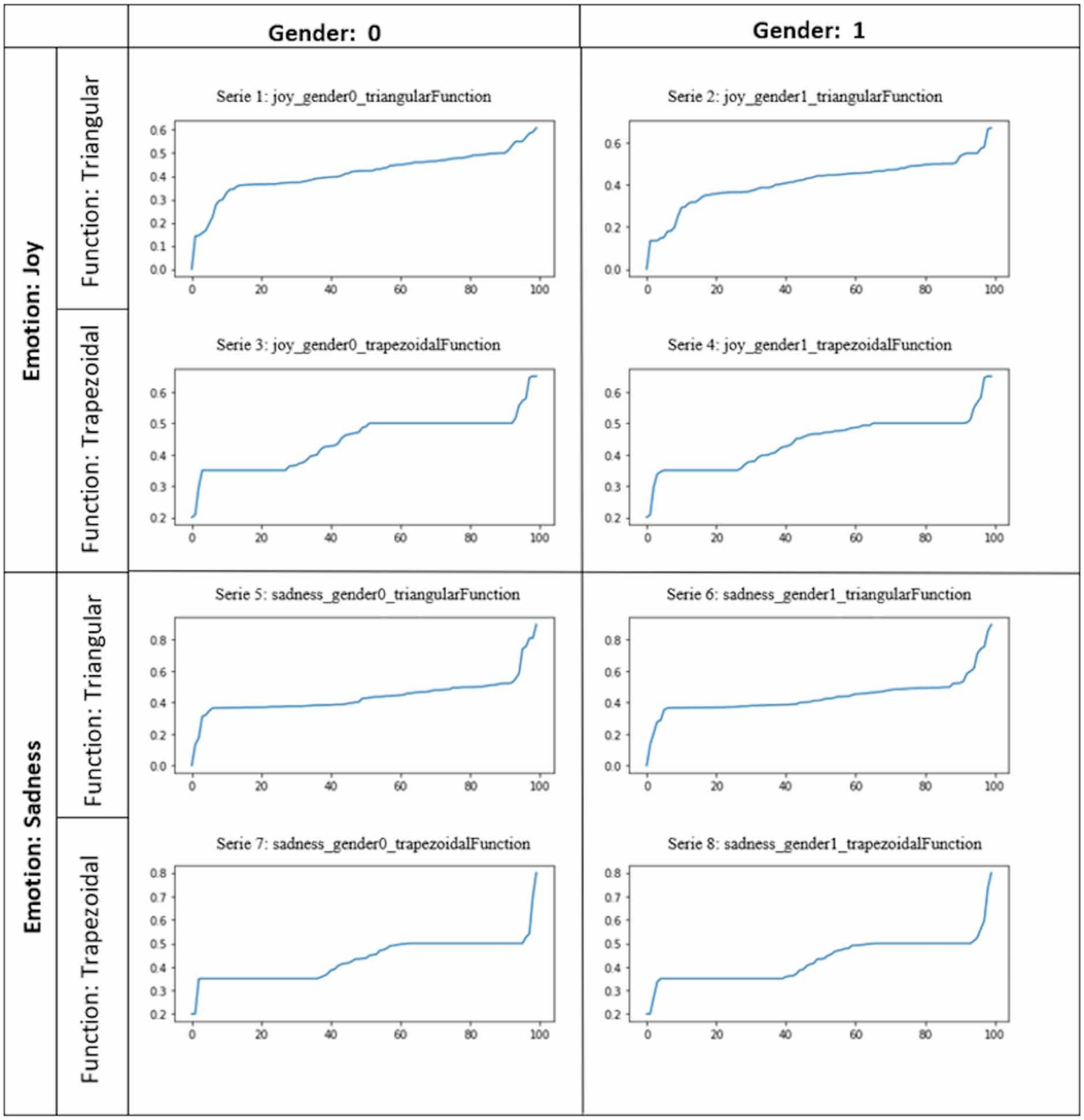
From the results obtained, the authors generate a knowledge base that will feed the fuzzy inference machine, the knowledge base is nothing more than a set of IF-THEN rules as shown in Table 6.

In order to illustrate the functioning of the schema proposed. Were generated 100 random vectors to represent 100 different entries. Due to the scope of this work, not all mechanisms for appraisal variables have been fully implemented. Then, using the rules obtained through the a priori algorithm for fuzzy inference getting the following results (see Figure 9):

Table 6. Resulting rules.

Emotion: Joy	Emotion: Sadness
Rule	**Rule**
IF pleasantness IS high THEN joy IS low IF unpleasantness IS low THEN joy IS low IF suddenness IS medium THEN joy IS low IF normViolation IS low THEN joy IS low IF consequencesExpected IS medium THEN joy IS low IF normViolation IS low THEN joy IS medium IF pleasantness IS high THEN joy IS medium IF moralAcceptability IS high THEN joy IS medium IF unfairness IS low THEN joy IS medium IF conduciveness IS high THEN joy IS medium IF unpleasantness IS low AND consequencesFelt IS low THEN joy IS high IF pleasantness IS high AND causedByMyself IS low THEN joy IS high IF unpleasantness IS medium AND normViolation IS low THEN joy IS high IF suddenness IS low AND causedByChance IS low THEN joy IS high IF unpleasantness IS medium AND conduciveness IS high THEN joy IS high	IF pleasantness IS low THEN sadness IS low IF unpleasantness IS high THEN sadness IS low IF normViolation IS low THEN sadness IS low IF consequencesExpected IS medium THEN sadness IS low IF intentionalSelf IS low THEN sadness IS low IF intentionalSelf IS low THEN sadness IS medium IF unpleasantness IS high THEN sadness IS medium IF pleasantness IS low THEN sadness IS medium IF consequencesFelt IS medium THEN sadness IS medium IF normViolation IS low THEN sadness IS medium IF predictability IS medium AND intentionalOther IS medium THEN sadness IS high IF predictability IS medium AND causedByMyself IS high THEN sadness IS high IF obstructiveness IS low THEN sadness IS high IF unpleasantness IS high AND intentionalSelf IS medium THEN sadness IS high IF suddenness IS high AND causedByMyself IS high THEN sadness IS high

Figure 9. Results of the tests performed by our computational scheme.



The influence model translated the influence factor (i.e., gender) to different configurations in the fuzzy logic scheme considering two types of functions (triangular and trapezoidal) of diffuse membership, from these results can interpret that:

1. The bias introduced by gender caused relatively small changes in the results of the model, both of joy and sadness. This due to the degree of correlation that gender had with each appraisal variable,

this may be, mainly due to the origin of the data, since it was not an experiment directed specifically for this purpose.

2. It seems that triangular membership functions are better for evaluating stimuli than trapezoidal membership functions. Triangular functions are more sensitive to changes, which produces more precise values. The main difference between both membership function is that trapezoids tend to evaluate a stimulus with the highest value (1), due to the range their function covers. The above is inconsistent with the literature, since very specific stimuli are required to generate such a high value (i.e, intensity).
3. Definition of rules, the rules that are defined are very important, however, we find the problem that there is no standard way to define them.
4. The rules generated seem to be consistent with what is observed in real life. For both emotions, the least predominant emotional level was high, followed by low and lastly medium. Taking into account that the fuzzy rules were mined from real-world data and regardless of the fact that the input appraisal vectors were randomly generated suggests that highly intense emotions are less frequent and may require very specific combinations of values of appraisal dimensions.

DISCUSSION

Throughout this work, issues arose that are worth discussing, such as i) the temporality of the cognitive components of the agent's architecture, ii) the correlation between influencing factors and appraisal variables, iii) Analyze other membership functions, as well as iv) use other techniques to carry out cognitive influence and v) define better rules for the knowledge base.

i) An aspect of interest for the modeling of the influence of cognition on the evaluation process in CMEs has to do with the temporality of cognitive components. For example, components such as those modeling personalities barely change over time. In contrast, components in charge of assessing the agent's social context change very frequently. In this case, both components influence the emotional evaluation of situations perceived by the agent and particularly both components may influence the evaluation of appraisal dimensions such as suddenness. This type of similarity suggests a grouping of cognitive components included in cognitive agent architectures. In the proposed computational scheme cognitive components are divided into two groups according to their temporality, components that change slowly over time (e.g., personality and culture) and components that change very frequently (e.g., the agent's physical and social context). In this manner, regardless the number and type of cognitive components in agent architectures, they are included in one of these two classes according to their characteristics. In turn, each group will exert a consolidated cognitive influence.

ii) As saw in results, gender doesn't have high correlation with the appaisal variables. However, it is possible to note a difference between one gender and another which corresponds to the literature. This suggests that there will be factors that influence to a lesser or greater extent. The problem is that it is very difficult to develop influence modulators, for this research the authors were fortunate to have access to a large amount of information and to find a suitable function between cognitive and affective dimensions, however, to create modulators such as culture or personality it is necessary to carry out experiments that are specifically responsible for finding a relationship with each appraisal variable and how influencing them.

iii) Analyze other membership functions, in addition to the triangular and trapezoidal functions tested in this paper, they must analyze other of the many functions that exist, such as, z-shape, s-shape, sigmoid and Gaussian, to name a few and study which ones are more suitable.

iv) Use other techniques to carry out cognitive influence, the researches adopted an approach using fuzzy logic, however, this decision was not the product of a comparative analysis with other techniques, such as neural networks or genetic algorithms. Which, could offer benefits that our approach does not allow. For example, modifying the weight of a neuron may be easier than modifying a full membership function.

v) Define better rules for the knowledge base. In particular, this issue seems very interesting and beneficial to address. To define the rules they use, they had to find the relationship that existed between an influencing factor and each appraisal variable. Then with data mining techniques found a deterministic function to apply in a computational component, which authors call, modulator. From the correlation found were able to determine a series of rules to link an emotion with the appraisal variables vector (i.e., joy and sadness). 100 rules were generated for each emotion, however, the vectors that represent the emotion did not consider all the appraisal variables. For example, for the algorithm if the stimulus was evaluated only with Pleasantness = 5 ConsequencesExpected = 4 it was enough to label the stimulus as joy. The authors believe that although the algorithm has a very high accuracy it contradicts the literature, which specifies that all appraisal variables should be considered since they evaluate a specific aspect of the agent and link it with the stimulus. Otherwise, they would be discarding valuable information, so it is very important to deepen especially on this issue. After all, our set of rules connects the result of the evaluation with the emotion and the better the rules, the resulting emotion will be more precise.

CONCLUSION

In this paper, was presented a scheme to modulate appraisal dimensions involved in the emotion evaluation process of autonomous agents. The level of modulation depends on the cognitive information projected from cognitive components of agent architectures. The proposed scheme is designed as part of an integrative framework which was developed to address a key challenge of designing integrative CMEs. A case of study to demonstrate the functionality of the mechanisms presented to model the influence of cognition on the appraisal dimensions involved in the evaluation of emotional stimuli perceived by an agent was also reviewed. This work presents a model that allows researchers to consider different appraisal theories by defining new influencing rules based on information reported in the literature about cognitive functions and their influence on the emotion process. In this sense, the current proposal promotes the design of CMEs whose underlying architecture includes mechanisms that consider that cognitive information available in cognitive architectures and are useful to achieve very consistent emotional states and emotional behaviors in autonomous agents. Based on the experimental results, it is possible to conclude that influencing models (expressing the relationship between influencing factors and appraisal variables) can properly affect the emotional evaluation of stimuli while preserving the overall features of CMEs. In addition, the authors found consistent differences in the emotional evaluation depending on what kind of membership function was utilized. Our future work will focus on Design and conduct an experiment that allows us to solve the issues presented in the discussion section.

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Localización del expertise en el desarrollo de software mediante una arquitectura basada en agentes

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Resumen

La experiencia es fundamental para la terminación de los proyectos en las organizaciones de software, ya que las tareas se resuelven de una manera más eficiente. La experiencia de una organización se encuentra en las personas, estos no son fáciles de identificar cuando es necesario, lo cual dificulta su gestión, consulta y distribución. Esto dificulta a los miembros de la organización encontrar los recursos adecuados para resolver un problema. Este trabajo presenta una arquitectura de agentes que apoya a la localización del *expertise*. Utilizando la metodología de identificación del flujo de conocimiento se identificaron las barreras que impiden el flujo de conocimiento y su interacción en las actividades de desarrollo de software, usando esta información los requerimientos fueron identificados. La arquitectura proporciona información sobre la ubicación del conocimiento adecuado haciendo uso de artefactos y expertos disponibles en la organización para resolver un problema planteado por un usuario.

Introducción

El entorno actual de las organizaciones se caracteriza por el cambio continuo y la evolución en cuanto a las prácticas y tecnologías utilizadas. Las acciones deben ser anticipadas y adaptativas, basadas en un ciclo rápido de creación de conocimiento. De ahí la necesidad de un proceso de negocio que formalice la gestión y aseguramiento de los activos intelectuales (Ammar-Khodja & Bernard, 2008; Serban & Luan, 2002). Es por ello que se han hecho esfuerzos por tener una adecuada gestión del conocimiento, la cual es ampliamente conocida y practicada por grandes organizaciones como una herramienta útil para que cada uno de los miembros de la empresa comparta su conocimiento para mejorar los resultados de sus actividades. De manera que las organizaciones puedan ser más eficientes mediante el manejo del proceso de aprendizaje, (Prusak, 2001). Este tipo de gestión se compone de una serie de prácticas que permiten identificar, crear, representar y distribuir el conocimiento para su reutilización, distribución y aprendizaje. Por ello existe un gran interés en el tratamiento de conocimiento como un recurso significativo en las organizaciones, enfocándose en los conocimientos humanos, y cómo explotarlos para tener el máximo rendimiento en la organización (Ponelis & Fairer-Wessels, 2014).

El creciente interés por el conocimiento y la gestión del conocimiento organizacional se deriva de la transición a la economía del conocimiento, donde el conocimiento es visto como la principal fuente de creación de valor y ventaja competitiva sostenible (Alavi & Leidner, 2001; Wang, Noe, & Wang, 2014). Esto añade un gran valor a las organizaciones, de manera que se pueden tomar mejores decisiones, tener un flujo libre de ideas que llevan al conocimiento e innovación, eliminar los procesos redundantes, mejorar el servicio al cliente y la eficiencia conduciendo a una gran productividad.

La gestión del conocimiento ha beneficiado a diferentes áreas, tales como de educación (Jones & Sallis, 2013; Petrides & Nodine, 2003), cuidado de la salud (Abidi, 2001; Nicolini, Powell, Conville, & Martinez-Solano, 2008), desarrollo de software (Jain, 2011; Rodríguez, Vizcaíno, Martínez, Piattini, & Favela, 2004) . Particularmente, en la industria del software se han abordado los retos de adaptación del conocimiento a las tecnologías emergentes, acceso al dominio del conocimiento, intercambio del conocimiento sobre las políticas y prácticas locales, capturar el conocimiento y saber qué es lo que sabe cada uno y colaboración e intercambio de conocimiento (Rus & Lindvall, 2002). El desarrollo de software se caracteriza por ser una actividad intelectual y compleja que requiere de la interacción constante con los colaboradores de la organización. Así mismo, el desarrollo de software es considerado un proceso de constante cambio, donde muchas personas trabajan en diferentes fases, actividades y proyectos. Tales características producen los siguientes inconvenientes (Rus & Lindvall, 2002): i) *Re-trabajo*: Se refiere a cuando un desarrollador trabaja sobre un artefacto que otro ya había realizado anteriormente para otro proyecto y que pudo haberse reutilizado, reduciendo así el tiempo para realizar dicha actividad. ii) *Fracaso en las Consultas*: Se refiere a cuando un usuario busca una solución a cierto problema en el código y tiene dificultades para encontrar una solución en algún foro de programadores en línea, manuales o video tutoriales. iii) *Asesoría Inadecuada:* Se refiere a cuando un usuario recibe consultoría de varias personas para solucionar un problema de código o de una actividad, y ninguna puede dar una solución adecuada al problema.

Este tipo de inconvenientes traen como consecuencia problemas de producción, comunicación, retrasos, clarificación (Espinosa & Carmel, 2003; Keil, Paulish, & Sangwan, 2006).

Una las maneras de abordar lo anterior es mediante la *localización de expertos,* puesto que se pretende encontrar personas con ciertas habilidades que pudieran ayudar a un colega a solucionar algún problema en particular que no le permite avanzar en su trabajo. En el caso de los desarrolladores de software, cuando tienen dificultad para realizar alguna actividad, suelen ir en busca de conocimiento, donde la meta es encontrar el *expertise* (conocimiento de mejor nivel). Es decir, quien posee experiencia es capaz de realizar una tarea mucho mejor que los que no la tienen. Se trata de un conocimiento específico en su mejor momento. Cabe mencionar que la palabra "experto" puede ser usado para describir a las personas que poseen altos niveles de habilidades o conocimientos

(Ericsson, Prietula, & Cokely, 2007). Por lo anterior, se definen las siguientes preguntas de investigación que guían este artículo:

- ¿Cuáles son las fuentes de conocimiento en el desarrollo de software?
- ¿Cuáles son los elementos de información clave para identificar a un experto y el *expertise*?
- ¿De qué manera está representada la información?
- ¿Cuáles son las barreras que impiden el flujo de la información?

Para responder estas preguntas se analizó el flujo del conocimiento para la búsqueda de *expertise* en el desarrollo de software. El objetivo de este artículo es obtener información para la creación de un mapa del conocimiento, el cual facilite la identificación de los elementos de información, cómo los desarrolladores buscan el *expertise* en su organización, y cuáles son los obstáculos a los que se enfrentan. Los resultados obtenidos en este trabajo son los mecanismos diseñados para dar soporte a la búsqueda de *expertise* dentro de las actividades del desarrollo de software mediante una arquitectura de sistema multi-agente.

Flujo del Conocimiento para la Búsqueda de Expertise en el Desarrollo de Software

La metodología para identificar el flujo de conocimiento para la búsqueda de *expertise* fue KoFI (Knowledge Flow Identification) (O. M. Rodríguez-Elias, A. Vizcaíno, A. I. Martínez-García, J. Favela, & M. Piattini, 2009; Oscar M Rodríguez-Elias, Aurora Vizcaíno, Ana I Martínez-García, Jesús Favela, & Mario Piattini, 2009), la cual consta de cuatro fases. La Fase 1 consiste en la identificación de las diferentes fuentes en las que se genera o almacena el conocimiento. La Fase 2 permite identificar los tipos de conocimiento utilizados y generados en los procesos principales de la organización, mientras que la Fase 3 identifica cómo fluye el conocimiento dentro de la organización. Por último, la Fase 4 consiste en la identificación de los principales problemas que obstaculizan el flujo de este conocimiento. Para esto, se realizó un estudio con desarrolladores de software de varias organizaciones, con diferentes tipos de prácticas de desarrollo (centralizado, distribuido y global). La característica común de estas organizaciones es que su proceso de producción está basado en metodologías ágiles. Participaron ocho trabajadores, incluyendo dos líderes de proyecto, cuatro desarrolladores y dos ingenieros en software. Para obtener la información de los participantes se utilizó la técnica de la entrevista semi-estructurada. La entrevista consistía en preguntas de temas relacionados a colaboración, coordinación, intercambio de conocimiento y la administración de los proyectos.

El propósito de las entrevistas fue entender cómo se realiza el proceso de búsqueda de *expertise* entre los miembros de los equipos de desarrollo de software. Se llevaron a cabo 8 entrevistas de forma individual y se guardó en formato de audio. La duración de las entrevistas fue de 40 minutos en promedio. Los datos fueron extraídos de las entrevistas usando diagramas de afinidad, que es una herramienta que sintetiza un conjunto de datos verbales (p. ej. ideas, opiniones, expresiones) agrupándolos en función de la relación que tienen entre sí (Martin, Hanington, & Hanington, 2012). Este proceso se inició con la transcripción de las entrevistas para encontrar los datos clave de las respuestas de los participantes. A partir de eso se clasificaron los datos de las respuestas que aparecían más recurrentemente. Posteriormente continuamos con el análisis de los datos para identificar las relaciones entre los procesos de búsqueda de *expertise*. Por último, a partir del diagrama de afinidad y las categorías definidas se obtuvieron conclusiones. Con la información recopilada, en los siguientes apartados se presentan los resultados obtenidos

Fase 1: Identificando las Fuentes del Conocimiento

En esta fase fue necesario tener en cuenta las fuentes de conocimiento que podrían ser utilizadas para localizar a un experto para dar solución a un problema dentro de una actividad. Los tipos de fuentes encontrados a partir de las entrevistas fueron libros, manuales, blogs, código reutilizado y consulta con compañeros o expertos externos. Esta información coincide con las categorías que propone (Becerra-Fernandez & Sabherwal, 2010), en las cuales el conocimiento se encuentra en: las *Personas (p. ej.* el conocimiento se almacena en las personas ya sea a nivel individual o dentro de un grupo o un conjunto de personas), los *artefactos (p. ej.* el conocimiento que se encuentra en las prácticas de la empresa como las rutinas diarias de trabajo, tecnologías o repositorios de documentos físicos o digitales tales como libros, manuales y videos).

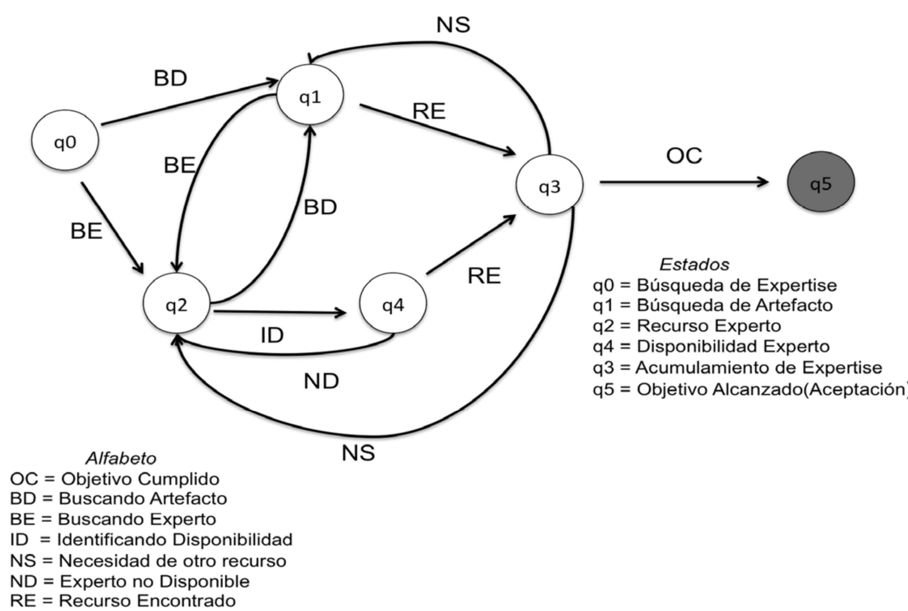
Fase 2: Identificando los Tópicos del Conocimiento

En esta fase fue necesario identificar los temas de conocimiento implicados en el proceso de búsqueda de *expertise* en el desarrollo de software, teniendo en cuenta los diferentes tipos de conocimientos generados por la organización. Los tipos de conocimiento relevantes para este trabajo están relacionados con las características de las actividades de los desarrolladores de software. La actividad en esta fase no trata de describir los temas en detalle, pero si identificarlos como parte de los requisitos de conocimientos. Los temas que se identificaron en esta fase se describen de la siguiente manera: i) *Perfil del conocimiento*, esto se refiere a describir el perfil de conocimiento de los expertos, para poder identificar qué es lo que saben y a qué nivel lo saben (Velázquez Mendoza, Rodriguez-Elias, Rose Gómez, & Meneses Mendoza, 2012). *ii) La información de Disponibilidad*, esto se refiere al conocimiento de las actividades que tienen relación con la actividad actual de un colega con el fin de iniciar la interacción con un experto. *iii) Ubicación del Conocimiento*, esto se refiere a la información sobre la manera en que está almacenado el conocimiento según la fuente (personas, artefactos, entidades organizacionales).

Fase 3: Identificando el Flujo del Conocimiento

Esta fase implicó la creación de un modelo de flujo de conocimiento del proceso de búsqueda de *expertise* en los equipos de desarrollo de software. Para este trabajo, el flujo del conocimiento está representado por un autómata finito (ver Figura 1). El autómata representa el flujo del conocimiento del proceso búsqueda de *expertise*, donde se inicia teniendo la necesidad de conocimiento para resolver alguna dificultad en una actividad (q0). Posteriormente se puede elegir entre hacer una búsqueda de artefactos (q1) o una búsqueda de un experto (q2). En el caso de elegir una búsqueda de artefactos (q1) se busca entre todos los artefactos disponibles (páginas, manuales, videos, código reutilizado), al encontrar un artefacto se verifica si este ayudó a cumplir el objetivo o aún es necesario buscar más artefactos (q3). Si no es necesario buscar más artefactos entonces el objetivo se cumplió (q5), de lo contrario se puede buscar más artefactos (q1). Un artefacto puede sugerir que se busque a un experto (q2). En el caso de elegir una búsqueda de experto (q2) se inicia buscando expertos con el grado de conocimiento para resolver la dificultad que se tienen en la actividad, una vez que se encuentra un experto se necesita comprobar su disponibilidad (q4) para iniciar una interacción con él, posteriormente se comprueba si la consulta del experto fue suficiente (q3) o se necesita consultar al experto o a otro (q2) , también en el caso de estar buscando un experto puede ocurrir que un experto sugiera algún artefacto (q1), si el objetivo se cumplió el proceso termina (q5).

Figura 1. Representación del flujo de conocimiento mediante un autómata



Fase 4: Identificando los Obstáculos en el Flujo del Conocimiento

Esta fase consiste en la identificación de los obstáculos que se presentan en el proceso de búsqueda de *expertise*, los cuales fueron obtenidos a partir de las entrevistas.

Tabla 1. Lista de problemas y situaciones identificadas.

Problemas	Situaciones
1.Administración de los artefactos (individual o grupal)	En algunos casos se conoce al proveedor del conocimiento pero no se tiene acceso a sus artefactos (blogs, manuales, código reutilizado).
2. Administración de los Expertos	Muchas veces es difícil encontrar a la persona con el nivel adecuado de expertise para poder consultar alguna duda o resolver un problema en una actividad.
3.Disponibilidad de los Expertos	En algunos casos no se sabe si el expertise o el experto está disponible para la persona que lo está buscando.
4.Tiempo de resolución de dificultades	En algunos casos se pierde mucho tiempo en la búsqueda de expertise por qué no se cuenta con el conocimiento de donde se encuentra o quiénes son los proveedores.

Los problemas identificados se describen en la Tabla 1. La primera columna define los problemas que surgieron a partir del análisis de las fuentes y temas de conocimiento. La segunda columna describe brevemente una situación de ejemplo para ilustrar el problema.

Implicaciones de Diseño

Con base en el conjunto de problemas de flujo de conocimiento identificados (ver Tabla 1), estos fueron transformados en características de la búsqueda de *expertise*. Por lo que en la Tabla 2 se presentan las implicaciones del diseño de un sistema que podría proporcionar un apoyo para la búsqueda de *expertise* en el desarrollo de software. La primera columna define la característica que sería deseables en el proceso de búsqueda de *expertise*. La segunda columna describe la implicación de diseño que se debe tomar en cuenta para poder dar soporte a la búsqueda de *expertise* durante las actividades del desarrollo de software.

Tabla 2. Implicaciones de diseño.

Características	Implicaciones de diseño
1. Gestión del conocimiento	I1. Uso de mecanismos que recolecten el conocimiento de la empresa (personas, artefactos, entidades organizacionales).
2. Búsqueda de Artefactos	I2.Uso de mecanismos que permitan dar acceso a los artefactos (prácticas, repositorios, tecnologías) de los miembros dentro de la empresa.
3. Búsqueda de Expertos	I3. Uso de mecanismos que permitan encontrar a los proveedores con el conocimiento y grado adecuado para consultar y para resolver dificultades con alguna actividad.
4. Acceso al Conocimiento	I4. Uso de mecanismos que permitan acceso al conocimiento (personas, artefactos y entidades organizacionales) por parte de cualquier miembro de la organización.

Trabajos Relacionados

Una manera de abordar la problemática planteada ha sido mediante el uso de algunos mecanismos para encontrar a personas expertas (Zhang, Ackerman, Adamic, & Nam, 2007). Presenta QuME, un prototipo de una interfaz web personalizada para los usuarios de comunidades de ayuda online de java. Este prototipo tiene un mecanismo para inferir el nivel de conocimiento en java de los usuarios, que se calcula utilizando parámetros como las preguntas que coloca en el foro, la frecuencia de respuesta, las palabras clave de su perfil y otros aspectos más que proporcionan el grado de *expertise* de la persona. También existen más trabajos enfocados a la búsqueda de expertos como el de (Vivacqua, 1999), que aborda el problema de encontrar expertos de acuerdo a las necesidades y al conocimiento que se tiene para ayudar a resolver algún problema dentro de las actividades de desarrollo de software. En este caso se utilizan agentes de software para mediar en el intercambio de conocimiento contactando a expertos con cierto conocimiento específico del lenguaje java. Por otro lado, existen trabajos que abordan la búsqueda de artefactos para dar soporte a las actividades en el desarrollo de software como (Grechanik et al., 2010), que presenta a Exemplar. Esta es una herramienta para la búsqueda de proyectos de software de gran relevancia para reutilizar el código fuente, para lo cual utiliza las palabras clave del proyecto y la descripción bien fundamentada, de manera que se busca hacer una coincidencia entre las palabras y que la descripción refleje las necesidades del usuario. En ese mismo sentido en (Brandt, Dontcheva, Weskamp, & Klemmer, 2010) se describe el diseño, implementación y evaluación de Blueprint, una interfaz de búsqueda Web integrada en el entorno de desarrollo de Adobe Flex Builder que ayuda a los usuarios a localizar ejemplos de código de proyectos anteriores utilizando palabras clave (e.g. lenguaje de programación, framework, nombre de la clase y/o método).

Soporte para la Localización del Expertise (ExLoc)

Con la información obtenida de la metodología KoFI fue posible identificar los requerimientos del sistema para la localización de los *expertise* (ver Tabla 3), con dichos requerimientos se plantea un modelo de una arquitectura multi-agente que denominamos ExLoc. El sistema propuesto para la localización de *expertise* pretende administrar, tanto a las personas expertas, como a los artefactos que contienen el conocimiento dentro de la organización.

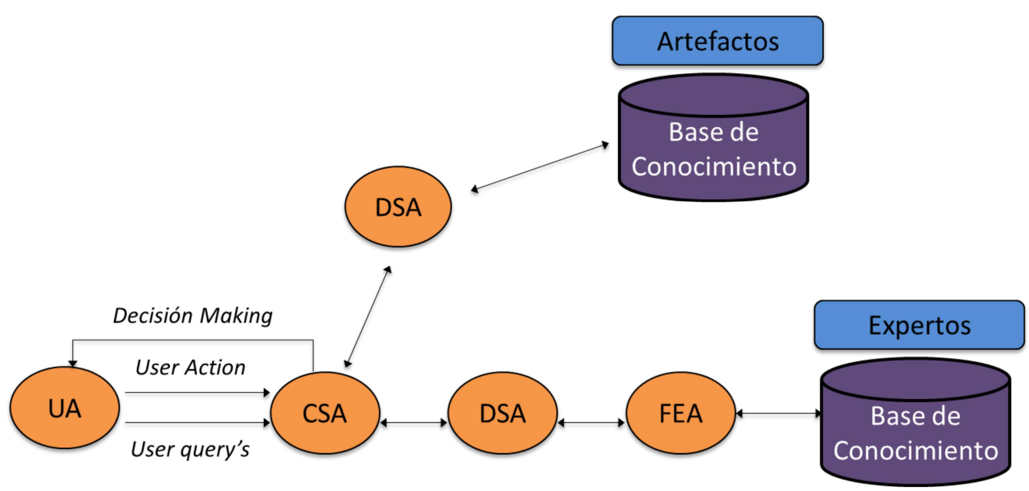
Tabla 3. Requerimientos Soporte localización del Expertise

Requerimientos
R1. El sistema tendrá una interfaz donde podrá hacer las consultas de información y dar de alta nuevo conocimiento.
R2. El sistema se encargará de capturar el conocimiento nuevo en los repositorios y realizará las búsquedas de los usuarios.
R3. El sistema se encargará de tomar decisiones para encontrar los mejores recursos para el usuario de acuerdo a sus necesidades.
R4. El sistema se encargará de hacer el cálculo de los posibles expertos que tengan el conocimiento y la disponibilidad para proveer de conocimiento al usuario.

El propósito del Sistema ExLoc es proveer los recursos adecuados a las necesidades de los usuarios, recolectar todo el conocimiento que se encuentra dentro de la organización, proveer el contacto con expertos que pudieran ayudar a resolver alguna problemática.

El sistema ExLoc estará basado en un modelo multi-agente cuya arquitectura se muestra en la Figura 2, y que se diseñó a partir de los requerimientos propuestos. Se puede notar que existen 4 agentes básicos en ExLoc que trabajan en conjunto para ejecutar en la localización del *expertise*, ya sea para capturarlo o buscarlo.

Figura 2. Arquitectura ExLoc



Dentro de la arquitectura se cuenta con dos repositorios de conocimiento de la organización: una base de conocimiento para artefactos y una base de conocimiento para contener el perfil de conocimiento de los trabajadores. En las siguientes sub-secciones se describen cada uno de los agentes, indicando los objetivos y tareas que cada uno debe cumplir.

Agente de Usuario (UA)

El objetivo principal del Agente de Usuario es proveer una interfaz que permita a los usuarios realizar búsqueda de *expertise*, así como también de capturar conocimiento nuevo. Existe un UA que interactúa con cada usuario permitiendo la personalización de las búsquedas por medio de los intereses o el historial de los usuarios. Cada UA se comunica con un Agente Central de Búsqueda (CSA) de manera que le envía o avisa de las acciones que realiza el usuario. El UA también recibe la información que obtiene como producto de dichas acciones para posteriormente mostrársela al usuario. Las tareas de este agente inciden directamente en el Requerimiento 1 "*El sistema tendrá una interfaz donde podrá hacer las consultas de información y dar de alta nuevo conocimiento*".

Agente Central de Búsqueda (CSA)

El objetivo principal de CSA es generar las mejores herramientas para solucionar algún problema presentado por el usuario. Existe un solo CSA en todo el sistema multi-agente, que es el encargado de procesar todas las acciones e inferir cuál es la mejor opción de acuerdo a las necesidades del usuario. También es el encargado de coordinar la búsqueda de *expertise* al enviar las consultas o actualizaciones de conocimiento en los distintos repositorios a través de Agente de Distribución de Búsqueda (DSA). Las tareas con la que cumple este agente son pertinentes al Requerimiento 3 que trata "*El sistema se encargara de tomar decisiones para encontrar los mejores recursos para el usuario de acuerdo a sus necesidades*".

Agente de Distribución de Búsqueda (DSA)

El objetivo principal de DSA es de buscar el conocimiento solicitado por el CSA en el repositorio correspondiente a ese agente. Existe un DSA por cada uno de los repositorios dentro del sistema (artefactos, expertos). Este agente contribuye a solventar con el Requerimiento 2 "*El sistema se encargará de capturar el conocimiento nuevo en los repositorios y realizará las búsquedas de los usuarios*".

Agente Experto Difuso (FEA)

El objetivo principal de FEA es hacer el cálculo de los expertos que pudieran ayudar al usuario en base a los requerimientos de su problema. Existe un FEA encargado de hacer el cálculo de los expertos utilizando el repositorio con la información de los miembros de la empresa. Posteriormente los candidatos encontrados son enviados al CSA. La tarea de este agente índice en el Requerimiento 4 "*El sistema se encargará de hacer el cálculo de los posibles expertos que tengan el conocimiento y la disponibilidad para proveer de conocimiento al usuario*.

Como se puede notar, los 4 agentes propuestos para dar soporte al sistema ExLoc cuentan con tareas particulares que pueden apoyar, de manera similar a como lo realiza un usuario en el contexto real de la organización. Es decir los agentes en su conjunto pretenden facilitar a los usuarios la búsqueda de *expertise* en la organización, de tal manera que apoye a las actividades de los trabajadores en el momento que se requiera solucionar una duda o problema para complementar un entregable o actividad de un proyecto. La intención de ExLoc es proporcionar, mediante una consulta, el *expertise* con el que se cuenta en la organización con base en la solicitud emitida por un usuario.

Conclusiones y Trabajos Futuros

La búsqueda de *expertise* implica la necesidad de interactuar con personas, así como también acceder a sus fuentes de conocimiento. En este artículo se determinaron las fuentes de conocimiento en el desarrollo de software mediante la metodología KoFI y se identificaron los elementos clave del *expertise*, que son la información relacionada a la disponibilidad de los proveedores del *expertise*, el conocimiento al que tienen acceso dichos proveedores, y la información del perfil de los proveedores. Se identificó el flujo del conocimiento en el desarrollo de software y los obstáculos que se presentan durante la búsqueda del *expertise* en el desarrollo de software, los cuales fueron la administración del conocimiento, la administración de los expertos y el tiempo de respuesta para dicha búsqueda. Para abordar estos obstáculos, se proponen mecanismos que permiten gestionar el conocimiento de la organización, buscar y tener acceso a dicho conocimiento, y contar con la información de la disponibilidad de los proveedores del *expertise*. Entre los resultados principales de este trabajo está la obtención de los requerimientos del sistema, con lo cual se propone una arquitectura de sistema multi-agente que soporta la búsqueda de *expertise*. Se definieron también las tareas y objetivos que cada agente de dicha arquitectura debe cumplir. Este trabajo proporciona las bases para el desarrollo de una herramienta tecnológica que facilite la distribución de este tipo de información de manera transparente a los usuarios.

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