Monitoring Eating Behaviors for a Nutritionist E-Assistant using Crowdsourcing

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The authors describe Lucy, a digital assistant that monitors eating behaviors to help users lose weight. Lucy's design was informed by a study of clients in a nutrition clinic, as well as by crowdsourcing to evaluate six approaches to assessing nutritional content or caloric intake based on meal photos.

Advances in behavior recognition and monitoring have fostered the development of applications aimed at supporting behavior change. While technologies for tracking behaviors such as caloric expenditure or sleeping habits have matured, tracking eating habits remains essentially unsolved.

Eating behaviors of interest might include eating late at night, prolonged fasting, or regular fast-food consumption. Estimating food intake is particularly relevant to health-related issues such as diabetes and obesity. Nutrition specialists usually tailor dietary regimens to patients' preferences and needs. However, patients might change dishes or ingredients due to availability or preferences. If changes in the dietary regimen are to occur (for example, no eggs available for breakfast), then it is important to make proper adjustments to the diet. Using a crowd to assess what patients are eating can be a convenient way to validate whether patients are following their diet.

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RELATED WORK: MONITORING EATING BEHAVIORS

Monitoring eating behaviors has been traditionally addressed with various strategies, including paper-based logs, computational systems that facilitate meal logging, and automatic-recognition approaches.

Paper-based methods for monitoring eating behaviors include food records, food-frequency questionnaires, and forms that include a meal description and time of intake. Mobile phones have been increasingly used to support this task, with apps such as Noom (noom.com) or Calorific (calorificapp.com) that help individuals record their meals and coach them on healthful habits. Both of these approaches rely on self-report, meaning that individuals must explicitly enter detailed data regarding their food intake on a daily basis. In the long run, this can be burdensome for individuals being monitored.

Ubiquitous technologies have also been proposed for automatic or semiautomatic recognition of food intake and eating habits, including when or where you are eating, identifying eating disorders, recognizing healthful food, portion size, and so on. Early work in the area addressed the problems of estimating portion sizes.[1] Other efforts include using crowdsourced rating of photos of meals to assess food intake and composition[2] and rating food on a "healthiness" scale.[3] However, the former requires multiple steps before a crowd-based rating can be obtained. On the other hand, the latter only supports rating food in a healthiness continuum (for example, fat versus fit), which can be subjective and limited in terms of food nutritional content. Anne Moorhead and her colleagues[4] compared the ability of experts and nonexperts to accurately estimate calorie count in photos of meals. The findings indicate that nonexperts achieved very low accuracy while experts had an average error of 8 percent in their estimation.

Additionally, wearables have been used recently for detecting when individuals are eating. For instance, Haik Kalantarian and his colleagues used a sensing necklace to detect throat motion and infer periods of food intake.[5] Also, Yujie Dong and his colleagues implemented a wristband to track eating periods.[6] Other works have aimed to automatically recognize food intake through sensors such as a microphone.[7] Of particular interest to our work are studies aimed at detecting the contents of meals. For example, Austin Meyers and his colleagues presented a system that can recognize the contents of meals from a single image, and then predict its nutritional contents.[8]

Conversely, some commercial mobile phone apps have aimed to help users achieve particular goals. DietApp is a mobile phone app that provides advice for a healthy diet according to age, clinical history, and physical condition.[9] Finally, Gerasimos Spanakis and his colleagues' Think Slim is a mobile phone app that can warn people prior to unhealthy eating events by using mood or location data.[10]

Despite these efforts, estimating what people are really eating has been remarkably challenging. This particular aspect is fundamental to the success of increasingly individual-centric approaches to healthcare (precision medicine), wherein individuals' health and behavior can be automatically monitored to provide patients and caregivers with better care and more accurate and timely information, and, ultimately, to improve quality of life.

We propose the use of crowdsourcing for monitoring dietary intake. In this article, we describe six crowdsourced approaches based on 51 participants' assessment of photos of meals and compare them on accuracy, latency, and cognitive load. We also describe the integration of one of these approaches into a conversational coaching agent to assist individuals who want to change their eating behaviors. For a brief review of related work, please see the sidebar.

RESEARCH PROCEDURE

We worked in collaboration with the "En línea" nutrition clinic, established in 2000 in Ensenada, Mexico. A physician nutrition specialist leads the clinic, supported by another physician and two nurses. In this clinic, approximately 100 patients receive treatment, all with the goal of losing weight.

We carried out the following studies for the design of a nutritionist e-assistant:

- *Stage 1 (S1):* a mixed-method study for understanding nutritionists' and patients' practices

in weight-loss programs to inform the design of an e-coach to assist patients.
- *Stage 2 (S2):* an empirical study for evaluating six photo-based, crowdsourced approaches for inferring food intake.
- *Stage 3 (S3):* development and evaluation of Lucy, a conversational software agent, for assisting patients who participate in the nutritionist program.

S1 and S3 were carried out in the clinic, while S2 was carried out with individuals with no training in nutrition.

STAGE 1: INFORMING THE DESIGN OF A NUTRITIONIST E-ASSISTANT

We conducted a 3-month study in the clinic to better understand the needs of the nutritionist and the individuals undergoing treatment and how to best support them. To this aim, we collected data from various sources. For instance, we interviewed the nutrition specialist, and surveyed 95 patients of the clinic to determine their technology usage and behaviors related to eating, such as whether they took pictures of meals. Moreover, two of the authors attended five weekly sessions at the clinic, as well as participated in the program for three weeks to better understand the challenges faced by the patients. Data were aggregated and later analyzed in interpretation sessions by the authors and the nutritionist to obtain design insights for the nutritionist e-assistant.

Briefly, the patient treatment process followed by the clinic is as follows. At the start of treatment, new patients must complete a short questionnaire about their eating habits. Then, the patients attend an informative session about the clinic methods, and the nutritionist sets a target body weight. After that, the nutritionist designs a one-week meal plan for each patient to follow for the next three weeks. Throughout treatment, patients must attend a weekly group session for nutrition counseling and weight measurement, until the target weight is reached. Patients usually enquire about their diets through occasional calls to the clinic.

The study yielded design insights, which were turned into the following functional (FR) and nonfunctional requirements (NFR):

- *FR1: Meal logging*. Allow the patient to keep a log of meals.
- *FR2: Diet compliance*. System must oversee dietary regime compliance, without demanding additional effort from patients or the nutritionist.
- *FR3: Ingredient exchange*. Provide alternatives for ingredient and dish substitutions.
- *FR4: Meal assessment*. Estimate nutritional content, without giving the nutritionist additional burden.
- *FR5: Nutritional counseling*. Provide nutritional counseling for diet compliance.
- *FR6: Weight tracking*. Oversee progress in weight loss.
- *FR7: Motivation*. Deliver motivational messages based on the patient's goals.
- *NFR1: Reliability*. Answers to patients should be reliable.
- *NFR2: Rapidness*. Answers should be provided quickly.
- *NFR3: Cost-effective*. System should run on hardware available to the patient.
- *NFR4: Mobility*. Patients should be able to access the system anywhere.
- *NFR5: Engaging*. The agent should be engaging either by voice or text.

Informed by these requirements, we propose the design of a conversational agent that provides personalized support to patients during the intervention. The application is aimed at reducing some of the burden of counseling from the nutritionist. In addition, to achieve FR2 and FR4, we propose the use of semiautonomous, crowdsourced-based food intake assessment of patient-taken photographs of meals. The following scenario illustrates how the system can benefit patients:

> *Sara is a 56-year-old teacher concerned about being overweight. Her older daughter is planning to marry in eight months and this has motivated Sara to attend the nutrition clinic. On her first visit, the physician asks her to take photographs of her meals before the second appointment. This information is used by the nutritionist to complete her assessment and recommend a meal plan. Sara also participates in an introductory session in which general advice on the intervention and suggestions for adhering to the diet are provided. She is also asked to download and install "Lucy," an app that can help her follow the program. The clinic personalizes her Lucy account with her current diet, motives, and goals. For the next four months, Sara follows the program, attending sessions, personal consultations every two weeks, and interacting with Lucy. She has found it*

more practical to ask Lucy for the diet of the day than to look at the hardcopy plan. The system also suggests changes she can make when eating out and serves as an assistant to record her weight and remind her of her main motivation and the progress she is making toward it. A feature that Sara particularly enjoys is that sometimes after taking a photo of a meal, Lucy will compliment her for adhering to the plan by having a healthful meal. She understands that Lucy relies on other people to assess the nutritional content of the meals she photographs and is considering volunteering to classify the photos posted by fellow patients.

A key challenge in the design of the e-assistant is the proper assessment of food intake to estimate whether the individual is following the proposed regimen. To address this, in S2 we investigated six crowdsourced, photo-based approaches to analyze the nutritional content of meals.

STAGE 2: CROWDSOURCED ASSESSMENT OF FOOD INTAKE

Assessing food intake and nutritional content involves estimating certain nutritional properties of the food in a photograph. Some properties are difficult to detect; for instance, it is challenging for a person to estimate the amount of carbohydrate, proteins, or fats just by looking at a photograph. Nonetheless, a person can identify salient ingredients, estimate quantities, select similar images, or estimate calories. These activities were the basis of the design of our approaches. Additional considerations included ensuring that individuals can perform the task with no expertise in nutrition and within a few seconds, and that accuracy increases as more people rate the photograph.

We used the following six crowdsourced, photo-based approaches to assess the nutritional content of meals:

- *A1: Number of calories*. The individual estimates the number of calories contained in a meal by looking at the photograph.
- *A2: Food groups*. The individual selects the food groups perceived from the photograph. The participant has to estimate the quantities (none, some, adequate, plenty) of each of the following food groups: fruits, vegetables, cereals, legumes, and animal origin. This is based on the Official Mexican Standard NOM-043-SSA2-2005 for a balanced diet.
- *A3: Healthfulness scale*. The approach is designed to assess the healthfulness of the food in the images. The user rates the photograph on a scale from 1 (not healthful) to 7 (very healthful).
- *A4: Caloric range*. This approach is similar to A1—calories in the meal shown in the photo are estimated by selecting one of six 200-calorie intervals (for example, 401–600).
- *A5: Ingredients*. The user types in all the ingredients that he or she thinks are contained in the meal shown in the photograph, even those not visible, such as salt or cooking oil.
- *A6: Similar images*. The participant selects from a set of nine images the one he or she believes is the most similar to the photograph presented. This action is repeated twice, with the second set of images depending on the first image selected.

We compared these approaches with regard to latency, cognitive load, and accuracy. The ideal crowdsourcing strategy would minimize latency and cognitive load (cost) while maximizing accuracy. We defined and estimated these constructs for our study as follows:

- *Latency*. We defined latency as the time taken to assess one image, measured from the moment the photograph is shown, until the user records the answer.
- *Cognitive load*. We used the NASA-Task Load Index (NASA-TLX) instrument, which uses six subscales (mental demand, physical demand, temporal demand, performance, effort, and frustration measures) to measure the perceived amount of mental effort required by a person to execute a task, and a pairwise comparison between subjects. For this experiment, we removed the pairwise comparison and dropped the physical and temporal subscales because they were not relevant.
- *Accuracy*. We defined accuracy as the degree of confidence in the participant's answers with respect to the ground-truth values of the nutritional content of the meals shown in the photographs. To measure accuracy, we compared the individual values registered by the participants with the ground truth of the images. Because of the uniqueness of the approaches, this

process was different for each of them. For instance, to compute accuracy for A5, we cross-checked the list of ingredients typed in with the actual list of ingredients. We considered different names for the same ingredient (for instance, slice of bread versus wheat bread), typos, and incomplete names. Furthermore, we estimated the collective accuracy of the crowd for a particular photograph, meaning that we computed the mean (or mode, depending on the approach) per photograph and took that value as the answer of the crowd for that particular photograph.

Evaluating crowdsourced approaches for inferring food intake

A total of 51 subjects (8 females, 43 males) participated in the study. Participants were college students majoring in software engineering, with no formal training in nutrition. A database with 45 preclassified images was utilized for this study. We used FatSecret (fatsecret.com.mx) to obtain the nutritional information and ingredients of the food presented in the pictures.

The study was carried out over two days in a computer lab. Each participant required approximately 45 minutes to classify 90 photographs using all six approaches (15 images per approach). Each preclassified image was shown twice using two different approaches. To minimize threats to internal validity, we created 45 different arrangements in which images and approaches were shown to participants (a collection of 15 consecutive images per approach; in each arrangement, both lists of images and approaches were shifted). This was done for the images to receive approximately the same number of ratings across the different participants and approaches, and for the order in which the images were shown not influence the rating (for example, being tired or bored by the last image). After each approach, the user answered the NASA-TLX questions.

Results

We compared the approaches on latency, cognitive load, and accuracy.

Latency. As Figure 1a shows, participants required, on average, less than 30 seconds to assess one photograph across all approaches. Nonetheless, four approaches had a latency under 15 seconds (see Table 1). As expected, A5 was the approach with highest latency. In contrast, participants took less than 7 seconds, on average, to assess A4 and A3.

Cognitive load. Table 1 shows the cognitive load results in its third column (range 0–100). All approaches scored 50 or less; thus, the approaches do not demand much mental effort from participants. A1 scored the largest cognitive load of all, which might have been due to the fact that estimating the number of calories from a photograph can be frustrating and requires considerable effort (Figure 1b). In contrast, A3 and A6 were perceived as requiring less cognitive load, influenced mainly by mental demand and effort.

Accuracy. In Table 1, the approaches related to calories, A1 and A4, had low accuracy scores. On the other hand, A5 and A6 registered acceptable accuracy, which improved with additional answers from the crowd. It was not possible to calculate the accuracy of A3 because we were not able to assess how healthful a meal was with no additional information; that is, what might be healthful for some, might not be so for others. For the other approaches, ground truth was obtained from the source of the image.

Table 1 also shows how the accuracy of each approach changed as more participants (the crowd) classified the images. Again, the approaches related to counting calories, A1 and A4, showed poor results; interestingly, accuracy actually decreased as more answers were collected. Thus, these approaches are clearly not adequate for crowdsourcing. In contrast, the accuracy of the other three approaches (A2, A5, and A6) increased with additional answers from participants. Noticeably, A5 and A6 presented a crowd-based accuracy of 75 percent or higher with the answers of just five participants, reaching nearly 90 percent.

Although A2's accuracy increases, albeit not to acceptable levels, the information conveyed by this approach (the relative amounts of fruits, vegetables, cereals, legumes, and animal origin) is rather limited in terms of monitoring dietary intake. In contrast, from A5 and A6, we can obtain a good estimate of the main ingredients contained in the dish and, thus, obtain a calorie count.

An additional advantage of A5 and A6 is that criteria can be defined for hard-to-assess images, taking into account the varying ratings of the crowd. One such criterion for A6 is to accept a classification when the difference between the image with the most selections and the rest is of at least three votes, having a maximum of 15 votes per image. We used these criteria with the 45 images of the experiment with the following results (average of 30 random runs): the algorithm

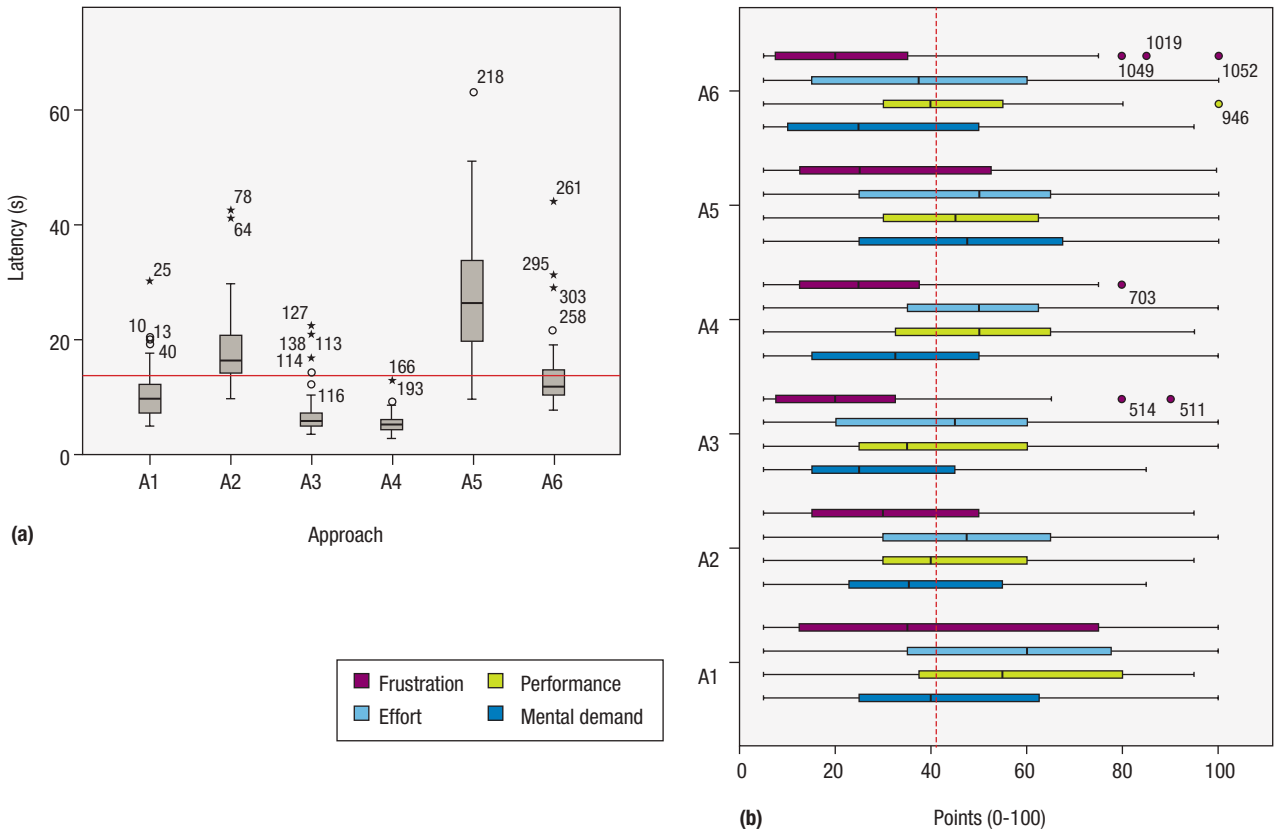


FIGURE 1. Comparison of six crowdsourced, photo-based approaches to assess the nutritional content of meals (see main text). (a) Latency per approach. (b) Cognitive load per approach across the four utilized subscales of the NASA-Task Load Index (NASA-TLX). Circles are suspected outliers; stars are outliers (with their corresponding observation number). Red lines show the overall mean across all approaches.

stopped, on average, at 7.75 votes per image; 78 percent of the images were classified correctly; 5.4 percent were false positives; and the remaining 16 percent were labeled as uncertain, 6 percent of which were false negatives. The images labeled as uncertain could potentially be sent to an expert for approximating nutritional content.

While some approaches are more suitable than others for certain applications, some of them provide very low accuracy or require considerable effort. For instance, A1 and A4 can easily provide an approximation of caloric intake, but do so with low precision, making them of limited use. On the other hand, A2 can help identify if the dish is well balanced, but is not useful in estimating caloric intake. Finally, A5 and A6 provide a good estimate of caloric intake as well as a good approximation of how balanced a dish is.

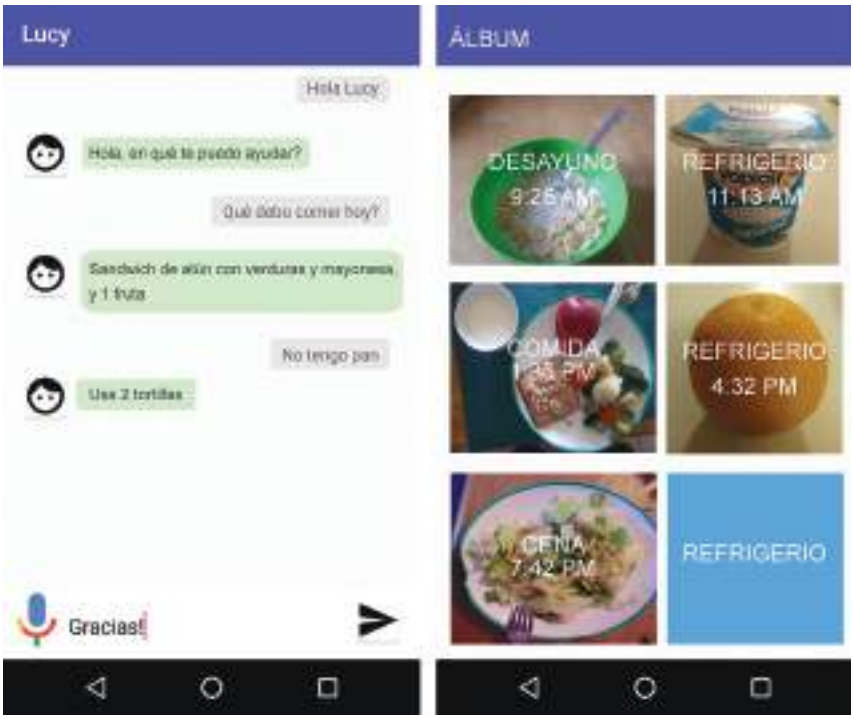
TABLE 1. Comparison of latency (LAT), cognitive load (CL), and accuracy (ACC) for crowdsourced approaches to assessing the nutritional content of meals.

	Individual			Crowdsourced		
Approach	LAT (s)	CL (%)	ACC (%)	ACC, n = 5 (%)	ACC, n = 10 (%)	ACC, n = 15 (%)
A1	10.60	50.40	28.81	27.63	24.37	22.22
A2	18.49	40.11	34.20	38.89	44.48	57.78
A3	7.04	**32.30**	—	—	—	—
A4	**5.61**	38.72	21.51	13.04	13.78	13.33
A5	28.02	42.39	**80.15**	**88.22**	**88.30**	**88.89**
A6	13.74	33.89	58.66	75.74	85.63	**88.89**

n = number of individual answers taken per image. Numbers in bold represent the best approach per condition.

STAGE 3: LUCY—A NUTRITIONIST ASSISTANT CONVERSATIONAL AGENT

To assist the patients in the nutritionist program, we developed a conversational agent named Lucy, based on the requirements and scenario described above. The agent's main purpose is to answer frequent, simple questions related to diets and provide general nutritional advice. Lucy was designed to interact with the patient through



(a) (b)

FIGURE 2. The Lucy conversational agent: (a) sample interaction with a patient, and (b) log of photographs of meals consumed in a given day.

speech, although it also includes a text interface. Figure 2a shows a simple interaction with Lucy in which the patient is told that today's planned lunch is a tuna sandwich, vegetables, and a piece of fruit. When the patient tells Lucy that she has no bread, Lucy proposes that she use tortillas instead. The dialogue is voice-based, but the app displays a transcript of the interaction as well. Figure 2b shows the day's log of photographs of the meals eaten by the patient that day.

To estimate eating behaviors, Lucy is designed to use a variation of the crowdsourced approach A5 (referred to as A5*). Since the patient has a diet designed by the nutritionist, the crowd member doing the assessment is initially presented with an ingredient list for that meal. The crowd member can mark if each ingredient is present, absent, or not sure. The rater can also type in ingredients, not originally listed, as done in A5. This variant helps deal with the main limitation of A5: latency. We evaluated A5* using the methods reported earlier but with images of meals taken by participants in the intervention. The latency recorded by 15 participants evaluating 15 images was 20 percent lower than for A5.

Lucy offers answers to the following type of queries:

- *Current diet*. What is for dinner today? What will I have for breakfast? (Figure 2a).
- *Ingredient/meal substitution*. The nutritionist offers substitute side items for meals. For instance, when the diet calls for one serving of fruit, this can include a small apple, or half a banana. At the patient's convenience, the meals for one day can be substituted for those indicated for tomorrow or the day after. Lucy can provide notification regarding these alternatives (see Figure 2a).
- *Recipes*. Lucy provides step-by-step instructions to cook all meals provided in the dietary regimen.
- *Log of meals*. The patient can register foods eaten by either telling Lucy or by taking a picture of the meal (Figure 2b). In the latter case, approach A5* will be used to validate that the patient is adhering to the diet. This can be used to make adjustments to the program. For instance, if the participant has eaten a heavy breakfast, the agent will suggest removing or reducing a portion during lunch or dinner.
- *Weight-loss monitoring*. A patient can share with Lucy his or her current weight, which can be queried later on. For instance, the user can ask, "How much weight have I lost this month?" or "How close am I to my target weight?"
- *Motivation*. As suggested in the intervention, the patient can register up to five reasons to lose weight. Lucy will occasionally remind the patient of these when reporting on the weight lost or when explicitly asked to recall them.

The implementation of Lucy is supported by three cognitive services from IBM Watson: Speech to Text, Text to Speech, and Dialog, which is used to indicate different ways in which the user can provide a query. Lucy runs on Android smartphones or tablets.

Evaluating Lucy

We evaluated Lucy with clinic patients. We attended four weekly meetings coordinated by the nutrition specialist to present Lucy. We gave a 10-minute presentation about Lucy, described scenarios of use and demonstrated the system. Afterwards, we asked the participants to complete a questionnaire about user acceptance using the Technology Acceptance Model (TAM).[11] At the end, participants could suggest improvements or offer general comments about Lucy. Finally, they asked Lucy questions on their own.

Fifty-nine patients (70 percent female) participated in the evaluation. Seven participants (12 percent) were 20–29 years old, 17 (29 percent) were 30–39, 10 (17 percent) were 40–49, 16 (27 percent) were 50–59, and 6 were older than 60. Two participants did not provide their age in the questionnaire. Sixteen participants had been in the program for less than a month, 20 had attended for between 1 and 3 months, 9 between 3 and 6 months, and 12 had participated for 6 months or more.

Answers to the 10 TAM items were given on a 7-point Likert scale, with 1 indicating "completely disagree" and 7 "completely agree." We report on the constructs for technology adoption of the TAM model, namely ease of use and usefulness. The average scores indicate that the participants found Lucy to be useful (6.35) and easy to use (6.22) and seemed interested in adopting the system (6.33). The item with the lowest score (6.14) was "It will be easy for me to become an expert in the use of the system." In contrast, the item "Using Lucy would help me with tasks related to my diet" obtained the highest score (6.47). One of the participants gave a "neutral" answer to all questions, and two others had mostly negative ratings. All others seemed rather positive toward Lucy.

Thirty participants (51 percent) provided final comments. Seventeen made suggestions such as allowing personalization of the information and adding new features for Lucy to control water intake, give reminders, connect with a shopping list, and provide encouraging messages. The other 12 responses included mainly praises to the system and the initiative. Finally, a considerable majority (>76 percent) was interested in being notified when the system is available.

We presented Lucy, a digital assistant aimed at helping patients undergoing weight-reduction treatment. Lucy's design was informed by a study that we conducted in a nutrition clinic. To monitor eating behaviors for the assistant, we proposed and evaluated six approaches for assessing nutritional

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content or caloric intake by a crowd. The approaches offer different advantages in terms of latency, cognitive load, and accuracy. Based on our results, we devised a variant of A5 for Lucy, because it offered the highest accuracy with only a few raters required. Although A5 had the highest latency, the proposed variant reduced latency by 20 percent. Both Lucy and the crowd assessment have the potential to facilitate the work of nutrition experts in coaching multiple patients 24/7. Potential users were enthusiastic about adopting Lucy for future use.

Future work includes evaluating the use of Lucy in naturalistic environments to assess participants' performance when the digital assistant is incorporated into their nutritional program. We also plan to propose and evaluate incentives to encourage the crowd to rate photographs of meals.

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Eventos de Vida y su Relación con el Padecimiento de Cáncer de Mama: Un estudio Exploratorio

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Resumen. En este trabajo de tesis se estudian los eventos de vida de pacientes diagnosticadas con cáncer de mama. De manera retrospectiva, las pacientes cuentan aspectos importantes de su vida antes del diagnóstico. A través de la técnica de análisis cualitativo teoría fundamentada se busca explorar eventos de vida en pacientes sobrevivientes del cáncer de mama. Los resultados de este estudio exploratorio pueden servir como base para generar nuevos indicadores cuantitativos en el área de salud que permitan estudiar más a fondo el desarrollo de la enfermedad por medio de métodos computarizados.

Palabras clave: Cáncer de mama, teoría fundamentada, factores de riesgo.

1 Introducción

El cáncer de mama o cáncer de seno es un tumor maligno que se ha desarrollado a partir de células mamarias y es el tipo de cáncer más comúnmente diagnosticado en las mujeres. Los factores de riesgo tradicionales para el cáncer de mama incluyen el estado reproductivo, las mutaciones genéticas, la historia familiar y el estilo de vida [21]. En México, el gobierno federal, a través de la Secretaría de Salud, informa que a partir del año 2006, el cáncer de mama es la primer causa de muerte por cáncer en la mujer [18].

Más allá de los aspectos biológicos, en la literatura se ha planteado un vínculo entre el cáncer y los estados de ánimo particularmente estados afectivos que involucran pérdidas [10], depresión, preocupaciones y melancolía. De hecho, el cáncer de mama ha sido redefinido como una enfermedad biopsicosocial que involucra no solo al paciente, sino a su contexto y a quienes están en él [1]. A medida que la investigación se extiende más allá en el entorno psicosocial del paciente, las ideas con respecto a la causalidad pueden desarrollarse más completamente para incluir factores externos tales como el estrés que surge de las relaciones interpersonales [7].

En el presente documento se estudia de manera exploratoria acerca de los eventos de vida en mujeres mexicanas sobrevivientes del cáncer de mama. Los eventos de la vida y las

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reacciones psicológicas y de comportamiento que los acompañan con frecuencia tienen un impacto en la vida cotidiana de las personas y se cree que los predisponen a esta enfermedad [6][16]. Los estudios de observación han establecido que los acontecimientos estresantes de la vida, a menudo definidos como una acumulación de acontecimientos de la vida ordinarios o duelo, aumentan los riesgos de trastornos mentales, infecciones agudas como el resfriado común llegando a causar la muerte [23]. Otros estudios sugieren una relación causal entre el maltrato infantil no sexual y una variedad de trastornos mentales, uso de drogas, intentos de suicidio, infecciones de transmisión sexual y conductas sexuales de riesgo. Todas las formas de maltrato infantil deben considerarse riesgos importantes para la salud con un impacto considerable en los principales contribuyentes a la carga de la enfermedad en todas partes del mundo [17].

En este trabajo se realizaron entrevistas semi-estructuradas con pacientes diagnosticados con cáncer de mama. Se utiliza la técnica de teoría fundamentada para el análisis de los datos recolectados. Los resultados pueden servir como base para generar nuevos indicadores cuantitativos en el área de salud que permitan estudiar más a fondo el desarrollo de la enfermedad por medio de métodos computarizados.

Esta investigación se organiza como sigue. En la sección 2 se presentan trabajos relacionados que se han realizado. En la sección 3 se presenta la Metodología de este trabajo de tesis. En la sección 4 se muestran y discuten los resultados. Finalmente, se presentan las Conclusiones y Trabajo Futuro.

2 Marco Teórico

En la actualidad, la orientación de las áreas médicas se centran en el diagnóstico temprano del cáncer de mama por medio de la realización de estudios radiológicos de mastografía en periodos recomendados según el rango de edad, antecedentes genéticos y otros factores [11]. De esta manera, se permite la temprana detección y tratamiento para este diagnóstico. Sin embargo, como se puede apreciar, mucho de esto se basa en la detección temprana, y no necesariamente en modelos de prevención adecuados.

La prevención inicia antes de la etapa de diagnóstico de cáncer de mama, por lo que se considera de suma importancia el estudio de diversos factores procedentes de diferente naturaleza como estado de salud, antecedentes genéticos, tabaquismo, proximidad a áreas geográficas donde se manejen productos químicos. Sin embargo, factores como los que se mencionan previamente como los eventos de vida normalmente no son considerados. En este estudio se centra en los eventos de vida del paciente como posibles factores con cierta influencia para este padecimiento.

Existen estudios donde se analizan factores de riesgo como son hábitos de vida [2] ,uso prolongado de tratamientos hormonales [5], relación o cercanía al uso de productos químicos o agroquímicos [3], [14], [25]. Hasta el mejor saber de los autores, pocos trabajos se han centrado en entender factores emocionales y su influencia en el padecimiento de cáncer de mama [6]. Más allá de eso, tampoco se han definido indicadores que permitan

cuantificar y estudiar a gran escala si es que en realidad existe una relación causal en cierta medida.

Otros trabajos han relacionado algunos aspectos emocionales derivados de la personalidad, y han estudiado algunos de estos aspectos en personas que padecen cáncer. La personalidad puede entenderse como un sistema interno automático de entornos únicos para cada individuo e incluye modelos de pensamientos, emociones y comportamientos junto con algunos patrones adquiridos [8].

A pesar de la relación bien establecida entre los rasgos de personalidad y la depresión y la ansiedad [1], se identificaron pocos estudios que examinaran esta relación en pacientes oncológicos [6]. Estudios sugieren que niveles más altos de neuroticismo aumentan el riesgo de depresión y ansiedad en pacientes con varios tipos de cáncer [15]. Por ejemplo, entre las mujeres con cáncer de mama que se sometieron a tratamiento quirúrgico, la personalidad neuroticista en estas pacientes aumentó el riesgo de depresión, de igual forma entre los pacientes con cáncer de pulmón. Muchos otros artículos han examinado la relación entre la personalidad y los síntomas físicos (por ejemplo, dolor, fatiga) en pacientes con cáncer [15] [4]. Como se puede apreciar, la personalidad, la manera de expresar las emociones, y la manera en que se afrontan las situaciones difíciles pueden tener efectos negativos en la salud, incluyendo el cáncer. Debido a esto, no es descabellado pensar que los eventos de vida negativos en la vida de las personas pueden tener efectos adversos en la salud de las mismas.

3 Métodos

3.1 Pregunta de investigación y objetivo general

La pregunta principal que guía esta investigación de carácter exploratorio es ¿Qué patrones se pueden observar en cuanto a los eventos de vida negativos en los sobrevivientes de cáncer de mama?

Por otro lado, el objetivo general de este trabajo de tesis es identificar eventos de vida negativos con mayor incidencia para el grupo de mujeres sobrevivientes de cáncer.

3.2 Participantes

Los participantes son mujeres pertenecientes a un grupo de apoyo para sobrevivientes de cáncer de mama. Se reclutaron nueve participantes. En la siguiente Tabla 1 se presentan los datos demográficos. Todas las participantes con diversas características educativas, ocupacionales y socio-económicas, a quienes se les había diagnosticado cáncer de mama, y con capacidad para hablar. Se firmaron cartas de confidencialidad y consentimiento informado para participar en el estudio.

Tabla 1. Datos demográficos de las participantes

ID	Edad	Peso Kg.	Ocup.	Hijos	Procedimiento quirúrgico	Seno afectado	Estado civil	Diagnóstico
E1	63	49	Ama casa	2	Mastectomía parc.	Izquierdo	Viuda	Dic 2016
E2	50	74	Ama casa	3	Mastectomía parc.	Izquierdo	Casada	Nov 2015
E3	41	85	Empleada	2	Ninguno	Derecho	Casada	Ene 2017
E4	47	64	Enfermera	1	Mastectomía parc.	Derecho	Divorciada	Feb 2015
E5	56	85	Ama casa	3	Mastectomía total	Derecho	Casada	Mar 2015
E6	44	78	Empleada	2	Mastectomía total	Izquierdo	Divorciada	Mar 2012
E7	54	59.5	Enfermera	2	Mastectomía total	Izquierdo	Casada	Feb 2018
E8	47	63	Empleada	3	Mastectomía total	Izquierdo	Divorciada	Jul 2017
E9	48	79	Empleada	3	Mastectomía total	Izquierdo	Unión libre	Sept 2017

3.3 Recolección de datos.

Se realizaron nueve entrevistas semi-estructuradas, las cuales fueron grabadas en audio. Las entrevistas tuvieron una duración promedio de 01:14 horas. El protocolo de entrevista consistió de 54 preguntas. Los tópicos incluidos son: aspectos de familia nuclear y extensa, relaciones laborales, relaciones sentimentales, situaciones fortuitas a lo largo de su vida. Previo a la entrevista, se realizó una breve conversación donde se comparte la razón y objetivos de la entrevista, posteriormente la sensibilización y motivos por las cuales debe haber apertura mental y emocional al compartir la información, las participantes llenaron un formulario de consentimiento previo al inicio de las preguntas.

3.4 Análisis de los datos.

Para el análisis se siguieron los lineamientos de la teoría fundamentada [9], [12]. La Teoría Fundamentada tiene por objetivo comprender la realidad a partir de la percepción o significado que cierto contexto u objeto tiene para la persona, generando conocimientos, aumentando la comprensión y proporcionando un guía significativo para la acción. Consiste en metodología de investigación cualitativa que extrae de las experiencias vividas por los actores sociales aspectos significativos, posibilitando conectar constructos teóricos, potencializando la expansión del conocimiento en enfermería y de otras áreas como psicología, sociología, medicina y otras [9], [20].

La primera etapa es la codificación de cada una de las transcripciones (la asignación de las unidades de texto a cada categoría de análisis, en cada una de las transcripciones). Esta etapa, conocida como codificación abierta, se ha realizado mediante el análisis individual de cada entrevista y la posterior asignación de códigos a las unidades de texto para terminar en la creación y agrupación de las categorías. En una segunda etapa, en la codificación axial, se redefinen y refinan las categorías depurando aquellas que según el criterio de investigación no sean de gran aporte al objetivo del estudio o bien que no se relacionen de

manera estrecha con el objetivo. En la tercera etapa, codificación selectiva, se selecciona una de las categorías principales para construir una teoría final.

4 Resultados

Con referencia a los resultados de la investigación cualitativa que arroja la codificación y categorización se encuentra lo siguiente. Se identificaron un total de 234 códigos en la primera etapa. Dichos códigos generaron 4 categorías principales que fueron agrupadas para su análisis, las cuales se describen a continuación:

4.1 La familia generadora de entornos influyentes en emociones

Existe una enorme coincidencia en la agrupación de los códigos encontrados sobre el cómo las relaciones familiares han creado los entornos que han influido en las emociones experimentadas en diferentes etapas de la vida, citaremos algunas de estas situaciones. Por ejemplo, E2 nos comenta: "*Mi relación con mi papá era muy buena, él era pescador y cuando llegaba a la casa yo lo abrazaba y me sentaba a platicar con él y yo era su preferida como fui muy enfermiza, yo me refugiaba mucho en mi papá. Cuando él se iba a pescar, duraba un mes o más y ahí era cuando pensaba que era mucho tiempo sin verlo. Mi mamá era muy estricta y nos pegaban a diario, y por cualquier cosa y nos decía 'pobre de ti si lloras', y después de eso me costaba mucho trabajo poder llorar, nos chicoteaba y eran fuertes sus golpes nos dolían mucho*". En el caso particular de E2, se desarrolló en un entorno familiar donde predominaban las agresiones físicas y emocionales, así como la represión de sentimientos.

Por otro lado, E3 nos comenta de manera similar que: "*Mi papá siempre fue una persona muy seria. Él siempre trabajaba. Siempre estaba trabajando. Es chofer y fue un papá ausente y pues así crecí, y me acostumbré a esa situación. Mi papá es alcohólico y me daba miedo cuando llegaba tomado a la casa que discutiera con mi mamá. Eso me dolía mucho y siempre tuve ese temor. Así fue durante todo el tiempo que viví con ellos, que duró 19 años. También me dolió mucho el saber que mi papá tenía relaciones con otras mujeres, y pues me dolía mucho por mi mamá*". Aquí podemos encontrar de igual forma un entorno familiar donde prevalecían emociones de incertidumbre, temor, agresiones verbales que mantuvieron por un largo periodo perturbando el desarrollo psicosocial de E3. Los entornos de agresiones físicas y verbales parecen ser algo frecuente en nuestras informantes. De igual forma E7 nos comparte "*Mi mamá nos pegaba mucho. Quería educar a base se golpes y mi papá no. Era todo lo contrario. Cuando estaba chica sentía que la odiaba*". En este caso, E7 nos habla de un sentimiento de odio hacia su progenitora, pero también de comparación de su padre y su madre, y las diferentes estrategias que E7 percibía que usaban para tratar de imponer disciplina.

El comportamiento actúa recíprocamente con la salud del propio individuo de manera que el nivel de salud es, en parte, función del comportamiento del sujeto, y éste a su vez está condicionado por las características psicológicas, biológicas y de ecosistema del propio

individuo [24]. Por lo anterior, se puede concluir que en el núcleo familiar existía violencia física y emocional además de represión por expresar sentimientos y emociones mismos que fueron bloqueados y acumulados por largos periodos de tiempo pudiendo así afectar el desarrollo biopsicosocial, comprometiendo el futuro de la salud de los sujetos de estudio.

4.2 Profanación de su cuerpo y pensamientos

En su totalidad, todas las entrevistadas (9 de 9) comparten haber sido hostigadas y abusadas física y/o emocionalmente en algún momento de la vida. Por ejemplo, E2 nos comparte: "*En otra clínica donde trabajé, un doctor me acosaba. Según él me estaba dando mi tratamiento para embarazarme [pero] después cambie de médico, pero él me decía que mi esposo no podía y que él podía influir para que yo me embarazara y yo le dije que no. Primero pierdo el trabajo a que pasara algo. En una ocasión entré al consultorio a llevarle expedientes y ahí me agarro a la fuerza y… (llora fuertemente)*". Casos como el que menciona E2 son comunes en nuestras informantes. En el caso de E2, fue víctima de agresión emocional y sexual por parte de un superior, influyendo de modo biopsicosocial en el desarrollo integral de modo permanente en su vida.

Por otro lado, E3 comenta de manera similar: "*Tengo un vecino. Es abogado. El llevó mi caso cuando demandé hace 12 años, [él] iba a mi casa y siempre me pedía dinero y como que iba también con otras intenciones, y me molestaba mucho, y eso duró como un año y hasta la fecha lo veo y me molesta*". De igual forma E8 nos comparte: "*con mi primera pareja, pues él era un hombre muy prepotente. Tomaba mucho y había agresión verbal y física, aunque no de alto grado, pero si había también infidelidades de su parte y cuando llegaba a la casa en la madrugada me sacaba a empujones de la casa que porque no le tenía la comida lista, y pues yo me quedaba callada, y ahora veo que fue un error. Yo le tenía mucho resentimiento. Yo estaba consciente que fui una mujer abnegada y le tenía miedo, pero si deseaba que se muriera. El abusaba física, sexual y emocionalmente de mi*". Aun cuando los casos de E2 y E8 difieren en que una era abusada por su esposo, y una por un superior, sus casos no son particularmente raros. Todas nuestras informantes reportaron haber sufrido abuso en algún momento de su vida. Tal como se ha reportado, el acoso emocional y el abuso sexual tiene repercusiones somáticas, psicológicas y psicofisiológicas [19]. De manera adicional, se identifican a la violación y a la violencia doméstica como causas significativas de trastorno por estrés postraumático y depresión en mujeres de todo el mundo afectando de manera significativa su salud.

4.3 Muerte de familiares y seres allegados

Todas nuestras informantes (9 de 9) reportaron haber sufrido una pérdida de familiares cercanos y/o seres allegados que representaban algo muy importante en su vida. Por ejemplo, E1 nos comenta: "*Tuve 2 hijas. Con la primera, excelente. Es lo máximo para mí, muy buena relación. Todo lo que guardo en mi corazón son puras cosas bonitas sobre ella. Es una hija excelente. Y la segunda nació prematura. A los 7 meses, y murió*". E1 nos

comparte un enorme gozo, orgullo y satisfacción por su primera hija. Sin embargo, la gran pérdida de su segunda hija en el embarazo no llevado a término la sigue perturbando enormemente, aun en estos días después de más de 30 años de sucedido. Por otro lado, E2 dijo: "*Yo tuve 3 abortos. No se me lograban los bebés. Los 2 primeros de 4 meses y el otro fue provocado por una cuñada que me dio una patada en el abdomen en una discusión que tuvimos en la casa de mi suegra. Después de ese aborto, tuve una niña que nació y murió de insuficiencia cardiaca. Mi hermano, el de en medio, murió hace 23 años. Murió cuando tenía 22 años. Él era mi aliado. Yo lo quería mucho. Murió en un accidente automovilístico y más porque yo no sabía llorar y me tuvieron que hospitalizar. También la muerte de mi papa me pudo mucho. Murió hace 16 y también la muerte de mi hermano, el mayor, hace 8 años*". En este caso, E2 expresa su gran dolor al perder sus 2 primeros bebés. Sin embargo, comparte que la pérdida del tercer bebe fue aún más dolorosa por las condiciones en que sucedió, resultado de una agresión física. De acuerdo a lo que comenta, el dolor parece incrementar en ella por la gran cantidad de pérdidas presentadas a lo largo de su vida. De manera adicional, E3 nos comparte: "*En noviembre 2017, falleció una sobrina de cáncer, hija de un primo hermano ella tenía 19 años y tenía cáncer en los pulmones. Su problema duró como 8 meses, me revivió mis miedos, volví a sentir todo por lo que pasé, cuando yo tuve mi problema*".

Por otro lado, E4 nos comparte lo siguiente: "*Yo tenía como 9 o 12 años cuando una de mis hermanas falleció. Ella tenía como 18 años. Iba con un grupo de amigos al mar y a mí y a una prima nos mandaron con ella, y ahí ella se ahogó. No me di cuenta porque yo estaba jugando, y luego la empezaron a buscar y no la encontraban, y ahí fue cuando me di cuenta y pues nos asustamos, y no recuerdo yo hasta que nos dijeron que se había ahogado. En ese momento no era consciente. Ya en mi casa, mi mamá estaba llore y llore y recuerdo que la llevaron a mi casa [a mi hermana], y mi mamá la bañó y ahí la velaron. Yo me sentí culpable y más que dolor sentía miedo de eso que pasó*". De acuerdo a [13], existen casos en que las reacciones iniciales posteriores al duelo se acentúan y prolongan por algunos años, que resultan ser autolimitadores para quien lo padece. Además, desencadenan alteraciones físicas o mentales de gran relevancia que pueden aumentar la probabilidad de morbilidad y mortalidad en determinados tipos de poblaciones. Lo anterior sustenta las afecciones mentales y emocionales sufridas por la muerte de familiares en nuestras entrevistadas volviéndolas vulnerables a múltiples padecimientos tanto físicos como emocionales.

4.4 Abuso de sustancias tóxicas en integrantes de la familia

Seis de nuestras informantes comparten que algunos de los integrantes de su familia consumieron sustancias tóxicas como alcohol, marihuana, o cocaína. E9 nos comparte: "*Cuando él [su papá] ganaba dinero, se iba a las cantinas y se lo acababa todo tomando. Aunque cuando yo crecí, ya no tomaba tanto y tengo recuerdos muy malos de esa etapa, y recuerdo que mis papás duraban meses sin hablarse a causa de borracheras e infidelidades de mi papá, dolía, aunque estaba muy chica*". Además, E5 nos comparte de modo similar

respecto a su esposo: "*también tuvo problemas de alcoholismo y adicción a las drogas durante 15 años y teníamos muchos problemas por ese motivo*". Además, E5 nos comenta: "*Una de mis hijas se fue a estudiar a EU, y si me dolió, sobre todo cuando supe que tenía problemas de drogadicción. En 3 ocasiones tuvo ese problema. Perduró por casi 6 años. Mostraba conductas violentas hacia todo mundo, pero ya salió adelante*". Como se aprecia, la violencia puede ocurrir en cualquier etapa de la vida de la mujer y muchas mujeres experimentan múltiples episodios durante sus vidas, lo cual puede tener efectos inmediatos y acumulativos sobre su salud y desarrollo de sus capacidades cognoscitivas, afectivas, económicas y de relación [22].

5 Conclusiones y Discusión

En este trabajo se presentó un estudio exploratorio de mujeres sobrevivientes con cáncer de mama. Nuestras informantes reportan que habrían podido evitarse sufrimientos emocionales vistos como innecesarios durante algunas etapas de su vida. Tal reflexión puede ir encaminada hacia el manejo integral del cáncer, asociando al psiquiatra, para que este pueda tratar o prevenir los trastornos mentales que puedan surgir durante el desarrollo de la enfermedad y sus tratamientos.

De manera adicional nuestras informantes reportan sobre los eventos de vida negativos con mayor incidencia para el grupo de mujeres sobrevivientes de cáncer. En la gran mayoría de los casos convergen en situaciones de abuso físico y emocional, pérdida de integrantes de la familia con los que mantenían relaciones estrechas, y la gran influencia de las emociones generadas en los entornos de familia de origen y familia nuclear, sin perder de vista las afectaciones emocionales generadas por integrantes de familia que usaron sustancias tóxicas.

Los hallazgos reportados en este estudio muestran que todas las participantes presentan situaciones en cuando menos dos de las dimensiones encontradas en la investigación. Debido a eso, se requieren estudios más profundos para tratar de asociar de manera significativa estos eventos. Indicadores emocionales normalmente no son considerados dentro de los estudios clínicos, por lo que no se descarta que podrían aportar información de interés, y complementaria sobre este tema.

Una de las limitantes de este trabajo es el número reducido de sobrevivientes participaron en el estudio. Otra más es que al aun encontrarse en tratamientos paliativos, se programan entrevistas que frecuentemente son canceladas por las entrevistadas al ser llamadas para atención médica. Como trabajo futuro, se pretende explorar la relación de ciertos rasgos de personalidad con la intensidad con que afrontan diversos eventos de vida negativos.

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A Flexible Scheme to Model the Cognitive Influence on Emotions in Autonomous Agents

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ABSTRACT

Autonomous agents (AAs) are designed to embody the natural intelligence by incorporating cognitive mechanisms that are applied to evaluate stimuli from an emotional perspective. Computational models of emotions (CMEs) implement mechanisms of human information processing in order to provide AAs for a capability to assign emotional values to perceived stimuli and implement emotion-driven behaviors. However, a major challenge in the design of CMEs is how cognitive information is projected from the architecture of AAs. This article presents a cognitive model for CMEs based on appraisal theory aimed at modeling AAs' interactions between cognitive and affective processes. The proposed scheme explains the influence of AAs' cognition on emotions by fuzzy membership functions associated to appraisal dimensions. The computational simulation is designed in the context of an integrative framework to facilitate the development of CMEs, which are capable of interacting with cognitive components of AAs. This article presents a case study and experiment that demonstrate the functionality of the proposed models.

KEYWORDS

Cognitive Model of the Brain, Emotion Process, Fuzzy Logic, Software Agent

INTRODUCTION

Autonomous Agents (AAs) are software and robot entities that act on behalf of users or other programs with certain degree of independence and autonomy. In doing so, AAs make use of knowledge about the environment and representations of desires and goals (Franklin & Graesser, 1997; Wang, 2010; Wang, Zatarain, & Valipour, 2017). This type of intelligent system has been crucial for the advance of fields such as software engineering (SE), human-computer interaction (HCI), and artificial intelligence (AI). 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 (Ligeza, 1995; Maes, 1995; Sun, 2009). Giving AAs such cognitive functions allow them to carry out more complex tasks by minimizing human intervention. That is why research in these fields (e.g., AI, HCI, and SE) focuses on improving problem solving, reasoning, and communication skills of AAs. Particularly, the research

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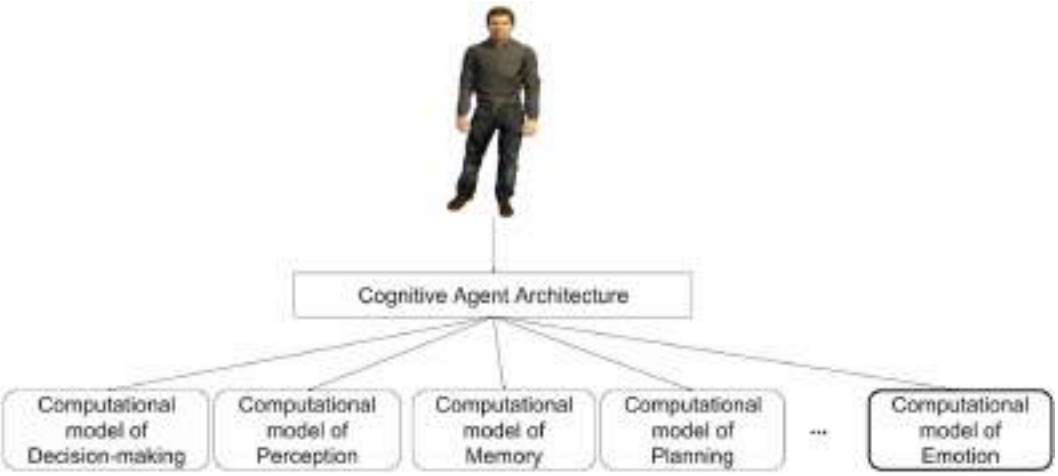
community in the AI field has devoted efforts to create human-like systems for communication and reasoning as well as to reproduce in computer environments the associated brain processes (Ligeza, 1995). In the HCI field some interfaces and mechanisms that improve the interaction of these systems with other agents (computational or human agents) have also been developed (Martínez-Miranda & Aldea, 2005; Perlovsky & Kuvich, 2013).

Evidence shows that emotions influence cognitive functions (Ayesh, Arevalillo-Herráez, & Ferri, 2016; Hurtubise, 1995; Phelps, 2006). The emotional significance of perceived stimuli influences the normal operation of brain processes such as attention, perception, and decision making. According to fields such as psychology and neuroscience, emotions result from the interaction of several cognitive and affective processes, including memory, perception, motivations, and attention (Frijda, 2005; Goldie, 2002; LeDoux, 2000; Smith & Lane, 2016). Emotions are psychophysiological reactions that represent ways of adapting to perceived stimuli from an important object, person, place, event, or memory. Psychologically, emotions alter attention, trigger certain behaviors, and activate relevant associative networks in memory (Wang, 2012). According to Breazeal (1998) and Wang (2010), emotions are necessary to establish long-term memories. In addition, emotions play a key role in learning, from simple reinforcement learning to complex and conscious planning.

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 (Cañamero, 1997; Dias, Mascarenhas, & Paiva, 2014; Gebhard, 2005; Rodriguez, Ramos, & Wang, 2011; Wang et al., 2012; Wang, Wang, Patel, & Patel, 2006). Recent works have proposed the incorporation of affective processing in AAs by designing Computational Models of emotions (CMEs), which are software systems designed to synthesize the mechanisms of the human emotion process (Rodríguez, Ramos, & Ramos, 2014; 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. Ortony, Clore, & Collins (1990) propose that CMEs provide AAs with the capacity for affective processing; they synthesize operations and architectures of some components that represent aspects of the human emotional process. In general, CMEs include mechanisms for the evaluation of stimuli, generation of emotions, and generation of emotional responses, providing this type of intelligent systems with the ability to recognize emotions of humans and other virtual agents. For example, Alma is a CME designed to provide virtual humans with emotions, mood and personality, facilitating the generation of emotions by evaluating the stimuli coming from agents' verbal and non-verbal expressions such as wording, length of phrases, and facial expressions (Gebhard, 2005; Gebhard, Kipp, Klesen, & Rist, 2003).

Despite of the importance of the relationship between cognitive and affective processes in humans, such interaction is not usually considered in the design of cognitive agent architectures (Rodríguez, Gutierrez-Garcia, & Ramos, 2016) (Figure 1 shows an example of the types of components included in a representative cognitive agent architecture). Moreover, although the literature reports a variety of CMEs, most of them do not take into account the influence on the emotion evaluation process of human key aspects such as personality, culture, past experiences, social context, and physical context, among others, which are processes that may be implemented in cognitive agent architectures and which influence human emotions (Gebhard, 2005; Martínez-Miranda & Aldea, 2005; Wang, 2007; Wang et al., 2006). In this context, although findings in psychology and neuroscience indicate that (1) the evaluation of emotional stimuli is influenced by the results of various cognitive functions and that (2) elicited emotions modulate cognitive processes (e.g., attention, perception, and decision-making), there are several challenges to be addressed in the modeling of this extensive interaction between mechanisms associated with cognitive and emotional functions in cognitive agent architectures (Wang, 2007, 2011).

Figure 1. Representative cognitive agent architecture



The following are some of such challenges and issues involved in the modeling of the interaction between cognition and emotion in cognitive agent architectures (Castellanos, Rodríguez, Castro, & Gutierrez-Garcia, 2018; Rodriguez et al., 2011; Wang, 2007; Wang et al., 2006):

- A cognitive agent architecture may include a variable number of cognitive components. As we discuss above, there are many cognitive processes involved in the emotional process which makes it complex 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 data 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 very specific perspectives and for specific objectives. This leads to different models that make it difficult their integration, due to, for example, these would hardly share the same format;
- 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 changes 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 influence. Mainly because if a same stimulus is perceived more than once, the agent learns how to deal with it and is already prepared. It is possible that the result is very similar, but the emotion intensity should vary.

In addition, Ojha & Williams (2017) state that CMEs have the following limitations regarding their underlying design in cognitive agent architectures:

- **Low replicability:** The design and implementation of the underlying components of CMEs are explained only at high-level description;
- **Domain dependency:** The model design of CMEs is only applicable in one or very few predefined scenarios or domains. Also, CMEs model emotions according to specific implementation needs. Depending on the problem, the emotional evaluation process is designed by selecting one or

two aspects of the complex human cognitive-affective interrelationship (Ortony, 2003; Paiva, Parada, & Picard, 2007);

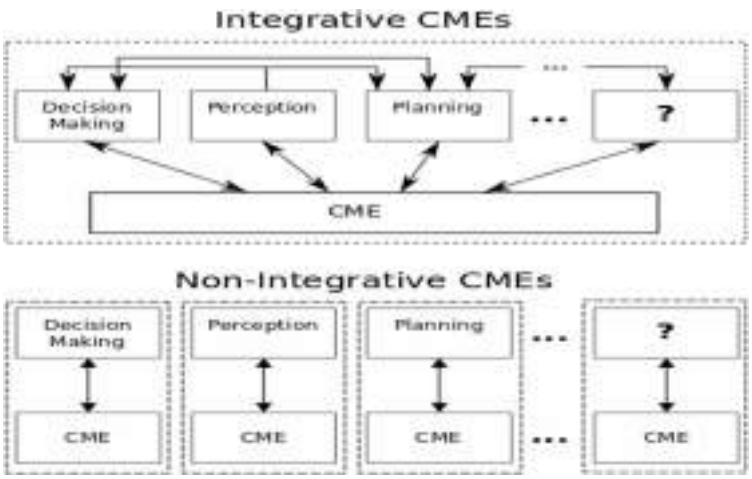
- **Poor scalability and integration:** It is hard to add new components to CMEs because their design is domain-specific.

In this paper, we present a computational scheme designed to model the influence of cognitive information on the emotional evaluation process of CMEs in autonomous agents. The level of influence on such evaluation process depends on the cognitive information projected from components of cognitive agent architecture. The evaluation process in a CME is responsible of assessing from an emotional perspective the stimuli perceived by an agent. The evaluation process is a crucial phase of the operating cycle of CMEs since the consistency of the results of other phases (e.g., emotion and behavior generation) depend on the consistency of such emotional assessment. In turn, the consistency of the evaluation process in a CME depends on the cognitive information taken into account. In particular, the computational scheme is designed in the context of the Integrative Framework proposed by Rodríguez et al. (2016), which is a framework designed to facilitate, through input and output interfaces, the development of CMEs capable of interacting with cognitive components implemented in a given cognitive agent architecture and which are involved in the emotion process (e.g., personality, culture, perception, motivations, and attention). Importantly, the proposed computational scheme is designed to promote the modeling of the interaction between cognitive and affective processes in autonomous agents as occurs in the human brain.

RELATED WORK

The literature reports a variety of CMEs designed to be included in cognitive agent architectures. These computational models consider a variety of cognitive information in their emotion evaluation phase. In this section, we analyze influential CMEs and some frameworks (integrative and non-integrative frameworks, see Figure 2) in order to understand the role of cognitive information in their evaluation process and how researches incorporate them into CMEs (Castellanos et al., 2018; Wang, 2007; Wang et al., 2006). There are several efforts that attempt to provide AAs with emotional components; we review some of the strategies used in different CMEs. We provide a detailed description of the role of some key human elements such as motivations, internal drives, personality, and learning in some CMEs and analyze their influence in AAs.

Figure 2. Integrative and non-integrative frameworks of CMEs



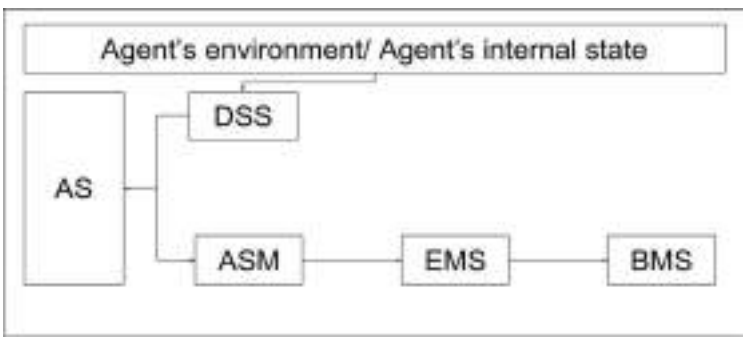
In non-integrative CMEs, their underlying architecture represents a closed system that does not allow including new components (at least not in a simple way). Non-integrative models are developed for a specific purpose and context. This type of model includes one or two emotional aspects in their evaluation process, which in many cases is sufficient to obtain a functional system (see Figure 2). For example, Armony (2010) presents EMA, a computational model of emotions designed to integrate the emotional component in a cognitive-emotional agent architecture. EMA is based on the psychological theory of appraisal, which consists in 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.

There are more recent designs of CMEs dealing with the problem of complexity in emotional appraisal from another perspective, not as part of a CME intended for a specific application, but as a more complete and varying representation of the process. These proposals focus on modeling the complexity of emotional assessment through scalability-oriented mechanisms and are considered as integrative models (see Figure 2). An example of this type of integrative model is FeelMe (Broekens & Degroot, 2004), which 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 include new characteristics to the emotional model to make it more complete. FeelMe is based on the psychological theory of appraisal, which characterizes emotion as the result of a process of evaluation of events that occurs differently in each individual, usually taking into account aspects such as their goals, beliefs, and past experiences.

FeelMe is proposed with a modular scheme, in which the emotional process is separated into five steps (see Figure 3):

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.

Figure 3. Framework FeelMe (Broekens & Degroot, 2004)



Modular FATIMA (FearNot Affective Mind Architecture) (Dias et al., 2014) is an architecture for autonomous agents that implements personality and emotions to generate an influence on the agent's behavior. This architecture proposes a modular scheme to provide the scalability feature. Figure 4 shows the operation of FATIMA. First, FATIMA perceives information from 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 (Reisenzein, 2001).

In Table 1 we present a summary of the role of cognitive functions in the emotion process of some CMEs reported in the literature (Armony, 2010; Breazeal, 2003; El-Nasr et al., 2000; Hudlicka, 2005; Gebhard, 2005; Velásquez, 1996; Becker-Asano & Wachsmuth, 2009). In the rest of the section we provide a detailed description of the role of Motivations and Internal Drives in Kismet (Breazeal, 2003), Learning (El-Nasr et al., 2000), and the role of personality in Mamid (Hudlicka, 2005), which are CMEs that have proven useful in several application domains.

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; Rodriguez et al., 2011; Wang, Patel, & Patel, 2013; Wang et al., 2006). Motivations 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 their 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 5.

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 5, when the intensity of a drive is within the overwhelmed regime, the valence of

Figure 4. Architecture of Fatima (Dias et al., 2014)

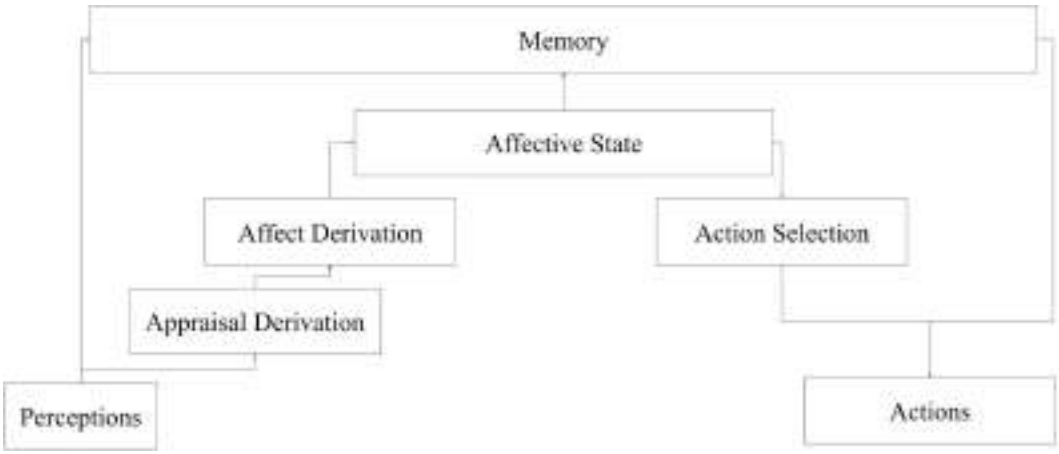
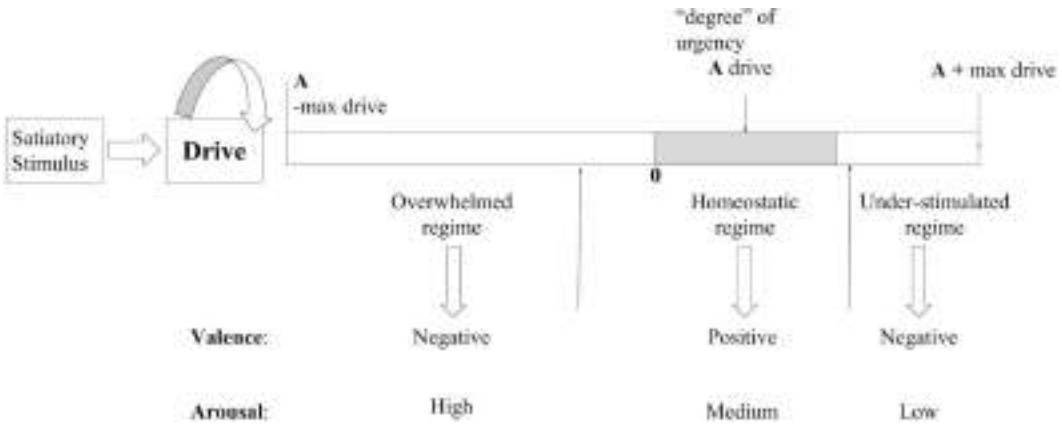


Table 1. Cognitive processes involved in the emotion process in some CMEs

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 (Cynthia 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).

Figure 5. The model of internal drives in Kismet (Breazeal, 2003)



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 (Breazeal, 2003). In this manner, the intensity of emotions in Kismet depends on the status of its drives.

Personality

This term is seen in the domain of CMEs as the set of individual traits in which people differ from each other (Averill, 1997; Hampson, 2006). 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. These traits are combined 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 valence 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 (El-Nasr et al., 2000). This model implements decision-making process, memory systems based on experience, and processes of learning and adaptation to elicit a coherent emotion and different states for each agent; these experiences contribute a degree of individuality to the agent, which helps to elicit different emotions for a same stimulus according to the bias that was experienced from the past events.

As seen in Table 1 and the analysis of models presented in this Section, cognitive information plays a key role in the emotion evaluation 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 (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 (Castellanos et al., 2018; Rodriguez et al., 2011; Wang et al., 2006). The consistency of the emotional evaluation process in CMEs depends on projections from several cognitive processes. Therefore, CMEs should be designed considering that the 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, we can approach this problem by creating a framework that enables 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 for an example of representative cognitive agent architecture and its components). 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 6 and Table 2).

Based on this assumption for the InFra's design (mentioned above), there are two key characteristics that were considered:

Figure 6. Design of the integrative framework. It shows the relationships of a CME (part 'B') with cognitive agent architectures (part 'A' and part '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.

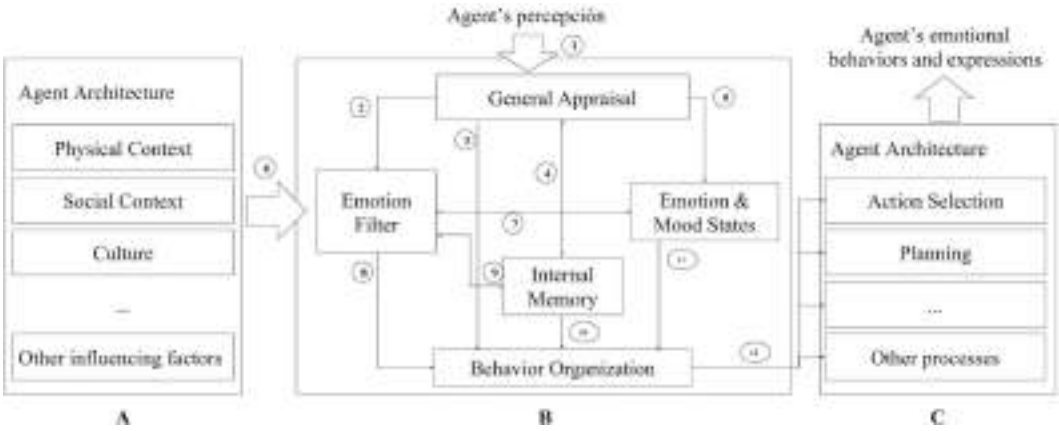


Table 2. Components of the InFra

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 Organization	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.

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;
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 6 and Table 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, the indirect route in the InFra 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 enables 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 carries out 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 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). For instance, these components may handle information underlying the processing of the following cognitive functions and psychological constructs:

- The agent's culture;
- The agent's motivations;
- The agent's personality;

Table 3. Interactions among the InFra's components (numbers in the first column correspond to the numbers in Figure 6)

	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.

- The agent's social norms;
- The agent's beliefs;
- The agent's goals and desires;
- The agent's physiological signals;
- The agent's expectations;
- The agent's past experiences;
- The agent's physical context;
- The agent's social context; and
- The agent's current situation.

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

As shown above, most CMEs have been designed to address a particular problem or application, reducing the complexity of modeling the human emotion process to an implementation of specific mechanisms according to specific design goals. A novel approach promotes the development of CMEs whose architecture integrates cognitive information in the emotion evaluation 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 this section, we present a computational scheme designed to provide mechanisms for the cognitive modulation of appraisal variables used in the emotion evaluation process of autonomous agents.

As mentioned above, the proposed computational scheme addresses some of the design requirements of the integrative framework proposed by Rodríguez (2016). In the InFra the evaluation of emotional stimuli takes place in the EF component (see Figure 6). This process of evaluating stimuli from an emotional perspective is based on the Appraisal Theory, a psychological theory that explains the elicitation of emotions based on the relationship between individuals and their environment as shown in (Ortony et al., 1990; Roseman, Spindel, & Jose, 1990). This evaluation of the individual-environment relationship is carried out using a series of appraisal dimensions such as pleasantness; goal conduciveness, suddenness, and controllability (see Figure 7).

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 8. A computational schema for modeling the influence of cognition on appraisal dimensions, which characterize emotions, involves two main challenges:

1. Given that cognitive components in agent architectures vary in terms of their relevance to the emotion evaluation process, it is necessary to define the particular influence that a cognitive function exerts on each appraisal dimension implemented to carry out the evaluation of emotional stimuli; and
2. The mapping of the information projected from cognitive components should be translated into dimensional values that characterize an emotional state and which are integrated into the evaluation process.

Figure 7. Evaluation of emotional stimuli in the appraisal theory

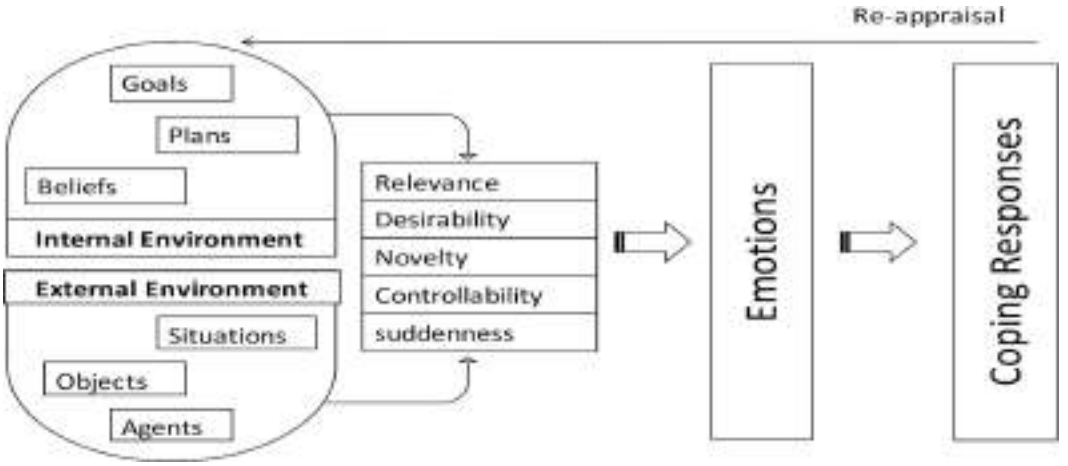
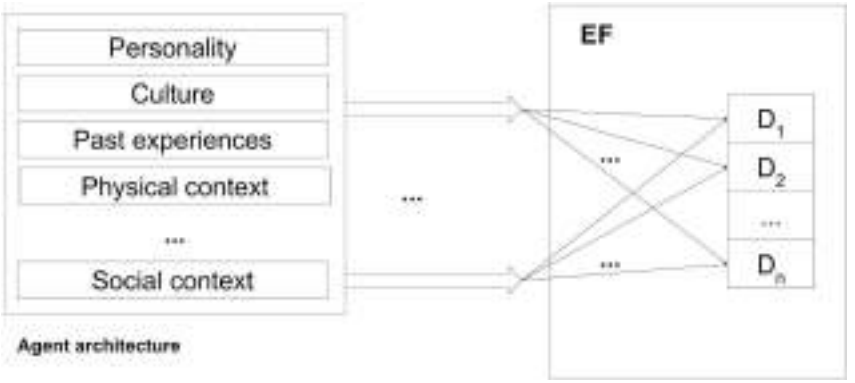


Figure 8. Influence of cognitive components of agent architectures on appraisal dimensions



The proposed schema assumes that the GA module in the InFra assigns an initial value to each appraisal dimension according to the stimuli perceived by the agent. 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) present a study that 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. Moreover, the scheme takes advantage of similarities among some aspects of cognitive components to classify cognitive information and thus manages specific types of influence on appraisal dimensions.

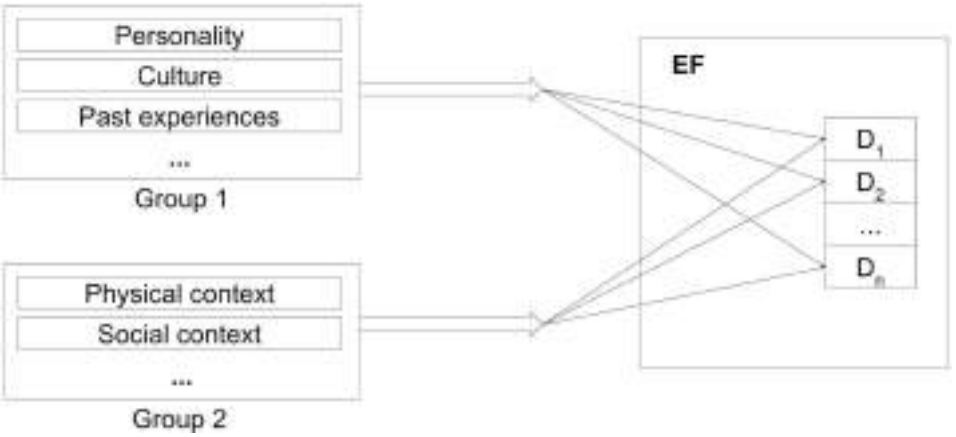
An aspect of interest for the modeling of the influence of cognition on the evaluation process in CMEs has to do with the temporality of cognitive components. For example, components such as those modeling personalities barely change over time. In contrast, components in charge of assessing the

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 (see Figure 9): 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 of 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.

The model associates a fuzzy membership function to each appraisal dimension so that the values generated by the GA component of the InFra are analyzed in terms of such membership functions. In this way, the influence of cognitive components (grouped in the two mentioned categories) is represented by the alteration of the limits of membership functions. Figure 10 shows this computational scheme for the cognitive modulation of appraisal dimensions. The modulation in the evaluation process occurs as follows:

1. The General Appraisal (GA) component calculates an initial value to each appraisal dimension based on the event perceived by the agent and the internal mechanisms of the InFra;
2. These initial values are then fuzzified using the membership functions defined for each appraisal dimension. Initially, the limits of these membership functions are predefined;
3. Each component in the agent architecture that conform the first group of cognitive information (i.e., components that change slowly) is analyzed in terms of the structure and the format of the information it sends. For example, the component of personality will send a type of personality such as neuroticism or extraversion. Information provided by all components of the group are consolidated and sent to the modulation component (i.e., the EF component in the InFra);
4. The modulation component modifies the limits of the membership functions for each appraisal dimension according to the received information. Afterwards, this component analyzes the initial values assigned by the GA to each appraisal dimension considering the adjusted membership functions;
5. The third and fourth steps are repeated in order to consider the influence of cognitive information of the second group (i.e., components that change very frequently);
6. Finally, the modified values of each appraisal dimension are sent as the output to other components in the CME.

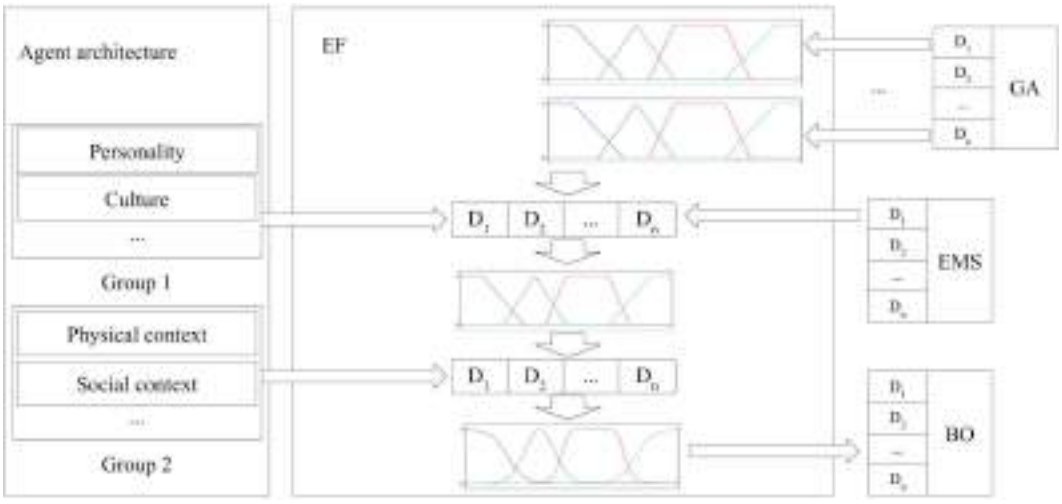
Figure 9. Grouping of components



The following pseudocode illustrates the modulation in the evaluation process carried out by the scheme (see Figure 10):

```
Start
   General Appraisal Component
      Novelty(event)
      Pleasure(event)
      Goal_Orientation(event)
      ...
      Nth-appraisal_variable(event)

   Emotional Filter
      modulation_Group1(Novelty)
      modulation_Group1(Pleasure)
      modulation_Group1(Goal_Orientation)
      ...
      modulation_Group1(Nth-appraisal_variable)

      modulation_Group2(Novelty)
      modulation_Group2(Pleasure)
      modulation_Group2(Goal_Orientation)
      ...
      modulation_Group2(Nth-appraisal_variable)

      ...

      modulation_GroupNth(Nth-appraisal_variable)

      calculateEmotion(Novelty, Pleasure, Goal_Orientation, ...
      Nth-appraisal_variable)
End
```

Figure 10. Model of appraisal dimensions modulation



As mentioned above, the cognitive modulation on appraisal dimensions is reduced to the influence of two types of cognitive components (organized in two groups). However, there are still two key challenges: 1) the integration of individual outputs of cognitive components so that these are represented by a consolidated value that influences appraisal dimensions, and 2) the structure and format of the output information of each cognitive component. The first challenge may be addressed by performing the summation of the outputs of each cognitive component multiplied by an adjustment factor. Regarding the second challenge, although each cognitive component may represent the information in different ways, we consider that cognitive components deliver a limited number of outputs.

A CASE STUDY TO ILLUSTRATE THE SCHEME

In order to illustrate the functioning of the schema proposed to modulate appraisal variables, let's suppose the following situation: it is the day of a very important job interview and the agent finds itself driving when suddenly a tire bursts, immediately there is an emotional reaction to that event, surely the agent would feel angry, frustrated, desperate; the agent could even take it with calm, it depends on the agent's personality, state of mind, past experiences among other aspects.

How does the proposed scheme evaluate this situation? The scheme is implemented within the modules of the InFra, which receives an event and runs two evaluation circuits: direct route for handling fast reactions and an indirect route for handling more cognitive biased responses. As mentioned above, we focus on the indirect circuit as in this route takes place the cognitive evaluation, which involves all cognitive modules of this framework.

In the InFra, first the stimulus is received by the general evaluation component (GA). In our case study the event is *get a flat tire*. This component implements a series of dimensions that allow us to evaluate the stimuli and assign them an emotional meaning; these can be any type of variable. We use the following appraisal variables: Desirability, Expectation, Novelty, Pleasure, Goal Orientation, and Coping Potential. The event *get a flat tire* is evaluated first according to the desirability, that is, the degree to which we want an event to occur. Obviously, the agent does not want anything to stop from getting to the job interview, so the event would be evaluated as undesirable.

We then evaluate whether we expected or contemplated that this event (*get a flat tire*) occurred. Some people try to think about everything that could go wrong and prepare for it and if something happens does not take them by surprise. In other cases, it may be because of the characteristics of the environment we see that something will happen. For example, if we go down a poor road, we can expect with a certain probability that we strike a tire of our car. Let us think that, in our case study, it never crossed the agent's mind that a tadpole would strike it, being "unexpected" the value for the *Expectative appraisal dimension*.

Then we evaluate the *novelty dimension* of the event that just happened, i.e. if the agent had already experienced the same event or one very similar. The memory of the agent is consulted in this dimension. Suppose that the agent had already experienced this event in the past, the intensity of anger or frustration would be higher than if it were the first time it happened. Memory has the memories and the number of times an event occurs to us, so it is easier to access past emotions and use them to amplify or minimize emotions to current events. So, suppose that the event had already happened before, and the agent was late and lost that job, the *novelty dimension* would have the value "not novel".

Once we evaluate the *novelty dimension*, we calculate the pleasure that causes the agent the occurrence of the event. Pleasure is a positive feedback mechanism that motivates the system to recreate situations that were pleasant and evade those that caused pain. When presenting the same situation, we know the possible result, not getting employment. Thus, the value for this dimension when the event *get a flat tire* happens again when we go to another interview is "unpleasant".

We then assess how much it affects the objectives, *goal conduciveness dimension*, of the agent. The agent has a series of goals that it is always looking to fulfill. The initial goal was to arrive at

the interview as a possibly sub-goal of the goal "obtain work", so the event *get a flat tire* directly obstructs one or more objectives of the agent giving it a value of *goal conduciveness* is "negative".

Finally, we evaluate the potential of facing the event that occurs to us, i.e. if we can somehow face a negative event and minimize its impact or solve the problem. Returning to the event *get a flat tire* the agent asks itself what to do or whether it has to ask for a taxi or if it needs to change the tire or If it has time to do that and to arrive at time to the interview. Imagine that the agent does not have the tool to change the tire or has no money to ask for a taxi, the *potential dimension* to face this event and get to the interview is null.

From the values obtained by the appraisal variables and the use of a series of fuzzy rules we relate the event to an emotion. We use Plutchik's theory, Plutchik (2001) proposes a circle of emotions to generate rules for emotion generation (see Table 4).

Having the following results in appraisal dimensions: Desirability is *undesirable*, Expectation is *unexpected*, Novelty is *not_novelty*, Pleasure is *not_pleasant*, Goal-conduciveness is *negative*, and Coping potential is *null*. Deriving in "Anger" as the emotion resulting from the first step of evaluation. All this happens, as we mentioned above, in the GA (general appraisal) component of the Infra.

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:

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

$$\mu MEDIUM = \{0, si\ \ y \leq 0.3 \frac{y - 0.3}{0.4 - 0.3},$$
$$si\ \ 0.3 < y \leq 0.41, si\ \ 0.4 < y \leq 0.7 \frac{1 - y}{1 - 0.7}, si\ \ 0.7 \left\langle y \leq 0.10, si\ \ y \right\rangle 1$$

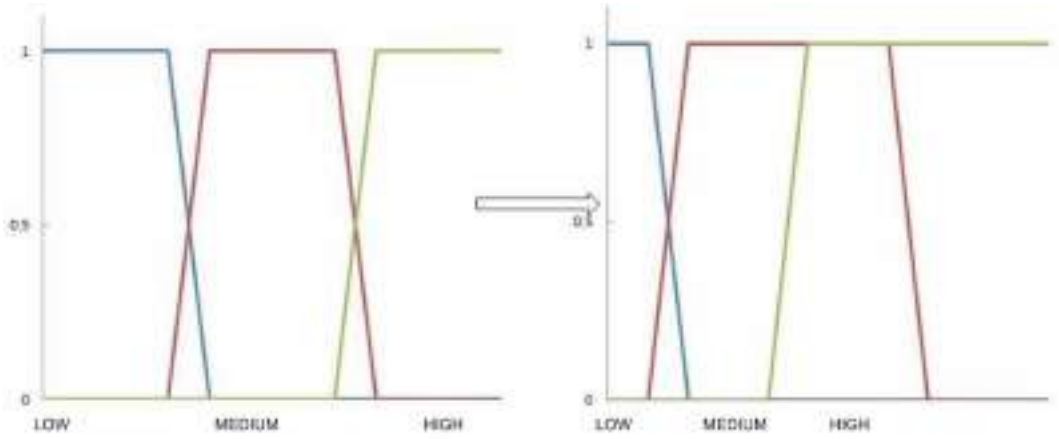
$$\mu HIGH = \{0,\ si\ \ z \leq 0.6 \frac{z - 0.6}{0.1},\ si 0.6 \left\langle z \leq 0.71,\ si z \right\rangle 0.7$$

These functions are initially predefined and are then adjusted according to the cognitive modulation exerted by the two groups of cognitive components. Let's assume that the literature

Table 4. Representative rules to generate emotions

Emotion	Rules
Sadness	**IF** Desirability (E) **IS** highly undesirable **AND** Expectation (E) **IS** expected **AND** Novelty (E) **IS** low_novelty **AND** Pleasure (E) **IS** not_pleasant **AND** Goal-conduciveness (E) **IS** negative **AND** Coping potential (E) **IS** approachable **THEN** Emotion (E) **IS** Anger
Anger	**IF** Desirability (E) **IS** undesirable **AND** Expectation (E) **IS** unexpected **AND** Novelty (E) **IS** not_novelty **AND** Pleasure (E) **IS** not_pleasant **AND** Goal-conduciveness (E) **IS** negative **AND** Coping potential (E) **IS** null. **THEN** Emotion (E) **IS** Anger

Figure 11. A possible effect of the agent's personality on the membership functions associated to the novelty dimension



reports that the personality and other factors such as the physical context influence the emotion evaluation. For example, considering the calculation of the *novelty dimension* and that in the past the agent already experienced the event *get a flat tire on Sunday* (not exactly the same situation as to *getting a flat tire on the way to an important interview*). 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 associated to each appraisal dimension (including the *novelty dimension*). 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 11). As mentioned above, this second evaluation takes place in the emotional filter (EF) component of InFra.

CONCLUSION

In this paper, we presented a scheme to model the cognitive bias on 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. We presented a case 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. 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.

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Research article

A computational model of emotion assessment influenced by cognition in autonomous agents

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ABSTRACT

In this paper, we present a computational model of emotions based on the context of an Integrative Framework designed to model the interaction of cognition and emotion. In particular, we devise mechanisms for assigning an emotional value to events perceived by autonomous agents using a set of appraisal variables. Defined as fuzzy sets, these appraisal variables model the influence of cognition on emotion assessment. We do this by changing the limits of fuzzy membership functions associated to each appraisal variable. In doing so, we aim to provide agents with a degree of emotional intelligence. We also defined a case study involving three agents, two with different personalities (as a cognitive component) and another one without a personality to explore their reactions to the same stimulus, obtaining as a result, a different emotion for each agent. We noticed that emotions are biased by the interaction of cognitive and affective information suggesting the elicitation of more precise emotions.

1. Introduction

Autonomous Agents (AAs) are software entities designed to show autonomous, proactive, and social behavior. Their underlying architectures include components that implement mechanisms of cognitive and affective processing. These AAs are capable of reasoning, learning from previous experiences, and making decisions that allow them to achieve their objectives (Marsella, Gratch, & Petta, 2010; Franklin & Graesser, 1997). A key characteristic of AAs is their ability to communicate with human and artificial agents when cooperating or negotiating to achieve common goals (Ortony, Clore, & Collins, 1988). The research community in this domain focuses on improving such underlying mechanisms of AAs and their underlying cognitive architectures.

According to Salovey and Mayer (1990), social skills are a set of behaviors that manifest themselves in interpersonal situations and are based on the domain of communication skills (verbal or non-verbal such as gestures or tone of voice). Emotions have a very important role in the development of communication skills associated with the social behavior of human beings. Furthermore, it is known that emotions also influence behavior biasing the normal operation of cognitive processes associated with intelligence (Becker-Asano & Wachsmuth, 2009; Marsella et al., 2010; Pérez, Cerezo, & Serón, 2016).

Traditionally, the definition of intelligence is associated, among other aspects, with memory and capacity to learn or to reason (Scherer, 2001). However, such definition fails to consider the importance of the emotional process known as Emotional Intelligence (EI), which is object of study in fields such as artificial intelligence, cognitive sciences, and social sciences due the influence that emotions have on human behavior. According to Salovey and Mayer (1990), emotional intelligence is the ability to manage one's and others' feelings and emotions, to discriminate between them, and use this information to guide actions and behavior. Their model includes four capabilities:

1. Emotional perception: this capability perceives, evaluates, and expresses emotions through language or behavior.
2. Tendencies of thought: the emotional state facilitates or inhibits the effects of favorable or unfavorable events altering the perspective of the individual when dealing with some action or event.
3. Emotional comprehension: it allows labeling emotions to recognize the relationships between words or actions and emotions.
4. Emotional modulation: this capability mitigates negative emotions and enhances the positive ones, without overriding or exaggerating the information they transmit.

In this context, emotions are crucial in the development of AAs endowed with coherent and consistent behavior with respect to human

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behavior. As mentioned above, humans are emotional beings. Emotions influence cognitive and affective functions underlying our behavior and intelligence (Martínez-Miranda & Aldea, 2005).

A plausible design of AAs involves the construction of a cognitive architecture endowed with mechanisms for the generation of intelligent behavior. However, this type of architecture has been designed to implement mainly cognitive functions (e.g., memory, decision-making, and reasoning), leaving aside affective aspects. It is expected that through the interaction of cognitive and affective processes, AAs may be able to replicate the intelligent behavior observed in humans and thus improving the quality and believability of their expressions (Rodríguez, Gutierrez-Garcia, & Ramos, 2016). Given the great influence that emotions have on the cognitive components of agents, it is reflected in the literature an interest in including affective components that reproduce such influence and at the same time integrating emotions with the current architectures of agents easily.

Computational models of emotions (CMEs) (i.e., software systems designed to model the mechanisms of the human emotional process) represent an effort to provide AAs with affective processing. CMEs are intended to be included in cognitive agent architectures and, in this way, provide AAs with mechanisms suitable to (1) process affective information, (2) create synthetic emotions, and (3) generate emotional behaviors (Rodríguez et al., 2016).

Integrating affective processes into an already defined cognitive architecture is a difficult task that involves many challenges. One challenge is that cognitive architectures are composed of various cognitive components that were not designed to interact with each other. Another challenge is that a cognitive agent architecture may include a varying number of cognitive components and each cognitive component projects very particular information using different structures and formatting. In addition, the information provided by cognitive components changes frequently depending on the type of cognitive function these components implement (Castellanos, Rodriguez, Castro, & Perez, 2017). The challenge is to define a mechanism for integrating affective processes into cognitive architectures and emotionally influence all the cognitive components of agents, regardless of the amount or type of information they handle, resulting in a human-like behavior.

It is also important to note that currently there are CMEs such as FATiMA, ALMA or FLAME (Dias, Mascarenhas, & Paiva, 2014; Gebhard, 2005; El-Nasr, Yen, & Ioerger, 2000), that incorporate affective mechanisms to alter their cognitive processes. However, each of them has different limitations, which according to Ojha and 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; Ana & Parada Rui, 2007).
- Poor scalability and integration. It is hard to add new components to CMEs because their design is domain-specific.

In order to solve the limitations of current CMEs and, in turn, face the challenges presented above, Rodríguez et al. (2016) proposed the Integrative Framework (InFra). The InFra was designed to create CMEs capable of generating AAs with consistent emotional states and believable emotional behaviors, integrating affective components into the cognitive architecture of AAs. On the one hand, we say that the behavior of an AA is consistent if it behaves in a similar way over time during the occurrence of the same event. On the other hand, a behavior is classified as believable, if the behavior is consistent with what a human being would have done.

The InFra resolves these constraints by designing a framework that determines the necessary components for the generation of emotions. In addition, it indicates the need for an input interface responsible for interconnecting the cognitive components of agents with their corresponding CMEs. There is also a need for an output interface to communicate the result of the cognitive-affective evaluation to those cognitive components involved in the generation of behavior (component of facial expressions, voice or body language) (Rodríguez et al., 2016). These components are inspired by models and theories that explain the mechanisms and phases of human emotions (Phelps, 2006; Ledoux, 2000). Rodríguez et al. (2016) indicate that taking into account the influence of affective states on cognitive processing gives credibility to the behavior of AAs that implements a CME resulting from applying this framework. Nevertheless, the InFra is defined at a conceptual level, i.e., its modules are described at a high-level perspective without providing computational implementation details.

The main objective of this paper is to propose a CME designed on the context of the integrative framework. In particular, the proposed model focuses on the implementation of mechanisms for the emotion assessment phase and emotion generation process. In this work, we develop a CME capable of solving the limitations of current CMEs and, in turn, define the way in which cognitive information is influenced by the emotional evaluation of stimuli perceived by agents. The resulting CME provides concrete mechanisms for representing emotional stimuli and evaluating them using appraisal variables. In addition, the proposed CME implements a mechanism that biases the emotional evaluation with cognitive information projected by cognitive components of the agent architecture. By implementing the model in the context of the integrative framework, we aim to take into account and resolve the limitations presented above regarding low replication, domain dependency, scarce scalability, and integration.

This paper is structured as follows. In Section 2 we discuss related work, explain the phases of the emotional cycle, and present a brief comparison of current CMEs according to the affective and cognitive components that determine an emotion. In addition, we describe the components of the InFra. In Section 3, we present the proposed computational model of emotion assessment influenced by cognition. A case study is presented in Section 4. Finally, in Section 5, we present some concluding remarks.

2. Related work

This work focuses on defining mechanisms to evaluate emotional stimuli and generate emotions in AAs. Therefore, in order to identify what aspects should be taken into account, it is important to define what an emotion is. This section defines emotions and the phases of the emotional cycle implemented in most AAs. We compare some existing CMEs and finally describe the role of each component in the InFra and how they relate to the emotional cycle.

2.1. Emotional cycle

Emotions can be defined as psychophysiological reactions produced in response to stimuli that an individual perceives from an event, action or object (Ortony et al., 1988). Psychologically, emotions alter attention, prioritize individual actions, facilitate decision-making and activate associative networks in memory. Physiologically, emotions determine the configuration of facial expressions, body postures and voice modulation (Ledoux, 2000; Damasio, 1995). Emotions can be regarded as a sequential cycle of three phases: emotional evaluation of stimuli, generation of synthetic emotions, and generation of emotionally-biased responses (Rodríguez et al., 2016). This perspective is adjusted with the model of Salovey and Mayer (1990) as discussed below.

Emotional evaluation of stimuli

In this phase, the stimuli that an agent perceives is identified, interpreted, and evaluated to assign them an emotional meaning. The perception process is carried out using appraisal theory, which states

that emotions are produced by our estimations of events. In this theory, emotions are obtained from the relationship of the individual with his environment. According to Ortony et al. (1988), an emotion can arise from the evaluation of events, object's properties, or actions of other agents that impact the fulfillment of agents' objectives.

Generation of synthetic emotions

Once an agent evaluates the stimuli perceived from the environment, an emotion is generated. In psychology, there are different approaches that try to explain how emotions are elicited. Among the most important are the theory of primary and secondary emotions. According to Damasio (1995), primary emotions are those generated from preprogrammed external stimuli in our brain. Secondary emotions are complex emotions that require a certain degree of cognitive development in the individual to be elaborated. Secondary emotions are also known as social emotions, as they arise in contexts of interpersonal relationship. This type of emotion emerges from human experience and is very influenced by learning and socialization (Becker-Asano & Wachsmuth, 2009).

Generation of emotionally-biased responses

In this last phase of the cycle, the type of emotional behavior that the agent must implement to deal with the perceived stimulus is decided based on the emotion produced in the previous phase. In this phase, the components responsible for the agent behavior (i.e., verbal and non-verbal behavior components) are activated (Rodríguez et al., 2016).

2.2. Current computational models of emotions

Due to the high complexity of implementing a computational model that considers all the cognitive and affective aspects associated with the human emotional process, the existing computational models of emotions are forced to (1) abstract some cognitive and affective aspects and (2) focus on only one or two aspects. Table 1 includes a summary of current CMEs and the cognitive and affective aspects they implement.

2.3. Integrative framework

The InFra is a framework designed to create CMEs capable of generating consistent and coherent emotional states that promote believable emotional behaviors in AAs. A behavior is believable if the exhibited behavior is the same or similar to what a human being would have done in the same situation. Due to its modular design, the InFra facilitates the addition of new components that initially were not considered in the design of the CMEs and that can have influence on emotion generation process.

As shown in Fig. 1, the InFra integrates information from the cognitive architecture responsible for perceiving the environment (part A), then performs an emotional assessment of the stimuli perceived (part B), and finally influences the behavior of the agent by passing the result of the affective evaluation to the components responsible for agent behavior (part C). Table 2 includes a summary of the InFra's main components.

The CMEs developed in the context of the InFra, in addition to evaluating stimuli like any other CMEs, should have a cognitive modulation of the emotional evaluation. This work proposes and implements this cognitive modulation taking into account information provided by the components of a given cognitive agent architecture. The cognitive modulation is designed to bias the result of the affective evaluation, see Section 3 for details. In doing so, we combine cognitive and affective processing, which produces consistent and believable agent behaviors.

2.4. The InFra and the operating cycle of emotions

The emotional cycle is implemented as follows:

1. The emotional evaluation of stimuli takes place in the InFra's component *General Appraisal* (GA), which is responsible for receiving stimuli from the environment and evaluating them from an emotional perspective. This evaluation begins when the agent receives and identifies a stimulus.
2. The second phase of the emotional cycle (generation of synthetic emotions) also takes place in the component of *General Appraisal*. This component evaluates the stimuli sent by the perception component. The evaluations are carried out using appraisal variables (or appraisal dimensions). These dimensions allow establishing a relationship between what happens in the environment and the objectives, desires and/or intentions of agents. In doing so, we assign an emotional meaning to a stimulus. The InFra provides mechanisms to implement different appraisal theories and therefore takes into account any appraisal dimension to calculate and represent the importance of perceived stimuli.
   As shown in Fig. 2, each cognitive component of an agent architecture affects each appraisal dimension. The *Emotional Filter* (EF) is in charge of receiving the information from all the cognitive components and modifying the result obtained by each appraisal variable.
   The InFra's evaluation phase also takes into account the internal emotional state of the agent, so that the appraisal variables in the EF component are influenced by the *Emotional and Mood State Component* as well as by past experiences provided by the *Internal Memory Component*. Once each appraisal variable is re-evaluated, a label representing an emotion is assigned, i.e., emotions are defined by the result of a set of appraisal variables or dimensions.
   The result of each appraisal variable along with the label representing the resulting emotion is sent to the *Behavioral Organization component*.
3. The influence on behavior (by generating emotionally-biased responses) occurs in the third phase. The information resulting from the pre-evaluation process generates action trends, which are sent to the components of the agent architecture where each cognitive component is responsible for carrying out the actions needed for

Table 1
Comparative table of cognitive and affective processes implemented by some current CMEs.

Model	Cognitive processes	Affective processes	Effect on AA's architecture
Alma (Gebhard et al., 2003)	Dialogue generation, decision making, motivation, behavior and expression generation	Emotions and mood	Generation of verbal and non-verbal expressions, analysis of sentence lengths and facial expressions, bias in cognitive processes such as decision making
EMA (Gratch & Marsella, 2005)	Provides support for cognitive, perceptive and motor operators	Emotions and mood	Generation of facial, non-verbal and voice expressions
Cathexis (Velásquez, 1996)	Perceptual, memory systems, behavior systems and motor processes	Emotions, personality and mood	Decision support in virtual and physical agents aimed at goals and personality management
Flame (El-Nasr et al., 2000)	Decision making, memory systems, learning and adaptation	Emotions, motivational states and mood	Decision support in virtual human beings developed for educational purposes

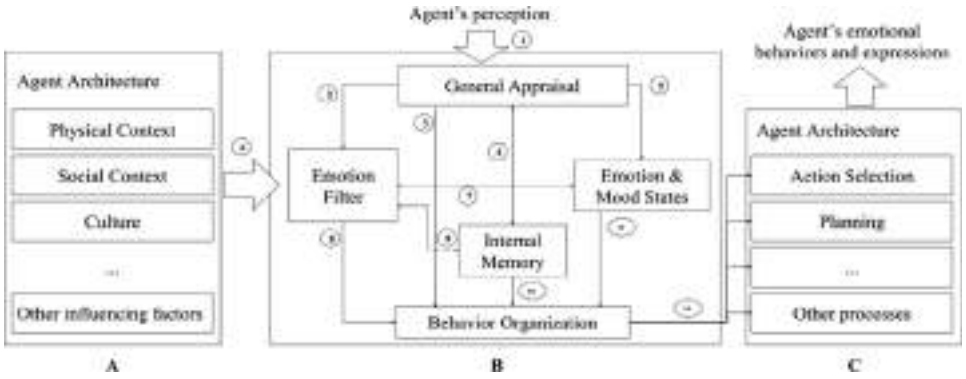

Fig. 1. Components of the Integrative Framework (InFra).

Table 2
Description of the components of the integrative framework (InFra).

Component	Description
General Appraisal	Determines the emotional value of the stimuli perceived by agents
Emotional Filter	Amplifies, attenuates or maintains the emotional significance of the stimuli perceived by agents
Behavioral Organization	Decides the type of emotional behavior that agents should implement to deal with the perceived emotional stimulus
Emotion and Mood State	Manages the emotional state and the mood of agents
Internal Memory	Provides knowledge by storing past experiences. It is associated with learning

producing the agent behavior.

3. Computational model of emotion assessment influenced by cognition

In this section, we propose a CME based on the context of the InFra. We present the mechanisms for influencing the emotion assessment process based on cognitive information. In particular, we devise mechanisms for assigning an emotional value to the events perceived by agents using a set of appraisal variables. Defined as fuzzy sets, these appraisal variables model the influence of cognition on emotion assessment. We do this by changing the limits of fuzzy membership functions associated to each appraisal variable. In doing so, we aim to provide agents with a degree of emotional intelligence.

3.1. General concepts

The InFra proposes a set of components (see Table 2) needed to perceive stimuli from the environment and assign an emotional meaning to them. According to Ortony et al. (1988), a stimulus arises from (1) the occurrence of an event, (2) the judgment an agent makes on the actions of other agents (or its own actions) or (3) the characteristics of objects with which it interacts. A stimulus is taken into consideration if it impacts (positively or negatively) the fulfillment of one of the objectives of the agent. A stimulus is evaluated by establishing a relationship between what happened and the objectives affected by the appraisal variables.

It should be noted that this work considers stimulus that arise only from the occurrence of an event. An event occurs as a result of any action of the agent itself, actions of another agent, or actions caused by the environment itself. We assume that the agent has a perception component implemented by its cognitive architecture, which is in charge of collecting information from the environment. In particular, the model considers the data perceived as *facts*, which are propositions that express semantic content, which is either false or true. Propositions are expressed in natural or mathematical language.

According to Novak and Cañas (2008), a proposition is a semantic structure composed by two or more concepts joined by linking phrases to create units with significance. A proposition states something, whether true or false. In this context, we can say that a proposition is a declarative sentence whose structure is as follows:

```
Proposition: [subject] joint [predicate]
```

Propositions must have (1) a subject that refers to the object of interest; (2) a predicate that makes a statement about the object; and (3) a joint that has an assertive or referential function:

```
Proposition: The traffic light is in red
Proposition: Russia's capital is Moscow
Proposition: Sugar sweetened coffee
```

Also, we take for granted that the agent has a component in charge of planning capable of establishing the actions that agents must perform to deal with the events. *Actions* are the available operations that agents can perform on a given environment. Actions are almost always

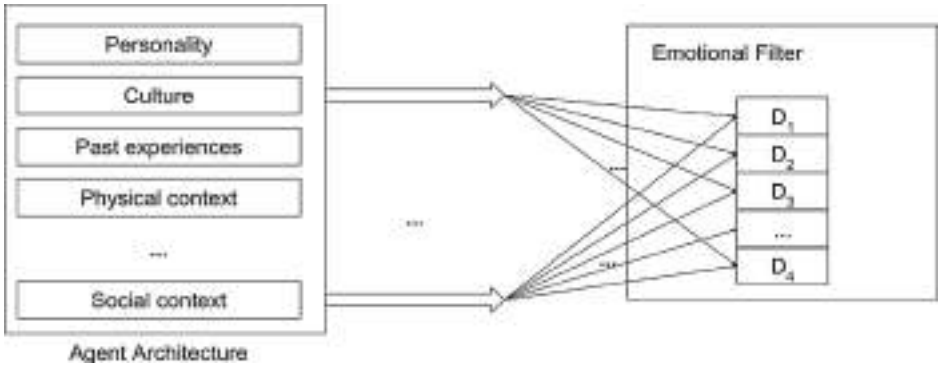

Fig. 2. Influence of the cognitive components on appraisal variables.

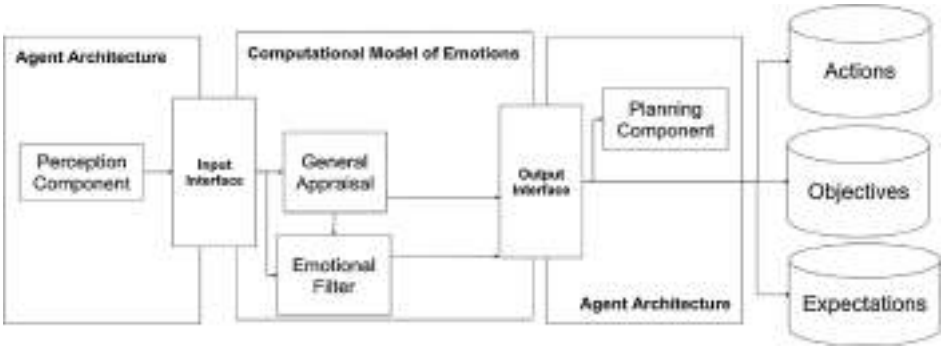

Fig. 3. The relationship between external storage components and the agent architecture.

represented with verbs like sing, eat, or search and their structure is very similar to that of the facts with the only difference that these have a verb instead of a subject and the objective for which it was defined.

```
Action: [verb] joint [predicate]
```

This component also establishes future events called *Expectations*, which represent a future assumption that can be accurate or not. The structure of expectations is as follows.

```
Expectation: [subject] joint [predicate]
```

As shown in Fig. 3, all the actions, expectations, and objectives (explained above) are not part of the architecture of AAs or the CME. These are stored in a database accessed only by the agent's output interface. All the stimuli are represented in an XML file as we can see in Fig. 4. The stimulus begins by indicating only the fact and, at the moment that the evaluations are carried out (described in the following sections), the XML file is modified.

3.2. General appraisal component

The *General Appraisal Component* of the InFra is responsible for determining the emotional value of the events that an agent perceives. To do this, we use a set of appraisal variables that establish a relationship between the event and the agent's objectives. The appraisal variables are criteria for evaluating the emotional meaning of a situation. For example, a pleasant situation (modeled as an appraisal variable whose value is defined by means of likening the situation with the objectives of the individual) leads to a positive emotion such as *joy* (Scheutz, 2002).

Each of the appraisal variables implemented in the proposed CME uses fuzzy sets to accurately define the result of each selected variable. The appraisal variables used in the emotion assessment of the proposed model are *Expectedness*, *Desirability*, *Novelty*, *Goals conduciveness*, *Pleasure*, and *Coping potential*. These variables were selected combining the theories of Scherer (2001) and Ortony et al., 1988. We also consider that this set of appraisal variables accurately evaluates the three types of stimuli proposed by Ortony (2003).

Once the above variables are evaluated, the results are sent to the Emotional Filter component to reevaluate each appraisal variable but now taking into account cognitive information related to personality, culture, or any other cognitive aspect implemented in a given agent architecture. As a result of the re-evaluation process, we obtain an

Fig. 4. An XML stimulus before and after evaluation.

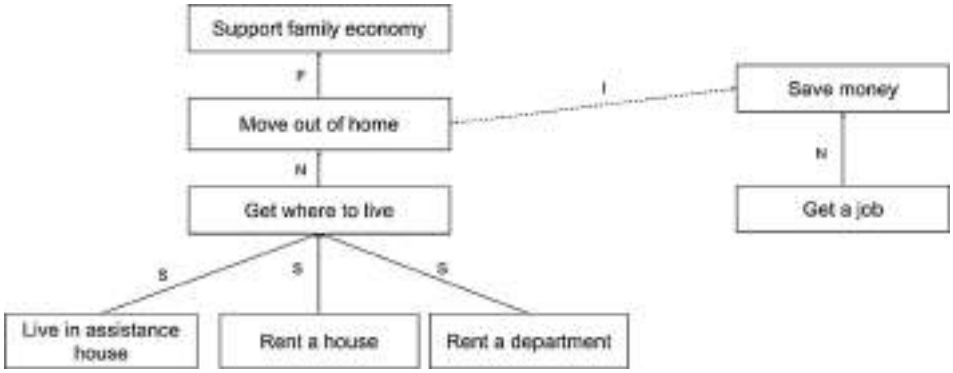

Fig. 5. Hierarchical representation of objectives.

emotion, which is a label passed to the set of results obtained by the appraisal variables after the two evaluations take place.

The rest of this section describes each appraisal variable of the proposed emotion assessment process.

Goal conduciveness

This variable determines the degree of impact of an event on the objective of an agent. First, when an event is perceived by an agent, it is transformed into a *Fact*, which is associated with one or more objectives to determine how it affects them considering the relationship and the importance of every target.

Objectives are a set of states that an agent desires to achieve. As defined by Ortony et al. (1988), we represent the objectives as a hierarchical tree (see Fig. 5) where each node is a goal, the edges indicate the relationships among the goals, and the levels represent goal hierarchy. High-level nodes represent goals, aspirations, or general concerns, whereas goals at the lowest level are immediate objectives. On the other hand, the relationships among nodes allow us to link the events that occur to an agent with its goals, and when considering the importance of the event, they allow us to evaluate the impact on the objectives of the agent. Table 3 describes the types of relationship between objectives, which are *inhibitory*, *sufficient*, *facilitating*, and *necessary*. As seen in Fig. 3, there is a database where the objectives of agents are stored. The process of establishing relationships among objectives is conducted manually, nevertheless, default relationships are established from events to the objectives affected by the events.

Once the initial link between events and objectives is established, it is possible to determine the degree of impact by traversing each one of the objectives (affected by a given event). In addition, each objective has an importance value. The objective's importance inhibits or increases a positive or negative impact. On the one hand, a fact may have a *positive* target if the overall number of necessary, sufficient, and facilitating connections is greater than the number of inhibitory relationships activated. On the other hand, a fact may have a *negative* target if the number of inhibitory relationships is greater than the number of positive relationships. To determine the impact of an objective, we assign a numeric value to each relationship, as reported in Table 4.

Each objective has a parameter called *Importance*, whose function is to increase/decrease the effect of an event. Possible values of *Importance* are the following: NotImportant $= \mathbf{0.25}$, SlightlyImportant $= \mathbf{0.5}$, and HighlyImportant $= \mathbf{0.75}$.

So the *Goal Conduciveness* of an event is given by the following equation.

$$Impact_{OO} = \sum_{n=0}^{nObj} \frac{type * Importance}{nObj}$$

Where *nObj* is the target number affected, *type* is the relationship type of the n-th objective, and *Importance* is the importance of the n-th objective. Once the dimension *target orientation* is evaluated, the result is classified according to a fuzzy set (notOriented, negative, positive) as shown in the next membership functions.

$$\mu_{notOriented} \begin{cases} 1 & ifx \leqslant 0.3 \\ \frac{0.4-x}{0.4-0.3} & \text{if } 0.3 < x \leqslant 0.4 \\ 0 & \text{if } x \geqslant 0.4 \end{cases}$$

$$\mu_{negative} \begin{cases} 0 & \text{if } y \leqslant 0.3 \\ \frac{y-0.3}{0.4-0.3} & \text{if } 0.3 < y \leqslant 0.4 \\ 1 & \text{if } 0.4 < y \leqslant 0.7 \\ \frac{1-y}{1-0.7} & \text{if } 0.7 < y \leqslant 1 \\ 0 & \text{if } y > 1 \end{cases}$$

$$\mu_{positive} \begin{cases} 0 & \text{if } z \leqslant 0.6 \\ \frac{z-0.6}{0.7-0.6} & \text{if } 0.6 < z \leqslant 0.7 \\ 1 & \text{if } z \geqslant 0.7 \end{cases}$$

Coping potential

In order to meet each goal, agents have plans (i.e., a series of actions) and expectations that are required to carry out their goals. From the actions, we can determine how capable agents are at dealing with unfavorable events.

When an event occurs resulting in the inhibition of some objective, it is sought to define whether an agent has any action capable of turning from a negative effect to a positive effect. It should be noted that any

Table 3
Relationship types among objectives.

Relationship	Description
Sufficient (S)	A set of (minor) objectives linked to a major objective via a sufficient relationship indicates that the major objective can be achieved by attaining any of the minor objectives
Necessary (N)	A set of (minor) objectives linked to a major objective via a necessary relationship indicates that the major objective can only be achieved by attaining all the minor objectives
Facilitator (F)	This relationship indicates that an objective is facilitator of another objective when achieving the former increases the likelihood of achieving the latter (although there is no guarantee of success)
Inhibitory (I)	This relationship (denoted by a dotted arrow) indicates that two objectives are opposite to each other

Table 4
Values assigned to relationship types.

Relationship	Value
Sufficient (S)	**S = 1**. A sufficient relationship maintains a positive tendency towards objectives
Necessary (N)	$N = \frac{1}{k}$. Where k is the number of required relationships associated with a given event. The objective is fulfilled until all the N-type objectives are fulfilled
Facilitator (F)	**F = 0.25**. A facilitator relationship amplifies or attenuates a trend either positive or negative
Inhibitory (I)	**I = −1**. According to Ortony et al. (1988) and Scherer (2001), an inhibitory relationship may cause a negative impact. It is assumed that the negative impact has more influence than the positive impact

Table 5
Rules for defining the novelty of an event.

isMemory	Similarity	Familiarity	Novelty
false	dissimilar	unfamiliar	high novelty
false	similar	unfamiliar	high novelty
false	similar	low familiarity	low novelty
false	similar	high familiarity	without novelty
false	very similar	unfamiliar	high novelty
false	very similar	low familiarity	novelty
false	very similar	high familiarity	without novelty
true	equals	low familiarity	high novelty
true	equals	high familiarity	novelty

action is related to at least one objective. This relationship is assigned at the time of making the plan that determines the actions needed for the fulfillment of the objective. The coping potential of an agent indicates to what extent the agent is capable of dealing with unfavorable events.

In order to evaluate the potential of facing an event, agents must be aware of the actions they are provided with and the actions' impact. Similar to the evaluation of *Goal Conduciveness*, which measures the actions' impact. The fuzzy set for this appraisal variable is *NotApproachable*, *Approachable* and *HighlyApproachable*. The corresponding membership function is as follows.

$$\mu_{NotApproachable} \begin{cases} 1 & \text{if } x \leqslant 0.3 \\ \frac{0.4-x}{0.4-0.3} & \text{if } 0.3 < x \leqslant 0.4 \\ 0 & \text{if } x \geqslant 0.4 \end{cases}$$

$$\mu_{Approachable} \begin{cases} 0 & \text{if } y \leqslant 0.3 \\ \frac{y-0.3}{0.4-0.3} & \text{if } 0.3 < y \leqslant 0.4 \\ 1 & \text{if } 0.4 < y \leqslant 0.7 \\ \frac{1-y}{1-0.7} & \text{if } 0.7 < y \leqslant 1 \\ 0 & \text{if } y > 1 \end{cases}$$

$$\mu_{HighlyApproachable} \begin{cases} 0 & \text{if } z \leqslant 0.6 \\ \frac{z-0.6}{0.7-0.6} & \text{if } 0.6 < z \leqslant 0.7 \\ 1 & \text{if } z \geqslant 0.7 \end{cases}$$

Pleasure

Pleasure is a concept that refers to the enjoyment in doing or achieving something. This feeling helps us approach or evade a stimulus depending on whether it is pleasurable or not. In this sense, pleasure is measured based on the sufficient or necessary objectives that are fulfilled when an event occurs. The impact is also measured as in the previous appraisal variables, however, we take into account only those objectives fulfilled by a given event. Events can be either *Highly Pleasant*, *Slightly Pleasant* or *Unpleasant*. Thus, a metric is obtained to evaluate pleasure, which is measured as the result of the sum of the fulfilled and affected objectives.

Novelty

The novelty of a stimulus depends on the previous experiences and the familiarity that agents have with the elements that stimulate them. The more familiar a stimulus is, the easier is to match it with schemes to determine an emotion (Ortony et al., 1988).

To determine the novelty of an event, agents should be endowed with a memory in order to keep track of previous events. Memories are past events stored in the memory of agents. In addition to storing the events, their resulting emotions and their consequences should be also stored. We use a boolean variable called *isMemory* to indicate whether an event has happened before (isMemory = true) or not (isMemory = false). The memory of an event is formally defined as follows.

$$Memory_{event} = Fact \cup Emotion \cup Actions \cup Goals$$

Other variables used to determine novelty are *Similarity* and *Familiarity*. First, Similarity refers to how similar is an event to another. This is done by searching for similar events in the internal memory component (of agents) whenever the value of isMemory is false. It is acknowledged that the current mechanism to determine the similarity of events is limited to a predefined table that indicates what events relate to each other. Finally, Familiarity refers to the number of times agents have experienced a similar event. The rules for defining novelty are listed in Table 5.

Expectedness

Expectedness evaluates to what extent an agent expected an event to occur. Expectations represent events that agents anticipate in the future. Expectations are future assumptions that can be either right or wrong. We assume that by adopting a goal, an agent generates a plan in order to achieve it. For this reason, expectations must be already defined and stored in an external component. Then, the fact of the occurrence of an event is matched against the fact of expectations stored in the bank of expectations (see Fig. 3).

Desirability

The mechanisms proposed for this variable are based on the model of El-Nasr et al. (2000). The desirability is obtained by measuring the impact (as evaluated in the target variable) as well as the importance of the target being affected. In order to calculate the desirability of an event, we use the membership function for the desirability variable, which is shown in Fig. 6.

As in El-Nasr et al. (2000), we determine the desirability of events based on their impact on goals and the goals' importance. To model this, we use the following fuzzy rule:

```
IF   Impact(G1, E) IS A1
     AND   Impact(G2, E) IS A2
…
     AND   Impact(Gk, E) IS Ak
     AND   Importance(G1) IS B1
     AND   Importance(G2) IS B2
…
     AND Importance(Gk) IS Bk
THEN Desirability E is C
```

Where k is the number of goals involved and Ai, Bj, and C are fuzzy sets. This rule is read as follows: if goal G1 is affected by event E to the extent A1 and goal G2 is affected by event E to the extent A2, and so on,

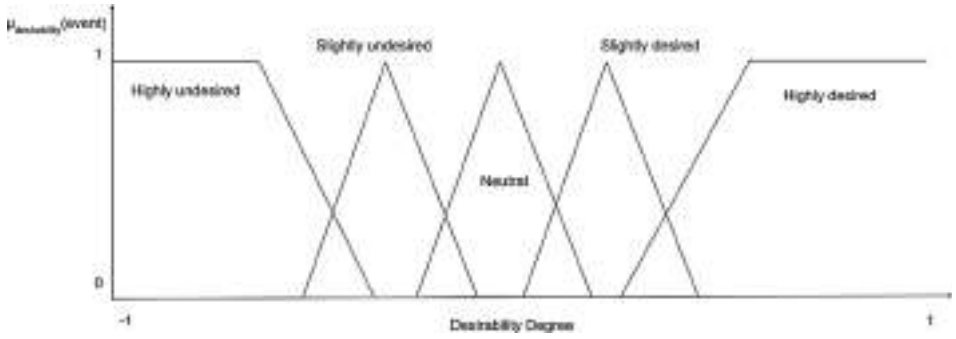

Fig. 6. Membership function for the desirability variable.

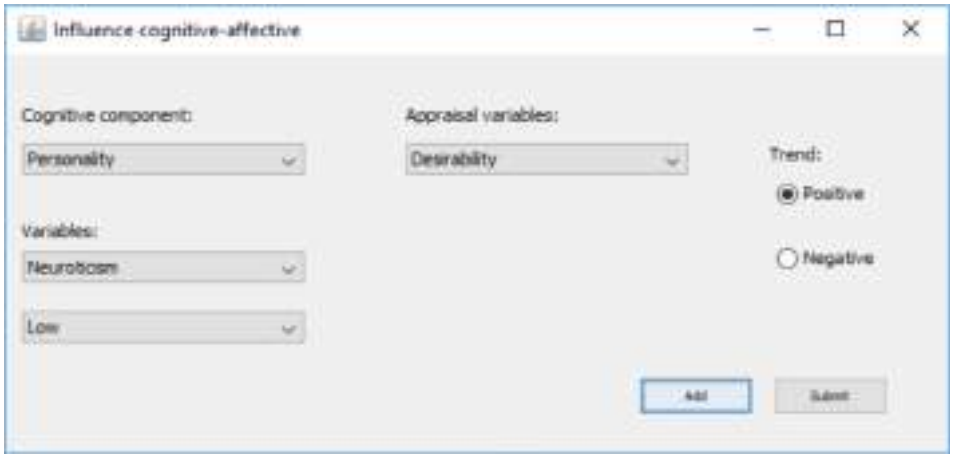

Fig. 7. Positive influence of the personality component assigned manually on appraisal variable desirability.

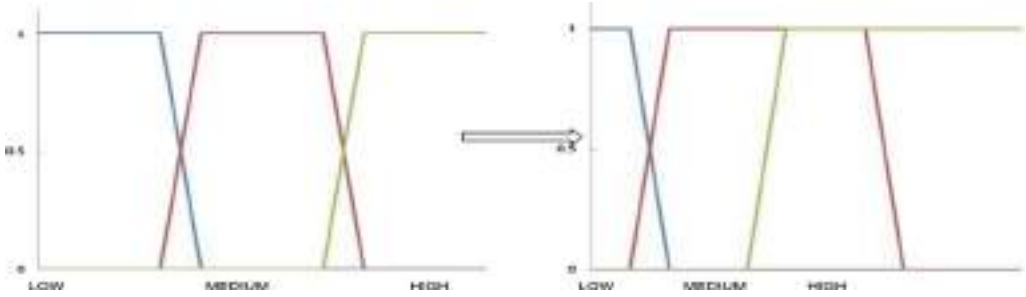

Fig. 8. Representation of a membership function before and after cognitive modulation.

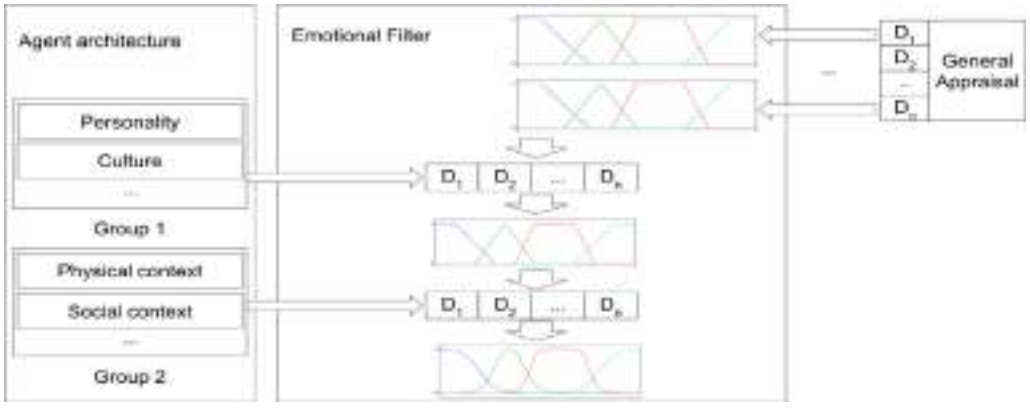

Fig. 9. Scheme of appraisal dimensions modulation.

Table 6
A sample rule for defining sadness.

Emotion	Cause	Rules
Sadness	Unwanted event (E) occurred	IF Consequence (E) IS [myself OR another]
		AND Goal conduciveness (E) IS negative
		AND Coping potential (E) IS positive
		AND Pleasantness(E) IS unpleasant
		AND Expectedness(E) IS expected
		AND Desirability(E) IS highly undesirable
		AND Novelty (E) IS low novelty
		THEN Emotion E is sadness

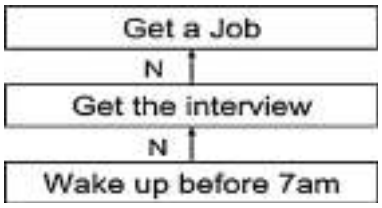

Fig. 10. Agent objectives for the case study.

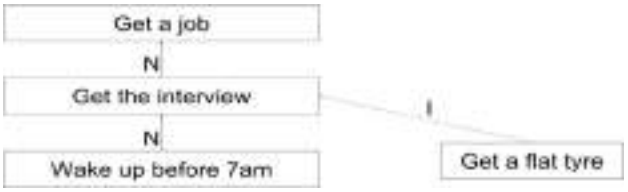

Fig. 11. An inhibitory event for the case study.

and the importance of goal G1 is B1 and the importance of goal G2 is B2, and so on, then the desirability of event E is C.

3.3. Emotional filter component

In the previous section, we described the appraisal variables implemented as part of the emotion assessment process of the proposed CME. The objective of these variables is to establish a relationship between agents and the perceived stimuli. To establish a cognitive-affective evaluation (capable of taking into account the information generated by cognitive components such as personality), a second evaluation is carried out to bias the results of the appraisal variables and, as a consequence, assign a more precise emotional meaning.

The second evaluation integrates both cognitive and affective aspects into the agent behavior, as a consequence, the agent behaves in a unique way when dealing with the same event. According to the architecture of the InFra, cognitive components in agent architectures project their information to the CME to skew their evaluation process (as illustrated in step 6 of Fig. 1).

This work proposes a modulation scheme that works as an input interface between CMEs and the cognitive architecture of agents. In doing so, a large number and variety of cognitive components can be handled.

Cognitive modulation

The proposed computational scheme addresses some of the design requirements of the InFra (Rodríguez et al., 2016). In particular, in the InFra, the evaluation of emotional stimuli takes place in the Emotional Filter component (see Fig. 1). The proposed scheme assumes that the InFra's General Appraisal module assigns an initial value to each appraisal dimension according to the stimuli perceived by agents. The modulation of these values is then determined based on the theories and models that explain the influence of cognition on the emotion process in humans.

The proposed model associates a fuzzy membership function with each appraisal dimension so that the values generated by the InFra's General Appraisal component are analyzed in terms of such membership functions. In this way, the influence of cognitive components is represented by the alteration to the membership functions' limits, as can be seen in Fig. 8. This scheme allows relating cognitive components to the appraisal variables and assigning them an impact either positive or negative (see Fig. 7 for an example).

The cognitive modulation of appraisal dimensions (see Fig. 9) is as follows:

- Step 1. The General Appraisal component sends the numerical values of each appraisal variable to the emotional filter. The appraisal variables are Expectedness, Desirability, Novelty, Goal Conduciveness, Coping Potential and Pleasure.
- Step 2. The Emotional Filter receives the information of each cognitive component by extracting and making a list of the variables that the component takes into account. For example, the personality component, based on the The Big Five model (Cattell, 1947) would get a list of variables with the following elements: openness, extraversion, kindness, emotional stability, and neuroticism.
- Step 3. The effect of each variable (of the list generated in step 2) on each appraisal variable is calculated. For instance, using the Big Five model example, it should be defined how the variable openness affects Pleasure, Novelty, Coping Potential, and Goal Conduciveness. The same should be defined for extraversion, kindness, emotional stability, neuroticism. Steps 2 and 3 are repeated for each cognitive component included in a given cognitive agent architecture. It is acknowledged that the degree to which a variable of a cognitive component affects an appraisal variable must be defined by an expert.
- Step 4. The trend determines what fuzzy sets of appraisal variables are favored or disfavored. This represents the influence that cognitive components have on agents' affective information. This step modifies the limits of membership functions in each appraisal variable based on the previously identified trend.
- Step 5. Once the membership functions are modified, a series of fuzzy rules are applied to determine the elicited emotion, based on the results from evaluating perceived stimuli by the different appraisal variables.

Table 7
Summary of the characteristics of the agents involved in the case study.

Agent	Personality	Goal conduciveness	Coping potential	Pleasantness	Expectedness	Desirability	Novelty	Emotion
A1	neuroticism: low (positive trend)	0.29	0.4	0.25	0.0	0.0	0.33	anger
		0.29	0.61	0.55	0.0	0.0	0.34	rage
A2	neuroticism: high (negative trend)	0.16	0.36	0.20	0.019	0.011	0.42	anger
		0.16	0.35	0.05	0.019	0.011	0.43	annoyance
A3	none	0.34	0.27	0.19	0.011	0.03	0.68	anger
		0.34	0.26	0.19	0.011	0.03	0.66	anger

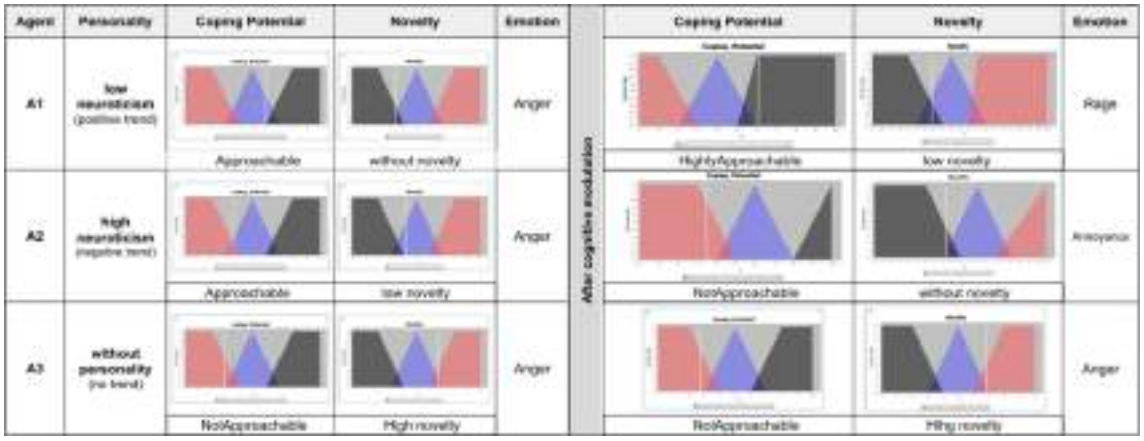

Fig. 12. Reaction to an event by agents endowed with different characteristics.

Generation of emotions

The model has a rule base to infer the emotion based on all the previous evaluations. The emotion types are based on the wheel theory of emotions by Plutchik (2001). This theory divides emotions into eight basic categories: fear, surprise, sadness, disgust, anger, hope, joy, and acceptance. In the wheel of emotions, each emotion has its opposite. According to this theory, it is impossible to feel opposite emotions at the same time. In addition, emotions vary in their degree of intensity, for instance, rage is less intense than anger, and annoyance is more intense than anger. The rest of the emotions are combinations of these primary emotions. Table 6 shows a sample rule for defining an emotion.

4. Case study

A case study was implemented to better explain the functioning of the mechanisms implemented in the proposed CME as part of the InFra. The case study involved three different agents and it was observed how they reacted to the same stimulus. The situation is as follows: let's assume the agents sought employment and got a job interview at 9 a.m. Each agent has a unique personality based on the Big Five model (Cattell, 1947). In addition, all the agents have the same objectives (see Fig. 10): (1) get the job, (2) get on time for the interview, and (3) wake up before 7 a.m. The first and second objectives are highly important whereas the third objective is slightly important.

Let's assume that the agents wake up the next day on time (6:40 am) fulfilling their first objective, prepare and exit towards their interviews. It is assumed that these actions (and their order) were defined in their plans based on their objectives. However, while on their way to the interview, a car tire bursts. This generates the event *Get a flat tire*. This event is categorized as inhibitory (I) to the objective of reaching the interview (see Fig. 11).

It should be noted that the event *get a flat tire* is exogenous to the agents and out of their control. In addition, the agents had no prior experience with the event, i.e., the event was not previously stored in their memory.

Cattell's theory (Cattell, 1947) indicates that personality is composed of five traits. One of these factors is the N Factor: emotional stability, which defines how well a person faces complicated situations in life. Subjects with a high degree of emotional stability are less likely to feel anger, are enthusiastic and manage their personal crises better. In order to contrast the difference between agents who consider cognitive aspects in their affective evaluation and agents who do not consider cognitive aspects, this case study includes an agent with no personality component. Table 7 presents a summary of the characteristics of the agents involved in the case study.

Results

A series of tests were carried out using agents with different personalities with the aim of verifying whether there is a difference in how agents evaluate events. The results indicate that most of the values resulted in the same fuzzy set, however, some values almost resulted in another set as can be seen in Fig. 12 and Table 7.

Test after cognition influence (Fig. 12) confirms that agents expressed the same emotion, but with a different intensity. The results also show that agents with opposite personalities obtained different values for variables such as coping potential. In this regard, in this case study, the neurotic personality trait affected the agent's action. This confirms that cognitive and affective aspects are closely related.

According to the literature, cognitive components influence the generation of emotions. So, to emulate such influence during the executions, the limits of the membership functions were re-evaluated based on the agents' personalities. It was also observed that the outcome of each appraisal variable was the same when the agents did not receive any type of cognitive influence. This confirms that the cognitive influence brings credibility to the result of emotion evaluation because each agent evaluated differently the same event.

5. Conclusions

This work presents a CME that implements mechanisms for emotion assessment capable of evaluating events from a cognitive-affective perspective by using a series of appraisal variables. These variables are used to establish a relationship between agents and events. According to a given event, this relationship indicates the resultant emotion of agents. After evaluating events, their emotional significance is re-evaluated in order to take into account the influence of cognitive components. This was explored using a case study that involved three agents with different personalities. In the case study, the resultant emotion of agents was anger. However, the evidence indicated that by influencing the emotional significance of an event with cognitive information, a more precise emotion is obtained.

This work also added new functionalities to the InFra, a framework to create CMEs capable of generating AAs with consistent emotional states and believable emotional behaviors. The mechanisms proposed in this work were implemented in the general appraisal and emotional filter of the InFra. These mechanisms implemented in the components of the InFra also validated its modularity. Finally, as shown in the case study, the proposed CME generates believable emotions consistent with cognitive components in a given cognitive architecture.

Potential future research directions are: (1) designing a mechanism to relate stimuli with objectives; (2) investigating indirect effects of events in a structure of related objectives; (3) designing an ontology to

support a semantic match between objectives and/or stimuli; and (4) defining a direct relationship between cognitive components and variables of appreciation.

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Design and Implementation of a Data Warehouse to Support Decision-Making in a Health Environment

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Abstract. One of the most common challenges in the management of electronic medical records (EMR) is to extract critical knowledge that could serve to enhance collaboration among medical doctors to support decision-making. In this paper, we present the design and implementation of a data warehouse designed to strengthen decision-making related to epidemiological patterns, trends, areas of influence and other pathologies. The data warehouse is based on a relational model that contains information about EMR of different states of Mexico. We used the Business Event Analysis and Modeling (BEAM) methodology for the design and implementation of the data warehouse, a novel methodology to design agile data warehouses. Using BEAM, we created a star dimensional model and defined the Extract, Transform and Load (ETL) processes to transfer the data to the new model. In order to show the potential of our data warehouse, an interactive dashboard with different indicators was built. We close discussing how the medical doctors could use our data warehouse to support the decision-making process.

Keywords: decision support systems, data warehouse, health environment, BEAM, ETL.

1 Introduction

In recent years, the use of electronic medical records (EMR) has increased considerably, changing the way traditional records are stored and managed [1]. In EMR, the data is managed and stored digitally, enabling health professionals to maintain information in one place. The use of these systems has enabled the accumulation of large amounts of data, opening up opportunities for analyzing and obtaining relevant information from them [2].

However, in most cases, besides data queries, these data are not analyzed, leaving aside all the knowledge that can be obtained from them. These large amounts of data and the knowledge that can be obtained from them open the possibility of supporting decision-making in the health environment, as well as promoting communication and collaboration among health professionals. Having a tool to support decision-making that could provide knowledge based on patients' historical data stored in EMR, might help to a great extent to improve health services.

An alternative to support this problem is the use of a data warehouse, a repository that preserves the historical context to accurately assess an organization's performance over time [3]. It is optimized for high-throughput queries, since user queries often require that hundreds or thousands of transactions are searched for and compressed into a set of responses. Data warehouses are the basis of the processing of Decision Support Systems (DSS). They facilitate the analysis since all data are concentrated in a single data source, which can integrate both structured and unstructured data, with different granularity. A data warehouse based on the data of an EMR could support health professionals to obtain relevant knowledge to enhance the decision-making process. However, the design and construction of a data warehouse is not an easy task. First, the preparation and cleaning of large amounts of data present some challenges such as the concentration of heterogeneous data, incomplete records, and integrity errors, among others. On the other hand, the design of the data warehouse has to be done in such way that the response time of the queries is fast and the results are correct.

An optimal design of the data warehouse is required to facilitate the extraction and analysis of the stored data. The use of agile methodologies (e.g., SCRUM [4]) have presented multiple advantages in software development such as customer satisfaction by the rapid and continuous delivery of useful software. Agile methodologies are characterized by emphasis on stakeholders and interactions rather than processes and tools [4]. On the side of the design of data warehouses, the Business Event Analysis and Modeling (BEAM) methodology [5] offers several advantages for designing data warehouses. For example, individuals and interactions over processes and tools, working software over comprehensive documentation, and customer collaboration over contract negotiation. BEAM upholds these values and the agile principle of data warehouse practitioners to work directly with stakeholders to produce data models rather than requirements documents, and working Business Intelligence (BI) prototypes of reports / dashboards rather than mockups.

This paper presents the design and implementation of a data warehouse using BEAM methodology, which information was obtained from EMR. This data warehouse provides information in the form of indicators that summarize what is happening in a health environment and support appropriate and timely decision making through the identification of diseases by geographic zones, diseases by stage of life and diseases by season of the year.

The illustration of the usefulness of the designed data warehouse, following, we present a usage scenario where health professionals use the information they visualize in an interactive dashboard to support decision making:

A health professional is concerned that many patients are presenting with a rare disease in their geographical area and he is not sure that the medications he is prescribing to his patients are the most appropriate. The health professional reviews the information provided by an interactive dashboard and he realizes that the disease which

he is dealing with is very common in another geographic area of Mexico. Thus, the health professional starts to get in touch with other health professionals in that geographical area to ask for opinions and share experiences in the treatment and intervention of that disease.

2 Related Work

Research contributions have been made in the areas of data warehouse design, data staging for ETL processing, data quality assurance, and healthcare data warehouse applications, mainly in developed countries, such as the United States. Existing EMR [6] data are made available in a standardized and interoperable format, thus opening up a world of possibilities for semantic or concept-based reuse, consultation and communication of clinical data. The Community Health Applied Research Network (CHARN) [7], in the United States, represents more than 500,000 patients from diverse safety nets in 11 states, aims to create a national and centralized data warehouse with multiple partners from the Center for Community Health using different EMR systems.

The work [8] describes a virtual data warehouse (VDW) of the Health Maintenance Organization Research Network (HMORN), a public, research-centric data model implemented in 17 health care systems across the United States. At the Catholic Health Initiatives research institute, data consultation tools [11] are implemented to enable end users to access the VDW for simple consultation and research readiness activities, capture for collection of study-specific data and results reported by the patient. On the other hand, the decision support system [9] based on multi-criteria data analysis – Annalisa, is an online decision support tool for individuals and clinicians interested in making a shared decision.

In Mexico, there have been initiatives and programs of innovation and technological development of the public and private sectors that have begun to get involved in the subject of e-health. In the early 1990s, the State Basic Information System (SEIB) was centralized and encompassed all 32 states by The Ministry of Health (SSA, for its acronym in Spanish). In 1995, the National Epidemiological Surveillance System (SINAVE) was created. Its coordination is carried out by SSA and it is supported by the Single Information System for Epidemiological Surveillance (SUIVE).

In 2007, SSA initiated the development of the Mexican electronic clinical record standard. In 2011, a study was conducted in Mexican Institute of Social Security (IMSS, for its acronym in Spanish) [10] to develop Quality of Care Indicators (QCI) for Type 2 Diabetes Mellitus (T2DM). The goal was to determine the feasibility of constructing QCI using IMSS's EMR data and assessing the Quality of Care (QC) provided to IMSS patients with T2DM. As a result of this study [10], 18 QCIs were developed, of which 14 were possible to construct using available EMR data. ICQs comprised both the care process and health outcomes.

The related work shows that there is a potential of using EMR to enhance health care services. However, there are few studies that use the EMR data to obtain knowledge that could support the decision-making process in the healthcare environment. In this work, we propose to use EMR data to design and implement a data warehouse aimed at supporting the decision-making in the healthcare environment. In the next section,

we describe the BEAM methodology, following by the results of the design of the data warehouse and its implementation.

3 BEAM Methodology

We used the Business Event Analysis and Modeling (BEAM) methodology to design the proposed data warehouse. To the best of our knowledge, BEAM is one of the most recent and the first agile methodology in the area of Data Warehouse and Business Intelligence (DW / BI) [5]. The BEAM methodology comprises a set of collaborative techniques for modeling BI data requirements and translating them into dimensional models on an agile time scale. Among the techniques used by the BEAM methodology are the 7W's Framework, BEAM*tables, Event Matrix and Enhanced Star Schema.

3.1 7W's Framework and BEAM*tables

The 7W's framework uses questions about who, what, where, when, how many, why, and how[5], data modelers design the model by asking BI stakeholders to tell data stories using these questions. BEAM uses tabular notation and data stories to define business events in a format that is easily recognizable and understandable to BI stakeholders. It uses spreadsheets that enable an easy translation into detailed star schemas.

BEAM*tables help engage BI stakeholders to define reports that answer their specific business questions. They are used to define fact and dimension tables, and they use natural language enable BI stakeholders easily imagine, sort, and filter the low-level detail columns of a business event using the top-level dimensional attributes. BEAM*tables can describe facts, events in terms of measures, and dimensions, descriptions of the facts, which can be used to filter, group and aggregate measurements.

3.2 Event Matrix

The Event matrix documents the relationships between all events and dimensions within a model. Event matrices record events in value chain sequences and promote the definition and reuse of conformed dimensions through dimensional models.

3.3 Enhanced Star Schema

A star schema consists of a central fact table surrounded by a series of dimension tables. The fact table contains facts: the numerical (quantitative) measures of a business event. Dimension tables contain mainly textual (qualitative) descriptions of the event and provide the context for the measurements. Enhanced star schemas are standard star schemas that use BEAM short codes to record dimensional properties and design techniques that are not directly supported by generic data modeling tools.

In the following section, we describe the obtained results of applying the above BEAM techniques to design a data warehouse, as well as, the data warehouse' implementation is described.

DiseasexVectorxMunicipality [FE]

Patient	Disease	Municipality	State	Date	Amount
[who]	[what]	[where]	[where]	[when]	[how many]
Jaime Rodriguez	Peste bubónica	Cajeme	Sonora	22/01/2011	1
María Luisa Aceves	Tifus	Salina Cruz	Oaxaca	22/08/2013	3
Fernando López	Tifus	El Fuerte	Sinaloa	22/01/2017	3
José García	Tifus	Ahome	Sinaloa	25/08/2017	3
Luis Soto	Peste neumónica	Huetamo	Michoacan	12/08/2017	1

Fig. 1. Event to show diseases by municipalities and states of Mexico.

TREATMENT [FF]

PRESCRIPTION_ID	PATIENT	DISEASE	DOCTOR	MEDICAL
	[who]	[what]	[who]	[what]
74626	Paciente 49697	Meningitis viral, sin otra especificacion	Medico 21263	AUTRIN600
74626	Paciente 49697	Meningitis viral, sin otra especificacion	Medico 21263	BENADRA
70891	Paciente 105464	Fiebre exantematica entericoral [exantema de kawa]	Medico 21115	BUEMILPLUS ARAC
73850	Paciente 218889	Vertigo epidemico	Medico 21364	DICLOGUIN
74404	Paciente 105507	Otras infecciones virales del sistema nervioso central	Medico 13388	INVIRASE
317922	Paciente 105546	Otras infecciones virales del sistema nervioso central	Medico 21374	INVIRASE
70809	Paciente 105569	Otras fiebres virales transmitidas por mosquitos	Medico 28873	
361289	Paciente 218936	Fiebre del valle del rift	Medico 21181	PANBOEN
74729	Paciente 218968	Fiebre del valle del rift	Medico 22176	PANBOEN

Fig. 2. Fact table that contains the IDs that relate the dimensions.

EVENT (who does what)	Dimensions	Importance	Estimate	Doctor	Patient	Medical	Disease	Colony	Municipality	State	Treatment	Prescription	Doctor	Patient
				who		what		where			why & how		Datawarehouse group	
Importance														
Estimate														
Evaluate the patient	5	300		✓	✓			✓	✓	✓			*	✓
Diagnose the patient	7	200		✓	✓		✓	✓	✓	✓	✓		*	✓
Give medical treatment	6	100		✓		✓		✓	✓	✓		✓	*	✓

Fig. 3. Event matrix.

4 Results

The data repository used to design and implement the data warehouse is a relational database derived from EMR system, containing 316,295 records of medical consultations from different patients living in different cities and states of Mexico. The structure of this relational database was analyzed and only the required tables to create the data warehouse with the dimensional model obtained using BEAM were extracted.

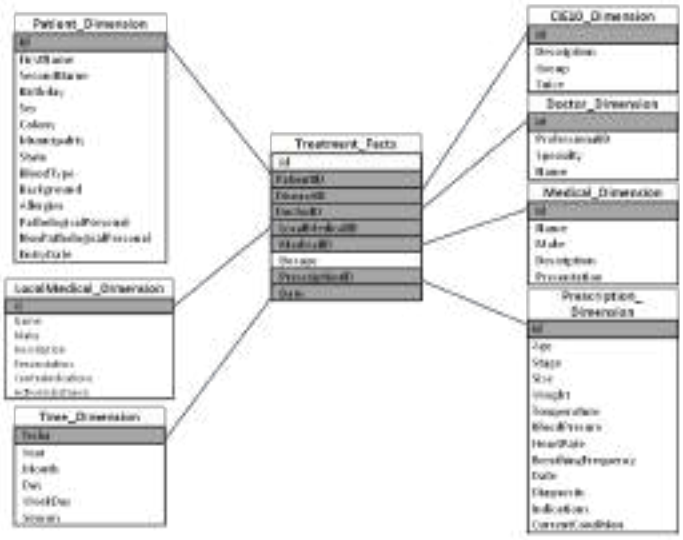

Fig. 4. Star Schema showing the dimensional model of the data warehouse.

Fig. 5. Interactive dashboard connected to the dimensional model of the data warehouse.

The tables were identified according to the indicators that the stakeholders (doctors from Obregon city identified and prioritized the indicators) defined in the business events of the BEAM methodology, which would be useful for decision making. The indicators are disease by stage of life, diseases by season of the year, epidemiology surveillance diseases, all can be filtered by municipality and state. The relational database consists of 172 tables. The tables that contain the required data to create the

business events are only 7. These tables record data about patients, doctors, medications, diseases, treatments of the patients and the prescriptions that the doctors issue at the end of each medical appointment.

Once the relational database was analyzed, following the BEAM methodology, the 7W's framework technique was applied, several BEAM*tables and the event matrix were created and finally the star dimensional model was created.

7Ws Framework and BEAM*Tables. Events were defined with the help of stakeholders. In our case, the stakeholders are healthcare professionals. Examples of the defined events are Disease by stage of life, Disease by season of the year, Epidemiology surveillance diseases by municipality and state. The event shown in Fig. 1 is an example of a query to display records of patients' diseases, with granularity by municipalities and states of Mexico.

Fig. 2 shows an example of the fact table of the model that contains the IDs of the prescriptions, patients, diseases, doctors, medicines. All the descriptions corresponding to the IDs of this table are found in the derived dimension tables. This can be observed in the star dimensional model (Fig. 4), where the relationship between the IDs of the fact table and the dimension tables is defined.

Event matrix. Fig. 3 shows the event matrix with the events that happen during a medical consultation and relates them to the data of the dimensions that are involved in the development of the medical consultation.

Star dimensional model. As a result of using the BEAM techniques, we obtained the star dimensional model (Fig. 4). The dimensional model has seven dimension tables and a fact table, which contains the IDs that relate the facts to each of the dimensions. Patient dimension contains the records of the registered patients. Medical dimension contains the names, and specialty of health professionals. Medication and Medication Local dimensions are the Descriptions and brands of prescription drugs. CIE10 dimension includes the diseases and their classification SUIVE, in case of being considered epidemiological. Prescription dimension contains the symptoms of the patients at the time of the medical appointment. Time dimension is tied to the dates of the facts recorded and it enables to achieve the required granularity for the events. The relationships between the fact and the dimension tables enable agile and efficient queries, compared with the E-R model.

Validation. In order to validate the functionality of the dimensional model of the data warehouse, we performed the Extraction, Transformation and Load (ETL) processes of the data, as well as we created an interactive dashboard that shows the indicators resulting from the queries to the data warehouse.

ETL processes. The required tables were extracted from the relational database, completed and stored in temporary tables using SQL code. Next, there is an example of the code that we used to perform the extraction of the data:

*select * into DW.dbo.paciente from mmanik_completa.dbo.paciente*

*select * into DW.dbo.municipio from mmanik_completa.dbo.municipio*

*select * into DW.dbo.estado from mmanik_completa.dbo.estado*.

After the extraction process, the extracted data were transformed using the tables and fields of interest and loaded into the tables of the dimensional database. An example of the code used to perform the transformation and load processes is the following:

select m.id,cedula,u.nombre,e.nombre as especialidad,cedula_validada insert into DW.mm.medico from medico as m left join especialidad as e on especialidad_id=e.id left join usuario as u on usuario_id=u.id.

Interactive dashboard. We designed and created an interactive TABLEAU [1] dashboard once the ETL processes were finished to validate the efficiency of the data warehouse design. This dashboard is connected with the data of the dimensional model and performs queries to extract the stored data in a rapid and simple way. The dashboard shows the diseases by stage of life presented by patients (Fig 5). The dashboard also shows the diseases by seasons of the year, with the same adjustments as the indicator of diseases by life stage. Additionally, the dashboard shows the diseases that are classified in the SUIVE in a geographical map.

Thus, the health professionals can observe the map with all the diseases or select one that is of his/her interest. All indicators can be filtered by state and municipality.

5 Conclusion

With our results it is possible to support the decision making related to epidemiological patterns, trends, areas of influence and other pathologies, based on the indicators that emerged in the business events of the proposed dimensional model.

This paper shows how the BEAM methodology can be applied to design a data warehouse based on EMR system. In the future, we plan to evaluate the use of the dashboard with health professionals to investigate the potential of the data warehouse in supporting decision making in a real-case scenario.

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Desafíos y oportunidades de aplicar tecnología de almacenamiento de datos como apoyo en la toma de decisiones gerenciales en una PyME de la industria fotovoltaica

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Resumen. Las PyMES (Pequeñas y Medianas Empresas) mexicanas de la industria fotovoltaica, actualmente pasan por una etapa de evolución tecnológica. Por esta razón, es de su interés adoptar recursos tecnológicos para obtener una ventaja competitiva en el mercado. En el presente artículo se propone un análisis sobre los desafíos y oportunidades mediante el uso de tecnología de un sistema de inteligencia de negocios para el apoyo a la toma de decisiones estratégicas de una empresa de la industria fotovoltaica.
Palabras clave: Almacenamiento de datos, soporte para toma de decisiones, inteligencia de negocios, análisis de requerimientos.

1 Introducción

Los sistemas de inteligencia de negocios (BI, *Business Intelligence*), han sido una de las principales propuestas de solución tecnológica desde hace varias décadas ya que permiten analizar información crítica y con ello, entender desde otra perspectiva el negocio y el mercado [1-3]. Para esto, el diseño y construcción del almacén de datos (datawarehouse) es fundamental en este tipo de sistemas ya que es la fuente de información donde el sistema de inteligencia de negocios lleva a cabo las consultas estratégicas que facilitarán la toma de decisiones. De esta manera, existen diferentes metodologías para el diseño de un datawarehouse [4-6], no obstante la metodología de Ralph Kimball es la mas utilizada por varias decadas en diferentes organizaciones por su centralización en la empresa y la naturalidad del proceso.

En ese sentido, en la Figura 1 se muestra la estructura de un almacén de datos, en donde se extrae la información de diversas fuentes (CRM, ERP, Web), para después ser transformados siguiendo el proceso de Extracción, Transformación y Carga conocido como

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ETL (Extract, Transform and Load). La finalidad del ETL es contar con la información depurada y estructurada para llevar a cabo distintos análisis con los datos, para identificar patrones, relaciones y tendencias que son de utilidad para la toma de decisiones, alertando a los gerentes sobre posibles amenazas u oportunidades para el negocio, [7]. Los empresarios de las PyMEs en México por lo regular toman decisiones con base en la información que tienen en ese momento, que generalmente son reportes en físico, o bien, necesitan que sus empleados les hagan llegar la información requerida para tomar una decisión. Por lo tanto, resulta para el empresario inversión de tiempo y esfuerzo, así como muchas veces pérdida de dinero y de recursos.

En ese sentido, un sistema de BI resulta ser una excelente opción, mediante el cual podrían obtener diversos beneficios presentados en múltiples casos de éxito [1-3]. En el caso de las empresas dedicadas a la energía fotovoltaica en Ciudad Obregón, México, no cuentan con un sistema de inteligencia de negocio que les permita crear nuevas estrategias para obtener mayor ventaja competitiva. Para esto, se está trabajando con una empresa dedicada a proveer servicios de energía fotovoltaica quien será de las primeras en contar con esta tecnología en Ciudad Obregón.

Las empresas de este giro, brindan a los clientes soluciones solares para la reducción de dióxido de carbono en el ambiente y ahorro de energía mediante la auto suficiencia que permiten los sistemas fotovoltaicos siendo una tecnología emergente y en crecimiento. En ese sentido, los empresarios necesitan tomar decisiones que marcan el rumbo de la organización por lo que la información debe ser sólida y en tiempo real para que pueda cumplir sus objetivos empresariales de la mejor manera. El objetivo de este estudio es brindar una visión clara de los desafíos y oportunidades de aplicar la tecnología de almacenamiento de datos (datawarehouse) para la toma de decisiones de la alta gerencia en un PyME mexicana de la industria fotovoltaica.

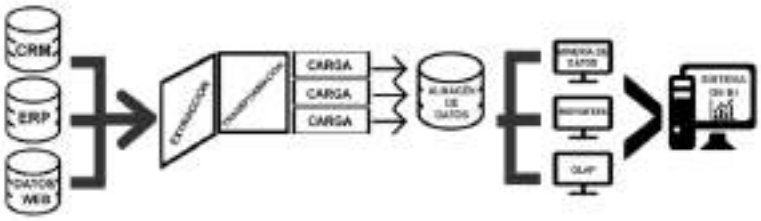

Figura 1. Esquema general de un sistema de inteligencia de negocios.

2 Marco teórico

La inteligencia de negocios es una fuente de información y conocimiento valioso para los responsables de la toma de decisiones al aprovechar una variedad de fuentes de datos, así como información estructurada y no estructurada. La información y los datos pueden residir dentro o fuera de la organización, también pueden obtenerse de múltiples fuentes y estructurarse de diferentes formas [8]. De esta manera, un almacén de datos

(datawarehouse) es un repositorio que almacena la información de forma estructurada que para su construcción, es necesario llevar a cabo el proceso de Extracción, Transformación y Carga denominado ETL. El proceso ETL es una parte de la integración de datos, cuya función completa el resultado de todo el desarrollo de la cohesión de aplicaciones y sistemas. Gracias a los procesos ETL es posible que cualquier organización mueva datos desde una o múltiples fuentes, formatee esos datos y los limpie, cuando sea necesario y los cargue en otro lugar como el almacén de datos, [9]. Una vez que el proceso ETL finaliza se carga la información al almacén de datos para ser usado por el sistema de inteligencia de negocios en el cual se mostrará información relacionada a los requerimientos solicitados por los empresarios.

3 Descripción del problema

Hoy en día, las empresas hacen frente a la competencia globalizada donde la preparación científico-tecnológica y la capacidad de innovación del ser humano están haciendo la diferencia en esta época, presenciando rápidos desarrollos mediante el uso de la tecnología. Dentro de este contexto, tanto las grandes como las pequeñas empresas deben hacer frente al avance tecnológico para poder confrontar las amenazas generadas por la competitividad. En ese sentido, el soporte de toma de decisiones gerenciales es de vital importancia en una empresa en crecimiento, por lo que cada una de las decisiones que tome el empresario direcciona el rumbo al éxito o fracaso de la organización. Un sistema de BI no solo da el soporte necesario para que esta actividad sea sólida y segura, sino que además con la misma información se pueden llegar a desarrollar diferentes técnicas para un análisis más complejo sobre los datos de la organización. Para esto, se llevó a cabo un análisis de las empresas del giro fotovoltaico y de otros giros, en Ciudad Obregón, donde se identificaron desafíos y oportunidades al aplicar tecnología de almacenamientos de datos como apoyo en la toma de decisiones gerenciales, así como también, un análisis de requerimientos como inicio del diseño e implementación de un sistema de BI en una empresa del giro fotovoltaico.

4 Desafíos y oportunidades de aplicar tecnología de almacenamiento de datos en la toma de decisiones gerenciales.

Una empresa se plantea objetivos medibles, claros y alcanzables pero a su vez desafiantes y coherentes con su misión y visión, con la finalidad de lograr un buen posicionamiento y perdurar en el mercado. Por tal motivo, para los empresarios es importante incrementar sus ventas, mantener e incrementar la fidelidad de clientes, tener mayor visibilidad en el mercado, mejorar su competitividad, entre otros.

En ese sentido, el apoyo de la tecnología es crucial para crecer y mejorar la toma de decisiones estratégicas que lleven al negocio a cumplir con su visión y misión. Para ello, los sistemas de BI, son una excelente opción que les permite contar con información en

tiempo real, conocer mejor a sus clientes, identificar patrones y tendencias, así como llevar a cabo reportes avanzados.

Es por ello, que este artículo introduce algunos desafíos y oportunidades referente a los sistemas de BI para la toma de decisiones estratégicas. Para ello, partimos de la identificación de algunas decisiones estratégicas que las PyMEs por lo regular se enfrentan como: administración de los recursos, inversión de nuevos productos o servicios, monitorear las ventas, monitorear la productividad de los empleados, fidelización de clientes, estrategias de mercadeo, entre otros.

En el caso de la empresa de estudio, el interés principal es en el área de ventas, donde interesa conocer clientes frecuentes, así como nichos de mercado desconocidos o en etapa de crecimiento como oportunidad a desarrollar estrategias, también conocer el número de ventas totales por sucursal, entre otros. Así mismo, la empresa se enfrenta a ciertos desafíos al momento de querer invertir en la implementación de un sistema que cuente con este tipo de tecnología, pero a su vez, el implementar estos tipos de sistemas en la organización representa oportunidades de crecimiento y posicionamiento en el mercado.

4.1. Desafíos.

4.1.1 Grado de inversión de software.

El costo de inversión en software dependerá de las funcionalidades que la empresa requiera. En la actualidad, se cuenta con una gran variedad de software para el desarrollo de aplicaciones de inteligencia de negocios tanto de acceso libre como de licencia. En el caso de las PyMEs regionales se conoce que actualmente en el estado de Sonora se cuenta con diez parques solares fotovoltaicos que se encuentran en constante incremento. Respecto al software en este tipo de empresas se sugiere comenzar con software libre o de licencia de bajo costo como PowerBI[‡]. Es importante mencionar que el número de usuarios es de vital importancia para la selección del software que se utilizará, ya que en algunos como PowerBI se paga por usuario, la metodología de Kimball es una excelente opción para una PyME regional, ya que su costo inicial es bajo y el tiempo de desarrollo es inferior [4], en comparación con otras metodologías [5].

4.1.2 Infraestructura tecnológica.

Por lo regular una PyME carece de información almacenada en bases de datos, o en el peor de los casos, no cuentan con información histórica de las operaciones diarias, registros de clientes, compras, etc. Por tal motivo, es un desafío para las PyMEs empezar a implementar estrategias para generar información histórica de tal forma que el sistema de BI pueda ser una realidad ya que muchas de las veces no cuentan con la infraestructura

tecnológica necesaria, y con ello, el desafío es mayor al incrementarse el costo de la inversión. En este caso, la metodologia de Kimball [4] también se ajusta de manera conveniente a estas empresas, ya que el alcance puede ser a departamentos individuales con la tecnología existente de la empresa.

4.1.3 Resistencia al cambio.

El avance tecnológico muchas de las veces no va de la mano con la evolución de las organizaciones, tal es el caso de las PyMEs. La experiencia en este sentido, es que al principio la mayoría de las PyMEs desconocen la existencia de este tipo tecnología pero al conocer los beneficios, su interés es inmediato. Sin embargo, hay diversos factores de resistencia, entre los que destacan los cambios internos que eso conlleva, cambio de estrategias y de procesos, así como la resistencia por parte de los empleados quienes prefieren hacer las cosas como tradicionalmente lo hacen. Por lo que una buena metodología como la de HEFESTO [10] sería de gran ayuda, ya que involucra al usuario final en cada etapa para que tome decisiones respecto al comportamiento y funciones del datawarehouse.

4.2. Oportunidades.

4.2.1 Proporciona información clave para la toma de decisiones empresariales.

Al llevar a cabo un análisis de requerimientos, se establece la importancia de las decisiones estratégicas que la empresa necesita llevar a cabo. De esa manera, se diseña el almacén de datos para que pueda responder a las consultas requeridas por los empresarios, la etapa de análisis de requerimientos la desglosan varios autores de metodologías, sin embargo el que más se centraliza en ello es HEFESTO [10] ya que los identifica con el fin de entender los objetivos de la organización y su estructura se adapta con facilidad y rapidez ante los cambios en el negocio.

4.2.2 Permite una mayor flexibilidad y rapidez en el acceso a la información.

El sistema permite llevar a cabo consultas avanzadas desde cualquier dispositivo electrónico (tabletas, teléfono inteligente, computadora, laptop) con conectividad a internet, mediante el cual se pueden generar reportes *ad-hoc*, gráficos personalizados que ayudarán a la alta gerencia contar con información en tiempo real para tomar decisiones tanto estratégicas como operativas. En ese sentido, la mayoría de las metodologías para el diseño del datawarehouse proveen de flexibilidad y rapidez al accesar a la información. Sin embargo, la metodología ágil propuesta por Corr [6], es la que cuenta con un mejor potencial de respuesta al cambio, brindando mayor satisfacción al cliente, a través de la entrega temprana y retroalimentación continua.

4.2.3 Permite hacer planes de forma más efectiva.

Al contar con información confiable, en tiempo real y analizada por el sistema, es posible que el empresario pueda llegar a conclusiones de comportamientos recurrentes ya sea en clientes, proveedores, ventas, etc., permitiéndole generar nuevas estrategias de forma efectiva y rápida, en vez de tomar decisiones por medio de la intuición y experiencia como ocurre actualmente en la mayoría de las PyMEs. De esta manera, con los entregables periódicos que se realizan por medio de la metodología ágil [6] se minimizan riesgos durante la realización del proyecto de manera colaborativa lo que incrementa la productividad y calidad mediante un seguimiento diario.

5 Conclusiones

Las empresas hoy en día se enfrentan a una competitividad cada vez mayor por lo que el buen uso de la tecnología como elemento impulsor de cambios, es crucial para sobresalir en el mercado y contar con procesos más eficientes. Por ello, se llevó a cabo un análisis sobre la situación actual de las empresas del giro fotovoltaico para conocer su percepción sobre la utilización de tecnología de almacenamiento de datos y conocer los principales desafíos a los que se enfrentan y las oportunidades que esta tecnología les ofrece. Se determinó que las empresas de este giro en Ciudad Obregón, no cuentan con esta tecnología y la mayoría toma decisiones gerenciales utilizando información desactualizada, incompleta, por intuición y experiencia. En este momento, se está trabajando con una empresa del giro fotovoltaico para el diseño e implementación de un sistema de inteligencia de negocios. Para ello, se obtuvieron los requerimientos del negocio, se acordaron indicadores relacionados al área de ventas para comenzar a trabajar en el diseño del almacén de datos. Finalmente, pese a los desafíos que las empresas enfrentan al adoptar este tipo de tecnología, hay empresas dispuestas a tomar retos para innovar, crecer y mejorar su competitividad.

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Arbitrary Overlap Constraints in Graph Packing Problems

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In earlier versions of the community discovering problem, the overlap between communities was restricted by a simple count upper-bound. In this paper, we introduce the Π-Packing with $\alpha()$-Overlap problem to allow for more complex constraints in the overlap region than those previously studied. Let $\mathcal{V}^r$ be all possible subsets of vertices of $V(G)$ each of size at most r, and $\alpha : \mathcal{V}^r \times \mathcal{V}^r \to \{0, 1\}$ be a function. The Π-Packing with $\alpha()$-Overlap problem seeks at least k induced subgraphs in a graph G subject to: (i) each subgraph has at most r vertices and obeys a property Π, and (ii) for any pair H_i, H_j, with $i \neq j$, $\alpha(H_i, H_j) = 0$ (i.e., the pair H_i, H_j does not *conflict*). We also consider a variant that arises in clustering applications: each subgraph of a solution must contain a set of vertices from a given collection of sets $\mathcal{C}$, and no pair of subgraphs may share vertices from the sets of $\mathcal{C}$. In addition, we propose similar formulations for packing hypergraphs. We give an $O(r^{rk}k^{(r+1)k}n^r)$ algorithm for our problems where k is the parameter and c and r are constants, provided that: (i) Π is computable in polynomial time in n and (ii) the function $\alpha()$ satisfies specific conditions. Specifically, $\alpha()$ is hereditary, applicable only to overlapping subgraphs, and computable in polynomial time in

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n and r. Motivated by practical applications we give several examples of $\alpha()$ functions which meet those conditions.

Keywords: Graph packing; set packing; overlapping communities; fixed-parameter algorithm.

1. Introduction

Many complex systems arising in the real world can be represented by networks, e.g., social and biological networks. In these networks, a node represents an entity, and an edge represents a relationship between two entities. A *community* arises in a network when two or more entities have common interests. In this way, members of a community tend to share several properties. Extracting the communities in a network is known as the *community discovering problem* [13].

In practice communities may overlap by sharing one or more of their members [7, 13, 33]. In [12, 23], the $\mathcal{H}$-Packing with t-Overlap was proposed as an abstraction for the community discovering problem. The goal is to find k subgraphs in a given graph G (the network) where each subgraph (a community) should be isomorphic to a graph $H \in \mathcal{H}$ where $\mathcal{H}$ is a family of graphs (the community models). Every pair of subgraphs in the solution should not overlap by more than t vertices (shared members).

However, in some cases the type of overlap that is allowed may be more complex. For example, it has been observed in [34] that overlapping regions are denser than the rest of the community. Also, in [17] it is suggested that overlapping regions should contain nodes which have a relationship with all the communities they belong to. Moreover, in [35] only *boundaries nodes* can happen in the overlapping regions. The notion that overlap is a natural but not a trivial feature among communities has also been suggested by Kelley *et al.* [20] and Goldberg *et al.* [15]. Furthermore, the authors also propose a set of metrics to validate the overlap between a pair of communities.

Motivated by this, we generalize the $\mathcal{H}$-Packing with t-Overlap to restrict the pairwise overlap by a function $\alpha()$ rather than by an upper-bound t. We also consider other communities models besides a family $\mathcal{H}$. The scope of community definitions is vast, see [13]. Thus, we define the much more general problem of Π-*Packing with* $\alpha()$-*Overlap*.

The Π-Packing with $\alpha()$-Overlap problem
Input: A graph G and a non-negative integer k.
Parameter: k
Question: Does G contain a (k, α)-Π-packing, i.e., a set of at least k induced subgraphs $\mathcal{K} = \{H_1, \ldots, H_k\}$ subject to the following conditions: i. each H_i has at most r vertices and obeys the property Π, and ii. for any pair H_i, H_j, with $i \neq j$, $\alpha(H_i, H_j) = 0$?

The landscape of the computational complexity of our generalized problem for any function $\alpha()$ remains much unexplored. In addition to the original NP-complete H-Packing, we list next the particular cases of Π and $\alpha()$ for which this problem has been shown to be NP-complete. H. Fernau *et al.* [12] showed that there always exists a connected graph on t vertices H_t such that the Π-Packing with $\alpha()$-Overlap problem is NP-complete, when $\Pi = \{H \text{ is isomorphic to } H_t\}$ and $\alpha(H_i, H_j) = 0$ if $|V(H_i) \cap V(H_j)| \leq t$. Similarly, A. Agrawal *et al.* [2] showed that the Π-Packing with $\alpha()$-Overlap problem is NP-complete when $\Pi = \{H \text{ is isomorphic to a cycle}\}$ and $\alpha(H_i, H_j) = 0$ if $|V(H_i) \cap V(H_j)| \leq 1$.

We also propose a similar generalization for the problem of packing sets with pairwise overlap that we call the *r-Set Packing with $\alpha()$-Overlap problem*. Let $\mathcal{U}^r$ be all possible subsets of elements of $\mathcal{U}$ each of size at most r, and $\alpha : \mathcal{U}^r \times \mathcal{U}^r \to \{0, 1\}$ be a function.

The r-Set Packing with $\alpha()$-Overlap problem
Input: A collection $\mathcal{S}$ each of size at most r, drawn from a universe $\mathcal{U}$, and a non-negative integer k.
Parameter: k
Question: Does $\mathcal{S}$ contain a $(k, \alpha())$-*set packing*, i.e., at least k sets $\mathcal{K} = \{S_1, \ldots, S_k\}$ where for each pair S_i, S_j $(i \neq j)$ $\alpha(S_i, S_j) = 0$?

Our goal is to achieve *fixed-parameter* (or *FPT*) algorithms which are algorithms that provide a solution in $f(k)\, n^{O(1)}$ running time, where f is some arbitrary computable function depending only on the parameter k. In all our problems, k (the size of the solution) is the parameter, r is a fixed constant, and n denotes the order of the graph or the number of elements in the universe (depending on the problem).

Related Work. H. Fernau *et al.* [12] provide an $O(r^r\, k^{r-t-1})$ kernel for the $\mathcal{H}$-Packing and r-Set Packing with t-Overlap problems. In addition, an $O(r^{rk}\, k^{(r-t-1)\,k+2}\, n^r)$ algorithm for these problems can be found in [23]. A $2\,(rk-r)$ kernel when $\mathcal{H} = \{K_r\}$ and $t = r - 2$ is given in [23]. Agrawal *et al.* [2] give an $O(k^4 \log k)$ kernel for the problem of packing cycles that pairwise overlap in at most 1 vertex, i.e., the $\mathcal{H}$-Packing with t-Overlap problem where $\mathcal{H}$ is the family of cycles and $t = 1$.

The H-Packing problem has an $O(k^{r-1})$ kernel, where H is an arbitrary graph on r vertices [26]. Kernelization algorithms when H is a prescribed graph can be found in [4, 11, 19, 28]. The r-Set Packing problem has an $O(r^r k^{r-1})$ kernel [1].

The community discovering problem has gained considerable attention in the recent years [3, 7, 10, 15, 16, 18, 20, 25, 27, 35]. Designing an efficient algorithm that outputs the communities is not the only goal when studying this problem. For instance, reaching a standard community definition (at least for each type of network) is another research problem. Mostly, the community definition is mainly dependent on the algorithm implementation. In that direction, Kelley *et al.* [20]

and Goldberg *et al.* [15] provide a set of axioms that a subgraph of a social network should have to be considered as a community.

Another subject of research interest is to characterize the network itself. Liu *et al.* [22] analyze the structure of affiliation networks (a type of social networks where communities are cliques). The authors determine statistics for the number of communities, the size of the communities, the size of the overlap, the number of communities each community has at least one node in common, among others.

Other studies evaluate and compare the algorithms that find communities in networks. Xie *et al.* [33] and Devi and Poovammal [9], for example, provide a survey and comprehensive comparative studies of such algorithms. Wang *et al.* [32], on the other hand, formulate the first framework to analyze and compare this type of algorithms (for non-overlapping communities) under the same experimental conditions.

In addition of finding communities in networks, the problem of finding subgraphs has also applications in pattern recognition and computer vision [6, 30].

Our Results. In this work, we introduce the r-Set Packing and Π-Set Packing with $\alpha()$-Overlap problems as more universal versions for the problem of packing graphs and sets subject to overlap constraints modeled by a function $\alpha()$. Our generalizations capture a much broader range of potential real life applications.

We start in Sec. 3 by giving specific examples of well-conditioned $\alpha()$ functions, some motivated by practical applications while others by theoretical considerations. Specifically, a well-conditioned $\alpha()$ can restrict (but it is not limited to): (i) the size of the overlap, (ii) the weight in the overlap region, (assuming as input a weighted graph), (iii) *the pattern* in the overlap region, i.e., the induced subgraph in the overlap should be isomorphic to a graph in $\mathcal{F}$, where $\mathcal{F}$ is a graph class that is hereditary, (iv) that all overlapping vertices must satisfy a specific property ξ, (v) that the overlap region should have a specific density, and finally, (vi) a specific distance between any pair of vertices in the overlap.

We show in Sec. 4 that the r-Set Packing with $\alpha()$-Overlap problem is fixed-parameter tractable when $\alpha()$ meets specific requirements ($\alpha()$ is *well-conditioned*, see Definition 1). Our FPT-algorithm generalizes the algorithm by A. López-Ortiz and J. Romero [23]. That algorithm only considers one specific type of conflict between a pair of sets: overlap larger than t. In our extended algorithm, we will consider the more general *α-conflicts*. To solve the Π-Packing with $\alpha()$-Overlap problem, we reduce it to its set version. This allows us to achieve an algorithm with $O(r^{rk}k^{(r+1)k}n^r)$ running time, provided that $\alpha()$ is well-conditioned and Π is verifiable in polynomial time.

Lastly, we study the PCH-r-Set Packing with $\alpha()$-Overlap problem in Sec. 5. In this setting, every set in the solution must contain a specific set of elements from a given collection of sets $\mathcal{C}$. This problem remains fixed-parameter tractable if $|\mathcal{C}| = O(g(k))$ for some computable function g dependent on k and independent of n.

2. Preliminaries

Let $\mathcal{U} = \{u_1, \ldots, u_n\}$ be a universe of elements and $\mathcal{S} = \{S_1, \ldots, S_m\}$ be a collection of sets, where $S_i \subset \mathcal{U}$. We will use the letters u, s, S in combination with subindices to refer to elements in $\mathcal{U}$, sets of elements of $\mathcal{U}$, and members of $\mathcal{S}$, respectively. Notice that we will identify a subset of elements of $\mathcal{U}$ (that is not necessarily a member of $\mathcal{S}$) using a lower-case s with a subindex, while we restrict the use of upper-case letters to identify members of $\mathcal{S}$. Let $\mathbb{R}^+$ denotes the set of all non-negative real numbers.

For $\mathcal{S}' \subseteq \mathcal{S}$, $val(\mathcal{S}')$ denotes the union of all members of $\mathcal{S}'$. We say that a subset of elements s is *contained* in a set S, if $s \subseteq S$. In addition, let $\mathcal{S}(s)$ be the collection of all sets in $\mathcal{S}$ that contain s. That is, $s \subseteq S$ for each $S \in \mathcal{S}(s)$ and $s \not\subset S'$ for each $S' \in (\mathcal{S} \backslash \mathcal{S}(s))$. For any two sets $S, S' \in \mathcal{S}$, $|S \cap S'|$ is the *overlap size* while $\{S \cap S'\}$ is the *overlap region*.

Let $\mathcal{U}^r$ be all possible subsets of elements of $\mathcal{U}$ each of size at most r, where r is a constant. There are $O(n^r)$ sets in $\mathcal{U}^r$ each one explicitly represented in memory requiring $O(r \log n)$ bits. In this way, the representation of $\mathcal{U}^r$ requires $O(n^r r \log n)$ bits.

Definition 1. Let $\alpha : \mathcal{U}^r \times \mathcal{U}^r \to \{0, 1\}$ be a function. A pair of sets $s_i, s_j \in \mathcal{U}^r$ *α-conflicts* if $\alpha(s_i, s_j) = 1$ else it *does not α-conflict*. If $\alpha()$ satisfies the following requirements, we say $\alpha()$ is *well-conditioned*.

(i) $\alpha()$ is *hereditary*. Specifically, if s_i and s_j do not α-conflict ($\alpha(s_i, s_j) = 0$), $\alpha(s'_i, s'_j) = 0$ for any pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$.
(ii) If s_i and s_j α-conflict ($\alpha(s_i, s_j) = 1$), $|s_i \cap s_j| \geq 1$. Furthermore, for any pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with $\alpha(s'_i, s'_j) = 0$ ($(s_i \cap s_j) \backslash (s'_i \cap s'_j)) \neq \emptyset$. The elements in $s_i \cap s_j$ are referred to as the *conflicting elements*.
(iii) $\alpha(s_i, s_j)$ for any $s_i, s_j \in \mathcal{U}^r$ is verified in at most polynomial time in n and r.

We will define some $\alpha()$ well-conditioned functions by using a type of monotone sub-additive functions.

Definition 2. Let $f : \mathcal{U}^r \to \mathbb{R}^+$ be a function computable in polynomial time.

(i) f is *non-negative* if $f(s) \geq 0$,
(ii) f is *normalized*, if $f(s) = 0$, if $s = \emptyset$,
(iii) f is *monotone*, if $f(s') \leq f(s)$, if $s' \subseteq s$, and
(iv) f is *sub-additive* $f(s \cup p) \leq f(s) + f(p)$, for any $s, p \in \mathcal{U}^r$.

A *maximal $\alpha()$-set packing* $\mathcal{M} \subseteq \mathcal{S}$ is a maximal collection of sets from $\mathcal{S}$ such that for each pair of sets $S_i, S_j \in \mathcal{M}$ $(i \neq j)$ $\alpha(S_i, S_j) = 0$, and for each $S \in \mathcal{S} \backslash \mathcal{M}$, S α-conflicts with some $S' \in \mathcal{M}$, i.e., $\alpha(S, S') = 1$.

All graphs in this paper are undirected and simple, unless otherwise stated. For a graph G, $V(G)$ and $E(G)$ denote its sets of vertices and edges, respectively. $|V(G)|$ is the order of the graph. For a set of vertices $S \subseteq V(G)$, $G[S]$ represents the

subgraph induced by S in G. The distance (shortest path) between two vertices u and v is denoted as $dist_G(u, v)$. We use the letter n to denote both $|\mathcal{U}|$ and $|V(G)|$.

In the Π-Packing with $\alpha()$-Overlap problem, we regulate the pairwise overlap with a function $\alpha : \mathcal{V}^r \times \mathcal{V}^r \to \{0, 1\}$ where $\mathcal{V}^r$ is the collection of all possible subsets of vertices of $V(G)$ each of size at most r, where r is constant. We say that two subgraphs H_i and H_j *α-conflict* if $\alpha(H_i, H_j) = 1$. Abusing the terminology, we extend the definition of a well-conditioned $\alpha()$ (Definition 1) to consider subsets of vertices as well. This implies that $\mathcal{U}^r = \mathcal{V}^r$, $s_i = V(H_i)$ and $s_j = V(H_j)$ in Definition 1.

3. Well-Conditioned Overlap Constraints

In the next section, we provide several examples of functions that are well-conditioned. That is, they satisfy the conditions in Definition 1. In the first section, we focus on functions concerning the r-Set Packing with $\alpha()$-Overlap problem that could be used to restrict the overlap for graph version as well. After that in Sec. 3.2, we provide functions that consider graph properties.

3.1. *Restricting the overlap between sets*

For a function f that satisfies the properties in Definition 2, we define a well-conditioned function α-Monotone(s_i, s_j), where $s_i, s_j \in \mathcal{U}^r$ that returns 0 or *no-conflict* if $f(s_i \cap s_j) \leq t$ (for $t \geq 0$) otherwise returns 1 or *α-conflict*. Notice that $s_i \cap s_j \in \mathcal{U}^r$ as well.

Lemma 1. *The function α-Monotone is well-conditioned.*

Proof. (i) α-Monotone is *hereditary*. Suppose otherwise that α-Monotone $(s_i, s_j) = 0$ but there is a pair of subsets $s'_i \subseteq s_i, s'_j \subseteq s_j$ with α-Monotone$(s'_i, s'_j) = 1$. This implies that $f(s_i \cap s_j) \leq t$ but $f(s'_i \cap s'_j) > t$. First, $s'_i \cap s'_j \neq \emptyset$, otherwise, $f(s'_i \cap s'_j) = 0$ and since $t \geq 0$ there would be a contradiction. Second, $s'_i \cap s'_j \subseteq s_i \cap s_j$, thus by the monotone property of f, $f(s'_i \cap s'_j) \leq f(s_i \cap s_j)$. Since $f(s_i \cap s_j) \leq t$, the claim holds.

(ii) If α-Monotone(s_i, s_j)=1 (i.e., α-conflict), $|s_i \cap s_j| \geq 1$. Assume by contradiction that α-Monotone(s_i, s_j)=1 and $s_i \cap s_j = \emptyset$. Since α-Monotone $(s_i, s_j) = 1$, $f(s_i \cap s_j) > t$. However, $f(s_i \cap s_j) = f(\emptyset) = 0$ and since $t \geq 0$, $f(s_i \cap s_j) \leq t$, a contradiction.

Let $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ be a pair of subsets with α-Monotone$(s'_i, s'_j) = 0$, (i.e., $f(s'_i \cap s'_j) \leq t$). Note that at most one $s'_i = s_i$ or $s'_j = s_j$; otherwise α-Monotone$(s'_i, s'_j) = 1$. Since $f(s_i \cap s_j) \geq t + 1$, $f(s_i \cap s_j) - f(s'_i \cap s'_j) > 0$ and $((s_i \cap s_j) \backslash (s'_i \cap s'_j)) \neq \emptyset$.

(iii) The function f is computed in polynomial time; thus, we can verify in constant time whether α-Monotone$(s_i \cap s_j) > t$ or not. □

Next, we give two examples of monotone functions that can be used to define a well-conditioned $\alpha()$. The motivation behind these functions arise mainly for the graph version of our problems.

Constant Overlap. Gossen *et al.* [17] and Freeman [14] suggest that when communities are defined in contexts, the overlap size is usually small. That is, the number of members that a pair of communities share is not large. Motivated by this, we define an $\alpha()$ function to upper-bound the size of the overlap.

We define a function $f_o : \mathcal{U}^r \to \mathbb{R}^+$ that simply returns the number of elements in the input, i.e., $f_o(s) = |s|$. It is not difficult to see that f_o is a monotone subadditive function that satisfies the conditions in Definition 2.

We use this function to define a well-conditioned $\alpha()$ to upper-bound the overlap size by a constant t, where $0 \leq t \leq r-1$. The function α-Constant(s_i, s_j) returns 0 (*no-conflict*) if $f_o(s_i \cap s_j) \leq t$, otherwise it returns 1 (α-*conflict*). By Lemma 1,

Corollary 1. *The function α-Constant is well-conditioned.*

Weighted Overlap. Suppose that each node of the network has associated a non-negative weight. This weight could represent the cost that each node pays for doing a certain action, e.g., transmitting a message. When overlap is allowed between the communities, the cost of each shared node is payed only once. However, it could be the case that the cost payed by the overlapping nodes should not overpass a specific bound. With this scenario in mind, we introduce the next function.

Let us assume that each $u_l \in \mathcal{U}$ has associated a non-negative weight $w(u_l)$, where $w(u_l) \geq 0$. Let $f_w : \mathcal{U}^r \to \mathbb{R}^+$ be a function that returns $f_w(s) = \sum_{u \in (s)} w(u)$.

Lemma 2. *The function f_w satisfies the conditions in Definition 2.*

Proof. (i) Since the weights are non-negative $f_w(s) \geq 0$, for any $s \in \mathcal{U}^r$. (ii) If $s = \emptyset$, $f(s) = \sum_{u \in (s)} w(u) = 0$. (iii) Assume otherwise that $f_w(s') > f_w(s)$ for some subset $s' \subseteq s$. Since $f_w(s') = \sum_{u \in s'} w(u)$, and $s' \subseteq s$, this could only be possible if some elements in $s \backslash s'$ have negative weights. A contradiction since the weights are non-negative. (iv) By using similar arguments we can see that $f_w(s \cup p) \leq f_w(s) + f_w(p)$, for any $s, p \in \mathcal{U}^r$. □

We could restrict the overlap region by its weight. We define the function α-Weight(s_i, s_j) that returns 0 (i.e., *no-conflict*), if $f_w(s_i \cap s_j) \leq w_t$ where $w_t \geq 0$ is a constant, else returns 1 (i.e., α-*conflict*). By Lemma 1,

Corollary 2. *The function α-Weight is well-conditioned.*

We could also restrict the overlap region by both its size and its weight. This combined restriction is a well-conditioned function as well.

Metric Overlap. Let us assume that $\mathcal{U}$ is a metric space. That is, there is a *metric* or *a distance function* that defines a distance between each pair of elements u, v of $\mathcal{U}$, subject to the following conditions: $dist_{\mathcal{U}}(u, v) \geq 0$, $dist_{\mathcal{U}}(u, v) = 0$ if

$(u = v)$, $dist_{\mathcal{U}}(u, v) = dist_{\mathcal{U}}(v, u)$ and $dist_{\mathcal{U}}(u, w) \leq dist_{\mathcal{U}}(u, v) + dist_{\mathcal{U}}(v, w)$. In addition, the distance of the empty set is considered as zero, i.e., $dist_{\mathcal{U}}(\emptyset) = 0$. For a constant $d_t \geq 0$, we define the function α-Metric(s_i, s_j) which returns *no-conflict* $dist_{\mathcal{U}}(u, v) \leq d_t$ for each pair u, v $(u \neq v)$ in $s_i \cap s_j$ else returns *α-conflict*.

Lemma 3. *The function α-Metric is well-conditioned.*

Proof. (i) α-Metric is hereditary. For any pair of sets s_i,s_j that do not α-conflict (i.e., α-Metric$(s_i, s_j) = 0$), there is no pair of subsets $s'_i \subseteq s_i$, $s'_j \subseteq s_j$ with α-Metric$(s'_i, s'_j) = 1$. Assume the opposite by contradiction. $|s'_i \cap s'_j| \geq 1$, otherwise s'_i and s'_j would not α-conflict. Observe that $(s'_i \cap s'_j) \subseteq (s_i \cap s_j)$. In addition, since $\mathcal{U}$ is a metric-space and $\alpha(s_i, s_j) = 0$, $dist_{\mathcal{U}}(u, v) \leq t$ for each pair u, v $(u \neq v)$ in $(s_i \cap s_j)$. Given that we are using $dist_{\mathcal{U}}$ and not $dist_{s'_i \cap s'_j}$, there is no pair of elements in $(s'_i \cap s'_j)$ with $dist_{\mathcal{U}}(u, v) > t$.

(ii) Since $d_t > 0$, for any pair s_i, s_j with α-Metric$(s_i, s_j) = 1$, $|s_i \cap s_j| > 1$. Let $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ be a pair of subsets with α-Metric$(s'_i, s'_j) = 0$. Note that at most one $s'_i = s_i$ or $s'_j = s_j$; otherwise α-Metric$(s'_i, s'_j) = 1$. $dist_{\mathcal{U}}(u, v) \leq t$ for each pair u, v $(u \neq v)$ in $(s'_i \cap s'_j)$. Since $\alpha(s_i, s_j)$-Metric$= 1$ but α-Metric$(s'_i, s'_j) = 0$ then it must exists at least one element u in $((s_i \cap s_j) \backslash (s'_i \cap s'_j))$ such that $dist_{\mathcal{U}}(u, v) > t$ for some v in $(s_i \cap s_j)$. In this way, $((s_i \cap s_j) \backslash (s'_i \cap s'_j)) \neq \emptyset$.

(iii) Assuming as input a metric space $\mathcal{U}$, α-Metric is verified in $O(r^2)$ time. □

3.2. *Restricting the overlap between subgraphs*

Prescribed Pattern. It has been observed in social networks that the overlap region is often more densely connected than the rest of the community [34]. Inspired by this, we will allow pairwise-overlap in a $(k, \alpha())$-Π-packing if the overlap region has a specific pattern, for example, if it is a clique. More precisely, we say that a pair of subgraphs H_i,H_j does not α-conflict if $G[V(H_i) \cap V(H_j)]$ is isomorphic to a graph F in a class $\mathcal{F}$. To define a well-conditioned $\alpha()$, $\mathcal{F}$ is a graph class that is hereditary (i.e., it is closed under taking induced subgraphs). Examples of $\mathcal{F}$ are cliques, planar and chordal graphs. Indeed this applies to any graph class that is closed under minors, since this is hereditary and by the Robertson-Seymour theorem the graph is polynomially testable by checking for the forbidden minors [29]. We define the function α-Pattern(s_i, s_j) that returns *no-conflict* if $|s_i \cap s_j| = 0$ or if $G[s_i \cap s_j]$ is isomorphic to a graph F in $\mathcal{F}$; otherwise, it returns *α-conflict*.

Lemma 4. *The function α-Pattern is well-conditioned.*

Proof. (i) α-Pattern is hereditary. Assume by contradiction that there is a pair s_i,s_j with α-Pattern$(s_i, s_j) = 0$ but there is a pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with α-Pattern$(s'_i, s'_j) = 1$. If $\alpha(s'_i, s'_j)$-Pattern$= 1$ this implies that $G[s'_i \cap s'_j]$ is not isomorphic to a graph F in $\mathcal{F}$. Notice that $(s'_i \cap s'_j) \subseteq (s_i \cap s_j)$. In addition, $(G[s_i \cap s_j])$ is isomorphic to a graph $F \in \mathcal{F}$ (otherwise, α-Pattern$(s_i, s_j) = 1$).

Since $\mathcal{F}$ is a graph class that is hereditary, $G[s'_i \cap s'_j]$ is also isomorphic to F and s'_i and s'_j do not α-conflict.

(ii) It follows by definition of α-Pattern(s_i, s_j) that for any pair s_i, s_j that α-conflicts (i.e., α-Pattern$(s_i, s_j) = 1$) $|s_i \cap s_j| \geq 1$. Let $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ be a pair of non-empty subsets where α-Pattern$(s'_i, s'_j) = 0$. This implies that $G[s'_i \cap s'_j]$ is isomorphic to a graph $F \in \mathcal{F}$. Recall that $(s'_i \cap s'_j) \subseteq (s_i \cap s_j)$. Since $G[s_i \cap s_j]$ is not isomorphic to a graph in $\mathcal{F}$ but $G[s'_i \cap s'_j]$ is, and $\mathcal{F}$ is closed under taking induced subgraphs, $((s_i \cap s_j) \backslash (s'_i \cap s'_j)) \neq \emptyset$.

(iii) In our case, $|s_i \cap s_j| \leq r - 1$ and r is a constant. Therefore, verify α-Pattern would take constant time. □

Distance. In [35], overlapping nodes occur only in the *boundary* regions of overlapping communities in sensor networks. Motivated by this, we consider in the overlap region nodes that are "closer" to each other. In this way, two subgraphs H_i, H_j do not α-conflict if the distance in G between any pair of vertices u, v in $V(H_i) \cap V(H_j)$ is at most a constant $d_t > 0$, i.e., $dist_G(u, v) \leq d_t$. Recall that a subgraph H_i is represented by a set $S_i = V(H_i)$ in $\mathcal{S}$. Since the graph distance is a metric on $V(G)$, we use the function α-Metric defined previously (Lemma 3).

Corollary 3. *The function α-Distance is well-conditioned.*

Note that we are using $dist_G(u, v) \leq d_t$ instead of $dist_{G[S_i \cap S_j]}(u, v) \leq d_t$. The second one is not an hereditary property and thus not well-conditioned.

Property. There are several vertex properties that are relevant to the analysis of real networks: vertex strength [5, 24], vertex weight [21], and disparity [24], among others. Hence, we suggest considering only overlapping nodes that present the same property ξ (or properties). We assume however that the properties values for each vertex are given as part of the input.

We define the following monotone sub-additive function. Let $f_p : \mathcal{U}^r \to \{0, 1\}$. $f_p(s) = 0$ if $|s| = 0$ or if each element $u \in s$ satisfies a property ξ. Otherwise, $f_p(s) = 1$. That is, $f_p(s) = 1$ if and only if there is at least one element in s that does not satisfies ξ.

Lemma 5. *The function f_p satisfies the conditions in Definition 2.*

Proof. Conditions (i) and (ii) follow by definition. Assume by contradiction that $f_p(s') > f_p(s)$ for some $s' \subseteq s$. That is, assume that $f_p(s') = 1$ and $f_p(s) = 0$. This would imply that there is one element in s' that does not satisfy ξ. However, $s' \subseteq s$, and all elements in s satisfy ξ (otherwise $f_p(s)$ would be 1), a contradiction. This shows that f_p follows (iii). Condition (iv) $f(s \cup p) \leq f(s) + f(p)$, for any $s, p \in \mathcal{U}^r$ follows by similar arguments. □

Suppose instead that we are interested in overlapping regions with all elements being "free" of some property. For example, none of the nodes in the overlapping

region could be a "loner" (an isolated member of a network). We re-formulate f_p for this purpose. Let $f_p : \mathcal{U}^r \to \{0, 1\}$. $f_p(s) = 0$ if $|s| = 0$ or if none element $u \in s$ satisfies a property ξ. Otherwise, $f_p(s) = 1$. That is, $f_p(s) = 1$ if and only if there is at least one element in s satisfying ξ. By using similar ideas as in Lemma 5, we know that this alternative function f_p also satisfies the conditions in Definition 2.

Using f_p (any of the above definitions) we define the well-conditioned function α-Property(s_i, s_j) which simply returns 0 or *no-conflict* if $f_p(s_i \cap s_j) = 0$. Otherwise, it returns 1 or α-*conflict*. By Lemma 1,

Corollary 4. *The function α-Property is well-conditioned.*

Dense Overlap. We design another α function to model the behavior that the overlap region is densely connected. To that end, we define α-DenseOverlap(s_i, s_j) that returns *no-conflict* if $|s_i \cap s_j| = 0$ or $|E(G[s_i \cap s_j])| \geq \frac{O(O-1)}{2} - c$, where $O = |s_i \cap s_j|$ and $c \geq 0$ is a constant; otherwise, it returns α-*conflict*.

Lemma 6. *The function α-DenseOverlap is well-conditioned.*

Proof. (i) α-DenseOverlap is hereditary. Assume by contradiction that there is a pair of sets s_i, s_j with α-DenseOveralp$(s_i, s_j) = 0$ but there is a pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with α-DenseOverlap$(s'_i, s'_j) = 1$. Notice that $(s'_i \cap s'_j) \neq \emptyset$; otherwise, α-DenseOverlap$(s'_i, s'_j) = 0$ Therefore, if α-DenseOverlap$(s'_i, s'_j) = 1$ then $|E(G[s'_i \cap s'_j])| < \frac{O'(O'-1)}{2} - c$, where $O' = |s'_i \cap s'_j|$. However since $G[s'_i \cap s'_j]$ is an induced subgraph of $G[s_i \cap s_j]$, then $|E(G[s_i \cap s_j])| < \frac{O(O-1)}{2} - c$, a contradiction.

(ii) If α-DenseOverlap$(s_i, s_j) = 1$, $|s_i \cap s_j| \geq 1$. Furthermore, for any pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with α-DenseOverlap$(s'_i, s'_j) = 0$ $(s_i \cap s_j) \backslash (s'_i \cap s'_j) \neq \emptyset$. Assume otherwise by contradiction. If α-DenseOverlap$(s'_i, s'_j) = 0$ then $|E(G[s'_i \cap s'_j])| \geq \frac{O'(O'-1)}{2} - c$, where $O' = |s'_i \cap s'_j|$. Thus, if $(s_i \cap s_j) \backslash (s'_i \cap s'_j)$ would be the empty set, then $|E(G[s_i \cap s_j])| \geq \frac{O(O-1)}{2} - c$, where $O = |s_i \cap s_j|$, a contradiction to our assumption that α-DenseOverlap$(s_i, s_j) = 1$.

(iii) We can verify in polynomial time this condition. □

Density. We could ask that the subgraph induced by the overlapping vertices has both at most $t \geq 0$ vertices and $c \geq 0$ edges. To that end, the function α-Density returns *no-conflict* if $|s_i \cap s_j| = 0$ or $(|s_i \cap s_j| \leq t$ and $|E(G[s_i \cap s_j])| \leq c)$ else returns α-conflict.

Lemma 7. *The function α-Density is well-conditioned.*

Proof. (i) α-Density is *hereditary*. Assume by contradiction that there is a pair s_i,s_j with α-Density$(s_i, s_j) = 0$, but there is a pair of subsets α-Density$(s'_i, s'_j) = 1$ where $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$. Since α-Density$(s_i, s_j) = 0$, both $(s_i \cap s_j) \leq t$ and $|E(G[S_i \cap s_j])| \leq c$. For any pair of sets s_i,s_j with α-Density$(s_i, s_j) = 0$,

$|s_i \cap s_j| \leq t$. Thus, there cannot be a pair of subsets $s'_i \subseteq s_i, s'_j \subseteq s_j$ with $|s'_i \cap s'_j| > t$. Given that $(s'_i \cap s'_j) \subseteq (s_i \cap s_j)$, $|E(G[s'_i \cap s'_j])| \leq |E(G[s_i \cap s_j])| \leq c$.

(ii) For any pair s_i, s_j that α-conflicts (i.e., α-Density$(s_i, s_j) = 1$) $|s_i \cap s_j| \geq 1$. In addition, for any pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with α-Density$(s'_i, s'_j) = 0$ both $|s'_i \cap s'_j| \leq t$ and $E(G[s'_i \cap s'_j])| \leq c$. Since α-Density$(s_i, s_j) = 1$ either $|s_i \cap s_j| > t$ or $|E(G[s_i \cap s_j])| > c$. In the first case, since α-Density$(s'_i, s'_j) = 0$, $|s'_i \cap s'_j| \leq t$. Therefore, $((s_i \cap s_j) \backslash (s'_i \cap s'_j)) \neq \emptyset$. For the second case, $|E(G[s_i \cap s_j])| - |E(G[s'_i \cap s'_j])| > 0$. Therefore, $|(s_i \cap s_j) \backslash (s'_i \cap s'_j)| \geq 1$.

(iii) In $O(r)$ time, we can verify if $|E(G[s_i \cap s_j])| \leq c$. □

4. Packing Problems with Well-Conditioned Overlap

In this section, we develop an FPT-algorithm for the r-Set Packing with $\alpha()$-Overlap problem. After that, we provide a solution for Π-Packing with $\alpha()$-Overlap by reducing it to the set version. Our FPT-algorithm assumes that the function $\alpha()$ is well-conditioned.

4.1. *An FPT algorithm for the r-set packing with α()-overlap*

The next lemmas state important observations of a maximal $\alpha()$-set packing and are key components in the correctness of our algorithm.

Lemma 8. *Let $\mathcal{M}$ be a maximal $\alpha()$-set packing. If $|\mathcal{M}| \geq k$, then $\mathcal{M}$ is a $(k, \alpha())$-set packing.*

Proof. Assume otherwise that $\mathcal{M}$ is not a $(k, \alpha())$-set packing. This would be only possible if there is at least one pair of sets S_i, S_j in $\mathcal{M}$ for which $\alpha(S_i, S_j) = 1$ but in that case $\mathcal{M}$ would not be a maximal $\alpha()$-set packing. □

Lemma 9. *Given an instance $(\mathcal{U}, \mathcal{S}, k)$ of r-Set Packing with $\alpha()$-Overlap, where $\alpha()$ is well-conditioned, let $\mathcal{K}$ and $\mathcal{M}$ be a $(k, \alpha())$-set packing and a maximal $\alpha()$-set packing, respectively. For each $S^* \in \mathcal{K}$, S^* shares at least one element with at least one $S \in \mathcal{M}$.*

Proof. If $S^* \in \mathcal{M}$, the lemma simply follows. Assume by contradiction that there is a set $S^* \in \mathcal{K}$ such that $S^* \notin \mathcal{M}$ and there is no set $S \in \mathcal{M}$ α-conflicting with S^*. However, we could add S^* to $\mathcal{M}$, contradicting its maximality. Thus, there exists at least one $S \in \mathcal{M}$ α-conflicting with S^*. Since $\alpha()$ is well-conditioned, by Definition 1 (ii) $|S \cap S^*| \geq 1$. □

Our Bounded Search Tree algorithm (abbreviated as `BST-α()-Algorithm`, Algorithm 1) for r-Set Packing with $\alpha()$-Overlap has three main components: `Initialization`, `Greedy`, and `Branching`. We start by computing a maximal $\alpha()$-set packing $\mathcal{M}$ of $\mathcal{S}$. If $|\mathcal{M}| \geq k$ then $\mathcal{M}$ is a $(k, \alpha())$-set packing and the

Algorithm 1 `BST` $\alpha()$`-Algorithm`

1: Compute a maximal $(\alpha())$-set packing $\mathcal{M}$
2: **if** $|\mathcal{M}| \geq k$ **then** Return $\mathcal{M}$ **end if**
3: T=`Initialization`($\mathcal{M}$)
4: **for** each node i of T **do**
5: Let $\mathbf{Q^i}$ be the collection of sets at node i
6: $\mathbf{Q^{gr}}$ =`Greedy`($\mathbf{Q^i}$)
7: **if** $\mathbf{Q^{gr}}! = \infty$ **then**
8: **if** $|\mathbf{Q^{gr}}| == k$ **then** Return $\mathbf{Q^{gr}}$ **end if**
9: `Branching`(T,node i,$\mathbf{Q^i}$,$\mathbf{Q^{gr}}$)
10: **end if**
11: **end for**

`BST-`$\alpha()$`-algorithm` stops (Lemma 8). Otherwise, we create a search tree T where at each node i, there is a collection of sets $\mathbf{Q^i} = \{s_1^i, \ldots, s_k^i\}$ with $s_j^i \subseteq S$ for some $S \in \mathcal{S}$. The goal is *to complete* $\mathbf{Q^i}$ to a solution, if possible. That is, to find k sets $\mathcal{K} = \{S_1, \ldots, S_k\}$ of $\mathcal{S}$, such that $s_j^i \subseteq S_j$ for $1 \leq j \leq k$ and $\mathcal{K}$ is a $(k, \alpha())$-set packing.

The children of the root of T are created according to a procedure called `Initialization`. After that for each node i of T, a routine called `Greedy` will attempt to complete $\mathbf{Q^i}$ to $(k, \alpha())$-set packing. If `Greedy` succeeds then the `BST-`$\alpha()$`-algorithm` stops. Otherwise, the next step is to create children of the node i using the procedure `Branching`. The `BST-`$\alpha()$`-algorithm` will repeat `Greedy` in these children. Eventually, the `BST-`$\alpha()$`-algorithm` either finds a solution at one of the leaves of the tree or determines that it is not possible to find one.

We next explain the three main components of the `BST-`$\alpha()$`-algorithm` individually. Let us start with the `Initialization` routine (Algorithm 2). By Lemma 9, if there is a solution $\mathcal{K} = \{S_1^*, \ldots, S_k^*\}$ each S_j^* contains at least one element of $val(\mathcal{M})$. Notice that each element of $val(\mathcal{M})$ could be in at most k sets of $\mathcal{K}$. Thus, we create a set $\mathcal{M}_k$ that contains k copies of each element in

Algorithm 2 `Initialization`($\mathcal{M}$)

1: Replicate k times each element $u \in val(\mathcal{M})$ and identify them as $u_1, \ldots, u_k$.
2: Let $\mathcal{M}_k$ be the enlarged set $val(\mathcal{M})$
3: $i = 0$, $T = null$
4: **while** $i < |\binom{\mathcal{M}_k}{k}|$ **do**
5: Let $\mathbf{Q^i} = \{s_1^i, \ldots, s_k^i\}$ be the ith combination of $\binom{\mathcal{M}_k}{k}$
6: `CreateNode(`T`,root,node` i`,`$\mathbf{Q^i}$`)`
7: $i = i + 1$
8: **end while**
9: Return T

$val(\mathcal{M})$. That is, per each element $u \in val(\mathcal{M})$ there are k copies $u_1, \ldots, u_k$ in $\mathcal{M}_k$ and $|\mathcal{M}_k| = k|val(\mathcal{M})|$. The root will have a child i for each possible combination of k elements from $\mathcal{M}_k$. A set of $\mathbf{Q^i}$ is initialized with one element of that combination. For example, if the combination is $\{u_1, u_2, u_k, a_1, b_1\}$, $\mathbf{Q^i} = \{\{u_1\}, \{u_2\}, \{u_k\}, \{a_1\}, \{b_1\}\}$. After that, we remove the indices from the elements in $\mathbf{Q^i}$, e.g., $\mathbf{Q^i} = \{\{u\}, \{u\}, \{u\}, \{a\}, \{b\}\}$.

At each node i, the `Greedy` routine returns a collection of sets $\mathbf{Q^{gr}}$ (Algorithm 3). Initially, $\mathbf{Q^{gr}} = \emptyset$ and $j = 1$. At iteration j, `Greedy` searches for a set S that contains $s^i_j \in \mathbf{Q^i}$ (the jth set of $\mathbf{Q^i}$) subject to two conditions (**): (1) S is not already in $\mathbf{Q^{gr}}$ and (2) S does not α-conflict with any set in $\mathbf{Q^{gr}}$ (i.e., $\alpha(S, S') = 0$ for each $S' \in \mathbf{Q^{gr}}$). If such set S exists, `Greedy` adds S to $\mathbf{Q^{gr}}$, i.e., $\mathbf{Q^{gr}} = \mathbf{Q^{gr}} \cup \{S\}$ and continues with iteration $j = j + 1$. Otherwise, `Greedy` stops executing and returns $\mathbf{Q^{gr}}$. If $|\mathbf{Q^{gr}}| = k$, then $\mathbf{Q^{gr}}$ is a $(k, \alpha())$-set packing and the `BST-`$\alpha()$`-algorithm` stops. If $\mathbf{Q^i}$ cannot be completed into a solution (Lemma 12), `Greedy` returns $\mathbf{Q^{gr}} = \infty$. `Greedy` searches for the set S in the collection $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha) \subseteq \mathcal{S}(s^i_j)$ which is obtained as follows: add a set $S' \in \mathcal{S}(s^i_j)$ to $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$, if S' does not α-conflict with any set in $(\mathbf{Q^i} \backslash s^i_j)$ and S' is distinct of each set in $(\mathbf{Q^i} \backslash s^i_j)$ (Algorithm 4).

The `Branching` procedure (Algorithm 5) executes every time that `Greedy` does not return a $(k, \alpha())$-set packing but $\mathbf{Q^i}$ could be completed into one. That is, $\mathbf{Q^{gr}} \neq \infty$ and $|\mathbf{Q^{gr}}| < k$. Let $j = |\mathbf{Q^{gr}}| + 1$ and s^i_j be the jth set in $\mathbf{Q^i}$. `Greedy` stopped at j because each set $S \in \mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ either it was already contained in $\mathbf{Q^{gr}}$, or it α-conflicts with at least one set in $\mathbf{Q^{gr}}$ (see **). We will use the conflicting elements between $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ and $\mathbf{Q^{gr}}$ to create children of the node i. Let I^* be the set of those conflicting elements. `Branching` creates a child l of the node i for each element $u_l \in I^*$. The collection $\mathbf{Q^l}$ of child l is the same as the collection $\mathbf{Q^i}$ of its parent i with the update of the set s^i_j as $s^i_j \cup u_l$, i.e., $\mathbf{Q^l} = \{s^i_1, \ldots, s^i_{j-1}, s^i_j \cup u_l, s^i_{j+1}, \ldots, s^i_k\}$. The set I^* is obtained as $I^* = I^* \cup ((S \backslash s^i_j) \cap S')$ for each pair $S \in \mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ and $S' \in \mathbf{Q^{gr}}$ that α-conflict ($\alpha(S, S') = 1$) or that $S = S'$.

4.1.1. *Correctness*

With the next series of lemmas we establish the correctness of the `BST-`$\alpha()$`-algorithm` for any well-conditioned function $\alpha()$.

A collection $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j, \ldots, s^i_k\}$ is a *partial-solution* of a $(k, \alpha())$-set packing $\mathcal{K} = \{S^*_1, \ldots, S^*_j, \ldots, S^*_k\}$ if and only if $s^i_j \subseteq S^*_j$, for $1 \leq j \leq k$. The next lemma states the correctness of the `Initialization` routine and it follows because we created a node for each selection of k elements from $\mathcal{M}_k$, i.e., $\binom{\mathcal{M}_k}{k}$.

Lemma 10. *If there exists at least one $(k, \alpha())$-set packing of $\mathcal{S}$, at least one of the children of the root will have a partial-solution.*

Proof. By Lemma 9, every set in $\mathcal{K}$ contains at least one element of $val(\mathcal{M})$. It is possible that the same element be in at most k different sets of $\mathcal{K}$. Therefore,

Algorithm 3 `Greedy`($\mathbf{Q^i}$)

Q^gr = ∞
//Check if **Q^i** could not be a partial solution
if there is no pair s_f^i,s_g^i in **Q^i** ($f \neq g$) with $\alpha(s_f^i, s_g^i) = 1$ **then**
  Q^gr = ∅; $j = 0$
  repeat
    Let s_j^i be the jth set of **Q^i**
    if $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha) == \emptyset$ **then**
      Q^gr = ∞
    else
      //Choose arbitrarily a set S from $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$ such that
      //S does not α-conflict with any set in **Q^gr**
      //and S is not already in **Q^gr**
      $f = 0$
      while $f < |\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)|$ **do**
        Let S_f be the f-th set in $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$
        Conflicts = 0
        for each $S' \in \mathbf{Q^{gr}}$ **do**
          if ($\alpha(S_f, S') == 1$) OR ($S_f == S'$) **then**
            Conflicts = Conflicts + 1
          end if
        end for
        if Conflicts==0 **then** $S = S_f$; $f = |\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)| + 1$ **end if**
      end while
      //Add the set S to **Q^gr**
      if such set S does not exist **then**
        $j = k + 1$
      else
        Q^gr = Q^gr $\cup \{S\}$
      end if
      $j = j + 1$
    end if
  until ($j \geq k$) OR (**Q^gr** $== \infty$)
end if
Return **Q^gr**

we replicated k times each element in $val(\mathcal{M})$ collected in $\mathcal{M}_k$. Since we created a node for each selection of k elements from $\mathcal{M}_k$, i.e., $\binom{\mathcal{M}_k}{k}$, the lemma follows. □

The next lemma states that the `BST-`$\alpha()$`-algorithm` correctly stops attempting to propagate a collection $\mathbf{Q^i}$. Due to the (i) property of a well-conditioned $\alpha()$, we can immediately discard a collection $\mathbf{Q^i}$, if it has a pair of sets that α-conflicts.

Algorithm 4 `Compute` $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$

$l = 0$, $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha) = \emptyset$
while $l < |\mathcal{S}(s_j^i)|$ **do**
  Let S_l be the l-th set in $\mathcal{S}(s_j^i)$
  $f = 0$, conflicts= 0
  while $f < |\mathbf{Q^i}|$ **do**
    if $f \neq j$ **then**
      if $\alpha(s_f^i, S_l) == 1$ OR $(s_f^i == S_l)$ **then**
        conflicts = conflicts + 1
      end if
    end if
    $f = f + 1$
  end while
  if conflicts==0 **then** $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha) = \mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha) \cup \{S_l\}$ **end if**
  $l = l + 1$
end while
Return $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$

Algorithm 5 `Branching`(T,node i,$\mathbf{Q^i}$,$\mathbf{Q^{gr}}$)

Let s_j^i be the first set of $\mathbf{Q^i}$ not completed by GREEDY, i.e.,
$j = |\mathbf{Q^{gr}}| + 1$ and $s_j^i = \mathbf{Q^i}[j]$
$I^* = \emptyset$
for each $S \in \mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$ **do**
  for each $S' \in \mathbf{Q^{gr}}$ **do**
    if $\alpha(S, S') == 1$ OR $(S == S')$ **then** $I^* = I^* \cup ((S \backslash s_j^i) \cap S')$ **end if**
  end for
end for
$l = 0$
while $l \leq |I^*|$ **do**
  Let u_l be the lth element of I^*
  $\mathbf{Q^l} = \{s_1^i, s_2^i, \ldots, s_j^i \cup u_l, \ldots, s_k^i\}$
  CREATENODE(T,NODE i,NODE l,$\mathbf{Q^l}$)
  $l = l + 1$
end while

In addition, the collection $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$ contains all sets from $\mathcal{S}(s_j^i)$ that are not α-conflicting with any set in $\mathbf{Q^i}$ (excluding s_j^i). So again, if $\mathbf{Q^i}$ is a partial-solution, due to the (i) property, $\mathcal{S}(s_j^i, \mathbf{Q^i}, \alpha)$ cannot be empty.

The next lemma will help us to show the correctness of Lemma 12.

Lemma 11. *If* $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j, \ldots, s^i_k\}$ *is a partial-solution then* $S^*_j \in \mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ *for each* $1 \leq j \leq k$.

Proof. Assume by contradiction that $\mathbf{Q^i}$ is a partial-solution but $S^*_j \notin \mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ for some j.

If $\mathbf{Q^i}$ is a partial-solution, $s^i_j \subseteq S^*_j \in \mathcal{K}$ and $((\mathbf{Q^i} \backslash s^i_j) \cup \{S^*_j\})$ is a partial-solution as well. The set $S^*_j \in \mathcal{S}(s^i_j)$ and $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha) \subseteq \mathcal{S}(s^i_j)$ (see Algorithm 4 for the computation of $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$). The only way that S^*_j would not be in $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ is if there is at least one set S in $(\mathbf{Q^i} \backslash s^i_j)$ that α-conflicts with S^*_j or if S^*_j is equal to a set in $(\mathbf{Q^i} \backslash s^i_j)$ but then $((\mathbf{Q^i} \backslash s^i_j) \cup \{S^*_j\})$ would not be a partial-solution a contradiction to (i). □

Lemma 12. *Assuming* $\alpha()$ *is well-conditioned,* $\mathbf{Q^i}$ *is not a partial solution either*: *i. if there is a pair of distinct sets in* $\mathbf{Q^i}$ *that* α*-conflicts, or ii. if for some* $s^i_j \in \mathbf{Q^i}$ $\mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha) = \emptyset$.

Proof. (i) Suppose otherwise that $\mathbf{Q^i}$ is a partial-solution, but s^i_j, s^i_l α-conflict. Since $\mathbf{Q^i}$ is a partial-solution, $s^i_j \subseteq S^*_j$ and $s^i_l \subseteq S^*_l$ where S^*_j,$S^*_l \in \mathcal{K}$ and $\mathcal{K}$ is a $(k, \alpha())$-set packing.

The pair S^*_j,S^*_l does not α-conflict, otherwise, $\mathcal{K}$ would not be a solution. However, $\alpha()$ is hereditary, $s^i_j \subseteq S^*_j$, and $s^i_l \subseteq S^*_l$, thus, s^i_j and s^i_l do not α-conflict either.

(ii) The second part of the lemma follows by Lemma 11. □

`Branching` creates at least one child whose collection is a partial-solution, if the collection of the parent is a partial-solution as well. Recall that I^* is computed when `Greedy` stopped its execution at some $j \leq k$, i.e., it could not add a set that contains s^i_j to $\mathbf{Q^{gr}}$. If $\mathbf{Q^i}$ is a partial solution, $s^i_j \subset S^*_j$ and $S^*_j \in \mathcal{K}$. Given property (ii) for a well-conditioned $\alpha()$, S^*_j must be intersecting in at least one element with at least on set in $\mathbf{Q^{gr}}$. Therefore, at least one element of S^*_j will be in I^*.

Lemma 13. *If* $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j, \ldots, s^i_k\}$ *is a partial-solution then there exists at least one* $u_l \in I^*$ *such that* $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j \cup u_l, \ldots, s^i_k\}$ *is a partial-solution.*

Proof. Assume to the contrary that $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j, \ldots, s^i_k\}$ is a partial-solution but that there exists no element $u_l \in I^*$ such that $\mathbf{Q^i} = \{s^i_1, \ldots, s^i_j \cup u_l, \ldots, s^i_k\}$ is a partial-solution. This can only be possible if $(S^*_j \backslash s^i_j) \cap I^* = \emptyset$.

First, given that $\mathbf{Q^i}$ is a partial-solution $S^*_j \in \mathcal{S}(s^i_j, \mathbf{Q^i}, \alpha)$ (Lemma 11).

In addition, either S^*_j is already in $\mathbf{Q^{gr}}$ (i.e, it is equal to some set $S' \in \mathbf{Q^{gr}}$) or S^*_j must be α-conflicting with at least one set $S' \in \mathbf{Q^{gr}}$; otherwise, S^*_j would have been selected by `Greedy`. Any of these situations implies that $|S^*_j \cap S'| \geq 1$ (Definition 1(ii)). By the computation of I^* (Algorithm 5), $S^*_j \cap S' \subseteq I^*$.

Now it remains to show, that at least one element of $S_j^* \cap S'$ is in $S_j^* \backslash s_j^i$. This will guarantee that the set s_j^i will be increased by one element at the next level of the tree. This immediately follows if $S_j^* = S'$.

Thus, we will show it for the case that $S_j^* \neq S'$ but S_j^* α-conflicts with S'. Suppose that $(S_j^* \cap S') \cap (S_j^* \backslash s_j^i) = \emptyset$ by contradiction. Recall that S' contains some set s_h^i of $\mathbf{Q^i}$ (for some $h \leq j$). Furthermore, $S' \in \mathcal{S}(s_h^i, \mathbf{Q^i}, \alpha)$; otherwise S' would not have been selected by `Greedy`.

If S' is α-conflicting with S_j^* but S' is not α-conflicting with s_j^i (otherwise S' would not have been in $\mathcal{S}(s_h^i, \mathbf{Q^i}, \alpha)$), then $(S' \cap (S_j^* \backslash s_j^i)) \neq \emptyset$ by property (ii) in Definition 1. □

Theorem 1. *The* `BST-`$\alpha()$`-algorithm` *finds a* $(k, \alpha())$*-set packing of* $\mathcal{S}$*, if* $\mathcal{S}$ *has at least one and* $\alpha()$ *is well-conditioned.*

4.1.2. *Running time*

The number of children of the root is given by $\binom{|\mathcal{M}_k|}{k} \leq \binom{k(r(k-1))}{k} = O((rk^2)^k)$ and the height of the tree is at most $(r-1)\,k$. The number of children of each node at level h is equivalent to the size of I^* at each level h. The number of elements in $val(\mathbf{Q^{gr}})$ is at most $r(k-1)$, thus, $|I^*| \leq r(k-1)$. Therefore, the size of the tree is given by: $\binom{k(r(k-1))}{k} \prod_{h=1}^{(r-1)k} r(k-1)$ which is $O(r^{rk}k^{(r+1)k})$. Given that the input to the function α is two sets each one of size at most r, and r is considered a constant. Verify α takes constant time.

Theorem 2. *The* r*-Set Packing with* $\alpha()$*-Overlap problem can be solved in* $O(r^{rk}k^{(r+1)k}n^r)$ *time, when* $\alpha()$ *is well-conditioned.*

4.2. *The* Π*-Packing with* $\alpha()$*-Overlap problem*

The Π-Packing with $\alpha()$-Overlap problem generalizes the $\mathcal{H}$-Packing with t-Overlap problem [23] by including other community definitions in addition to prescribed graphs and by allowing more complex overlap restrictions.

We will represent a community through a graph property Π. Intuitively, if a subgraph H of order at most r has the property Π (called a Π-*subgraph*), H is a community. To obtain an FPT algorithm, we require however that Π be verifiable in polynomial time in n where $n = |V(G)|$.

Examples of properties Π that could represent communities are the following. Let S be an induced subgraph of G with at most r vertices. S is a community, if it has a density of at least t ($|E(S)| \geq t$) and the number of edges connecting S to rest of the network is at most a specific value [25]. S is a community, if every vertex in S is adjacent to at least $|V(S)| - c$ vertices in S (for some constant c). Observe that with our property Π, we still can use a family of graphs $\mathcal{H}$ to represent

a community as in the $\mathcal{H}$-Packing with t-Overlap problem. In that case, Π would correspond to the condition that S is a community if S is isomorphic to a graph H in $\mathcal{H}$.

To provide a solution for the Π-Packing with $\alpha()$-Overlap problem, we will basically follow the approach of reducing this problem to the set version, i.e., to the r-Set Packing with $\alpha()$-Overlap problem. To this end, we first compute the collection of all induced Π-subgraphs of G, and we collect them in Π_G. This is done by naively testing all sets of at most r vertices from G. We highlight that we are not asking to compute the largest subgraph of G that follows Π, but rather only verifying whether a specific induced subgraph of at most r vertices satisfies Π or not. In this way, $|\Pi_G| = O(n^r)$.

Next, we construct an instance of r-Set Packing with $\alpha()$-Overlap as follows. The universe $\mathcal{U}$ equals $V(G)$ and there is a set $S = V(H)$ in $\mathcal{S}$ for each $H \in \Pi_G$. Furthermore, we require that $\alpha()$ be well-conditioned.

Lemma 14. *The collection $\mathcal{S}$ has a $(k, \alpha())$-set packing if and only if G has a $(k, \alpha())$-Π-packing.*

Proof. We build a $(k, \alpha())$-set packing $\mathcal{K}_S$ from a (k, α)-Π-packing. For each Π-subgraph H_i in $\mathcal{K}$, we add a set $S_i = V(H_i)$ to $\mathcal{K}_S$. By our construction, $S_i \in \mathcal{S}$. Every pair of sets S_i, S_j in $\mathcal{K}_S$ does not α-conflict. This follows because every pair $H_i, H_j \in \mathcal{K}_S$ does not α-conflict, i.e., and $\alpha(H_i, H_j) = 0$.

Given a $(k, \alpha())$-set packing $\mathcal{K}_S$, we build a (k, α)-Π-packing $\mathcal{K}$ of G. For each set S_i in $\mathcal{K}_S$, we add a Π-subgraph $H_i = G[S_i]$. By our construction, H_i is a Π-subgraph of G. Any pair of Π-subgraphs in $\mathcal{K}$ does not α-conflict; otherwise, there would be a pair of sets in $\mathcal{K}_S$ α-conflicting. □

Given that Π and $\alpha()$ are verifiable in $O(n^c)$ time for some constant c, we can hence state:

Theorem 3. *Π-Packing with $\alpha()$-Overlap can be solved in $O(r^{rk} k^{(r+1)k} n^{cr})$ time, when $\alpha()$ is well-conditioned and Π is polynomial time verifiable.*

5. Predetermined Cluster Heads

The problem of discovering communities in networks has been tackled with clustering algorithms as well [27]. Many of these algorithms consider as part of the input a collection of sets of vertices $\mathcal{C} = \{C_1, \ldots, C_l\}$ where each set $C_i \subset V(G)$ is called a *cluster head*. The objective is to find a set of communities in G where each community contains exactly one cluster head. In addition, communities should not share members of the cluster heads [5, 8, 21, 31, 35].

Motivated by this, we introduce the PCH-r-Set Packing with $\alpha()$-Overlap problem, where PCH stands for Predetermined Clusters Heads. The input of this problem is as before a universe $\mathcal{U}$, a collection $\mathcal{S}$, an integer k, but now it also has

a collection of sets $\mathcal{C} = \{C_1, \ldots, C_l\}$ where $C_i \subset \mathcal{U}$. The goal there is to find a $(k, \alpha())$-set packing (PCH), i.e., a set of at least k sets $\mathcal{K} = \{S_1, \ldots, S_k\}$ subject to the following conditions: each S_i contains at least one set of $\mathcal{C}$; for any pair S_i, S_j with $i \neq j$, $(S_i \cap S_j) \cap val(\mathcal{C}) = \emptyset$, and the pair S_i, S_j does not α-conflict. Recall that a Π-subgraph (or a community) is represented by a set in $\mathcal{S}$ (Sec. 4.2). Thus, this problem translates into a PCH variation for our Π-Packing problem as well.

To solve the r-Set Packing with α-Overlap problem (PCH), we need to do two modifications to the `BST-algorithm` described in Sec. 4.

First, we redefine the routine that creates the children of the root of the search tree, and we call it `Initialization (PCH)` (Algorithm 6). By Lemma 9, a maximal solution $\mathcal{M}$ is used to determine the children of the root. In the (PCH)-variation, we no longer compute $\mathcal{M}$ but rather we use $\mathcal{C}$ to compute those children. That is, the root will have a child i for each possible combination of $\binom{\mathcal{C}}{k}$. Recall that a node i has a collection $\mathbf{Q^i} = \{s_1^i, \ldots, s_k^i\}$. Each set of $\mathbf{Q^i}$ is initialized with set of that combination.

Lemma 15. *If there exists at least one $(k, \alpha())$-set packing (PCH) of $\mathcal{S}$, at least one of the children of the root will have a partial-solution.*

Proof. It follows by the explicit condition that each set in a $(k, \alpha())$-set packing (PCH) should contain at least one set from $\mathcal{C}$ and because the routine `Initialization (PCH)` tries all possible selections of size k from $\mathcal{C}$ to create the children of the root. □

Second, we redefine the α function of the `BST-algorithm` as α-PCH. This new function returns 1 or α-*conflict* if $((s_i \cap s_j) \cap val(\mathcal{C})) \neq \emptyset$; otherwise executes the original $\alpha()$ function and returns $\alpha(s_i, s_j)$.

Lemma 16. *If the function $\alpha()$ is well-conditioned, the function α-PCH is also well-conditioned.*

Proof. (i) α-PCH is hereditary. Assume that $\alpha\text{-PCH}(s_i, s_j) = 0$, and there is a pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with $\alpha\text{-PCH}(s'_i, s'_j) = 1$. Since α is

Algorithm 6 `Initialization (PCH)`$(\mathcal{C})$

1: $i = 0$, $T = null$
2: **while** $i < |\binom{\mathcal{C}}{k}|$ **do**
3: Let $\{C_1^i, \ldots, C_k^i\}$ be the ith combination of $\binom{\mathcal{C}}{k}$
4: Make $\mathbf{Q^i} = \{s_1^i, \ldots, s_k^i\}$ equal to $\{C_1^i, \ldots, C_k^i\}$, i.e, $s_j^i = C_j^i$
5: `CreateNode(`T`,root,node` i`,`$\mathbf{Q^i}$`)`
6: $i = i + 1$
7: **end while**
8: Return T

well-conditioned, this is only possible if $((s'_i \cap s'_j) \cap val(\mathcal{C})) \neq \emptyset$. However, $(s'_i \cap s'_j) \subseteq (s_i \cap s_j)$ and by our assumption $((s_i \cap s_j) \cap val(\mathcal{C})) = \emptyset$, a contradiction.

(ii) If α-PCH$(s_i, s_j) = 1$, $|s_i \cap s_j| \geq 1$. Suppose by contradiction that $|s_i \cap s_j| = 0$ and α-PCH$(s_i, s_j) = 1$. Since α is well-conditioned, this is only possible if the extra condition in α-PCH returns *α-conflict* when $\{s_i \cap s_j\} = \emptyset$. However, in that case $(s_i \cap s_j) \cap val(\mathcal{C}) = \emptyset$, and α-PCH$(s_i, s_j) = 0$ instead. It remains to show that for any pair of subsets $s'_i \subseteq s_i$ and $s'_j \subseteq s_j$ with α-PCH$(s'_i, s'_j) = 0$, $(s_i \cap s_j) \backslash (s'_i \cap s'_j) \neq \emptyset$. Assume by contradiction that $(s_i \cap s_j) \backslash (s'_i \cap s'_j) = \emptyset$. In that case, $s'_i = s_i$ and $s'_j = s_j$. Therefore, $(s'_i \cap s'_j) \cap val(\mathcal{C}) = \emptyset$ and α-PCH$(s_i, s_j) = 0$.

(iii) Follows because α is well-conditioned, and it takes $O(r \log n)$ time to verify the extra condition in α-PCH. □

The above two modifications guarantee that the `BST Algorithm` will find a $(k, \alpha())$-Set Packing (PCH) if $\mathcal{S}$ has at least one. Given that each set in $\mathcal{S}$ has size at most r, we can immediately discard any set in $\mathcal{C}$ of size more than r. In this way, each set in $\mathcal{C}$ is be upper-bounded by a constant c, $1 \leq c \leq r - 1$. To maintain our running time, the size of $\mathcal{C}$ should be $O(g(k))$, where g is a computable function dependent only on k and possibly r but independent of n. Hence, we can state:

Theorem 4. *If $\alpha()$ is well-conditioned, the PCH-r-Set Packing with $\alpha()$-Overlap problem is solved in $O((g(k))^k (rk)^{(r-1)k} n^r)$ time, where $|\mathcal{C}| = g(k)$.*

We could also omit the condition that clusters cannot share members of the cluster heads as in [10]. In that case, we do not need to redefine the function $\alpha()$.

6. Conclusion

We have proposed a more general framework for the problem of finding overlapping communities where the pairwise overlap meets a constraint function $\alpha()$. This framework captures much more realistic settings of the community discovering problem and can lead to interesting questions on its own. We have also shown that our problems are fixed-parameter tractable when the overlap constraint $\alpha()$ is subject to a set of rather general conditions (Definition 1). In addition, we have given several $\alpha()$ functions that meet those conditions. Finally, we have shown that a natural variant of our problems that arises in clustering applications remains fixed-parameter tractable when subject to specific conditions.

There are several interesting paths remaining to explore. The computational complexity of our framework remains open. It would be interesting to define properties of the $\alpha()$ function for which the problem could be solvable in polynomial time. Also, it would be relevant to provide a fixed-parameter algorithm for our problems for functions other than those as in Definition 1. For example, when the overlap is bounded by a percentage of the sizes of the communities or when the overlap size has a lower-bound instead of an upper-bound. In addition, a natural step

would be to obtain kernelization algorithms for our problems. Finally, it remains to explore different parameterizations for this problem. For example, considering r as a parameter (together with k) instead of r as a fixed-constant.

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Agile Dimensional Model for a Data Warehouse Implementation in a Software Developer Company

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Abstract. Nowadays, the increasing development of Business Intelligence (BI) solutions in organizations, has enabled executives achieve a better understanding of business information for timely and rapid decision-making in a tremendously dynamic market. Although there is an increasing interest in adopting an agile approach to the software development, the emergent need of using agile methodologies in BI solutions is undeniable. This paper discusses the importance of using agile methods in the design and development of data warehouses taking into account the business processes, requirements analysis, and organizational objectives. Thus, we present a case study derived from a real-world business project where the agile methodology Business Event Analysis and Modeling (BEAM) is used to design the data warehouse. The project is based on a billing system with about one million operations on a daily basis with more than 15,000 clients. Finally, the results of this paper include the design of the dimensional model using an agile approach, the construction of the data warehouse through the ETL processes and an interactive dashboard according to the key performance indicators defined by the business decision-makers.

Keywords: business intelligence, agile dimensional model, data warehouse.

1 Introduction

In the business world we aim to obtain greater profits and a greater competitive advantage, *hence*, appropriate timely decision-making plays a very important role in the fulfillment of the organizational objectives. Thus, the use of Business Intelligence (BI) systems can help meet these needs as it provides a set of methodologies, applications, and practices focused on the information management for accurate, timely decisions making in an organization.

A major component of any BI model is the design and implementation of a data warehouse in organizations, since it provides valuable and strategic information to support decision-making through real-time access to business transactions and advanced business analytics [1]. According to Inmon [2] and Imhoff [3], a data warehouse in organizations is an integrated data collection, non-volatile and variable over time. Hence, it has a complete history of the organization, beyond the transactional and operational information favoring the data analysis for decision-making.

Today, the two most widely used methodologies for the design and implementation of data warehouses are the model of Inmon [2] and Kimball [4]. They consider the data warehouse as the central repository of data for organizations that is used to present business reports. The difference between these two methodologies lies in how to make deliveries of progress (time) and how to manage changes during the process (see Table 1).

Recent studies tend to show that use of agile methodologies for the design and implementation of data warehouse in organizations is playing an important role to obtain value information to help decision-makers and to generate competitive advantage by improving the extraction and processing knowledge. These studies present a structured methodology, inspired from the agile development models as Scrum, XP and AP [5]. Thus, an increasing number of companies are choosing for an agile philosophy in software development due to the constant need to be flexible and adaptable to the technological changes and the new user demands [6-10].

For this reason, it is important to consider agile methods for the design and implementation of a data warehouse in a BI system (see Table 1). In this regard, it has been shown that agile development processes increase the potential for developing the success of a data warehouse by solving many of the typical problems presented in traditional methodologies [11, 8, 12].

In this paper, we use the BEAM methodology in the design, modeling, and implementation of a data warehouse for a management system. This system processes one million operations on a daily basis from more than 15,000 clients. The agile design and modeling of the data warehouse are presented through a case study of a Software Development Company located in Mexico, which offers software solutions focused on meeting the needs of development, implementation and support to any business sector.

2 Agile Dimensional Modeling

Traditional data warehousing projects follow the waterfall structure to perform dimensional modeling [13]. However, its use is increasingly unlikely and alternatives of analyzing and designing similar to those used in software development projects such as agile methods are looked for [7, 12, 14]. In this respect, the agile dimensional modeling is being considered as a solution for BI systems since it allows developers to reduce the risks that the waterfall structure could produce [11, 14]. All this is possible by adopting a highly interactive, incremental and collaborative approach to the whole analysis, design and development activities of a data warehouse, such as the agile BEAM methodology [14] (see Figure 1).

Table 1. Comparison of the Inmon, Kimball, and Corr methodologies.

	Inmonn [2] (Traditonal)	**Kimball [4] (Traditonal)**	**Corr [14] (Agile)**
Business Decisions	Strategic	Tactical	Collaborative
Scope	Product owner	Project manager	Team
Approach	Top – down	Bottom – up	Bottom – up
Objective	Deliver a robust technical solution based on proven methods	Provide a solution that facilitates the end users to consult the data	Responding to change and user needs
Data requirements	Enterprise-wide	Business process	Individual business requirement (KPIs)
Data modeling	Normalized form (3NF)	Dimension model (Star or Snowflake)	Dimension model (Star or Snowflake)
Orientation	Enterprise-wide	Business process	People
Communication	Formal	Formal/Informal	Informal
Time	Longer start-up time	Shorter start-up time	Minimal start-up time
Project schedule risk	High	High	Low
Ability to respond to change	Low	Medium	High
End users involvement	Minimal	Oscillate depending on the project	High
Cost to build	High initial cost	Low initial cost	Minimal initial cost

2.1 BEAM Methodology

Corr [14] proposes the BEAM (Business Event Analysis and Modeling) methodology, an agile data modeling method for the design and development of data warehouses and data marts. This method combines analysis and modeling techniques to meet data requirements related to business events and data modeling for database design that is easy to understand by stakeholders and also, easy to translate into logical/physical models for IT developers. The BEAM methodology involves stakeholders who think beyond their current reporting requirements by describing data stories, that is, narratives that define the dimensional details of business activities necessary to be measured. In order to obtain these data stories, data modelers ask questions to stakeholders using a framework based on the 7Ws (who, what, where, when, how many, why and how) [14]. The way to find these answers of the 7Ws and make sure they inform data warehouse design is to ask end-users about the events that are happening in their business. Therefore, the enhanced Start Schema is used to generate and show schema of physical data bases, where are they involved Data Modelers, DBAs, DBMS, ETL Developers, BI Developers and Testers. This framework is one of the main activities of the BEAM methodology because it allows discovering and modeling data requirements and thus, to construct the table of dimensions and facts of the data warehouse depicted through the star model.

According to Corr [14], the BEAM methodology has several diagrams for the analysis and design of the data warehouse model, such as: BEAM Table, Hierarchy Chart, Timeline, Event Matrix and Enhanced Star Schema.

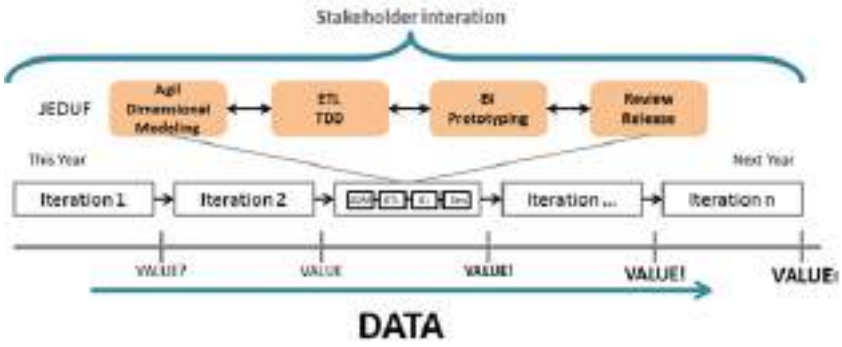

Fig. 1. Agile data warehouse development timeline. Source [14].

For instance, the BEAM Table is used to model business events and dimensions at the same time; people involved in this diagram are data modelers, business analysts, stakeholders and BI users. The Enhanced Star Schema is used to visualize the dimensional model for the implementation of the physical database schemas; the people involved in this diagram are Data Modelers, DBAs, DBMS, ETL Developers, BI Developers and Testers.

3 Agile Data Warehouse: A Case Study of a Billing System

This case study focuses on the design and implementation of a data warehouse using the BEAM methodology for a billing system of a company based in Mexico with operations in software development with around 15,000 active clients in 19 countries and more than a million operations on a daily basis. Despite all the information daily stored on the company's servers, this information is not used or analyzed so far by the working team, identifying an area of opportunity for the design and implementation of BI systems. Therefore, decision-makers could offer their customers significant knowledge through scorecards and thereby provide a competitive advantage. The management system access to a database based on the Entity-Relationship Model (ER) allowing to record, update, delete, and query information from the main business processes. This system has the following modules such as: billing, inventories, clients, payroll, branches, among others. Hence, in this case study, we focus on the billing module. The database used by the system contains around 70 tables using only the most relevant according to the key performance indicators (KPI).

3.1 Analysis, Design and Implementation of the Data Warehouse

Unlike the development of software applications, where the requirements of the organizations are often relatively well defined by the result of the stability of business rules over time; create a data warehouse depends on the reality of the company and its current conditions.

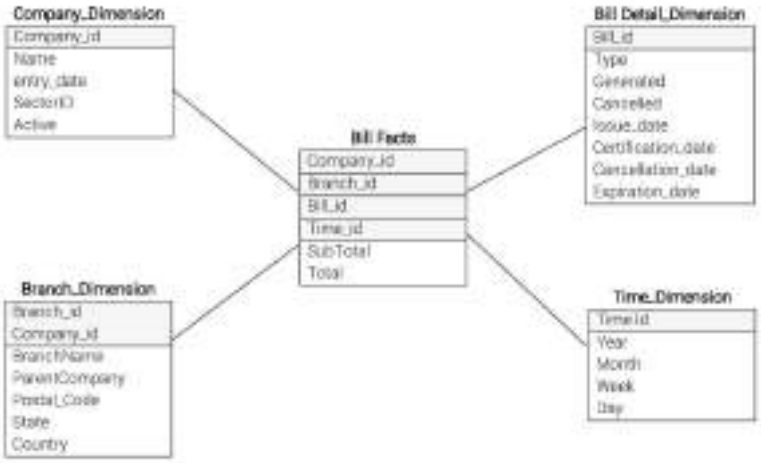

Fig. 2. Star schema for the proposed data warehouse.

Thus, the company requires identifying useful information in order to obtain significant information about its clients. In this way, the following key performance indicators (KPIs) were identified along with the business owners for the design and implementation of the data warehouse: a) Compare monthly growth of registered companies; b) Identify customer loyalty, through the use of the system more than 3 years; c) Identify quantity and list of branches by parent enterprise; d) Visualize the States where there are more than four companies using the management system; e) Measure different types of invoices volumes identifying the invoices variations not only by a time period but also, for company; f) Geographically view the top 10 companies that make the most invoices for a period of time; g) Compare the invoices by branch, time and state.

In order to model the data requirements, the 7Ws framework was used resulting in the identification of facts and dimensions in the star model, presented in Figure 2.

In this regard, the proposed dimensional model contains a fact table where the measurements or metrics of a specific event are recorded; for example, the invoice for a purchase and foreign keys referencing dimensional data tables (Company, Branch, Bill Detail and Time) which contain descriptive information. In order to implement the proposed model (see Figure 2), it is necessary to perform the ETL (Extraction, Transformation, Load) process which enables moving data from multiple sources, transform and load them into the data warehouse to analyze and thereby giving valuable information to organizations. In this way, Microsoft SQL Server Integration Services (SSIS) of Visual Studio 2015 was used to perform the ETL process. Finally, the information contained in the data warehouse was visualized through a scorecard developed using the Microsoft PowerBI tool. Thus, the KPIs were analyzed in order to identify the visual elements corresponding to each key indicator.

Once the visual elements are selected, the information about the clients is then shown in the scorecard by using queries in which decision-makers could use it interactively.

Fig. 3. Scorecard interface: Geographic coverage view of the system.

On the other hand, the software company's CEO was interested in seeing through graphs and trend lines, the situation and invoice generation behavior of those companies who use the management system.

In this way, it could be easily visualized when billing peaks are produced, i.e. sales generated by companies using the system. Figure 3 presents the view of the BI system that shows by state the number of companies who use the system, the bigger the circle the more companies that use the system are in the corresponding state. In this way, it is easy to identify the states where there is little or no presence of the system helping the decision-maker to pay attention in sale strategies. Likewise, Figure 4 presents the view related to invoice analysis where the number of invoices per type is visualized through an interactive list, a trend line to observe the behavior of the number of invoices is generated by each company who use the system and a pie chart showing the top 10 companies with the highest number of invoices issued by the system is shown.

In this way, it is possible to graphically observe the behavior of the number of invoices in a period of time by interacting with the system, allowing the decision-makers not only to know in what years more invoices per company are registered but also, detect those decreases that may indicate a risk in the strategic plan in order to develop an action plan.

3.2 Discussion of Results

The design and implementation of the proposed BI system using BEAM methodology allowed the analysis and design of the data warehouse through an agile method that focused on the users' needs and that easily respond to changes. Therefore, meetings with the working team, i.e., stakeholders, BI users, ETL developers, business analysts, among others, were held in order to compile information requirements during all stages of the project emphasizing uninterrupted communication and collaborative work.

Fig. 4. Number of invoices by time period.

On this basis, it ensures a greater understanding of the data warehouse information and the functionalities of the BI system. Moreover, the agile method maintains a logical data structure, scalable and adaptable to future functionalities such as the integration of other system's modules, predictive analysis, among others.

In this way, a robust and scalable BI system was designed and implemented where decision-makers can count on reliable, fast, flexible and easy-to-understand analyses through the scorecard, thereby facilitating the diagnosis of indicators and decision making. Accordingly, Figure 4 shows a scorecard of the invoices section, thus, the use of the scorecard provides reports of different participants in the decision-making process, representing an opportunity for homogenize and refine business processes. For this reason, it is expected to improve business opportunities through the use of key performance indicators by the extraction, processing and presentation of significant information according to the business strategic objectives. Eventually, the use of the BI system will positively impact the improvement of the company's value chain processes, its competitiveness and thus, the profitability of the business.

4 Conclusions and Future Work

Today, entrepreneurs need to analyze and interact with real-time visual information in order to support decision-making. In this regard, the methodologies used in the design of BI systems should consider the current needs and challenges where business requirements are not static and change constantly. Hence, this paper proposed the use of an agile dimensional model for the design and implementation of a data warehouse based on the BEAM methodology applied to a case study for a Software Development Company. In order to complete the project successfully, the organizational requirements were defined, the star schema was modeled, the ETL process was

executed, the data warehouse was implemented and finally, the KPIs were graphically displayed into the scorecard for decision-making.

The results obtained from the use of an agile methodology are found as a model easy- to-understand for the stakeholders; for this reason, it is mandatory to involve them in the whole process.

By adopting this agile approach, flexibility is ensure, as well as, personal coordination with the stakeholders, consistency and simplicity in the whole process.

As a future work, we plan to incorporate a predictive analysis section into the BI system allowing decision-makers to discover patterns, opportunities and prevent risks by increasing the profitability of the business.

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HERRAMIENTA DE VISUALIZACIÓN PARA LA TOMA DE DECISIONES EN EL PROCESO DE SELECCIÓN DE CANDIDATOS DE POSGRADOS DE CALIDAD: RESULTADOS PRELIMINARES

Lic. Anabel Encinas Balderrama[1], Dr. Guillermo Mario Arturo Salazar Lugo[2], Dr. Luis Felipe Rodríguez Torres[3], Ing. Beyda Mariana Trejo Román[4]

***Resumen*—Este proyecto tiene como finalidad dotar de una herramienta de inteligencia de negocios para visualización de datos (Dashboard), a los comités encargados del reclutamiento de estudiantes con perfil para ingresar a posgrados del Programa Nacional de Posgrados de Calidad. Se desarrolló un prototipo en la Maestría en Tecnologías de la Información para los Negocios, en el Instituto Tecnológico de Sonora, siguiendo las fases de Aplicación de la Metodología del Ciclo de Vida Dimensional del Negocio de Kimball. Con la herramienta se logró generar y visualizar información valiosa de los aspirantes a partir de datos recolectados mediante un sistema transaccional y la ponderación de los elementos del proceso de admisión en sus distintas fases de evaluación. Con pruebas de validación de datos mediante consultas "ad hoc" se contrastó la información, comprobando el adecuado funcionamiento del prototipo.**

***Palabras clave*—Inteligencia de negocios, herramienta de visualización, posgrados de calidad, selección de aspirantes, metodología Kimball.**

Introducción

Cada vez con más fuerza la información se ha convertido en uno de los recursos más apreciados en todos los ámbitos, y el campo de la gestión educativa no es la excepción. Los sistemas de información generan y almacenan una gran cantidad de datos que generalmente pasan desapercibidos. Algunos de estos datos como menciona Cano, J. (2007) tienen el potencial de convertirse en información y conocimiento útil para los tomadores de decisiones. Es decir, aplicando una serie de técnicas, operaciones y transformaciones en los datos, es posible obtener como resultado un nuevo conjunto de datos con características que permitirán dar soporte a la toma de decisiones.

En ese sentido, el ámbito de la educación y enfocado a posgrados de calidad, requiere de mayor atención de los datos que son almacenados desde que inicia el proceso de selección de aspirantes, ya que a través de pruebas y recolección de información se puede ir perfilando y clasificando a los estudiantes. Como Díaz, J. C. (2012) dice sobre tomar la tecnología para el apoyo a la toma de decisiones en una institución educativa es totalmente justificable, especialmente por lo complejo que sus procesos pueden llegar a ser y el paso de generaciones de estudiantes concibiendo enormes cantidades de datos, haría la implementación de un sistema de BI una herramienta indispensable.

Para las IES que cuentan con posgrados que particularmente se encuentran registrados en el Programa Nacional de Posgrados de Calidad (PNPC) del Consejo Nacional de Ciencia y Tecnología (CONACYT), la manutención del nivel del perfil de estudiantes que requiere, hace resaltar la calidad de estudiantes que se buscan para cursar y terminar en tiempo y bajo ciertas condiciones el posgrado. Algunos estudios (ANUIES, 2000; Sánchez, 2008; UNESCO, 2009; Yurén, 1999) describen en una visión general el perfil de un aspirante de posgrado, este se basa en las competencias científicas necesarias para producir y transferir conocimiento y tecnología, debe apropiarse de discursos científicos, generar conocimientos y contar con las habilidades para transferir toda esta investigación a la sociedad.

Actualmente no se tiene una metodología establecida o pasos concretos para el desarrollo del proceso de admisión en las IES con posgrados pertenecientes al PNCP (CONACYT, 2013), y la Maestría en Tecnologías de la Información para los Negocios (MTIN) en Instituto Tecnológico de Sonora (ITSON) requiere tener información

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oportuna de sus aspirantes para realizar una selección que asegure se adecue más al perfil de calidad que se le exige. Se necesita de un sistema de información que admita formular y responder determinadas consultas y tomar mejores decisiones, que permita visualizar información ad hoc de acuerdo a los indicadores de rendimiento (KPIs), extrayendo la información de la base de datos del posgrado. Sin que se tenga que invertir tiempo extra en la extracción y análisis de datos, la herramienta de visualización de datos podrá ser consultada y detectar problemas, patrones de comportamiento, tendencias, evitando incumplimientos académicos y deserciones futuras en cualquier aspecto a lo largo del posgrado, que pudiera perjudicar el status de calidad que dicta el PNPC (Sevilla, D., Martín, M. y Guillermo, M., 2009).

Este trabajo se centra en el desarrollo de una herramienta de visualización de datos (Dashboard), y forma parte de un proyecto para la integración de inteligencia de negocios en los procesos educativos. Se desarrolló un prototipo en un posgrado de calidad, donde se estableció un sistema de automatización del proceso de admisión, del cual se diseñó e implementó un Data Warehouse que puede ser consultado por el usuario final a través de la visualización de dos pantallas, siguiendo la línea de Aplicación de la metodología de Kimball y las pautas de diseño de Stephen Few, con el propósito de servir de apoyo a la toma de decisiones en la selección de aspirantes.

Metodología

Para la implementación de la herramienta de visualización de datos la metodología que se utilizó fue la denominada Ciclo de Vida Dimensional del Negocio de Kimball, llegando sólo a la fase de implementación como alcance de este proyecto, se dejaron fuera las fases de crecimiento y mantenimiento. Dicha metodología según Kimball, R., Reeves, L., Ross, M., y Thornthwaite, W. (1998) permite flexibilidad a ir integrando los requerimientos del cliente e inmediatez en la respuesta de resultados, y trabajar en forma iterativa e incremental.

Por ser un proyecto integrador y que conlleva continuidad de otro desarrollado bajo la misma metodología en donde se diseñó un Data Warehouse, se retomará la línea de Aplicación de la metodología en donde se encuentran las fases: Especificación de aplicaciones de BI y Desarrollo de la aplicación BI, que son las que se centran en las visualizaciones y reportes. Dichas fases y otras que apoyan a la línea de Aplicación son las fases que se tomarán para este proyecto las cuales se iluminan en la Figura 1.

Fig. 1. Línea de Aplicación de la Metodología de Kimball para el proyecto.

Desarrollo

Para comenzar el proyecto y comprender mejor la situación de un posgrado de calidad como la MTIN en ITSON, se realizó un análisis e investigación de su entorno, en donde se identificó a parte de sus necesidades y requerimientos, elementos claves de predicción para estudiantes con perfil adecuado para este tipo de posgrados. Siendo así que las fases de la metodología se llevaron a cabo de la siguiente manera.

Planificación del proyecto.

A partir de reuniones se especifica el propósito del proyecto, los objetivos y el alcance, y a grandes rasgos las etapas del proyecto para dar una aproximación de las necesidades de información que se tendría. Como parte importante del proyecto se determinó el alcance, estableciendo que culminaría con la fase de implementación. Además, se establecieron los criterios y recursos necesarios para el desarrollo de la herramienta de visualización, como una base de datos que integre las diversas fuentes de información, la cual se generó en MySQL, un Data Warehouse con las dimensiones necesarias para mostrar los KPIs requeridos, el cual fue desarrollado en Pentaho Data Integration.

Definición de los requerimientos del negocio.

Este proyecto tuvo como objetivo general "Implementar una herramienta de visualización de datos para el apoyo a la toma de decisiones en el proceso de admisión de un posgrado de calidad".

En esta fase se comenzó con el modelado del proceso de Admisión de la MTIN y se identificaron puntos claves a tomar en consideración para la elaboración de KPIs y así resolver las necesidades de información más críticas. Algunos de los requerimientos que se obtuvieron son:

• Mostrar en el Dashboard la información del proceso de admisión 2018 y de generaciones anteriores, según el periodo.

• Desplegar resultados de indicadores claves para el coordinador del posgrado y núcleo académico.

• Visualizar y analizar la información de tal forma que sea adecuada para la selección de aspirantes según sus resultados.

• Desplegar reportes de los datos contenidos en el Data Warehouse que también apoyarían la decisión final de la selección de candidatos.

• Generar tableros y uso de gráficas para una mayor comprensión de la información.

Los KPIs de mayor peso para el proceso de admisión de la MTIN, se denominan "Criterios para la selección", los cuales no sufrieron cambios en cuanto a ponderación para el prototipo: Resultados de EXANI III, Resultados de Examen de Conocimiento y Resultados de Entrevista.

Aunado a esto se integra un segundo nivel de indicadores, los cuales no se ponderan, pero son parte importante para la toma de decisión final: Promedio de licenciatura o grado anterior, Documentación requerida e Información personal de interés del aspirante.

El orden de visualización de los KPIs corresponde al nivel de importancia identificado y según ponderación asignada para la selección. En la mayoría de los KPIs los datos se visualizan a un nivel mayor de detalle, dependiendo de la necesidad.

Especificación de aplicaciones de BI.

Como anteriormente se identificó como requerimiento, la facilidad para la selección del aspirante debe de ser una prioridad para visualizar en el Dashboard, con lo cual se buscaron opciones dentro del diseño para jerarquizar la información de acuerdo fuera de importancia para el usuario. Así mismo, se tomaron en cuenta pautas para el diseño y visualización correcta de la información, en selección de tipo de gráficas y tablas (Few, S., 2012). Además se consultaron y analizaron herramientas que presentan información desde un Data Warehouse.

Desarrollo de la aplicación BI.

La herramienta seleccionada para el desarrollo del Dashboard fue la de Microsoft Power BI, pues da mayor facilidad en el aspecto de cómo se va desarrollando, se puede ir implementando y verificando resultados rápidos en cuanto consultas y uso de las gráficas, La información se actualiza en tiempo real y está disponible en cualquier dispositivo móvil, además que tanto el equipo como el usuario estaban familiarizados con dicha herramienta.

Se desarrollaron dos diferentes pantallas para cubrir los requerimientos, la visualización y consulta adecuada de los KPIs, La primera pantalla se desarrolló bajo el esquema de apoyo a la decisión en la selección del aspirante, fue ahí que se tomaron en cuenta los KPIs de mayor peso críticos en la formulación de la ponderación del aspirante (Figura 2).

Fig. 2. Vista de la pantalla 1.

T1.A. La distribución en la primera pantalla se da de acuerdo a jerarquización de los elementos, en primer lugar se muestra la selección del "Período" de los diferentes procesos de admisión.

T1.B. Enseguida y como elemento principal el "Ranking de aspirantes" o "Primeros seleccionados" el cual es una gráfica inamovible, da un espectro de los 15 mejores en promedio de ponderaciones, y están ordenados de mayor a menor.

T1.C. Enseguida se muestra la gráfica de "Promedios por áreas" que puede ser ordenada para conocer a detalle las calificaciones de Exani III, Examen de Conocimientos y Entrevista, esta da referencia de dónde se obtuvo el promedio final.

T1.D. En la posición inferior se encuentra la tabla de "Documentos" requeridos para el ingreso al posgrado, donde se identifica qué elementos han sido cargados o no en el sistema por parte del aspirante.

T1.E. En la tabla de "Datos académicos" está contenida información de la institución de correspondencia, el tipo de titulación y el promedio del último grado.

T1.F. También gráficamente se ve la cantidad de aspirantes por género.

La segunda pantalla se desarrolló bajo el esquema de "Comparación directa" (Figura 3) entre dos aspirantes, con el fin de apoyar a detalle en la decisión. La pantalla se distribuye de la siguiente manera según gráficas:

Fig. 3. Vista de la pantalla 2.

T2.A. Selección de "Período" en el que se encuentran.

T2.B. Selección individual de "Aspirante (1) y (2)". Automáticamente al elegir un aspirante las gráficas inferiores muestran la información almacenada de este y es así cómo se puede hacer la comparación de los resultados de ambos.

T2.C. Como primer segmento y en etiquetas se muestra el "Estado civil", el número de "Dependientes" económicos, y el "Promedio de Universidad".

T2.D. Se visualiza a detalle por categoría la calificación de cada una de las áreas de la entrevista.

T2.E. Se muestra en velocímetro el promedio de Exani III, dividiendo en colores rojos resultados de 700 a 900 puntos, amarillo de 900 a 1100 y en verde de 1100 a 1300, mostrando la media de estas secciones en el gráfico y el promedio del aspirante. En esa misma sección se divide por "Áreas de Exani III" por si una fuera de mayor interés para la elección del candidato a posgrado.

Implementación.

Una vez que se presentó el diseño final al usuario y este haya corroborado que la información que muestra el Dashboard es correcta se procede con la implementación. La validación en este caso se hizo elaborando un archivo de Excel para hacer consultas "ad hoc" con el método de Pruebas de validación de datos (Toledo, F., y Saráchaga, D., 2017), contrastando los resultados que se obtuvieron de la información en el sistema transaccional contra los resultados obtenidos por el Dashboard.

El usuario aprobó y validó los resultados, con lo que se pudo publicar el Dashboard desde la herramienta Microsoft Power BI, haciendo que automáticamente todo el proyecto que se desarrolló pudiera ser consultado desde distintos dispositivos conectados a internet.

Gestión de proyectos.

Esta fase se llevó a cabo desde inicio hasta final del proyecto, con reuniones periódicas donde se acordaban entregables y revisaban avances junto con el equipo de trabajo y manteniendo cercano y enterado del avance al usuario final, el cual verificaba el trabajo y retroalimentaba sin perder de vista el objetivo final y requerimientos iniciales.

Conclusiones

Dado que los programas de postgrado inscritos en el PNPC no cuentan con una metodología establecida para llevar a cabo el proceso de admisión, es de vital importancia contar con una herramienta que visualice en general el proceso actual que utiliza cada universidad, ya que sería útil para la gestión y toma de decisiones cuidar a detalle el perfil de estudiante para el PNPC y los criterios que según la literatura predicen el rendimiento de un buen estudiante.

Este proyecto partió de los datos generados por un sistema transaccional que permite recopilar y almacenar la información y documentos del aspirante. Posteriormente con base en la metodología de Kimball se diseñó un Data

Warehouse que permite la extracción y procesamiento de la información relevante del proceso. Para finalmente obtener una herramienta de visualización de datos en conexión con el Data Warehouse desarrollado en Pentaho, visualizando los KPIs distribuidos en dos pantallas diseñadas en la herramienta de Microsoft Power BI. Estableciendo y alimentando la base de datos con información de períodos anteriores, se pudo investigar y seleccionar gráficas adecuadas según la información, además programando la opción de actualización automática se dejó listo el Dashboard para visualizar en tiempo real el proceso de admisión del período 2018, resultando satisfactoria la funcionalidad técnica de la herramienta, validadas bajo consultas "ad hoc".

Ambas pantallas presentadas y validadas muestran de forma gráfica los KPIs de mayor importancia para el apoyo de la toma de decisiones en la selección del aspirante del posgrado de calidad en el que se desarrolló el proyecto, habilitando la visualización de un panorama general de los resultados que afectan directamente en la decisión, con esto se espera reducir tiempos por la eliminación de tareas (actualmente en medición), y evitar dejar fuera información relevante del aspirante que quiera ingresar al posgrado.

Recomendaciones

Es recomendable para el posgrado de la MTIN en ITSON replantear los criterios y la ponderación que se maneja actualmente. Incorporando el perfilado de estudiantes con base a datos históricos de selección y desempeño, identificando y dotando al estudiante con adquisición de competencias genéricas propias del programa, como pudiera ser: el análisis de los hábitos de estudio, la experiencia en investigación y los meses de pasante que ya se han identificado como significativos del rendimiento académico por Martín Pavón, M. J., Sevilla Santo, D. E., y Beltrán Poot, A. D. (2017).

Se prevé bajo esta premisa continuar en reuniones con el núcleo académico con el fin de afinar el proceso y mejorar el Dashboard mediante nuevos KPIs, de tal forma que se convierta en una herramienta indispensable para la selección de aspirantes.

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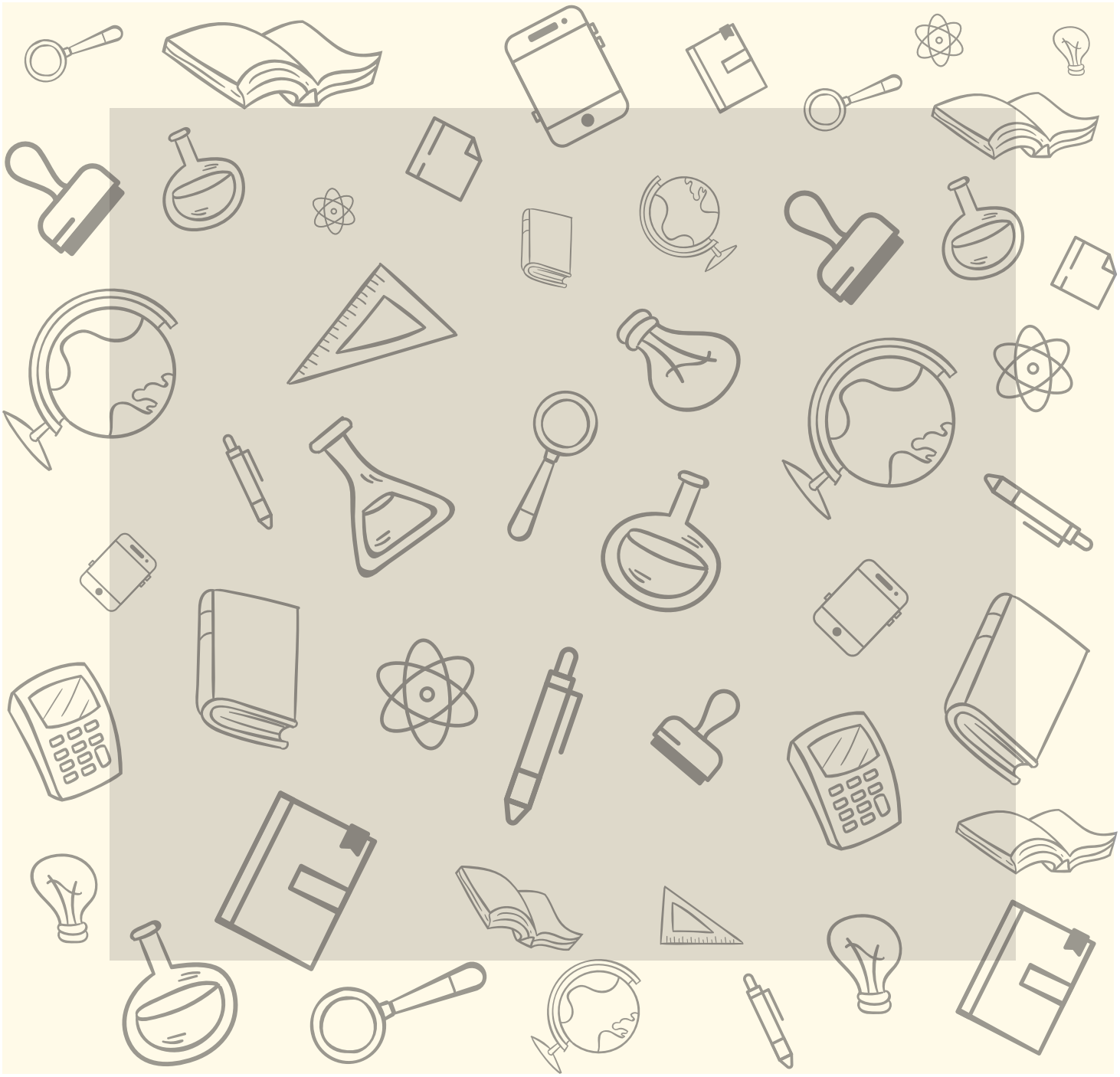

Oficina de Publicaciones

Contenido

Número 51 (Enero-Junio de 2018)

Applings: aplicación móvil para el monitoreo de emociones y su contexto

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RESUMEN
El estado afectivo es una reacción efímera que altera el equilibrio psicosomático (estado cognitivo, psicomotor o de salud) de un individuo, afectando de manera positiva o negativa en el desarrollo de sus actividades diarias y en su toma de decisiones. Se presenta Applings, una aplicación para dispositivos inteligentes diseñada para facilitar la recolección de datos asociados a las emociones de usuario (P. Ej. felicidad, sorpresa o tristeza) y el contexto en el que estos estados afectivos se presentan (P. Ej. ubicación, compañía o sensación térmica). La aplicación desarrollada fue validada tanto por los investigadores quienes realizan experimentos sobre emociones de usuarios y contexto, como por los sujetos que desean retroalimentación acerca de qué emociones experimentan durante sus rutinas diarias. Mostrando que Applings es una herramienta de gran utilidad para estos tipos de usuarios.

Palabras Claves: emociones de usuario, contexto, dispositivos inteligentes, cómputo afectivo.

INTRODUCCIÓN

El estado afectivo de un individuo puede ser perturbado por factores externos como su contexto (P. Ej., ubicación, compañía o clima) y factores internos como su fisiología (P. Ej., cansancio). Alteración que puede afectar de manera positiva o negativa su desempeño durante la realización de sus actividades diarias así como en su toma de decisiones. En particular, Piqueras Rodríguez (2009), menciona diversos impactos que tienen las emociones en la salud mental y física del individuo, y sobre cómo el miedo, la tristeza, la ira o el asco, al ser constantes y continuos, afectan su calidad de vida, ya que los fenómenos psicofisiológicos están relacionados con las emociones.

El análisis de las emociones que un individuo experimenta en conjunto con el contexto donde se presentan permite la detección de patrones de comportamiento que conducen a ciertos estados afectivos (Ellsworth, P.C., 1994). En este sentido, el análisis de información recopilada a través de los sensores integrados en dispositivos inteligentes permite la identificación de factores que pueden influir en el estado afectivo del individuo. La mayoría de las aplicaciones desarrolladas para dispositivos inteligentes apoyan la recolección de datos sobre emociones de usuario mediante el monitoreo de patrones de comportamiento respecto al uso cotidiano del teléfono móvil (Min Chen, Yin Zhang, Yong Li, Shiwen Mao, y Victor CM Leung, 2015).

En este trabajo se presenta el desarrollo de Applings, una aplicación para dispositivos inteligentes con sistema operativo Android que simula la detección de emociones y su contexto mediante la recolección de datos. A través de la interacción con Applings,

el individuo registra la emoción que experimenta, la cual puede ser feliz, triste, enojado, molesto, asustado, sorprendido, aburrido, nervioso o avergonzado (Scott Brave y Clifford Nass, 2003), y el contexto en el cual se está manifestando tal emoción (ubicación, actividad realizada, compañía, sensación térmica y fisiología). Los datos recolectados mediante Applings permiten, por ejemplo, a investigadores determinar la asociación (patrones) entre estados afectivos y el contexto de usuario, con el propósito de informar al individuo cómo mejorar su calidad de vida con base en una serie de recomendaciones informadas y centradas en el usuario.

FUNDAMENTACIÓN TEÓRICA

Actualmente, es muy común el registrar datos a través de aplicaciones en dispositivos móviles. Por ejemplo, los gastos económicos (DollarBird 2013), alimentos consumidos (MyFitnessPal 2014), tiempo de ejercicio efectuado (Runtastic 2018), entre otros. Sin embargo, es necesario analizar estos datos para la identificación de patrones y la generación de conocimiento a través de ellos para el apoyo en la toma de decisiones de los usuarios (Satterlee, McCullough, Dawson y Cheung, 2015).

En particular, Lisa Feldman (2017) habla sobre cómo las emociones surgen de manera instantánea y automática como respuesta a lo que piensa y experimenta un individuo. Rafael Echeverría (2015), sobre cómo el estado afectivo de una persona altera su capacidad de retención y concentración.

Mediante la interacción de un individuo con los sensores de sus dispositivos inteligentes, es posible la identificación de sus emociones y del contexto donde se manifiestan. A partir del análisis de esta información, es posible detectar las causas de las afecciones del individuo en particular (Abbas Abedi, 2016). Actualmente existe una aplicación móvil llamada "MoodNotes" (Pablo Espeso, 2015), en la cual el individuo registra sus emociones y recibe retroalimentación (P. Ej., comentarios, recomendaciones y estadísticas). Sin embargo, MoodNotes solamente considera la percepción emocional del usuario, y no el contexto en el que sucedieron. Limitante por la cual no se permite la predicción de estados afectivos a partir del análisis riguroso de datos relacionados a las actividades cotidianas del individuo.

METODOLOGÍA

Sujetos

Se consideran dos tipos de sujetos: 1) sujetos que interactúan con Applings con el fin de obtener retroalimentación por parte de la aplicación (usuario consumidor), y 2) sujetos quienes usan la aplicación y la información obtenida con ésta con fines académicos o de investigación (usuario investigador).

Instrumentos

Para el desarrollo de Applings, se utilizó el entorno de desarrollo Android Studio versión 3.0.1 en conjunto con SQL Server 2008 con el componente Microsoft SQL Server Managment Studio versión 10.0.6000.29 para el almacenamiento de los datos a recopilar. Se utiliza un equipo de cómputo con las siguientes características: Procesador

Intel(R) Core™ i7-4470, 8GB RAM DDR4, S.O. Windows 10. Finalmente, se hizo uso de un dispositivo inteligente (Samsung Galaxy S4) para las pruebas, y un servidor del tipo Internet Information Services (IIS), para la conexión entre los dispositivos y la base de datos.

La metodología de desarrollo de software utilizada para este proyecto fue Programación Extrema (XP), ya que se contaban con 4 personas para en un periodo de dos meses diseñar, implementar y evaluar mediante casos de prueba Applings. XP es una metodología ágil, donde no se genera un exceso de documentación y se presentan avances constantes de manera inmediata.

Procedimiento

1. Diseño conceptual de los elementos de la aplicación. Se definen los objetivos y requerimientos de la aplicación: escalabilidad y robustez (tolerable a fallos), y que registre con exactitud los datos requeridos.

2. Fundamentación de cada elemento dentro de la aplicación. Cada componente de la aplicación es justificado (ver sección Fundamentación Teórica). Los elementos a analizar que maneja Applings son emoción y contexto.

3. Desarrollo de la aplicación. Elaboración de la aplicación móvil, considerando los aspectos definidos en el punto 1, siguiendo los criterios de avance de la metodología utilizada (XP).

4. Diseño e implementación de casos de prueba. Se considera la participación de 32 sujetos de prueba (estudiantes del programa de Ingeniería en Software de ITSON) que utilizarán Applings desde sus dispositivos inteligentes.

5. Creación de encuesta para la evaluación de la aplicación. Finalmente, se diseña una encuesta para evaluar Applings desde el punto de vista del usuario consumidor. Esto se hace con la intención de recibir retroalimentación, para así, crear una herramienta que no altere las emociones del usuario al utilizarla (Hassan Montero, 2015).

6. Resultados a presentar al usuario investigador. Se analizan los datos obtenidos durante el caso de prueba con 32 sujetos por parte de un usuario investigador. Esto para identificar patrones de comportamiento y estados afectivos.

Tipo de Investigación

La propuesta que se presenta permite obtener datos no cuantificables como la emoción de usuario y su contexto. Información que puede ser después analizada a través de procedimientos estadísticos y algoritmos de aprendizaje máquina para evaluar hipótesis establecidas por investigadores. Por lo que se involucran tanto aspectos de investigación cualitativa y cuantitativa.

RESULTADOS Y DISCUSIÓN

En esta sección, se presentan 1) los resultados obtenidos del desarrollo e implementación de Applings, 2) los resultados de la evaluación

de diseño y usabilidad de la aplicación y 3) un análisis preliminar de datos recopilados en el caso de prueba con 32 participantes.

Primeramente, en la Figura 1 se presenta el diseño de la aplicación móvil, Applings, donde se pueden observar los módulos de emociones (Figura 1(a)), Y el contexto en el cual se manifiestan (Figuras 1b-f).

Figura 1. *Módulos de aplicación móvil, Applings*

En las figuras 2(a), 2(b) se expone un análisis de los resultados obtenidos en el instrumento de evaluación respecto al diseño y usabilidad de Applings. A partir de este análisis, se determina que la mayoría de los sujetos de prueba consideran que la aplicación posee un buen diseño, así como una alta facilidad de uso. Algunos de ellos argumentaron que prefieren recibir mayor retroalimentación de la que ofrece la aplicación para conocer más a fondo sus propios comportamientos.

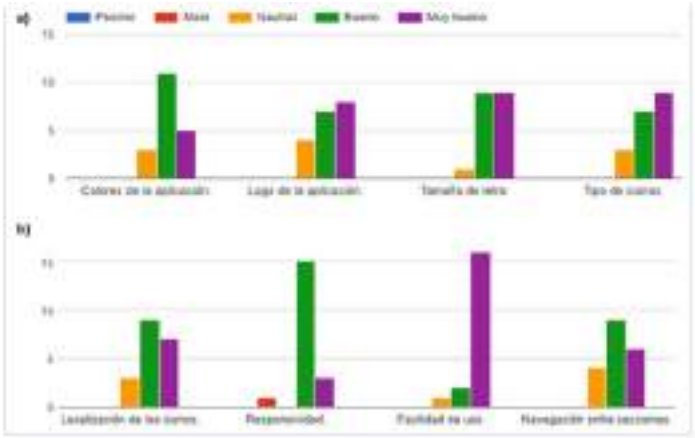

Figura 2. *Resultados de evaluación de diseño y usabilidad*

Respecto al análisis de datos recopilados en el caso de prueba, se realiza un estudio preliminar con los datos registrados por el participante P29. Se consideró el contexto específico:

ubicación: Escuela, Actividad: En clase, Compañía: Amigos, y Periodo: 14 de marzo al 02 de abril de 2018. En la Figura 3(a) se muestra que las tres emociones más frecuentes que presenta este individuo bajo ese contexto específico son Felicidad, Nerviosismo y Sorpresa. Por otro lado, en la Figura 3(b) se muestra un contraste del análisis presentado en la Figura 3(a), cuando el participante P29 se encuentra en otro contexto: ubicación: casa, actividad: (varias), compañía: nadie, y Periodo: 14 de marzo al 02 de abril de 2018, se tiene que sus estados afectivos más comunes son asustado, feliz y molesto.

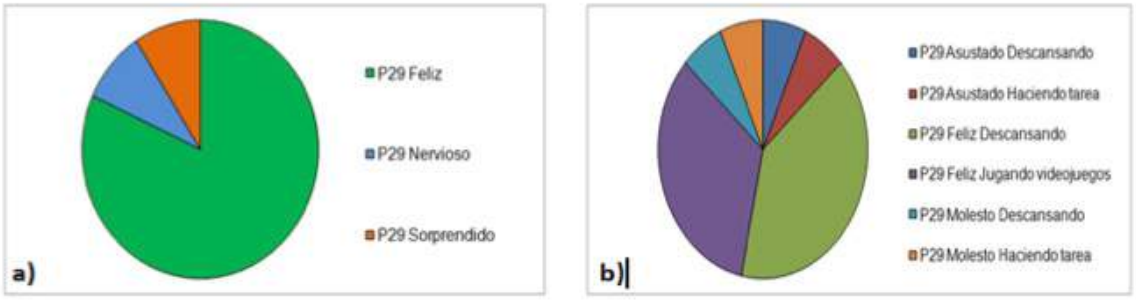

Figura 3. Registros acumulados bajo un contexto en particular del participante P29

CONCLUSIONES

A partir de los resultados obtenidos, se determina que la utilización de la aplicación debe de ser intuitiva y fácil, ya que, de lo contrario, el utilizar la aplicación puede alterar las emociones del usuario, generando ruido a la hora de analizar los datos obtenidos, los resultados del instrumento de evaluación demuestran que Applings cuenta con la usabilidad y diseño correcto para cumplir con el objetivo definido en la sección de Metodología.

La utilización de la información recolectada por Applings tiene grandes posibilidades de uso en áreas como la medicina o la psicología. Por ejemplo, se podrían determinar los hábitos del usuario a través del historial de sus registros y relacionarlos con su estado de salud. Observando posibles sugerencias para la mejora de esta. Información que será brindada por los investigadores que requieran de Applings, ya que ellos justificarán el contexto que necesitan.

El proyecto está considerado para ser escalable, lo cual significa que, en un futuro próximo, aspectos como las emociones de usuario y su contexto (P. Ej., sensación térmica o ubicación) podrán ser determinados de manera automática a través de diferentes dispositivos inteligentes (P. Ej., smartwatches o smartbands), recolectando más información del usuario sin necesidad de una interacción directa con el dispositivo. Además, la detección de patrones puede llegar a ser más exacta y útil para el análisis de los datos si, por ejemplo, se consideraran variables como sucesos recientes, factores biológicos, psicosociales o genéticos.

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Chapter 13
Technology and Aging: Ubiquitous Sensing Technology for Aging Research

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Abstract Advances in Information and Communication Technologies (ICT) are impacting aging research in multiple ways, ranging from analyzing large volumes of data from longitudinal studies to assessing the efficacy of assistive robots. This chapter focuses on using ubiquitous technologies for gathering behavioral data from individuals to understand how we age, assess the effectiveness of interventions, perform early diagnosis of diseases, or monitor disease progression. The ubiquity of inexpensive sensors, most notably in mobile and wearable devices, and advances in pattern recognition algorithms capable of reliably inferring activities and behavior is providing a new and powerful tool for aging research. We describe how these technologies can be used to monitor clinical variables and health outcomes in interventions for aging and illustrate their use with case studies on assessing frailty, inferring anxiety in caregivers of people with dementia and monitoring eating behaviors. We conclude by discussing some of the issues facing research in this area regarding data quality and privacy.

Keywords Gerontechnology · Ubiquitous sensing · ICT · Technology and aging

13.1 Introduction

Advances in ICTs are impacting aging research in numerous ways. One notable case is the use of sensing technologies to support epidemiological studies and clinical interventions in aging. Behavioral epidemiology studies how lifestyle and behavior relate to the occurrence of a disease and evaluates interventions aimed at

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changing unhealthy behaviors, such as overeating or smoking. Numerous diseases provide early evidence of their onset from changes in behavior, long before confirmed by clinical studies. In particular, mobile phones and wearable devices include a variety of sensors that can be used to gather data about users' behavior, such as the places they visit, their level of activity, and how frequently and with whom they socialize. The collection and analysis of these data have been the focus of recent attention in an emerging field known as mobile sensing, which can offer valuable data to aging research. One such example is the Health eHeart study at the University of California at San Francisco, which used smartwatches to collect heart rate data from 196,000 participants that have been used to predict hypertension, sleep apnea, and diabetes with 80 to 90% accuracy [1]. Epidemiological studies, such as the Framingham Heart study and the Women's Health study at Harvard, are increasingly incorporating data obtained from mobile and wearable sensors. A notable example is the Precision Medicine Initiative in the U.S., which aims at creating a cohort of one million participants who will contribute biological and genetic data, as well as behavioral and lifestyle information derived from sensors in the mobile devices they use and wear.

This chapter presents three case studies that exemplify how sensing technology can be used to support research on aging. Section 13.2 describes the field of mobile sensing for healthcare, including the ubiquity of mobile and environmental sensors, and how data on human behavior can be derived from it. We then present three case studies that illustrate how data for aging research can be obtained from individuals and populations. Finally, in Sect. 13.3 we discuss some of the challenges facing the development of this field regarding data quality and addressing privacy concerns.

13.2 Activity and Behavior Monitoring Through Mobile and Environmental Sensing

Self-report is a technique commonly used to collect data for aging research using questionnaires or surveys. Through this method, data regarding behaviors, activities, and beliefs are collected directly from the individual, or a third person such as family member or caregiver. While convenient and useful, self-report can provide unreliable information from users who might not be sufficiently aware of their activities, might not remember important details of their behavior, might be biased, inclined to exaggerate, or simply lie when answering questions from the researcher.

In contrast with self-report, studies that rely on Real World Evidence (RWE) use information obtained from data gathered from patients in real life settings. This is increasingly made possible by the ubiquity of mobile and wearable devices capable of sensing information related to the user's environment and the development of algorithms capable of inferring the activity and behavior of the users of these devices. For instance, while a frailty questionnaire might include questions on the amount of physical activity performed by the patient in the last few days (i.e. fre-

quency of performing moderate activity, such as walking), data from an accelerometer worn by the patient can be used to give a fair estimate of the number of steps walked, overall physical activity, and number of calories burnt.

Behaviors, mannerisms, or actions that can be estimated with good accuracy using mobile and wearable sensors and are relevant to research on aging, include physical activity, sleep, coughing [2], anxiety [3], or socialization [4]. These advances are making possible the use of behavioral cues as the basis for novel computing systems that can be used to support a range of healthcare solutions. This includes early diagnosis on conditions that might have distinct behavioral symptoms, such as Parkinson's disease; ambulatory assessment of patients under observation, such as those who have undergone surgery; assisting in the management of a disease by for instance recommending medication doses according to how it affects behavior in that individual; detecting problematic behaviors in conditions such as dementia to intervene before such behavior harms the patient (e.g., wandering); and in interventions aimed at inducing behavior change to assist the user to adopt healthier behaviors such as exercising more or stop smoking.

Mobile sensing is mainly carried out with modern mobile phones and wearables such as smartwatches. Those devices have been augmented with several built-in sensors that can provide information relevant to health studies. Some of these devices include up to 15 hardware-based sensors such as accelerometer, gyroscope, magnetometer, GPS, microphones, proximity, luminosity, among others. These sensors can be used to derive certain user behaviors. For instance, the accelerometer can be used for estimating gait speed, step counting, or physical activity. There are several technological frameworks that can help rapidly deploy these types of studies such as Funf (http://www.funf.org), AWARE [5] or InCense [6]. Deriving relevant healthcare variables from sensed data could be relatively straightforward, such as estimating geographic lifespace from GPS traces. However, other variables may require more sophisticated pattern recognition algorithms such as those used to estimate gait speed from accelerometer data from a smartphone, or even novel deep learning algorithms that have been used to find promising correlations between heart rate and diabetes. Interdisciplinary work from healthcare specialists and data scientists in this field will redefine how healthcare data are captured, analyzed, and used to diagnose, assess and manage healthcare.

In this section we illustrate how mobile and environmental sensing technology can be used to more reliably measure parameters of interest for functional assessment, detecting anxiety in caregivers and monitoring eating habits, which are traditionally obtained from self-report. Using sensing for assessment enables data to be gathered opportunistically as informants perform everyday activities through unobtrusive and ubiquitous sensors, such as mobile phones. This also allows for continuous monitoring rather than requiring patients to attend a clinic to complete surveys or be interviewed. We first present how mobile phones can be used to obtain behavioral data related to frailty, including data on mobility and activity. We then describe how wearable sensors can be used to detect anxiety in caregivers, and, finally, we describe how mobile technology can be used to monitor eating habits.

13.2.1 Functional Assessment of Older Adults Using Smartphones

Functional assessment often relies on self-report or is carried out at the doctors' office. This approach has validity problems as patients may under-report or exaggerate symptoms. Also, patient assessment at the clinic has ecological validity problems since it is based on occasional physical tests performed in a laboratory setting.

One such test at the doctor's office may include the Timed Up and Go test, which is used to assess older adults' functional mobility, gait speed, and risk of falling. Frenken et al. at OFFIS in Germany proposed an unsupervised approach to perform an equivalent test using ambient sensors in a domestic environment [7]. The test can be performed continuously, given the physician a more reliable assessment of functional mobility than a test that is performed in a lab every few months, at best. Walking speed and fatigue are among the factors associated with the frailty syndrome [8]. Unobtrusively monitoring gait speed over a period of time, for instance in a route frequently walked by an individual, could provide early evidence of fatigue.

The frailty syndrome is of particular interest for the functional assessment of older adults Frailty is a state of increased vulnerability to adverse health outcomes for people of the same age [9]. The frailty syndrome involves several aspects such as involuntary weight loss, exhaustion, muscle weakness, slow walking speed, and low physical activity [8]. Frail people are at high risk for major adverse health outcomes, including disability, falls, institutionalization, hospitalization, and mortality [10]. The clinical assessment of older adults is to a large extent based on retrospective accounts of incidents. This can be unreliable as patients often do not remember or try to hide or minimize negative incidents. For example, widely-accepted instruments to estimate frailty in older patients include questions such as "In the last week, in how many days you walked at least 10 min?" and "How frequently do you speak with your friends/spouse?" Often, responses to these questions are hardly precise, having older adults providing rather vague answers to questions of this nature. Therefore, mobile sensing represents an attractive approach for estimating some of those variables (e.g., physical activity, socializing with others) that could correlate to surveyed data of older adults pertaining to frailty.

We used a mobile phone and InCense [6] to assess frailty in older adults and compare it with the results of the clinical assessment. We recruited 15 community-dwelling older adults, average age was 75.3 (SD = 1.8), for gathering data from their activities and behaviors. Four of our participants were classified as frail, based on the frailty index developed by Fried [8]. We collected data from several sensors in the mobile phones including location, audio, and others. The functional assessment of frailty in elders included standard inventories such as the Katz instrument for measuring activities of daily living [11] and the SF-36 health survey [12].

From our results, which can be consulted at [6], we found that that sleeping time in frail participants was larger than for fit participants. Also, not surprisingly, frail

participants went out of their households less often than fit participants. In addition, we found that participants who were fit performed significantly more intense activity bouts than those who were frail. Finally, we were also able to estimate our participants' geographic life-space [13], which can be used to identify individuals in a community that may be at risk of not living a prosperous life or to determine early functional decline in older adults with a reduced life-space. Some of these results are not particularly astonishing from a medical point of view, but they were obtained through sensor data collected from their mobile phones. As opposed to conventional self-report methods, ambulatory assessment methods aim at measuring certain aspects while the participant undergoes normal daily activities. Therefore, mobile phones can be used for ambulatory assessment, which can support research in this area and provide reliable, ecologically-valid data.

13.2.2 Detecting Anxiety in Caregivers to Support Cognitive Behavioral Therapy

Caring for people with dementia (PwD) is a demanding and stressful activity that frequently causes anxiety and might lead to depressive disorders in caregivers. Cognitive behavioral therapies can assist caregivers by providing coping strategies, such as breathing exercises or seeking social support. Some of these strategies can be more successful if they are enacted when the person is experiencing anxiety, but even the caregiver might not realize that she is experiencing anxiety or its consequences, which is one of the main drawbacks of using subjective ratings based on questionnaires and self-report. Sensors in smartwatches can be used to obtain physiological data, which can be used to infer state anxiety when the subject is experiencing a stressful situation. This could trigger coping strategies to reduce anxiety and improve the caregiver-PwD relationship.

We conducted a study, using the naturalistic enactment technique, in which 10 subjects were asked to care for an older adult who acted as if she was experiencing dementia [14]. Each subject cared for the PwD in 3 sessions, one per week, which lasted approximately 30 min. We used wearable devices to record the following physiological signals from the participants: Galvanic Skin Response (GSR), Heart Rate (HR), and Electroencephalography. To establish ground truth, we analyzed the videos of the sessions and asked participants to take notes during the session including their level of perceived anxiety. The physiological signal was processed in periods of 30 s to calculate 9 features from GSR and HR data. We obtained an average precision of 78% when recognizing two possible states: "Anxious" and "Not anxious", using a Support Vector Machine classifier [15]. A Markov chain model was evaluated using Inter-beat Interval data obtained from the HR signal, to detect 4 internal states: "Relaxed", "Arousing", "Anxiety", and "Relaxing". The average accuracy obtained was 73%.

The results provide evidence that the experiment elicits state anxiety and that it can be detected using wearable sensors. While the analysis was conducted in short intervals, triggering a coping strategy would normally be done after accumulated evidence has been obtained from a few minutes of data, reducing the probability of incurring in false positives, or missing false negatives.

13.2.3 Monitoring Eating Behaviors from Photographs Using Crowdsourcing

One aspect of interest for aging research is monitoring food intake, given the implications that may have for several metabolic disorders and diseases diagnose and treatment. In particular, beyond identifying food that may be detrimental to the patient's health and wellness, monitoring nutritional content and caloric intake can be useful for clinical assessments. Advances in automatic behavior recognition and monitoring have fostered the development of computing systems aimed at supporting behavior change. Eating behaviors of interest might include eating late at night, prolonged fasting, or regular fast food consumption.

Monitoring eating behaviors by nutrition specialists has been traditionally addressed with various strategies including: a) paper-based logs and computational systems that facilitate meal logging, and b) automatic recognition approaches. Paper-based methods for monitoring eating behaviors include food records, food frequency questionnaires, or forms that include a meal description and time of intake. Mobile phones have been increasingly used to support this task, with apps to help individuals record their meals and coach them on healthful habits, such as Noom (noom.com) or Calorific (calorificapp.com). Regardless of the method used, both of these approaches rely on self-report, meaning that individuals must explicitly enter detailed data regarding their food intake on a daily basis. In the long run, this can be burdensome for individuals being monitored. Automatic recognition approaches are desirable due to low overhead but are of little practical use due to low accuracy.

To monitor food intake, it is desirable to burden subjects as little as possible without sacrificing accuracy. Burden-wise, an approach that is based on taking photos of the meals can be very convenient. Since high-precision automatic recognition is still underway, photos of meals can then be collectively analyzed by a crowd, who can help assess nutritional content or caloric intake. Still, knowing what type of approach to use for assessment to maximize accuracy and reduce burden in those rating photos is not a trivial question, for which we proposed and evaluated six assessment approaches (see Table 13.1), which were compared regarding Latency (time to make an assessment), Cognitive Load in raters, and Accuracy by raters.

From our results (see [16] for further details), in terms of Latency, participants required, on average, less than 30 s to assess one photograph across all approaches. Participants took less than 7 s, on average, to asses A4 and A3. In contrast, A5 was

Table 13.1 Six approached proposed for assessing nutritional content or caloric intake

Code	Approach	Description
A1	Number of calories	The individual estimates the number of calories contained in a meal, from looking at the photograph
A2	Food groups	The individual selects the food groups perceived from the photograph. The participant has to estimate the quantities (none, some, adequate, plenty) of each of the following food groups: fruits, vegetables, cereals, legumes, and animal origin. This is based on the Official Mexican Standard NOM-043-SSA2–2005 for a balanced diet
A3	Healthfulness scale	The approach is designed to assess the healthfulness of food in the images. The user rates the photograph in a scale from 1 (not healthful) to 7 (very healthful)
A4	Caloric range	This approach is similar to A1, calories in the meal shown in the photo are estimated by selecting one of six 200-cal intervals (e.g., 401–600)
A5	List of ingredients	The user types in all the ingredients that she thinks are contained in the meal shown in the photograph, even those not in sight such as salt or cooking oil.
A6	Similar images	The participant selects from a set of 9 different images the one she believes is the most similar to the photograph presented. This action is repeated twice, the second set of images depends on the first image selected.

the one with highest latency (28.02 s). Regarding Cognitive Load, A1 scored the highest cognitive load. Conversely, A3 and A6 were perceived as the tasks with less cognitive load. Finally, regarding Accuracy, A1 and A4 had a low accuracy score, and A5 and A6 registered an acceptable accuracy, which improved with additional answers from the crowd.

Based on a modified version of A5, we developed Lucy a digital assistant aimed at helping patients undergoing weight-reduction treatment. We worked closely with a nutritionist clinic, in which doctors and nurses consult around 100 patients in terms of nutrition. We evaluated Lucy with patients of the clinic. Both Lucy and the crowd assessment have the potential to facilitate the work of nutrition experts in coaching numerous patients 24/7. Potential users were positive about adopting Lucy for future use.

13.3 Data Quality in Behavior and Activity Monitoring for Aging Research

Studies in mobile sensing for healthcare produce large, complex datasets with information opportunistically gathered from distributed sensors in mobile devices. This raises issues regarding the organization and sharing of the large amounts of data collected. Some of these issues include the heterogeneity of the devices, diversity of sensors used, and the need for data provenance when integrating datasets from diverse studies. Assessing quality is of paramount importance for conducting

Table 13.2 Data management and collection issues for mobile sensing

Category	Issue	Responsible
Research	Heterogeneity in data gathering	Researchers
	Data annotation	Researchers
	Data pre-processing	Researchers
	Limited data sharing	Researchers
Legal	Privacy	Participants/Researchers
	Ethics	Researchers
Engineering	Heterogeneity in sensor data	Hardware vendors
	Dispersion	Researchers/stakeholders

longitudinal studies and building on historical knowledge as new data become available.

In mobile sensing for healthcare and aging research one of the main concerns is generating reliable datasets that can be used to push forward the boundaries of the area, which necessarily involves providing structure to the data. While current efforts have yielded promising results, we believe that scientists could benefit from a distributed repository of aging datasets. These datasets are to be curated and integrated to facilitate conducting new research in aging such as generalizing previous findings when comparing with new data from a different population and conducting longitudinal studies controlling for the conditions in which data were gathered over long periods of time.

In Table 13.2 we present some of the data management issues currently faced by the research community in mobile sensing for healthcare. These issues need to be addressed if a data infrastructure from which to continuously construct new knowledge and validate previous findings is to be made available. This is particularly important in aging research involving mobile or wearable devices, as the issues are to be increasingly present.

One issue that is of great concern for the development of aging research is that of preserving the privacy of participants, particularly since behavior and healthcare information are being recorded. Mobile and wearable devices collect large amounts of data from individuals and families. Although certain computational methods can be applied to data to remove sensitive information, it has been shown that with as little as the date of birth and zip code, one individual can be identified with a great degree of certainty.

One technical solution to partially address privacy concerns is for all data processing to be processed on the mobile device (e.g., mobile phone), but cost in terms of battery and processing power can be high. Other approaches involve data anonymization and encryption. Ultimately, addressing privacy involves considering social and technical approaches, and developing proper regulatory frameworks.

13.4 Conclusions

The emergence of these novel forms of ICTs offer unprecedented opportunities for scientists and practitioners to better understand and potentially influence patients and their contexts. These advances are being helpful in stepping up our understanding of human dynamics and contexts. Even more, a better understanding comes with an opportunity to provide adequate services to patients and potentially influence their attitudes and behaviors.

At the same time, these emerging technologies pose new challenges for well-established research methods as some of them will have to be rethought, reshaped, or overhauled. Technologies that could provide a continuous data stream of measurements for researchers and physicians were unthinkable two decades ago. Modern mobile and wearable devices, coupled with their augmented capabilities and ubiquity, are indeed creating new opportunities for measuring behavior, conducting epidemiological studies, and enacting interventions to change behavior. Mobile and wearable devices can boost medical studies by gathering data from larger populations, increasing the frequency of reporting and providing more reliable data based on the continuous monitoring of actual behavior rather than from sporadic interviews that rely on self-report. Analysis from larger populations, for instance, could result in findings that take into account differences in groups regarding gender, age, or upbringing, with results drawn rather rapidly and with higher ecological validity.

Finally, when comparing these emerging technologies to traditional approaches in research, there are stark differences between the types of data that can be collected (e.g., audio, video) as well as the frequency in which measurements can be taken (e.g., continuous), all of these with higher ecological validity. Nevertheless, there is plenty of work ahead to supplement current methods, rethink some of them, or perhaps create new methodologies that can take full advantage of the opportunities being offered to aging research by technology. Still, one of the big questions that will need to be addressed is whether revising current methods (and instruments) by increasing the frequency of measurements, increasing data quality, aggregating data from various sources, and having higher ecological validity will have, ultimately, medical significance. That is, if any improvements to current methods or new proposed methods will have an ultimate effect on the health outcomes of patients. Undoubtedly, incorporating these emerging technologies to research on aging will provide a different lens through which researchers, practitioners, and family members can scrutinize subtle changes in patient conditions and behaviors, perhaps before it is too late. Ultimately, what technology will surely provide, as it has been shown in other disciplines, is an increase of the scope, depth, and complexity in the design of much more comprehensive studies in the area.

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Agile Dimensional Model for a Data Warehouse Implementation in a Software Developer Company

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Abstract. Nowadays, the increasing development of Business Intelligence (BI) solutions in organizations, has enabled executives achieve a better understanding of business information for timely and rapid decision-making in a tremendously dynamic market. Although there is an increasing interest in adopting an agile approach to the software development, the emergent need of using agile methodologies in BI solutions is undeniable. This paper discusses the importance of using agile methods in the design and development of data warehouses taking into account the business processes, requirements analysis, and organizational objectives. Thus, we present a case study derived from a real-world business project where the agile methodology Business Event Analysis and Modeling (BEAM) is used to design the data warehouse. The project is based on a billing system with about one million operations on a daily basis with more than 15,000 clients. Finally, the results of this paper include the design of the dimensional model using an agile approach, the construction of the data warehouse through the ETL processes and an interactive dashboard according to the key performance indicators defined by the business decision-makers.

Keywords: business intelligence, agile dimensional model, data warehouse.

1 Introduction

In the business world we aim to obtain greater profits and a greater competitive advantage, *hence*, appropriate timely decision-making plays a very important role in the fulfillment of the organizational objectives. Thus, the use of Business Intelligence (BI) systems can help meet these needs as it provides a set of methodologies, applications, and practices focused on the information management for accurate, timely decisions making in an organization.

A major component of any BI model is the design and implementation of a data warehouse in organizations, since it provides valuable and strategic information to support decision-making through real-time access to business transactions and advanced business analytics [1]. According to Inmon [2] and Imhoff [3], a data warehouse in organizations is an integrated data collection, non-volatile and variable over time. Hence, it has a complete history of the organization, beyond the transactional and operational information favoring the data analysis for decision-making.

Today, the two most widely used methodologies for the design and implementation of data warehouses are the model of Inmon [2] and Kimball [4]. They consider the data warehouse as the central repository of data for organizations that is used to present business reports. The difference between these two methodologies lies in how to make deliveries of progress (time) and how to manage changes during the process (see Table 1).

Recent studies tend to show that use of agile methodologies for the design and implementation of data warehouse in organizations is playing an important role to obtain value information to help decision-makers and to generate competitive advantage by improving the extraction and processing knowledge. These studies present a structured methodology, inspired from the agile development models as Scrum, XP and AP [5]. Thus, an increasing number of companies are choosing for an agile philosophy in software development due to the constant need to be flexible and adaptable to the technological changes and the new user demands [6-10].

For this reason, it is important to consider agile methods for the design and implementation of a data warehouse in a BI system (see Table 1). In this regard, it has been shown that agile development processes increase the potential for developing the success of a data warehouse by solving many of the typical problems presented in traditional methodologies [11, 8, 12].

In this paper, we use the BEAM methodology in the design, modeling, and implementation of a data warehouse for a management system. This system processes one million operations on a daily basis from more than 15,000 clients. The agile design and modeling of the data warehouse are presented through a case study of a Software Development Company located in Mexico, which offers software solutions focused on meeting the needs of development, implementation and support to any business sector.

2 Agile Dimensional Modeling

Traditional data warehousing projects follow the waterfall structure to perform dimensional modeling [13]. However, its use is increasingly unlikely and alternatives of analyzing and designing similar to those used in software development projects such as agile methods are looked for [7, 12, 14]. In this respect, the agile dimensional modeling is being considered as a solution for BI systems since it allows developers to reduce the risks that the waterfall structure could produce [11, 14]. All this is possible by adopting a highly interactive, incremental and collaborative approach to the whole analysis, design and development activities of a data warehouse, such as the agile BEAM methodology [14] (see Figure 1).

Table 1. Comparison of the Inmon, Kimball, and Corr methodologies.

	Inmonn [2] (Traditonal)	**Kimball [4] (Traditonal)**	**Corr [14] (Agile)**
Business Decisions	Strategic	Tactical	Collaborative
Scope	Product owner	Project manager	Team
Approach	Top – down	Bottom – up	Bottom – up
Objective	Deliver a robust technical solution based on proven methods	Provide a solution that facilitates the end users to consult the data	Responding to change and user needs
Data requirements	Enterprise-wide	Business process	Individual business requirement (KPIs)
Data modeling	Normalized form (3NF)	Dimension model (Star or Snowflake)	Dimension model (Star or Snowflake)
Orientation	Enterprise-wide	Business process	People
Communication	Formal	Formal/Informal	Informal
Time	Longer start-up time	Shorter start-up time	Minimal start-up time
Project schedule risk	High	High	Low
Ability to respond to change	Low	Medium	High
End users involvement	Minimal	Oscillate depending on the project	High
Cost to build	High initial cost	Low initial cost	Minimal initial cost

2.1 BEAM Methodology

Corr [14] proposes the BEAM (Business Event Analysis and Modeling) methodology, an agile data modeling method for the design and development of data warehouses and data marts. This method combines analysis and modeling techniques to meet data requirements related to business events and data modeling for database design that is easy to understand by stakeholders and also, easy to translate into logical/physical models for IT developers. The BEAM methodology involves stakeholders who think beyond their current reporting requirements by describing data stories, that is, narratives that define the dimensional details of business activities necessary to be measured. In order to obtain these data stories, data modelers ask questions to stakeholders using a framework based on the 7Ws (who, what, where, when, how many, why and how) [14]. The way to find these answers of the 7Ws and make sure they inform data warehouse design is to ask end-users about the events that are happening in their business. Therefore, the enhanced Start Schema is used to generate and show schema of physical data bases, where are they involved Data Modelers, DBAs, DBMS, ETL Developers, BI Developers and Testers. This framework is one of the main activities of the BEAM methodology because it allows discovering and modeling data requirements and thus, to construct the table of dimensions and facts of the data warehouse depicted through the star model.

According to Corr [14], the BEAM methodology has several diagrams for the analysis and design of the data warehouse model, such as: BEAM Table, Hierarchy Chart, Timeline, Event Matrix and Enhanced Star Schema.

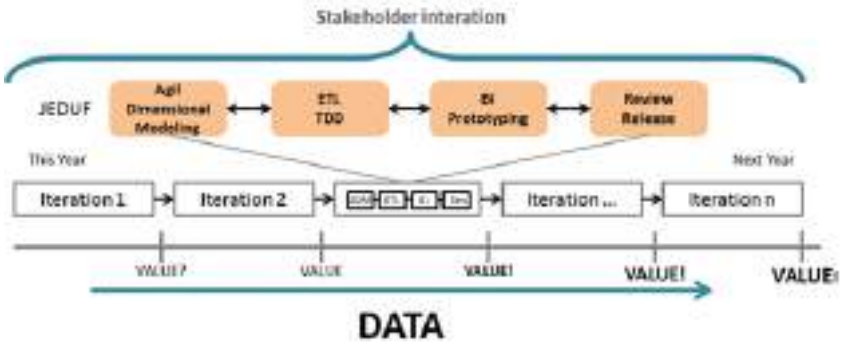

Fig. 1. Agile data warehouse development timeline. Source [14].

For instance, the BEAM Table is used to model business events and dimensions at the same time; people involved in this diagram are data modelers, business analysts, stakeholders and BI users. The Enhanced Star Schema is used to visualize the dimensional model for the implementation of the physical database schemas; the people involved in this diagram are Data Modelers, DBAs, DBMS, ETL Developers, BI Developers and Testers.

3 Agile Data Warehouse: A Case Study of a Billing System

This case study focuses on the design and implementation of a data warehouse using the BEAM methodology for a billing system of a company based in Mexico with operations in software development with around 15,000 active clients in 19 countries and more than a million operations on a daily basis. Despite all the information daily stored on the company's servers, this information is not used or analyzed so far by the working team, identifying an area of opportunity for the design and implementation of BI systems. Therefore, decision-makers could offer their customers significant knowledge through scorecards and thereby provide a competitive advantage. The management system access to a database based on the Entity-Relationship Model (ER) allowing to record, update, delete, and query information from the main business processes. This system has the following modules such as: billing, inventories, clients, payroll, branches, among others. Hence, in this case study, we focus on the billing module. The database used by the system contains around 70 tables using only the most relevant according to the key performance indicators (KPI).

3.1 Analysis, Design and Implementation of the Data Warehouse

Unlike the development of software applications, where the requirements of the organizations are often relatively well defined by the result of the stability of business rules over time; create a data warehouse depends on the reality of the company and its current conditions.

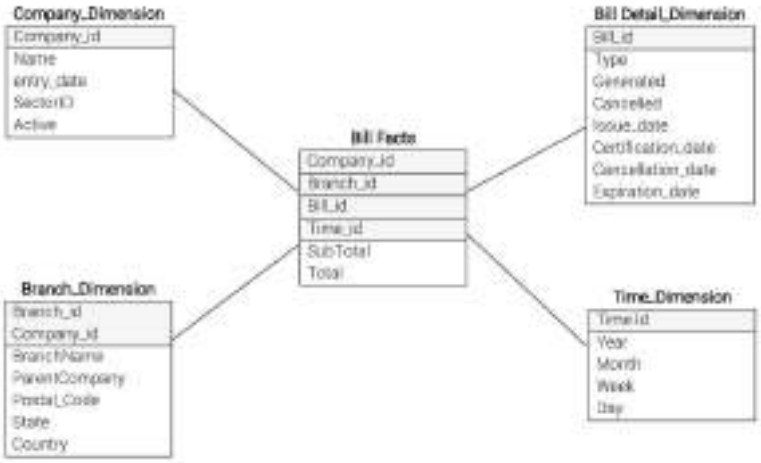

Fig. 2. Star schema for the proposed data warehouse.

Thus, the company requires identifying useful information in order to obtain significant information about its clients. In this way, the following key performance indicators (KPIs) were identified along with the business owners for the design and implementation of the data warehouse: a) Compare monthly growth of registered companies; b) Identify customer loyalty, through the use of the system more than 3 years; c) Identify quantity and list of branches by parent enterprise; d) Visualize the States where there are more than four companies using the management system; e) Measure different types of invoices volumes identifying the invoices variations not only by a time period but also, for company; f) Geographically view the top 10 companies that make the most invoices for a period of time; g) Compare the invoices by branch, time and state.

In order to model the data requirements, the 7Ws framework was used resulting in the identification of facts and dimensions in the star model, presented in Figure 2.

In this regard, the proposed dimensional model contains a fact table where the measurements or metrics of a specific event are recorded; for example, the invoice for a purchase and foreign keys referencing dimensional data tables (Company, Branch, Bill Detail and Time) which contain descriptive information. In order to implement the proposed model (see Figure 2), it is necessary to perform the ETL (Extraction, Transformation, Load) process which enables moving data from multiple sources, transform and load them into the data warehouse to analyze and thereby giving valuable information to organizations. In this way, Microsoft SQL Server Integration Services (SSIS) of Visual Studio 2015 was used to perform the ETL process. Finally, the information contained in the data warehouse was visualized through a scorecard developed using the Microsoft PowerBI tool. Thus, the KPIs were analyzed in order to identify the visual elements corresponding to each key indicator.

Once the visual elements are selected, the information about the clients is then shown in the scorecard by using queries in which decision-makers could use it interactively.

Fig. 3. Scorecard interface: Geographic coverage view of the system.

On the other hand, the software company's CEO was interested in seeing through graphs and trend lines, the situation and invoice generation behavior of those companies who use the management system.

In this way, it could be easily visualized when billing peaks are produced, i.e. sales generated by companies using the system. Figure 3 presents the view of the BI system that shows by state the number of companies who use the system, the bigger the circle the more companies that use the system are in the corresponding state. In this way, it is easy to identify the states where there is little or no presence of the system helping the decision-maker to pay attention in sale strategies. Likewise, Figure 4 presents the view related to invoice analysis where the number of invoices per type is visualized through an interactive list, a trend line to observe the behavior of the number of invoices is generated by each company who use the system and a pie chart showing the top 10 companies with the highest number of invoices issued by the system is shown.

In this way, it is possible to graphically observe the behavior of the number of invoices in a period of time by interacting with the system, allowing the decision-makers not only to know in what years more invoices per company are registered but also, detect those decreases that may indicate a risk in the strategic plan in order to develop an action plan.

3.2 Discussion of Results

The design and implementation of the proposed BI system using BEAM methodology allowed the analysis and design of the data warehouse through an agile method that focused on the users' needs and that easily respond to changes. Therefore, meetings with the working team, i.e., stakeholders, BI users, ETL developers, business analysts, among others, were held in order to compile information requirements during all stages of the project emphasizing uninterrupted communication and collaborative work.

Fig. 4. Number of invoices by time period.

On this basis, it ensures a greater understanding of the data warehouse information and the functionalities of the BI system. Moreover, the agile method maintains a logical data structure, scalable and adaptable to future functionalities such as the integration of other system's modules, predictive analysis, among others.

In this way, a robust and scalable BI system was designed and implemented where decision-makers can count on reliable, fast, flexible and easy-to-understand analyses through the scorecard, thereby facilitating the diagnosis of indicators and decision making. Accordingly, Figure 4 shows a scorecard of the invoices section, thus, the use of the scorecard provides reports of different participants in the decision-making process, representing an opportunity for homogenize and refine business processes. For this reason, it is expected to improve business opportunities through the use of key performance indicators by the extraction, processing and presentation of significant information according to the business strategic objectives. Eventually, the use of the BI system will positively impact the improvement of the company's value chain processes, its competitiveness and thus, the profitability of the business.

4 Conclusions and Future Work

Today, entrepreneurs need to analyze and interact with real-time visual information in order to support decision-making. In this regard, the methodologies used in the design of BI systems should consider the current needs and challenges where business requirements are not static and change constantly. Hence, this paper proposed the use of an agile dimensional model for the design and implementation of a data warehouse based on the BEAM methodology applied to a case study for a Software Development Company. In order to complete the project successfully, the organizational requirements were defined, the star schema was modeled, the ETL process was

executed, the data warehouse was implemented and finally, the KPIs were graphically displayed into the scorecard for decision-making.

The results obtained from the use of an agile methodology are found as a model easy- to-understand for the stakeholders; for this reason, it is mandatory to involve them in the whole process.

By adopting this agile approach, flexibility is ensure, as well as, personal coordination with the stakeholders, consistency and simplicity in the whole process.

As a future work, we plan to incorporate a predictive analysis section into the BI system allowing decision-makers to discover patterns, opportunities and prevent risks by increasing the profitability of the business.

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BeeSmart: A Videogame for Supporting Children with Down Syndrome in Eye-hand Coordination and Literacy Skills

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ABSTRACT

Children with Down Syndrome (DS) have deficits in eye-hand coordination skills. Deficits in eye-hand coordination could negatively impact the acquisition of literacy skills. In this paper, we present BeeSmart, a gesture-based videogame for supporting eye-hand coordination and literacy skills. BeeSmart is based on the Troncoso's method for literacy, and it uses a gesture tracking sensor. The interaction model of BeeSmart is through air gestures: children use the forefinger to play with the videogame. We describe the four playing levels of BeeSmart and how each one is aimed at supporting specific aspects of the literacy skills using eye-hand coordination.

CCS CONCEPTS

• **Social and professional topics → People with disabilities**;

KEYWORDS

Eye-hand coordination, literacy, Down Syndrome, videogame.

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1 INTRODUCTION

Down Syndrome (DS) is a genetic disorder caused by an extra chromosome, and it occurs in 1 about 700 births. Children with DS can have impairments in cognitive ability and physical growth, mild to moderate developmental disabilities, and a higher risk of some health problems (e.g., Alzheimer disease and epilepsy). Additionally, children with DS might experience deficits in eye-hand coordination [2]. That is, the ability to integrate both visual and motor abilities to accomplish a goal (e.g., reaching a ball). It involves using hands/fingers to reach a visual target. Deficits in eye-hand coordination could impact negatively on the acquisition of literacy skills (i.e., the ability to read and write [1][1]), as it is one of the main components that contribute to the quality of handwriting [5]. The Troncoso's method is an approach designed to teach children with DS read and write [4] and it is designed to recognize words as a whole, instead of breaking words into letters. The philosophy of the Troncoso's method is to recognize the meaning of written symbols (i.e., words) by association. Children recognize words making relationships between the written word and its associated pictogram.

Gesture-based videogames, digital games that are controlled using gestures without wearing additional aides (e.g., body markers) might have the potential to support eye-hand coordination of children with DS, as they can track hand movements to execute some actions on the screen, and due to its interactivity and engaging and immersive activities [3]. Also, gesture-based videogames can be a promising tool to support the literacy process, combined literacy methods for children with DS such as Troncoso [4], and gamification techniques, such as rewards. In this demo, we present BeeSmart, a gesture-based videogame for supporting eye-hand coordination and literacy skills of children with DS, based on the Troncoso's method for literacy.

[1]Literacy is an activity based on written and spelling systems.

Figure 1: BeeSmart levels. (a) Level 1; (b) Level 2; (c) Level 3; (d) Level 4.

2 SYSTEM DESCRIPTION

BeeSmart has four levels to be played by children with DS and a therapist module, where therapists can review details of the children's game sessions.

BeeSmart Levels

In each level, children use their forefinger to play the game, using air gestures. That is, children do not need to use any additional device to play the game. At the beginning, the therapist selects the topic (e.g., shapes, colors) and the word (e.g., triangle, yellow) that s/he wants to work with children.

Level 1: Drawing the pictogram. Children use their forefinger to draw pictograms (e.g., a square), following a dotted-path (Figure 1a). The written word associated with the pictogram is also shown on the screen and the pronunciation of the word is played at the beginning of the level. A button to replay the pronunciation of the word is available on the screen. In this level, children follow the dotted-paths, but at the same time, they are seeing the written word on the screen and listening to its pronunciation. The pronunciation feature is available in all levels as well as the pictogram and the written word are always shown on the screen to promote visual association of words and pictograms.

Level 2: Drawing the word.. Children use their forefinger to write a word following a dotted-path (each dot appears once the child joins the previous one) associated with the corresponding pictogram on the screen (Figure 1b).

Level 3: Ordering syllables. Children use their forefinger to move syllables to complete the word associated with the pictogram on the screen (Figure 1c) .

Level 4: Ordering letters. Children use their forefingers to move letters available on the screen to complete the word associated with the pictogram on the screen (Figure 1d).

Therapist Module

Although each BeeSmart's level requires a cognitive effort that is higher in the last levels and as each child with DS has a different cognitive and motor functioning level, it is the therapist who decides when the child should go on to the next level. To facilitate that, BeeSmart's therapist module enables therapists to review each game session played by children. For each game session, the therapist module shows the child's name, the level played, the duration of the game session (total and by trials), the successful and unsuccessful trials, as well as child's performance (displayed as a percentage of successful trials divided by the total trials).

Implementation Details

Gestures are tracked using the Intel®RealSense^{TM} SR300 Sensor. The tracking is activated once the therapist starts a level. Intel®RealSense^{TM} Sensor tracks children' forefinger, and it enables children to play all levels either with the right or the left hand. BeeSmart is implemented using C# language and Unity game engine development platform [2]. All data is stored on the local system (i.e., using a PC with an Intel Core i5 5th generation processor and 8 GB RAM).

An introductory video have been recorded available at YouTube at https://goo.gl/zJEM6j

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by **Asier Moreno (/search?authors=Asier%20Moreno&orcid=)**, **Pilar Elejoste (/search?authors=Pilar%20Elejoste&orcid=)**, **Antonio David Masegosa (/search?authors=Antonio%20David%20Masegosa&orcid=0000-0001-7759-9072)**, **Beatriz Rodriguez (/search?authors=Beatriz%20Rodriguez&orcid=)** and **Paula Perez (/search?authors=Paula%20Perez&orcid=)**

Proceedings **2018**, *2*(19), 1211; **https://doi.org/10.3390/proceedings2191211 (https://doi.org/10.3390/proceedings2191211)** - 23 Oct 2018

Viewed by 341

Abstract Many services and commodities have been deployed in airport terminals to provide additional conveniences. About half of revenues of airports in Europe come from the on-site non-aeronautical services offered. For this reason, the optimization of the existing resources is critical to maximize the **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1212/pdf)**

Multifunctional Interactive Furniture for Smart Cities (/2504-3900/2/19/1212)

by **Oihane Gómez-Carmona (/search?authors=Oihane%20G%C3%B3mez-Carmona&orcid=0000-0001-7439-2551)**, **Diego Casado-Mansilla (/search?authors=Diego%20Casado-Mansilla&orcid=0000-0002-1070-7494)** and **Diego López-de-Ipiña (/search?authors=Diego%20L%C3%B3pez-de-Ipi%C3%B1a&orcid=0000-0001-8055-6823)**

Proceedings **2018**, *2*(19), 1212; **https://doi.org/10.3390/proceedings2191212 (https://doi.org/10.3390/proceedings2191212)** - 01 Nov 2018

Cited by 1 (/2504-3900/2/19/1212#citedby) | Viewed by 431

Abstract The adaptation of cities to a future in which connectivity is at the service of the citizens will be a reality by creating interaction spaces and augmented urban areas. The research on this field falls within the scope of Smart Cities (SC) with **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1213/pdf)**

Flood Early Warning System by Twitter Using LoRa (/2504-3900/2/19/1213)

by **Ernesto Leon (/search?authors=Ernesto%20Leon&orcid=)**, **Cristian Alberoni (/search?authors=Cristian%20Alberoni&orcid=)**, **Miguel Wister (/search?authors=Miguel%20Wister&orcid=)** and **Jose A. Hernández-Nolasco (/search?authors=Jose%20A.%20Hern%C3%A1ndez-Nolasco&orcid=0000-0003-4671-0350)**

Proceedings **2018**, *2*(19), 1213; **https://doi.org/10.3390/proceedings2191213 (https://doi.org/10.3390/proceedings2191213)** - 24 Oct 2018

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Abstract In this paper, a sensor network architecture is presented. This work proposes an early warning system for river overflows. The sensor network consists of a river level sensor node that measures the distance between the sensor and the mass of water using a **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1214/pdf)**

Model of Dynamic Routes for Intelligent Police Patrolling (/2504-3900/2/19/1214)

by **Cesar Guevara (/search?authors=Cesar%20Guevara&orcid=0000-0003-1571-5829)**, **Janio Jadán (/search?authors=Janio%20Jad%C3%A1n&orcid=)**, **César Zapata (/search?authors=C%C3%A9sar%20Zapata&orcid=)**, **Luis Martínez (/search?authors=Luis%20Mart%C3%ADnez&orcid=)**, **Jairo Pozo (/search?authors=Jairo%20Pozo&orcid=)** and **Edison Manjarres (/search?authors=Edison%20Manjarres&orcid=)**

Proceedings **2018**, *2*(19), 1214; **https://doi.org/10.3390/proceedings2191214 (https://doi.org/10.3390/proceedings2191214)** - 24 Oct 2018

Viewed by 366

Abstract Patrolling and surveillance in cities around the world is a principal activity to guarantee the security of its citizens that is why nowadays the use of technology is of vital importance in order to identify offenses and criminal groups. The present article proposes **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1215/pdf)**

MUSA–I. towards New Social Tools for Advanced Multi-Modal Transportation in Smart Cities (/2504-3900/2/19/1215)

by **Víctor Manuel Padrón Nápoles (/search?authors=V%C3%ADctor%20Manuel%20Padr%C3%B3n%20N%C3%A1poles&orcid=)**, **Manuel de Buenaga Rodríguez (/search?authors=Manuel%20de%20Buenaga%20Rodr%C3%ADguez&orcid=)**, **Diego Gachet Páez (/search?authors=Diego%20Gachet%20P%C3%A1ez&orcid=0000-0001-6578-2275)**, **José Luis Esteban Penelas (/search?authors=Jos%C3%A9%20Luis%20Esteban%20Penelas&orcid=)**, **Alba Gutiérrez García-Ochoa (/search?authors=Alba%20Guti%C3%A9rrez%20Garc%C3%ADa-Ochoa&orcid=)** and **Alfonso López Pérez (/search?authors=Alfonso%20L%C3%B3pez%20P%C3%A9rez&orcid=)**

Proceedings **2018**, *2*(19), 1215; **https://doi.org/10.3390/proceedings2191215 (https://doi.org/10.3390/proceedings2191215)** - 19 Oct 2018

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Abstract Urban mobility optimization problem has a great focus in the context of Smart cities. To its solution a very important factor is the transport demand, which is mostly inferred using Big Data and Artificial Intelligence techniques from Automatic Fare Collection (AFC) and mobile **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1216/pdf)**

Using Graphs of Queues and Genetic Algorithms to Fast Approximate Crowd Simulations (/2504-3900/2/19/1216)

by **Ismael Sagredo-Olivenza (/search?authors=Ismael%20Sagredo-Olivenza&orcid=0000-0002-2921-0154)**, **Marlon Cárdenas-Bonett (/search?authors=Marlon%20C%C3%A1rdenas-Bonett&orcid=0000-0003-4371-4727)**,

Jorge J. Gómez-Sanz (/search?authors=Jorge%20J.%20G%C3%B3mez-Sanz&orcid=0000-0003-4534-378X) and
Juan Pavón (/search?authors=Juan%20Pav%C3%B3n&orcid=0000-0002-9553-8123)
Proceedings **2018**, *2*(19), 1216; **https://doi.org/10.3390/proceedings2191216 (https://doi.org/10.3390/proceedings2191216)**
- 25 Oct 2018
Viewed by 313

Abstract The use of Crowd Simulation for re-enacting different real life scenarios has been studied in the literature. In this field of research, the interplay between ambient assisted living solutions and the behavior of pedestrians in large installations is highly relevant. However, when designing **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1217/pdf)**

Using Data Mining to Analyze Dwell Time and Nonstop Running Time in Road-Based Mass Transit Systems (/2504-3900/2/19/1217)

by **Teresa Cristóbal (/search?authors=Teresa%20Crist%C3%B3bal&orcid=)**,
Gabino Padrón (/search?authors=Gabino%20Padr%C3%B3n&orcid=),
Alexis Quesada (/search?authors=Alexis%20Quesada&orcid=0000-0002-8313-5124),
Francisco Alayón (/search?authors=Francisco%20Alay%C3%B3n&orcid=),
Gabriel de Blasio (/search?authors=Gabriel%20de%20Blasio&orcid=0000-0002-6233-567X) and
Carmelo R. García (/search?authors=Carmelo%20R.%20Garc%C3%ADa&orcid=0000-0003-1433-3730)
Proceedings **2018**, *2*(19), 1217; **https://doi.org/10.3390/proceedings2191217 (https://doi.org/10.3390/proceedings2191217)**
- 17 Oct 2018
Viewed by 263

Abstract Travel Time plays a key role in the quality of service in road-based mass transit systems. In this type of mass transit systems, travel time of a public transport line is the sum of the dwell time at each bus stop and the **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1218/pdf)**

Safe Beacon: A Bluetooth Based Solution to Monitor Egress of Dementia Sufferers within a Residential Setting (/2504-3900/2/19/1218)

by **Joseph Rafferty (/search?authors=Joseph%20Rafferty&orcid=0000-0002-6318-8456)**,
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Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902),
Ian Cleland (/search?authors=Ian%20Cleland&orcid=), **Andrew Ennis (/search?authors=Andrew%20Ennis&orcid=)**,
Philip Catherwood (/search?authors=Philip%20Catherwood&orcid=),
Claire Orr (/search?authors=Claire%20Orr&orcid=), **Andrea Selby (/search?authors=Andrea%20Selby&orcid=)**,
Gary McDonald (/search?authors=Gary%20McDonald&orcid=) and
Gareth Morrison (/search?authors=Gareth%20Morrison&orcid=)
Proceedings **2018**, *2*(19), 1218; **https://doi.org/10.3390/proceedings2191218 (https://doi.org/10.3390/proceedings2191218)**
- 22 Oct 2018
Viewed by 385

Abstract The global population is ageing, as a consequence of this there will be a greater incidence of ageing related illnesses which cause cognitive impairment–such as Alzheimer's disease. Within residential care homes, such cognitive impairment can lead to wandering of individuals beyond the boundaries **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1219/pdf)**

Accessibility Index for Smart Cities (/2504-3900/2/19/1219)

by **Rafael Alejandro Mollá-Sirvent (/search?authors=Rafael%20Alejandro%20Moll%C3%A1-Sirvent&orcid=)**,
Higinio Mora (/search?authors=Higinio%20Mora&orcid=0000-0002-8591-0710),

Virgilio Gilart-Iglesias (/search?authors=Virgilio%20Gilart-Iglesias&orcid=0000-0001-7711-5357),
Raquel Pérez-delHoyo (/search?authors=Raquel%20P%C3%A9rez-delHoyo&orcid=) and
María Dolores Andújar-Montoya (/search?authors=Mar%C3%ADa%20Dolores%20And%C3%BAjar-Montoya&orcid=)
Proceedings **2018**, *2*(19), 1219; **https://doi.org/10.3390/proceedings2191219 (https://doi.org/10.3390/proceedings2191219)**
- 23 Oct 2018
Cited by 1 (/2504-3900/2/19/1219#citedby) | Viewed by 445

Abstract There is a growing social awareness about accessibility. The accessibility in cities and public spaces has become in an important issue in official agendas due to recent European directives. There are several studies on the way to improve accessibility in cities but they **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1220/pdf)**

A Cyclist Traffic Simulation and Analysis Tool (/2504-3900/2/19/1220)

by **Leo Ordinez (/search?authors=Leo%20Ordinez&orcid=)**,
Mauricio Savarro (/search?authors=Mauricio%20Savarro&orcid=),
Octavio Ascagorta (/search?authors=Octavio%20Ascagorta&orcid=),
Rodrigo René Cura (/search?authors=Rodrigo%20Ren%C3%A9%20Cura&orcid=),
Carlos Buckle (/search?authors=Carlos%20Buckle&orcid=),
Damián Barry (/search?authors=Dami%C3%A1n%20Barry%C2%A0&orcid=) and
Romina Stickar (/search?authors=Romina%20Stickar&orcid=)
Proceedings **2018**, *2*(19), 1220; **https://doi.org/10.3390/proceedings2191220 (https://doi.org/10.3390/proceedings2191220)**

Proceedings 2018, 2(19), 1220; https://doi.org/10.3390/proceedings2191220 (https://doi.org/10.3390/proceedings2191220)
- 02 Nov 2018
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Abstract The movement in favor of the use of bicycles as an alternative to mobility has been booming in the last two decades. This has been inserted within the policy of revaluation of the urban environment and improvement of the quality of life in **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1221/pdf)

Human Computation to Enhance E-Service Consumption among Elderlies (/2504-3900/2/19/1221)

by **Koldo Zabaleta (/search?authors=Koldo%20Zabaleta&orcid=)**,
Diego López-de-Ipiña (/search?authors=Diego%20L%C3%B3pez-de-Ipi%C3%B1a&orcid=0000-0001-8055-6823),
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Vincenzo Cartelli (/search?authors=Vincenzo%20Cartelli&orcid=),
Giuseppe Di Modica (/search?authors=Giuseppe%20Di%20Modica&orcid=0000-0003-4653-0480) and
Orazio Tomarchio (/search?authors=Orazio%20Tomarchio&orcid=)
Proceedings **2018**, *2*(19), 1221; **https://doi.org/10.3390/proceedings2191221 (https://doi.org/10.3390/proceedings2191221)**
- 18 Oct 2018
Viewed by 283

Abstract Smart Cities aim to increase citizens' quality of life. Smart Government is a part of Smart Cities domain aiming to enhance the communication and interactions of citizens and companies with government. The SIMPATICO framework combines machine and human intelligence to simplify e-services i.e., **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1222/pdf)

Discovering User's Trends and Routines from Location Based Social Networks (/2504-3900/2/19/1222)

by **Sergio Salomón (/search?authors=Sergio%20Salom%C3%B3n&orcid=)**,
Rafael Duque (/search?authors=Rafael%20Duque&orcid=) and
José Luis Montaña (/search?authors=Jos%C3%A9%20Luis%20Monta%C3%B1a&orcid=)
Proceedings **2018**, *2*(19), 1222; **https://doi.org/10.3390/proceedings2191222 (https://doi.org/10.3390/proceedings2191222)**
- 30 Oct 2018
Viewed by 296

Abstract Location data is a powerful source of information to discover user's trends and routines. A suitable identification of the user context can be exploited to provide automatically services adapted to the user preferences. In this paper, we define a Dynamic Bayesian Network model **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1223/pdf)

Impact of Beacon-Dependent Parameters on Bluetooth Low Energy Indoor Positioning Accuracy (/2504-3900/2/19/1223)

by **Gabriel de Blasio (/search?authors=Gabriel%20de%20Blasio&orcid=0000-0002-6233-567X)**,
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José Carlos Rodríguez-Rodríguez (/search?authors=Jos%C3%A9%20Carlos%20Rodr%C3%ADguez-Rodr%C3%ADguez&orcid=),
Carmelo R. García (/search?authors=Carmelo%20R.%20Garc%C3%ADa&orcid=0000-0003-1433-3730) and
Roberto Moreno-Díaz Jr. (/search?authors=Roberto%20Moreno-D%C3%ADaz%20Jr.&orcid=)
Proceedings **2018**, *2*(19), 1223; **https://doi.org/10.3390/proceedings2191223 (https://doi.org/10.3390/proceedings2191223)**
- 23 Oct 2018
Cited by 1 (/2504-3900/2/19/1223#citedby) | Viewed by 456

Abstract Blue Low Energy technology is playing an important role nowadays in ubiquitous systems, being the beacons a key element. The configuration of parameters related to the beacons, such as their transmission power or their advertising interval should be studied in order to build **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1224/pdf)

Determination of the Thermally Comfortable Air Temperature with Consideration of Individual Clothing and Activity as Preparation for a New Smart Home Heating System (/2504-3900/2/19/1224)

by **Alexander Peikos (/search?authors=Alexander%20Peikos&orcid=)** and
Carole Binsfeld (/search?authors=Carole%20Binsfeld&orcid=)
Proceedings **2018**, *2*(19), 1224; **https://doi.org/10.3390/proceedings2191224 (https://doi.org/10.3390/proceedings2191224)**
- 23 Oct 2018
Viewed by 335

Abstract The aim of this paper is to determine a thermally comfortable air temperature in an automated living room. This calculated temperature should serve as input for a user-specific and dynamic heating control in an automated living space. In addition to the usual physical **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1225/pdf)

Real-time Recognition of Interleaved Activities Based on Ensemble Classifier of Long Short-Term Memory with Fuzzy Temporal Windows (/2504-3900/2/19/1225)

by **Javier Medina Quero (/search?authors=Javier%20Medina%20Quero&orcid=0000-0002-8577-8772)**,
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Claire Orr (/search?authors=Claire%20Orr&orcid=), **Shuai Zang (/search?authors=Shuai%20Zang&orcid=)**,
Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902),
Alberto Salguero (/search?authors=Alberto%20Salguero&orcid=0000-0001-9221-7351) and
Macarena Espinilla (/search?authors=Macarena%20Espinilla&orcid=0000-0003-1118-7782)
Proceedings **2018**, *2*(19), 1225; **https://doi.org/10.3390/proceedings2191225 (https://doi.org/10.3390/proceedings2191225)** - 26 Oct 2018

Abstract In this paper, we present a methodology for Real-Time Activity Recognition of Interleaved Activities based on Fuzzy Logic and Recurrent Neural Networks. Firstly, we propose a representation of binary-sensor activations based on multiple Fuzzy Temporal Windows. Secondly, an ensemble of activity-based classifiers for **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1226/pdf)**

A Proposal for Supporting Learning Flute at Primary School (/2504-3900/2/19/1226)

by **Paloma Bravo (/search?authors=Paloma%20Bravo&orcid=)**,
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Cristina Cid (/search?authors=Cristina%20Cid&orcid=)
Proceedings **2018**, *2*(19), 1226; **https://doi.org/10.3390/proceedings2191226 (https://doi.org/10.3390/proceedings2191226)** - 22 Oct 2018

Abstract Music Education is a part of the Primary School curriculum in Spain. Students get only 45 min per week organized by group lessons. Thus, it is complicated for teachers to give individualized attention. Additionally, learning to play an instrument is difficult with the **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1227/pdf)**

Smart City Park Irrigation System: A Case Study of San Isidro, Lima—Peru (/2504-3900/2/19/1227)

by **Luis Cano (/search?authors=Luis%20Cano&orcid=0000-0003-3642-5783)**,
Claudio Ortega (/search?authors=Claudio%20Ortega&orcid=0000-0001-8423-7942),
Alvaro Talavera (/search?authors=Alvaro%20Talavera&orcid=0000-0002-2193-4270) and
Juan G. Lazo Lazo (/search?authors=Juan%20G.%20Lazo%20Lazo&orcid=0000-0001-7782-118X)
Proceedings **2018**, *2*(19), 1227; **https://doi.org/10.3390/proceedings2191227 (https://doi.org/10.3390/proceedings2191227)** - 25 Oct 2018

Abstract Water management has become a global priority in recent decades. The demand for water resources is increasing in cities due to the increase in population and the intensive use of water in economic activities and ornamentation. The problem is exacerbated when cities are **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1228/pdf)**

Enhancing Profile and Context Aware Relevant Food Search through Knowledge Graphs (/2504-3900/2/19/1228)

by **Unai Zulaika (/search?authors=Unai%20Zulaika&orcid=0000-0002-7366-9579)**,
Asier Gutiérrez (/search?authors=Asier%20Guti%C3%A9rrez&orcid=) and
Diego López-de-Ipiña (/search?authors=Diego%20L%C3%B3pez-de-Ipi%C3%B1a&orcid=0000-0001-8055-6823)
Proceedings **2018**, *2*(19), 1228; **https://doi.org/10.3390/proceedings2191228 (https://doi.org/10.3390/proceedings2191228)** - 25 Oct 2018

Abstract Foodbar is a Cloud-based gastroevaluation solution, leveraging IBM Watson cognitive services. It brings together machine and human intelligence to enable cognitive gastroevaluation of “tapas” or “pintxos” , i.e., small miniature bites or dishes. Foodbar matchmakes users’ profiles, preferences and context against an elaborated **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1229/pdf)**

A Research Agenda for IOT Adaptive Architectures (/2504-3900/2/19/1229)

by **Jairo Ariza (/search?authors=Jairo%20Ariza&orcid=0000-0002-2712-1633)**,
Camilo Mendoza (/search?authors=Camilo%20Mendoza&orcid=),
Kelly Garcés (/search?authors=Kelly%20Garc%C3%A9s&orcid=) and
Nicolás Cardozo (/search?authors=Nicol%C3%A1s%20Cardozo&orcid=)
Proceedings **2018**, *2*(19), 1229; **https://doi.org/10.3390/proceedings2191229 (https://doi.org/10.3390/proceedings2191229)** - 17 Oct 2018

Abstract Adaptation is very important in IOT systems, due to their continuously changing environments. Changes may come from different elements of the architecture underlying an IOT system. Existing literature pays special attention to changes in the Service layer using evolution agents or context aware **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1230/pdf)**

Blockchain Technologies for Private Data Management in AmI Environments (/2504-3900/2/19/1230)

by **Tomás Robles (/search?authors=Tom%C3%A1s%20Robles&orcid=0000-0002-6940-8421)**,
Borja Bordel (/search?authors=Borja%20Bordel&orcid=0000-0001-7815-5924),
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Diego Sánchez-de-Rivera (/search?authors=Diego%20S%C3%A1nchez-de-Rivera&orcid=)
Proceedings **2018**, *2*(19), 1230; **https://doi.org/10.3390/proceedings2191230 (https://doi.org/10.3390/proceedings2191230)** - 19 Oct 2018
Cited by 1 (/2504-3900/2/19/1230#citedby) | Viewed by 369

Abstract Blockchain enables the creation of distributed ledgers as a type of database that is shared, replicated, and synchronized among the members of a network. In this paper we analyze how distributed ledgers can be used for empowering end-users to self-manage their own data, **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1231/pdf)**

On The Case of Blockchain Adoption in the Internet of Things (/2504-3900/2/19/1231)

by **Davide Pedrini (/search?authors=Davide%20Pedrini&orcid=)**,
Mauro Migliardi (/search?authors=Mauro%20Migliardi&orcid=0000-0002-3634-7554),
Carlo Ferrari (/search?authors=Carlo%20Ferrari&orcid=) and **Alessio Merlo (/search?authors=Alessio%20Merlo&orcid=)**
Proceedings **2018**, *2*(19), 1231; **https://doi.org/10.3390/proceedings2191231 (https://doi.org/10.3390/proceedings2191231)** - 23 Oct 2018
Cited by 1 (/2504-3900/2/19/1231#citedby) | Viewed by 516

Abstract Recently blockchain technology has been advocated as a solution fitting many different problems in several applicative fields; among these fields there is the Internet of Things (IoT) too. In this paper we show the most significant properties of a blockchain, how they suite **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1232/pdf)**

RODEO: A Novel Methodology to Perform V2V Communications in the Scope of Internet of Vehicles. An Energy Performance Analysis (/2504-3900/2/19/1232)

by **Unai Hernandez-Jayo (/search?authors=Unai%20Hernandez-Jayo&orcid=)** and
Idoia De-la-Iglesia (/search?authors=Idoia%20De-la-Iglesia&orcid=)
Proceedings **2018**, *2*(19), 1232; **https://doi.org/10.3390/proceedings2191232 (https://doi.org/10.3390/proceedings2191232)** - 24 Oct 2018
Viewed by 289

Abstract In the framework of the Internet of Things (IoT) and more specifically the Internet of Vehicles (IoV), vehicles are called upon to play a key role as mobile sensors. Their high mobility and the large amount of electronics they currently deploy allow them **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1233/pdf)**

DNS-Based Dynamic Authentication for Microservices in IoT (/2504-3900/2/19/1233)

by **Daniel Díaz Sánchez (/search?authors=Daniel%20D%C3%ADaz%20S%C3%A1nchez&orcid=0000-0002-3323-6453)**,
Andrés Marín López (/search?authors=Andr%C3%A9s%20Mar%C3%ADn%20L%C3%B3pez&orcid=0000-0001-9350-0669),
Florina Almenares Mendoza (/search?authors=Florina%20Almenares%20Mendoza&orcid=0000-0002-5232-2031) and
Patricia Arias Cabarcos (/search?authors=Patricia%C2%A0Arias%C2%A0%20Cabarcos&orcid=)
Proceedings **2018**, *2*(19), 1233; **https://doi.org/10.3390/proceedings2191233 (https://doi.org/10.3390/proceedings2191233)** - 25 Oct 2018
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Abstract IoT devices provide with real-time data to a rich ecosystems of services and applications that will be of uttermost importance for ubiquitous computing. The volume of data and the involved subscribe/notify signaling will likely become a challenge also for access and core netkworks. **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1234/pdf)**

Protocol for Streaming Data from an RFID Sensor Network (/2504-3900/2/19/1234)

by **Laura Arjona (/search?authors=Laura%20Arjona&orcid=)**,
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Asier Perallos (/search?authors=Asier%20Perallos&orcid=) and
Gentza Souto (/search?authors=Gentza%20Souto&orcid=)
Proceedings **2018**, *2*(19), 1234; **https://doi.org/10.3390/proceedings2191234 (https://doi.org/10.3390/proceedings2191234)** - 01 Nov 2018
Viewed by 388

Abstract Currently, there is an increasing interest in the use of Radio Frequency Identification (RFID) tags which incorporate passive or battery-less sensors. These systems are known as computational RFID (CRFID). Several CRFID tags together with a reader set up an RFID sensor network. The **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1235/pdf)**

Assessment of Fitness Tracker Security: A Case of Study (/2504-3900/2/19/1235)

by **Florina Almenares Mendoza (/search?authors=Florina%20Almenares%20Mendoza&orcid=0000-0002-5232-2031)**,
Lucía Alonso (/search?authors=Luc%C3%ADa%20Alonso&orcid=0000-0002-5994-743X),
Andrés Marín López (/search?authors=Andr%C3%A9s%20Mar%C3%ADn%20L%C3%B3pez&orcid=0000-0001-9350-0669) and
Daniel Díaz Sánchez And Patricia Arias Cabarcos (/search?

Daniel Díaz-Sánchez and Patricia Arias-Cabarcos (/search?authors=Daniel%20D%C3%ADaz%20S%C3%A1nchez%20And%C2%A0Patricia%C2%A0Arias%C2%A0Cabarcos&orcid=)
Proceedings **2018**, *2*(19), 1235; **https://doi.org/10.3390/proceedings2191235 (https://doi.org/10.3390/proceedings2191235)** - 26 Oct 2018
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Abstract The wearable industry has experienced a notable growth over the last decade, especially in fitness or e-health trackers. These trackers bring new functionalities that require collecting a great amount of sensitive information about the user. This fact has made fitness trackers the target **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1236/pdf)**

Detection of Falls from Non-Invasive Thermal Vision Sensors Using Convolutional Neural Networks (/2504-3900/2/19/1236)

by **Javier Medina Quero (/search?authors=Javier%20Medina%20Quero&orcid=0000-0002-8577-8772)**, **Matthew Burns (/search?authors=Matthew%20Burns&orcid=)**, **Muhammad Asif Razzaq (/search?authors=Muhammad%20Asif%20Razzaq&orcid=0000-0002-0061-8834)**, **Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902)** and **Macarena Espinilla (/search?authors=Macarena%20Espinilla&orcid=0000-0003-1118-7782)**
Proceedings **2018**, *2*(19), 1236; **https://doi.org/10.3390/proceedings2191236 (https://doi.org/10.3390/proceedings2191236)** - 24 Oct 2018
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Abstract In this work, we detail a methodology based on Convolutional Neural Networks (CNNs) to detect falls from non-invasive thermal vision sensors. First, we include an agile data collection to label images in order to create a dataset that describes several cases of single **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1237/pdf)**

Multimodal Database for Human Activity Recognition and Fall Detection (/2504-3900/2/19/1237)

by **Lourdes Martínez-Villaseñor (/search?authors=Lourdes%20Mart%C3%ADnez-Villase%C3%B1or&orcid=0000-0002-9038-7821)**, **Hiram Ponce (/search?authors=Hiram%20Ponce&orcid=0000-0002-6559-7501)** and **Ricardo Abel Espinosa-Loera (/search?authors=Ricardo%20Abel%20Espinosa-Loera&orcid=)**
Proceedings **2018**, *2*(19), 1237; **https://doi.org/10.3390/proceedings2191237 (https://doi.org/10.3390/proceedings2191237)** - 22 Oct 2018
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Abstract Fall detection can improve the security and safety of older people and alert when fall occurs. Fall detection systems are mainly based on wearable sensors, ambient sensors, and vision. Each method has commonly known advantages and limitations. Multimodal and data fusion approaches present **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1238/pdf)**

High-Level Features for Recognizing Human Actions in Daily Living Environments Using Wearable Sensors (/2504-3900/2/19/1238)

by **Irvin Hussein López-Nava (/search?authors=Irvin%20Hussein%20L%C3%B3pez-Nava&orcid=)** and **Angélica Muñoz-Meléndez (/search?authors=Ang%C3%A9lica%20Mu%C3%B1oz-Mel%C3%A9ndez&orcid=)**
Proceedings **2018**, *2*(19), 1238; **https://doi.org/10.3390/proceedings2191238 (https://doi.org/10.3390/proceedings2191238)** - 24 Oct 2018
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Abstract Action recognition is important for various applications, such as, ambient intelligence, smart devices, and healthcare. Automatic recognition of human actions in daily living environments, mainly using wearable sensors, is still an open research problem of the field of pervasive computing. This research focuses **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1239/pdf)**

Intelligent Power Management System Using Hybrid Renewable Energy Resources and Decision Tree Approach (/2504-3900/2/19/1239)

by **Francisco-Javier Ferrández-Pastor (/search?authors=Francisco-Javier%20Ferr%C3%A1ndez-Pastor&orcid=0000-0002-3763-4790)**, **Sergio Gómez-Trillo (/search?authors=Sergio%20G%C3%B3mez-Trillo&orcid=)**, **Mario Nieto-Hidalgo (/search?authors=Mario%20Nieto-Hidalgo&orcid=)**, **Juan-Manuel García-Chamizo (/search?authors=Juan-Manuel%20Garc%C3%ADa-Chamizo&orcid=)** and **Rafael Valdivieso-Sarabia (/search?authors=Rafael%20Valdivieso-Sarabia&orcid=0000-0002-1846-2217)**

Proceedings **2018**, *2*(19), 1239; **https://doi.org/10.3390/proceedings2191239 (https://doi.org/10.3390/proceedings2191239)** - 19 Oct 2018
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Abstract Optimal power usage and consumption require continuous monitoring, forecasting electric energy consumption and renewable generation. To facilitate integration of renewable energies and optimize their resources, new communication and data processing technologies are used in new projects. This article shows the works and results **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1240/pdf)

Event-Driven Real-Time Location-Aware Activity Recognition in AAL Scenarios (/2504-3900/2/19/1240)

by **Antonio Jiménez (/search?authors=Antonio%20Jim%C3%A9nez&orcid=0000-0001-9771-1930)** and **Fernando Seco (/search?authors=Fernando%20Seco&orcid=0000-0002-2922-2710)**

Proceedings **2018**, *2*(19), 1240; **https://doi.org/10.3390/proceedings2191240 (https://doi.org/10.3390/proceedings2191240)** - 30 Oct 2018

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Abstract The challenge of recognizing different personal activities while living in an apartment is of great interest for the AAL community. Many different approaches have been presented trying to achieve good accuracies in activity recognition, combined with different heuristics, windowing and segmentation methods. In **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1241/pdf)

H^2Al—The Human Health and Activity Laboratory (/2504-3900/2/19/1241)

by **Kåre Synnes (/search?authors=K%C3%A5re%20Synnes&orcid=0000-0003-4549-6751)**, **Margareta Lilja (/search?authors=Margareta%20Lilja&orcid=0000-0003-1026-5419)**, **Anneli Nyman (/search?authors=Anneli%20Nyman&orcid=0000-0003-0467-4857)**, **Macarena Espinilla (/search?authors=Macarena%20Espinilla&orcid=0000-0003-1118-7782)**, **Ian Cleland (/search?authors=Ian%20Cleland&orcid=)**, **Andres Gabriel Sanchez Comas (/search?authors=Andres%20Gabriel%20Sanchez%20Comas&orcid=0000-0002-4280-8070)**, **Zhoe Comas-Gonzalez (/search?authors=Zhoe%20Comas-Gonzalez&orcid=)**, **Josef Hallberg (/search?authors=Josef%20Hallberg&orcid=)**, **Niklas Karvonen (/search?authors=Niklas%20Karvonen&orcid=)**, **Wagner Ourique de Morais (/search?authors=Wagner%20Ourique%20de%20Morais&orcid=)**, **Federico Cruciani (/search?authors=Federico%20Cruciani&orcid=0000-0002-1870-0203)** and **Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902)**

Proceedings **2018**, *2*(19), 1241; **https://doi.org/10.3390/proceedings2191241 (https://doi.org/10.3390/proceedings2191241)** - 22 Oct 2018

Viewed by 401

Abstract The Human Health and Activity Laboratory (H^2Al) is a new research facility at Luleå University of Technology implemented during 2018 as a smart home environment in an educational training apartment for nurses and therapists at the Luleå campus. This paper presents **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1242/pdf)

Human Activity Recognition from the Acceleration Data of a Wearable Device. Which Features Are More Relevant by Activities? (/2504-3900/2/19/1242)

by **Macarena Espinilla (/search?authors=Macarena%20Espinilla&orcid=0000-0003-1118-7782)**, **Javier Medina (/search?authors=Javier%20Medina&orcid=0000-0002-8577-8772)**, **Alberto Salguero (/search?authors=Alberto%20Salguero&orcid=0000-0001-9221-7351)**, **Naomi Irvine (/search?authors=Naomi%20Irvine&orcid=)**, **Mark Donnelly (/search?authors=Mark%20Donnelly&orcid=0000-0003-1250-265X)**, **Ian Cleland (/search?authors=Ian%20Cleland&orcid=)** and **Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902)**

Proceedings **2018**, *2*(19), 1242; **https://doi.org/10.3390/proceedings2191242 (https://doi.org/10.3390/proceedings2191242)** - 17 Oct 2018

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Abstract Data driven approaches for human activity recognition learn from pre-existent large-scale datasets to generate a classification algorithm that can recognize target activities. Typically, several activities are represented within such datasets, characterized by multiple features that are computed from sensor devices. Often, some features **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1243/pdf)

Human Behaviour Analysis through Smartphones (/2504-3900/2/19/1243)

by **Kostas Konsolakis (/search?authors=Kostas%20Konsolakis&orcid=0000-0002-7666-3308)**, **Hermie Hermens (/search?authors=Hermie%20Hermens&orcid=)**, **Claudia Villalonga (/search?authors=Claudia%20Villalonga&orcid=)**, **Miriam Vollenbroek-Hutten (/search?authors=Miriam%20Vollenbroek-Hutten&orcid=)** and **Oresti Banos (/search?authors=Oresti%20Banos&orcid=)**

Proceedings **2018**, *2*(19), 1243; **https://doi.org/10.3390/proceedings2191243 (https://doi.org/10.3390/proceedings2191243)** - 30 Oct 2018

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Abstract Human behaviour analysis through smartphone devices has been an active field for more than a decade and there are still a lot of key aspects to be addressed. This paper surveys the state-of-the-art in human behaviour analysis based on smartphones. We categorise prior **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1244/pdf)

Portal Design for the Open Data Initiative: A Preliminary Study (/2504-3900/2/19/1244)

by **Netzahualcoyotl Hernandez (/search?authors=Netzahualcoyotl%20Hernandez&orcid=0000-0002-3603-4806)**, **Ian McChesney (/search?authors=Ian%20McChesney&orcid=)**, **Joe Rafferty (/search?authors=Joe%20Rafferty&orcid=0000-0002-6318-8456)**, **Chris Nugent (/search?authors=Chris%20Nugent&orcid=0000-0003-0882-7902)**, **Jonathan Synnott (/search?authors=Jonathan%20Synnott&orcid=)** and **Shuai Zhang (/search?authors=Shuai%20Zhang&orcid=)**

Proceedings **2018**, *2*(19), 1244; **https://doi.org/10.3390/proceedings2191244 (https://doi.org/10.3390/proceedings2191244)** - 23 Oct 2018

Viewed by 299

Abstract The Open Data Initiative (ODI) has been previously proposed to facilitate the sharing of annotated datasets within the pervasive health care research community. This paper outlines the requirements for the ODI portal based on the ontological data model of the ODI and its **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1245/pdf)**

A Comparative Analysis of Windowing Approaches in Dense Sensing Environments (/2504-3900/2/19/1245)

by **Bronagh Quigley (/search?authors=Bronagh%20Quigley&orcid=)**, **Mark Donnelly (/search?authors=Mark%20Donnelly&orcid=0000-0003-1250-265X)**, **George Moore (/search?authors=George%20Moore&orcid=0000-0003-1623-0014)** and **Leo Galway (/search?authors=Leo%20Galway&orcid=)**

Proceedings **2018**, *2*(19), 1245; **https://doi.org/10.3390/proceedings2191245 (https://doi.org/10.3390/proceedings2191245)** - 17 Oct 2018

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Abstract Windowing is an established technique employed within dense sensing environments to extract relevant features from sensor data streams. Among the established approaches of Explicit, Time-based and Sensor-Event based windowing, Dynamic windowing approaches are beginning to emerge. These dynamic approaches claim to address the **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1246/pdf)**

A Computational Approach to Improve the Gathering of Ambient Assisted Living Requirements (/2504-3900/2/19/1246)

by **Noelia García Castillo (/search?authors=Noelia%20Garc%C3%ADa%20Castillo&orcid=)**, **Juan Luis Pérez (/search?authors=Juan%20Luis%20P%C3%A9rez&orcid=)** and **Jorge J. Gómez-Sanz (/search?authors=Jorge%20J.%20G%C3%B3mez-Sanz&orcid=0000-0003-4534-378X)**

Proceedings **2018**, *2*(19), 1246; **https://doi.org/10.3390/proceedings2191246 (https://doi.org/10.3390/proceedings2191246)** - 22 Oct 2018

Viewed by 289

Abstract Recent publications focus on the importance of designing an Ambient Intelligence that can be sensitive to human values and responsible for its societal impact. Obtaining and properly modeling these requirements can be a challenging task. Co-creation and social sciences methods are frequently applied **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1247/pdf)**

Associations between Commonly Used Characteristics in Frailty Assessment and Mental State in Frail Elderly People (/2504-3900/2/19/1247)

by **Iván González (/search?authors=Iv%C3%A1n%20Gonz%C3%A1lez&orcid=0000-0001-5302-1831)**, **Rocío De la Cruz Garrido (/search?authors=Roc%C3%ADo%20De%20la%20Cruz%20Garrido&orcid=)**, **Fco Javier Navarro (/search?authors=Fco%20Javier%20Navarro&orcid=)**, **Jesús Fontecha (/search?authors=Jes%C3%BAs%20Fontecha&orcid=0000-0001-6379-6841)**, **Ramón Hervás (/search?authors=Ram%C3%B3n%20Herv%C3%A1s&orcid=0000-0001-9924-5443)** and **José Bravo (/search?authors=Jos%C3%A9%20Bravo&orcid=)**

Proceedings **2018**, *2*(19), 1247; **https://doi.org/10.3390/proceedings2191247 (https://doi.org/10.3390/proceedings2191247)** - 17 Oct 2018

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Abstract This paper presents a cross-sectional study to analyze the impact on cognitive decline of a set of characteristics used for frailty assessment in elderly people. Considered characteristics come from several dimensions, including anthropometric, biological, nutritional, functional and mobility. Cognitive functioning is estimated by **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1248/pdf)**

A Qualitative Assessment of an Ambient Display to Support In-Home Medication of Older Adults (/2504-3900/2/19/1248)

by **Marcela D. Rodríguez (/search?authors=Marcela%20D.%20Rodr%C3%ADguez&orcid=0000-0002-6943-7812)**, **Ernesto Zarate-Bravo (/search?authors=Ernesto%20Zarate-Bravo&orcid=)**, **Juan-Pablo García-Vázquez (/search?authors=Juan-Pablo%20Garc%C3%ADa-V%C3%A1zquez&orcid=0000-0003-1787-7223)**, **Ángel G. Andrade (/search?authors=%C3%81ngel%20G.%20Andrade&orcid=0000-0003-0829-5803)**, **René F. Navarro (/search?authors=Ren%C3%A9%20F.%20Navarro&orcid=)**, **Engracia Torres-Cervantes (/search?authors=Engracia%20Torres-Cervantes&orcid=)** and **Gisela Ponce (/search?authors=Gisela%20Ponce&orcid=)**

Proceedings **2018**, *2*(19), 1248; **https://doi.org/10.3390/proceedings2191248 (https://doi.org/10.3390/proceedings2191248)**

- 22 Oct 2018
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Abstract Studies on ambient computing technologies have shown their potential for assisting older adults to manage medications. However, their results cannot be generalizable, since they were conducted in different settings. We assessed the feasibility of a Medication Ambient Display (MAD) to improve the medication **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1249/pdf)**

Seamlessly Mediation of Social Interaction Services Respecting Communication Preferences (/2504-3900/2/19/1249)

by **Felipe Rodríguez (/search?authors=Felipe%20Rodr%C3%ADguez&orcid=)**,
Sergio F. Ochoa (/search?authors=Sergio%20F.%20Ochoa&orcid=0000-0002-0431-8767) and
Francisco J. Gutierrez (/search?authors=Francisco%20J.%20Gutierrez&orcid=)
Proceedings **2018**, *2*(19), 1249; **https://doi.org/10.3390/proceedings2191249 (https://doi.org/10.3390/proceedings2191249)**
- 18 Oct 2018
Viewed by 267

Abstract The diversification and evolution of social media tools conveys users to adopt new systems and use new features of existing ones. Although this dynamism is suitably addressed by digital natives, it usually limits the technology adoption capability of digital immigrants, e.g., older adults, **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1250/pdf)**

Modeling Computer-Mediated User Interactions in Ubiquitous Collaborative Systems (/2504-3900/2/19/1250)

by **Maximiliano Canché (/search?authors=Maximiliano%20Canch%C3%A9&orcid=0000-0003-0427-5207)** and
Sergio F. Ochoa (/search?authors=Sergio%20F.%20Ochoa&orcid=0000-0002-0431-8767)
Proceedings **2018**, *2*(19), 1250; **https://doi.org/10.3390/proceedings2191250 (https://doi.org/10.3390/proceedings2191250)**
- 17 Oct 2018
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Abstract Modelling ubiquitous collaborative systems that support people-driven processes represents a major challenge for software designers, since there is no a workflow that helps identify the scenarios in which the interaction among the participants could take place. Typically, this reduces the effectiveness of the **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1251/pdf)**

Architecture for Efficient String Dictionaries in E-Learning (/2504-3900/2/19/1251)

by **Antonio Ferrández (/search?authors=Antonio%20Ferr%C3%A1ndez&orcid=0000-0003-3406-3838)**,
Jesús Peral (/search?authors=Jes%C3%BAs%20Peral&orcid=),
Higinio Mora (/search?authors=Higinio%20Mora&orcid=0000-0002-8591-0710) and
David Gil (/search?authors=David%20Gil&orcid=0000-0003-0791-8298)
Proceedings **2018**, *2*(19), 1251; **https://doi.org/10.3390/proceedings2191251 (https://doi.org/10.3390/proceedings2191251)**
- 18 Oct 2018
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Abstract E-Learning is a response to the new educational needs of society and an important development in Information and Communication Technologies. However, this trend presents many challenges, such as the lack of an architecture that allows a unified management of heterogeneous string dictionaries required **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1252/pdf)**

Towards a Taxonomy of Feedback Factors Affecting the User Experience of Augmented Reality Exposure Therapy Systems for Small-Animal Phobias (/2504-3900/2/19/1252)

by **Cristina Ramírez-Fernández (/search?authors=Cristina%20Ram%C3%ADrez-Fern%C3%A1ndez&orcid=)**,
Alberto L. Morán (/search?authors=Alberto%20L.%20Mor%C3%A1n&orcid=0000-0002-6540-0764) and
Victoria Meza-Kubo (/search?authors=Victoria%20Meza-Kubo&orcid=)
Proceedings **2018**, *2*(19), 1252; **https://doi.org/10.3390/proceedings2191252 (https://doi.org/10.3390/proceedings2191252)**
- 17 Oct 2018
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Abstract Small-animal phobias has been treated using in vivo exposure therapies (IVET) and virtual reality exposure therapies (VRET). Recently, augmented reality for exposure therapies (ARET) has also been presented and validated as a suitable tool. In this work we identified an ensemble of feedback **[...] Read more.**

Open Access Proceedings **(/2504-3900/2/19/1253/pdf)**

Designing Affordable Technologies to Integrate Citizens in Early Warning Activities (/2504-3900/2/19/1253)

by **Paloma Díaz (/search?authors=Paloma%20D%C3%ADaz&orcid=0000-0002-9493-7739)**,
Teresa Onorati (/search?authors=Teresa%20Onorati&orcid=),
Marco Romano (/search?authors=Marco%20Romano&orcid=) and
Ignacio Aedo (/search?authors=Ignacio%20Aedo&orcid=)
Proceedings **2018**, *2*(19), 1253; **https://doi.org/10.3390/proceedings2191253 (https://doi.org/10.3390/proceedings2191253)**
- 19 Oct 2018
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Abstract Early warning consists of monitoring precursors of a potential hazard to understand if it is evolving to a real risk and

then be able to orchestrate an early response before the event happens in order to reduce its impact and damages. It mainly **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1254/pdf)

Supporting Collaborative Preparation of Emergency Plans (/2504-3900/2/19/1254)

by **Nelson Baloian (/search?authors=Nelson%20Baloian&orcid=0000-0003-1608-6454)**, **Jonathan Frez (/search?authors=Jonathan%20Frez&orcid=)**, **José A. Pino (/search?authors=Jos%C3%A9%20A.%20Pino&orcid=)** and **Gustavo Zurita (/search?authors=Gustavo%20Zurita&orcid=0000-0003-0757-1247)**

Proceedings **2018**, *2*(19), 1254; **https://doi.org/10.3390/proceedings2191254 (https://doi.org/10.3390/proceedings2191254)** - 26 Oct 2018

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Abstract Effective preparedness for reacting in case of a severe emergency requires that many experts with various backgrounds evaluate the possible scenarios and come up with a single, unified plan which considers all opinions. This is a typical collaborative decision-making scenario, characterized by a **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1255/pdf)

Beacon-Based Fuzzy Indoor Tracking at Airports (/2504-3900/2/19/1255)

by **Josué Toledo-Castro (/search?authors=Josu%C3%A9%20Toledo-Castro&orcid=)**, **Pino Caballero-Gil (/search?authors=Pino%20Caballero-Gil&orcid=)**, **Nayra Rodríguez-Pérez (/search?authors=Nayra%20Rodr%C3%ADguez-P%C3%A9rez&orcid=)**, **Iván Santos-González (/search?authors=Iv%C3%A1n%20Santos-Gonz%C3%A1lez&orcid=)** and **Candelaria Hernández-Goya (/search?authors=Candelaria%20Hern%C3%A1ndez-Goya&orcid=)**

Proceedings **2018**, *2*(19), 1255; **https://doi.org/10.3390/proceedings2191255 (https://doi.org/10.3390/proceedings2191255)** - 19 Oct 2018

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Abstract An application of Bluetooth beacons is here proposed to perform real-time tracking of the locations and movements of airport staff through different monitored airport infrastructure elements, such as rooms, terminals or boarding gates. With respect to this, the aim is to provide an **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1256/pdf)

Disaster Risk Communication in Culturally and Linguistically Diverse Communities: The Role of Technology (/2504-3900/2/19/1256)

by **Robert Ogie (/search?authors=Robert%20Ogie&orcid=0000-0002-6476-2309)**, **Juan Castilla Rho (/search?authors=Juan%20Castilla%20Rho&orcid=)**, **Rodney J. Clarke (/search?authors=Rodney%20J.%20Clarke&orcid=)** and **Alison Moore (/search?authors=Alison%20Moore&orcid=)**

Proceedings **2018**, *2*(19), 1256; **https://doi.org/10.3390/proceedings2191256 (https://doi.org/10.3390/proceedings2191256)** - 26 Oct 2018

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Abstract Migrants, ethnic minorities and people from culturally and linguistically diverse (CALD) communities are often more vulnerable to natural disasters due to cultural barriers and limited proficiency in the dominant language, which sometimes undermine their ability to access, interpret and respond to warnings. Technology **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1257/pdf)

Real-Time Primitives for CoAP: Extending the Use of IoT for Time Constraint Applications for Social Good (/2504-3900/2/19/1257)

by **Gabriel M. Eggly (/search?authors=Gabriel%20M.%20Eggly&orcid=0000-0002-4328-0183)**, **Mariano Finochietto (/search?authors=Mariano%20Finochietto&orcid=)**, **Emmanouil Dimogerontakis (/search?authors=Emmanouil%20Dimogerontakis&orcid=)**, **Rodrigo M. Santos (/search?authors=Rodrigo%20M.%20Santos&orcid=0000-0003-0382-477X)**, **Javier Orozco (/search?authors=Javier%20Orozco&orcid=)** and **Roc Meseguer (/search?authors=Roc%20Meseguer&orcid=0000-0002-9414-646X)**

Proceedings **2018**, *2*(19), 1257; **https://doi.org/10.3390/proceedings2191257 (https://doi.org/10.3390/proceedings2191257)** - 24 Oct 2018

Viewed by 344

Abstract Internet of Things (IoT) have become a hot topic since the official introduction of IPv6. Research on Wireless Sensors Networks (WSN) move towards IoT as the communication platform and support provided by the TCP/UDP/IP stack provides a wide variety of services. The communication **[...] Read more.**

Open Access Proceedings (/2504-3900/2/19/1258/pdf)

The RIMO Gateway Selection Approach for Mesh Networks: Towards a Global Internet Access for All (/2504-3900/2/19/1258)

by **Khulan Batbayar (/search?authors=Khulan%20Batbayar&orcid=)**, **Emmanouil Dimogerontakis (/search?authors=Emmanouil%20Dimogerontakis&orcid=)**, **Roc Meseguer (/search?authors=Roc%20Meseguer&orcid=0000-0002-9414-646X)**, **Leandro Navarro (/search?authors=Leandro%20Navarro&orcid=)**

Leandro Navarro (/search?authors=Leandro%20Navarro&orcid=),
Esunly Medina (/search?authors=Esunly%20Medina&orcid=) and
Rodrigo M. Santos (/search?authors=Rodrigo%20M.%20Santos&orcid=0000-0003-0382-477X)
Proceedings **2018**, *2*(19), 1258; **https://doi.org/10.3390/proceedings2191258 (https://doi.org/10.3390/proceedings2191258)**
- 25 Oct 2018
Viewed by 345

Abstract Community wireless mesh networks have emerged as cooperative initiatives to provide Internet Access in areas where

traditional ISP costs are not affordable for the population. It is common in wireless mesh networks sharing several capacity limited Internet gateways to provide Internet access. As **[...] Read more.**

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An RFID-Based Digital Bracelet for the Timely Assistance of Indigents (/2504-3900/2/19/1259)

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Proceedings **2018**, *2*(19), 1259; **https://doi.org/10.3390/proceedings2191259 (https://doi.org/10.3390/proceedings2191259)**
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Abstract High rates of indigence characterize several countries in Latin America, such as Mexico. In the north of our country, the phenomenon of migration contributes to indigence. To get a preliminary understanding of the needs of indigents in our community, we conducted interviews with **[...] Read more.**

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Proceedings **2018**, *2*(19), 1261; **https://doi.org/10.3390/proceedings2191261 (https://doi.org/10.3390/proceedings2191261)**
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Proceedings **2018**, *2*(19), 1264; **https://doi.org/10.3390/proceedings2191264 (https://doi.org/10.3390/proceedings2191264)** - 18 Oct 2018
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Abstract This short paper presents the activity recognition results obtained from the CAR-CSIC team for the UCAmI'18 Cup. We propose a multi-event naive Bayes classifier for estimating 24 different activities in real-time. We use all the sensorial information provided for the competition, i.e., binary **[...] Read more.**

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Diego M. López (/search?authors=Diego%20M.%20L%C3%B3pez&orcid=) and
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Sozo INOUE (/search?authors=Sozo%20INOUE&orcid=)
Proceedings **2018**, *2*(19), 1266; **https://doi.org/10.3390/proceedings2191266 (https://doi.org/10.3390/proceedings2191266)** - 25 Oct 2018
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Abstract We detail the solution to the UCAmI Cup Challenge to recognizing on going activities at home from sensor measurements. We use binary sensors and proximity sensor measurements for the recognition. We use an hybrid strategy, combining a probabilistic model and a definition-based model. **[...] Read more.**

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UCAmI Cup. Analyzing the UJA Human Activity Recognition Dataset of Activities of Daily Living (/2504-3900/2/19/1267)

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Javier Medina (/search?authors=Javier%20Medina&orcid=0000-0002-8577-8772) and
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Proceedings **2018**, *2*(19), 1267; **https://doi.org/10.3390/proceedings2191267 (https://doi.org/10.3390/proceedings2191267)** - 26 Oct 2018
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Abstract Many real-world applications, which are focused on addressing the needs of a human, require information pertaining to the activities being performed. The UCAmI Cup is an event held within the context of the International Conference on Ubiquitous Computing and Ambient Intelligence, where delegates **[...] Read more.**

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InCense IoT: A Collective Sensing System for Behavior Data in Shared Spaces †

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Published: 23 October 2018

Abstract: Behavioral sensing systems collect data from smartphones, wearables, and other devices with the aim of analyzing and making sense of them. In this work, we present InCense IoT, a collective sensing system which uses mobile and ubiquitous sensors for collecting behavior data of groups of participants in shared spaces. This paper describes the concept of collective sensing, an implementation onto InCense called InCense IoT, innovative features, advantages over individual-centric sensing systems. Finally, this paper presents results of a use case using it in monitoring behaviors in mother-child interactions.

Keywords: collective sensing; mobile sensing; behavioral sensing system

1. Introduction

In recent years, the Internet of Things (IoT) has become popular due to the implementation of useful applications in different areas (e.g., activity recognition). Researchers typically relate this term with technologies such as sensors, actuators, and mobile devices, which combine efforts to solve problems of daily life. Due to the advancement and popularity of IoT, there is interest in using IoT-based systems in the industry such as security, transportation, environmental monitoring, and many others.

Researchers have created various tools which can be used for creating mobile sensing campaigns. These tools, which we refer to as Behavioral Sensing Systems (BSS), are responsible for monitoring human subjects using smartphones, wearables, and other devices. These BSSs have been applied in several domains such as health care. For instance, in [1] implemented a BSS as an alert mechanism for in-hospital emergencies. Also, there are specialized platforms in health monitoring for patients with chronic diseases for home care, hospital or in travel environments [2]. BSSs are used in transport domain to measure and locate delays in public roads and reroute the user [3]. Also, BSSs have been used to identify the user's transport method [4,5].

Although BSSs have been previously proposed, such as [6–10], they have several limitations, such as the following: (1) BSSs are not standardized nor very flexible, so each time an investigation or sensing campaign is planned, a sensing system is typically created or extended; (2) Apart from battery limitations, mobile phones, wearables are heterogeneous, meaning that the model and brand determines the types of sensors included, the quality of them, as well as the quality of data they can collect; (3) Finally, the majority of BSSs are individual-centric [6,7,10–12], therefore some group context can be difficult to infer. We will explain this in the following sections.

In scenarios in which studying family members and their context is important, an integral sensing system is required so that is can collect data from the family members' mobile phones and sensing devices positioned in locations where the family gathers such as the kitchen, the living room or the backyard. Beyond that, from a research point of view, the researcher must be capable of configuring the sensing system to collect and pre-process selective data without too much hassle. Although sensing platforms can indeed collect data from fixed sensors, they mainly focus on collecting continuous streams of data regardless of their significance or user privacy [13,14] or portraying objects as data/service providers [15,16]. Having a platform that can be configured to collect individual (e.g., mobile phone sensor data) and group context (e.g., sensor data from a fixed device in the living room) from the researcher's desk at pre-deployment or at runtime are particularly rare. This is desirable since sensing campaigns (i.e., data collection protocols) requirements can vary across time as they can be running for months.

Conventional BSSs mainly focused on the sensors placed in the mobile phone. Using fixed devices positioned at particular locations in the home setting can open the possibility of using much more specialized sensors than those used in mobile devices (e.g., indoor temperature, carbon dioxide levels). Needless to say, in particular scenarios or studies, this can enrich context to the extent that making sense of collected data would be otherwise difficult. Furthermore, since BSSs focus typically on inferring human activities, using individual and collective context can provide a better understanding of them. For instance, some studies have shown that there is a link between mood and outside weather [17]. Studying similar variables, and family dynamics, can help explain, and perhaps infer, much more complex variables such as mood changes in patient with bipolar disorder being monitored. Again, several sensors that may be of interest are not typically included in off-the-shelf devices such as smartphones.

In this work, we extend a mobile phone sensing platform [18–20] by including non-mobile sensors placed in commercial IoT devices such as Raspberry Pi or Intel Edison. By adding non-mobile sensors, and readily use them in a sensing campaign, altogether with smartphones, we are able to design a unique sensing campaign and collect behavior data from groups or collectivities. We also present how we extended the mobile phone sensing platform and how it was implemented in a semi-controlled setting to collect data from a dyad being monitored. Even when non-mobile sensors have been previously used in sensing campaigns, using a single platform to configure mobile phones and non-mobile devices can be useful for rapidly deploying sensing campaigns. This is indeed one of the advantages of the proposed approach.

This paper presents a novel approach for implementing sensing campaigns, using an extensible architecture of an existent sensing platform. In the following sections we describe the concept collective sensing, our implementation of a platform which supports collective sensing, its advantages over other similar platforms, and the main architecture and features of the platform. Also, we present a use case to illustrate how the platform can be deployed in such settings.

2. Collective Sensing

Collective sensing consists of using diverse mobile and non-mobile devices capable of selectively collecting group context when they interact with each other either in shared spaces or when they are not together. Also, collective sensing provides the ability to sense groups such as families, classroom or campus-wide studies, guest buildings, conferences, or any other type of groups or communities, which scientists can be interested in studying.

One of the appeals of collective sensing, as presented in this work, is not necessarily on full streams of raw data collected and aggregated on a central repository, which implies challenges of its own such as sensor stream synchronization or data fusion, but rather *when* those raw sensor data are collected and *how* are treated by the mobile and non-mobile devices. All this can be done at design stage of the sensing campaign from the researcher's desk. That is, the effort put when deploying devices and preparing them for a sensing campaign can be minimal, but also in redeploying a sensing campaign at runtime since once connected to the network participating devices can be (re)programmed from the researcher's desk through a web-based interface. The mobile and

non-mobile devices used run operating systems (OS) such as Android or Linux, which facilitate remote manipulation and configuration at runtime.

The advantages of collective sensing, when compared to most individual-centric sensing platforms, are (1) better understanding of group context, (2) greater coverage of the environment beyond the individual, (3) higher data richness due to specialized sensors typically lacking in mobile devices, and (4) greater control over the sensing platform at design stage and runtime through a single web-based interface through which configure and deploy sensing campaigns. The latter is particularly useful since researchers have typically little time or technical knowledge needed for reconfiguring or reprogramming smartphones or devices such as a Raspberry Pi.

We can envision several applications for collective sensing with the scope presented. First, studying the behavior of older adults in nursing homes, their affective state when they are together in a group, and the effects the environment may have on their wellness. Also, one could study dysfunctional families to better understand what and how family dynamics influence individual behavior, and the other way around. Another study of interest, such as the one of [21], can be students' performance with respect to their environment and group coexistence. The latter is a less controlled environment since student life can involve several locations such as the home, university campus (e.g., library, classroom), a friend's house, and public locations such as restaurants, which can be difficult to implement with some existing platforms.

Currently, there is no BSS that supports the requirements of collective sensing. As mentioned, most BSS are individual-centric, making use of mobile devices such as smartphones, typically leaving aside the group context. The implementation of collective sensing facilitates and enriches research that requires studying multiple participants who gather or cohabit in the same space. Important requirements for a collective sensing platform include: (1) flexible sensing campaign configuration at runtime, enabling the researcher to have multiple options for sensing (2) campaign editing at any time, in case the user has to make corrective changes on the fly, without delaying the re-deployment of devices, (3) automatic creation of sensing components, saving time of programming to the user, (4) automatic programming of non-mobile devices, and (5) security and privacy of collected data with isolated instances of relational databases and raw data preprocessed before leaving the participating devices.

There are several challenges associated with the implementation of collective sensing, among which are: (a) homogenization of collected data from different vendors; (b) aggregation of data for analysis; (c) web-based management of sensing campaigns; (d) support of both mobile (e.g., smartphones), and non-mobile devices (e.g., Raspberry Pi); (e) different energy consumption and uptime for mobile and non-mobile devices. Furthermore, in regards to formal research, there are also challenges associated with deploying a sensing campaign in scenarios like those discussed above. First, informed consent can be easier when dealing with individuals. Group members can surely sign informed consents, but it may be difficult to disaggregate group context when some of them do not consent to collect, say, temperature data from them.

A Scenario for Collective Sensing

"Andrew is a psychologist who wants to study dysfunctional families to a different level. He has been working for years on this topic, but would really like to have a breakthrough in his area. He just heard about a new way in which mobile technologies can be used. As a trial, he has invited a mid-class family who live in the suburbs, the Johnston family, to collaborate in the study. A few devices have been setup in their home, and everyone agreed to install an app in their mobile phones. Andrew was interested in the time they spent together, and types of places the members of the family were at when they were not together. The devices at home enabled Andrew to have an idea of when they were having conversations, and through their mobiles, he knew exactly who were talking to whom. In addition, Andrew had information about specific aspects of the house such as interior temperature per room, luminosity, motion sensors, and other aspects that haven been reported in the literature to have effects on day-to-day mood. Since he has a psychological background of each member, he knew that John, the youngest one, was particularly prone to detachment which affected

Julia, his mother, and this in turn affected Pedro, the father, who at the time was unemployed. Pedro was having episodes of substance abuse, which made him more verbally aggressive toward Julia and Mary, one of the oldest children. Julia felt overly neglected and had depressive symptoms. Mary, on the other hand, did not know if she was to blame for her father's behavior. After 16 weeks of collecting data, Andrew found that the more time they spent together in the kitchen, the less likely they displayed aggressive behaviors. He also found an interesting connection between the weather and mood changes of John. Andrew was very satisfied with the technology he acquired, since he did not consider himself to be tech-savvy"

3. InCense IoT: A Collective Sensing System for Sensing Campaigns

We extended InCense [7,19,20] a mobile sensing platform to include IoT devices. InCense is a mobile sensing platform running on Android powered devices (e.g., mobile phones, Google Glass) with which several investigations have been carried out. Some of the core features are: (a) Dynamic reconfiguration, (b) Data condensation, (c) Data transmission, and (d) Graphical User Interface (GUI) for configuring sensing campaigns [7].

We extended the physical architecture of InCense, which is now composed of different hardware and software components, we named this extension InCense IoT. The InCense server directs the flow of the configuration of the sensing campaigns. A web platform runs on the InCense server for configuring and setting up the sensing campaigns. An Application Programming Interface (API) is used for receiving the data coming from the IoT devices. Also, an encoder component is now responsible for generating source code for the IoT devices (e.g., Edison, Raspberry Pi) and the database, which at the moment is located on the InCense server.

In the extended architecture, mainly text-based data, mainly text-based are collected in JavaScript Object Notation (JSON) representations. Audio streams are collected in audio files, and then processed for extracting features of interest, usually without the captured audio file leaving the participating device for privacy and network performance. Once on the InCense server, preprocessed data are stored in the data structure (see Figure 1). For the scientist's convenience, the platform provides credentials for the direct management of the database, in case this is required. The owner of each campaign can provide data access to collaborators, according to the role they have in the study (e.g., participant, principal scientist, student).

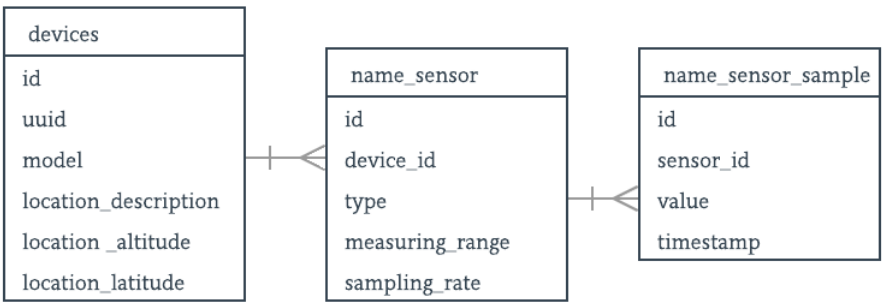

Figure 1. Basic data structure of the extended architecture of InCense.

The data structure is based on a relational database diagram, in which each device has a one-to-many relationship with the sensors, and the sensors a one-to-many relationship with the collected samples. In this structure, the device's universally unique identifier (UUID), model (i.e., Intel Edison), human-readable location, and geo-coordinates (i.e., latitude, longitude) of the device. The data stored for each sensor varies depending on its capabilities (e.g., celsius_accuracy for temperature sensor). A table was defined in the structure (schema) for each type of sample associated with a sensor. A value and a timestamp fields are defined for each sample. Using a data structure has some advantages such as the scientist has a greater understanding of the characteristics of the samples and sensors. It also allows making use of queries using database engines.

The scientist running the campaign can create several sensing campaigns at the same time. Each campaign is assigned an individual database to manage the collected data in an isolated and safe way. Only the owner of the campaign has full access to the collected data, the owner's collaborators have access to the features the owner wants, such as campaign editing, graphs visualization. Database credentials are provided only to the owner. Currently, the researcher cannot manipulate data through the web-based interface; the only way to manipulate the collected data is using standard SQL language using the credentials. Its storage efficiency is the same as a relational database with the pros and cons they currently have. To start the campaign, it is necessary to upload a configuration JSON file to the system through the web-based GUI. This file can be generated by the InCense platform or manually created by a programmer (if desired), and it includes the configuration file for the sensing campaign. At the moment, the GUI and the background routines translate this campaign into source code (e.g., Python) for the IoT devices. Once the campaign is configured, it can be modified by the InCense IoT platform, if necessary. Sensing campaigns metadata can also be modified: collaborators, devices, sensors, and the name, description and status of the sensing campaign (see Figure 2).

The configuration of the sensing campaign includes several sections. The Main section provides access to the following data: status, name, and description. The Collaborators section: A collaborator can be added by entering the email and the permissions (info campaign, edit campaign). The Device section: model, UUID, location description, location latitude, location longitude. The Sensors section: associated device, sensor type, sampling rate, and specific fields for each type of sensor. Once the sensing campaign is set up, the non-mobile devices are programmed automatically to collect data with the chosen configuration.

The GUI displays the information using time-based data graphs. In this way, the researcher has an overview of the data before analysis (Figure 3). This visualization allows monitoring the sensing campaign at any time with a dynamic interface, with the option of selecting the device, the sensor, and the time interval in which the data were collected. Finally, the geographical location of the associated device is shown on a map. This location is based on the Google Maps API, thus the granularity for indoor positioning can be still widely unavailable.

Following Figure 4, The *Encoder* interprets the configuration of the sensing campaign in JSON format to create the necessary scripts for sensing in non-mobile devices i.e., InCense IoT. What it does is that it takes the code template in Python (Figure 5) associated with the sensor, and replaces the indicated lines of code with the specifications of the campaign. This template file is manipulated through a JavaScript library. Based on this template, for each sensor configured a new file is created and stored in a Git repository, accessible to the non-mobile devices. Also, there is a file which is configured in the creation of the sensing campaign which is executed by the CRON (Daemon) of the OS. This python file executes all the scripts in a multithread way, which begins the sensing process transparently for the IoT device.

Figure 2. GUI of the Sensing Campaigns Manager.

Figure 3. GUI for data visualization.

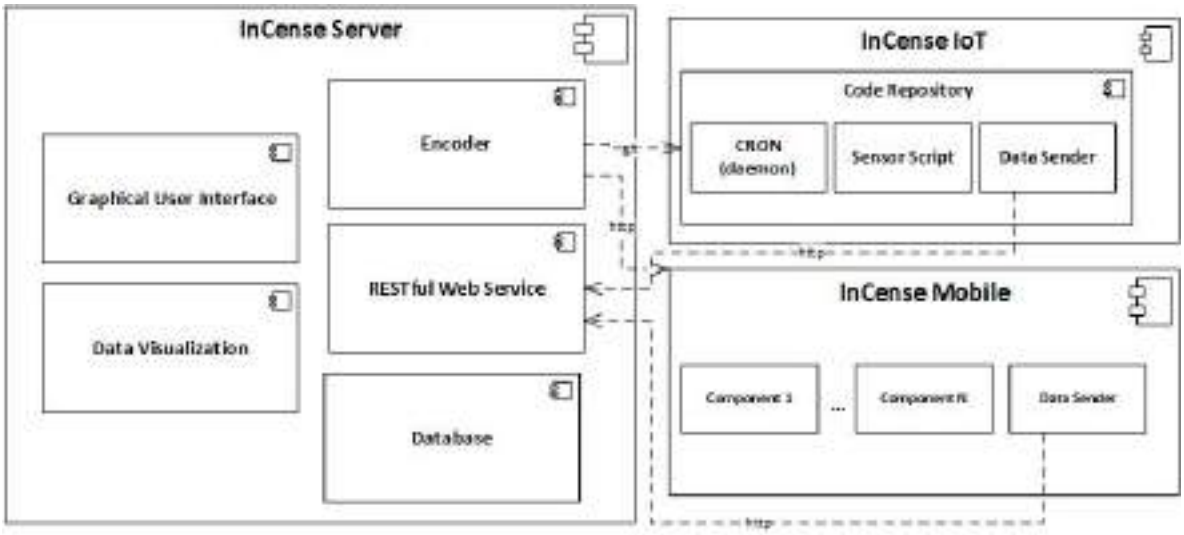

Figure 4. Extended InCense Architecture.

In the IoT device i.e., non-mobile device, data are stored in JSON representations. The devices are then synchronized to send the files to the server at a specific time of the day, usually at night. This configuration is executed by the CRON routines of the OS. Then, data are received by RESTful methods implemented on the InCense server, and are stored in the database associated with the

sensing campaign. Data can be accessed in three different ways: (1) a web-based visualization system, (2) accessing the database with the corresponding credentials, and (3) downloading the SQL file with the schema and data collected, that is, the SQL dump files.

```
MAIN ()
 1:   temperature <- grove->GroveTemp(__PIN__)
 2:   WHILE true THEN
 3:      begin <- time()
 4:      data->append([time(), __VALUE__])
 5:      cont ++
 6:      IF cont == __FILE__ THEN
 7:         finish <- time()
 8:         json->add(data)
 9:         cont <- 0
10:      END IF
11:      wait(__SAMPLE__)
12:   END WHILE
```

Figure 5. Pseudocode Script Example from the Encoder.

4. Use Case: Piloting InCense IoT and Collective Sensing

In order to illustrate how the InCense can be used by researchers from the social sciences, we include a use case in which we collected data from a mother-child in a semi-controlled environment. The purpose of this use case is two-fold: (1) illustrate how InCense IoT can be deployed to collect the data of interest, and (2) provide social scientists with a relatively simple use case that can help them envision the potential usefulness in their research.

This data collection protocol was designed by therapists of children with disabilities who were interested in studying how mothers behave when their children are faced with a mildly-challenging task. In particular, therapists were interested in mothers' directive behaviors, which are important since they can have several implications for child's self-management and self-determination.

For the data collection protocol, the task was defined to be putting a puzzle together, for which we implemented InCense IoT. The project was approved by an IRB, and we obtained an informed consent from all mothers.

For directive behaviors, we collected physical proximity and direct intervention, and voice directions or instructions by the parents. Through the therapists, we recruited 12 mother-child dyads. All children are individuals with Down syndrome. The sessions briefly consisted of a child putting 3 puzzles together in direct supervision of the mother (see Figure 6b). The child received three boxes, each containing a puzzle with increasing number of pieces, 4, 9 and 21 pieces, respectively. Each child received one box at a time, the ones with fewer pieces first.

(**a**) (**b**)

Figure 6. Collective sensing use case.

For this use case, we used a sensing campaign configured with the implemented platform creating components that could help us monitor parents' behavior (Figure 7). InCense Mobile was

running on an Android-based smartphone, using a mic headset. This was used for detecting the mother's voice directions. Audio data was treated in discrete samples of 1000ms. We used standard pitch-based algorithms for detecting when the mother was speaking. For inferring mother's intervention, we used an accelerometer sensor for the smartphone, and the ultrasonic sensor in the IoT device to detect when she approached her child. These two components can be combined to monitor mothers' directive behaviors using rule-based inferences or other approaches such as fuzzy logic or neural networks.


```
{
    "campaign": "Monitoring Parents' Behaviors for Self-management in Children with Disabilities",
    "begin": "1523718070",
    "end": "1523721670",
    "mobile-devices": [{
        "model": "Android Device",
        "os_version": "8.1",
        "participant_id": "1",
        "sensors": [{
                "component": "voice_directions",
                "filter": "volume",
                "sampling_rate": "1000ms",
                "type": "microphone_sensor"
            },
            {
                "component": "hands_motion",
                "sampling_rate": "500ms",
                "type": "accelerometer_sensor"
            }
        ]
    }],
    "iot-devices": [{
        "location_description": "Room A",
        "location_latitude": 27.4708107,
        "location_longitude": -109.93227,
        "model": "Intel Edison",
        "uuid": "480ccf9d-e05d-40b0-9ad5-9c5eefc69bbd",
        "sensors": [{
            "component": "physical_proximity",
            "pin": "AIO Pin 1",
            "sampling_rate": "1000ms",
            "type": "ultrasonic_sensor"
        }]
    }]
}
```


Figure 7. JSON representation of the sensing campaign.

For the audio data, a volume filter was applied combined with a rule-based for recording audio excerpts. It records an audio excerpt when it detects a pitch and it stops when it detects a 3-s silence. Also, a filter was applied to the distance data. The boundaries were configured 0–3 m distance between the parent and the child.

Apart from the technical aspects enabling the implementation of this data collection protocol, and the obvious limitations such as the reduced number of participants, it is important to highlight how a platform such this one can help social scientists, physicians, psychologists, or therapists. One of the most obvious ones is automatic labeling of events in semi-controlled or potentially naturalistic environments. Typically social scientists base their research on self-report through questionnaires or interviews. Self-report based on users' accounts has been reported to be prone to unintended bias and is often unreliable [7]. Other research methods used in controlled or semi-controlled environments by behavioral scientists is direct or indirect observation (using typically two observers for unbiased analysis) based on video analysis or in situ observation, which is time consuming and exhausting not only to plan, and perform, but also to analyze. Using automatic or semi-automatic labeling of events of interest can speed up and scale up studies such as the ones shown

5. Discussion

Technology such as the one discussed in this paper can help social scientists, physicians, psychologists, or therapists to better understand scenarios where multiple people interact with each other, particularly in contexts wherein group interaction can be meaningful. Apart from recording human activity of interest, researchers can utilize this technology to automatically label events of interest. This in turn can be used to better tailor certain therapies or non-pharmacological interventions.

There are several challenges associated with this. One of them is disaggregating group context, in case this is required. Having the individual and the group as separate units for analysis can be definitely useful for advancing research. We believe that collective context can have several implications for advancing research in areas where collective and individual contexts may both matter, as one may be interested in understanding which one influences the other.

Our technical work has still several limitations, like knowing in advance which IoT device i.e., hardware will be deployed, and which sensors and in what pins they have been mounted. This is because at design stage sensing campaigns program devices to selectively collect context, which implies that not all data streams are considered at once. Although for some areas collecting all raw sensor data can be desirable and may be needed at the same time (e.g., machine learning), in practical applications such as a household this can be unfeasible for privacy and security (i.e., on-device processing), network usage, and costs associated with storage, retrieval, and computing of those data.

6. Conclusions

In this paper, we presented a BSS that can be used for collective sensing, a paradigm for sensing campaigns which augments mobile sensing campaigns. It provides a paradigm capable of studying groups combining sensors in fixed locations with mobile sensing. Also, it makes use of a GUI for creating sensing campaigns without deep technical aspects of programming, since the platform is responsible for making the necessary code for the devices. It stores the data collected in a schema previously defined in a relational database. The researcher is provided with credential for accessing collected raw data.

Our current implementation enables adding more researchers to the campaign, so they can contribute, the owner grants privileges through the platform (information, edit, visualization). The visualization of the data is a feature in which the researcher can select the time interval of the data to visualize as well as the specific device and sensor can be selected. We are planning several improvements for this visualization feature, like adding new graphs which can give more sense to the data, the graphs interactions have a lot of potential for the researchers in terms of data analysis and advanced visualization features.

As future work, we are going to provide support to several IoT devices and typical sensors for behavior analysis. The reason for adding more devices is to give researchers more than one alternative in terms of the devices they can use. Our initial device (i.e., Edison) is no longer being manufactured by Intel. However, we are abstracting the complexity by using high-level languages running on Linux-based open-source boards such as Raspberry Pi 3. In the long run, we plan to implement a web-based tool capable of analyzing collected data, with the features to make statistical operations and apply strategies for patterns recognition such as fuzzy logic or neural networks using standard Python libraries. We plan to release a public version of our platform soon.

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Energy-aware Data Collection from the Internet of Things for Building Emotional Profiles

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***Abstract*—In the field of affective computing, a major goal has been the development of models to recognize the affective state of individuals. Data related to people such as physiological signals, facial expressions and speech enable the analysis and recognition of affective states. Currently, sensors integrated in smart devices (e.g., smartphone and smartwatch) allow the collection of this type of data. In this work, we present a platform composed of RESTful web services to collect data related to user emotions and its context through smart devices. Due to potential energy-constrained sensors, the platform is provided with an energy-aware data collection mechanism. Four series of experiments were conducted to evaluate both the energy efficiency and the scalability of the platform. The experimental results indicate that the platform is scalable and helps to save energy of data-collection sensors compared with a system unaware of energy consumption.**

Keywords: Smart Device, Internet of Things, Middleware, Energy Consumption, Emotional Profile.

1. Introduction

The extensive use of smart devices (e.g., smartphones, smartwatches, and smart glasses) by people enables the development of novel techniques to analyze and recognize affective states and the context in which these occur [1], [2]. An important characteristic of smart devices is the incorporation of various sensors that can be used to easily collect a diversity of user data such as physiological signals and facial expressions, which is useful to recognize users affective states [3].

Devices capable of collecting data such as smartphones, tablets, personal computers or laptops are usually called IoT (Internet of Things) nodes as they provide various ways of interacting with the user [4]. The IoT has become a reality. Every day, more smart devices are equipped with sensors and actuators and are interconnected with one another via the Internet and technologies such as wireless sensor networks or RFID [5]. In fact, multi-sensor platforms (collecting data from galvanic skin response sensors, accelerometers, temperature sensors, among others) are becoming pervasive [6].

Pervasive services aim to facilitate daily life activities based on web services using the paradigm of ubiquitous computing [7]. In this regard, the modeling of context awareness is vital because it allows IoT systems to provide a composite service relevant to users. In this paper, we take advantage of pervasive RESTful web services (with open interfaces) to collect data in order to establish a context for recognizing users' affective states.

In the fields of web services and IoT, this paper contributes an energy-aware data collection platform composed of RESTful web services. The platform is capable of reducing devices energy consumption by deduplicating available sensors (embedded into available IoT devices) and dynamically adjusting a monitoring rate based on the remaining energy of IoT devices. In the field of affective computing, this paper contributes a platform for collecting data associated with users' affective states and their context from multiple sensors integrated into smart devices such as microphones, infrared thermometers, or web cameras. The collection and analysis of this type of data also enable the identification of the causes that produce changes in users' affective states and suggest actions to improve or regulate detected affective states. Users can benefit from understanding the causes of their emotions (e.g., sadness or anger) as they know how to maintain positive emotional states (e.g., happiness).

This paper is organized as follows. Section 2 describes the architecture of the proposed platform. Section 3 explains the empirical evaluation and Section 4 presents the results of the experiments carried out. Section 5 presents some related work, and finally, Section 6 includes some concluding remarks and future research directions.

2. Energy-aware Data Collection Architecture

The architecture of the proposed energy-aware data collection platform (see Fig. 1) has three types of components: smart devices, central nodes, and RESTful web services.

1) *Smart devices*. Smart devices (utilized by users) should have a *data collection application* installed on them to allow the proposed platform to collect data about users' emotional state and its context. It should be noted that the processes for building emotional profiles and establishing the context are out of the scope of this paper. As shown in Fig. 2,

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smart devices interact with a central node in order to register themselves and send sensor data.

2) *Central nodes*. Central nodes serve as a hub for smart devices situated in a smart environment (e.g., a living room) and are in charge of establishing a link between smart devices and RESTful web services (e.g., the device registration service), see Fig. 2. A central node can be either a smart device, a personal computer or a special device made for this particular purpose such as the IoT hub proposed in [8]. The existence of the central node releases smart devices from complex (as well as energy-consuming) multi-party interactions that may require different data transmission protocols, among other aspects. The mechanisms of central nodes collaborate with RESTful web services in 1) discovering smart devices, 2) registering smart devices, 3) deduplicating available sensors, 4) managing energy consumption of smart devices, and 5) collecting data.
3) *RESTful web services*. In addition to smart devices and central nodes, the energy-aware data collection architecture is composed of six RESTful web services: device discovery, device registration, sensor deduplication, energy consumption management, sensor data collection and affective state profiler. We selected RESTful web services because, in general, they are more scalable than SOAP web services [9]. Please see Section 2.1 for a detailed description of each web service and their interaction.

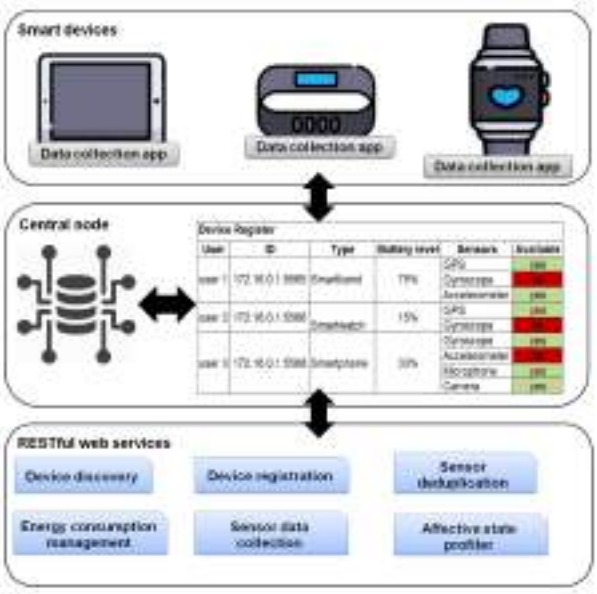

Figure 1. Energy-aware Data Collection Architecture

2.1. Choreography for energy-aware data collection

The global message sequence among the parties involved in the data collection process (Fig. 2) has five phases:

Phase 1: device discovery. The involved parties are a smart device, a central node, and the device discovery service. The interaction is as follows. The smart device sends a *hello* message containing its identifier to the central node to indicate its presence. The central node forwards the message to the device discovery service. The device discovery service verifies whether the smart device is registered (or not). If it is not registered, it registers the device and notifies the central node. Finally, the central node sends a message to request the smart device to send its data (see Phase 2 for details).

Phase 2: device registration. The involved parties are a smart device, a central node, and the device registration service. Once the smart device receives a request from the central node, the smart device replies with a message including its user identifier, IP address, port, type of device, battery level and its sensors (see the table reported in Fig. 1 for an example of a list of sensors). The central node forwards the information to the device registration service to include the device information in the central node's device list for a given user.

Phase 3: sensor deduplication. The involved parties are a smart device, a central node, and the sensor deduplication service. The interaction is as follows. Once a new smart device is registered, the central node forwards the device's list of sensors to the sensor deduplication service. The sensor deduplication service checks the availability of each sensor from each device registered on behalf of a given user. When a duplicate sensor (e.g., a GPS) is found, the platform collects data from only one of the available devices endowed with such sensor. To do so, the sensor deduplication service sends a list of the sensors (removing duplicate sensors) from which it will be collecting data to the central node. The central node notifies the smart device of the approved list of sensors whose data should be transmitted. In doing so, we eliminate unnecessary data collection from duplicate sensors and save devices' energy.

Phase 4: energy consumption management. The involved parties are a smart device, a central node, and the energy consumption management service. The interaction is as follows. The energy consumption management service sends a message to the central node requesting for the remaining battery level of devices registered for each user. The central node sends a request message to the smart devices, which reply with their remaining battery level. The central node collects this information and sends it to the energy consumption management service, which uses this information to set the sensors' monitoring rate. The energy consumption management service sends the corresponding monitoring rates to the central node, which notifies the smart devices. It should be noted that the monitoring rate of a smart device with a full battery level should be higher than the monitoring rate of a smart device with a battery level

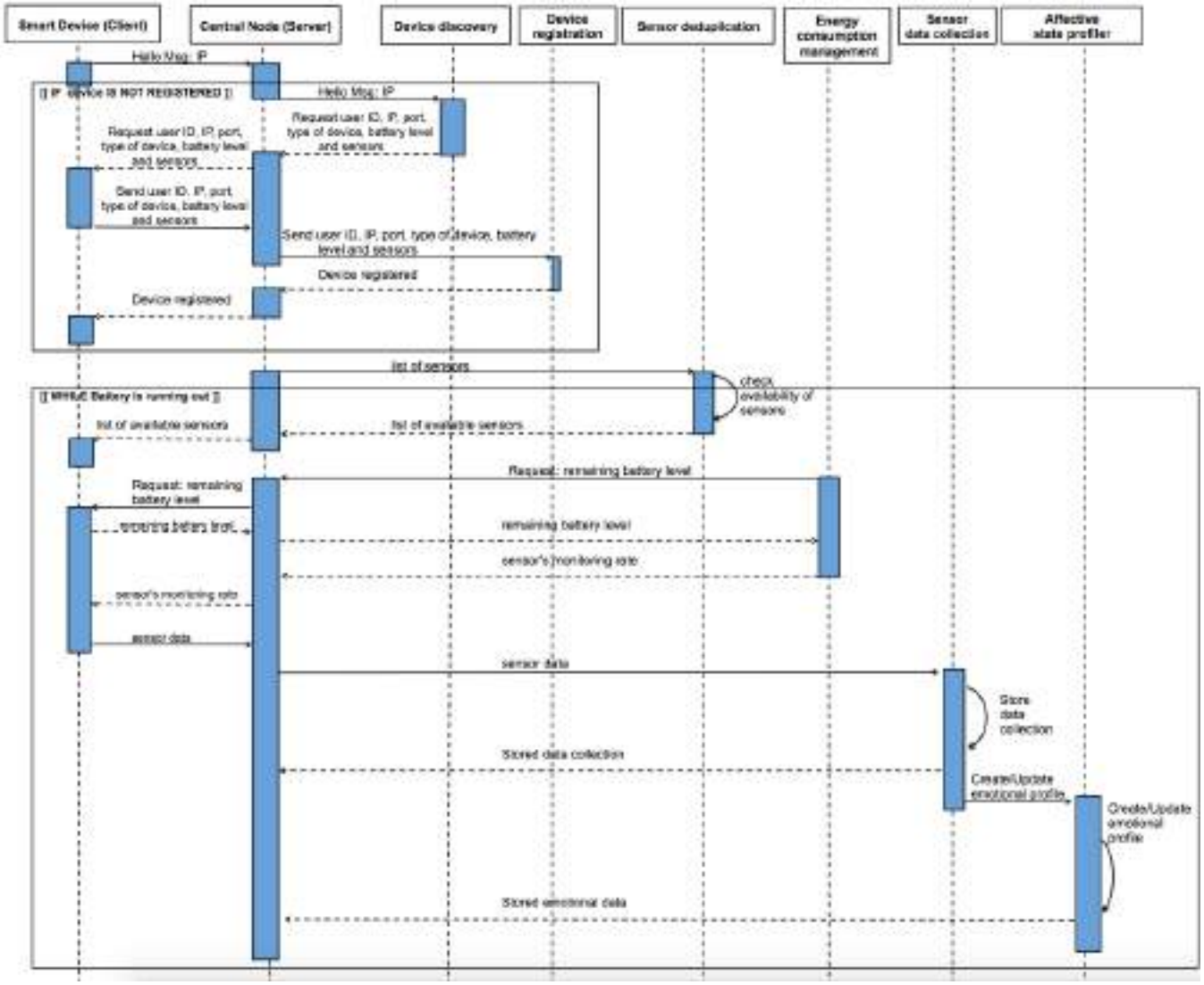

Figure 2. Global interaction protocol for energy-aware data collection

below a given threshold. In this paper, the battery level thresholds and monitoring rates were predefined.

Phase 5: energy-aware data collection. The involved parties are a smart device, a central node, and the sensor data collection service. The interaction is as follows. The smart device sends sensor data (using its predefined monitoring rate) to the central node by means of the data collection application. The central node collects this information and forwards it to the sensor data collection service that stores it in a database. The stored sensor data is used by the affective state profiler to build users' emotional profiles. The process of building emotional profiles is out of the scope of this paper.

3. Empirical Evaluation

We conducted four series of experiments for evaluating the scalability of the IoT data collection platform and its efficiency in energy savings. In Table 1 we present the assumptions on energy consumption of some smart devices and their sensors to perform the experiments. In addition, Table 1 includes the energy consumption of sending a message, which was constant for all the smart devices. We simulated different types of devices and different sets of

TABLE 1. ENERGY CONSUMPTION OF DEVICES AND SENSORS

Energy Consumption		
Sending a message		1.2μW
Sensors	**Gyroscope**	9.1μW
	GPS	24μW
	Accelerometer	0.58μW
	Microphone	6.7μW
	Temperature Sensor	0.021μW
Devices	**Smartphone**	41nW
	Smartwatch	0.042nW
	Smartband	0.040nW

sensors. Also, each device and each sensor has its own level of energy consumption when it is being used. For example, smartphones have a higher level of energy consumption than smartbands and smartwatches. Also, every sensor activated is consuming energy.

The IoT data collection platform was implemented using the JDK v1.8 and JAX-RS (the Java API for RESTful web services). Smart devices were simulated as threads. In addition, for simplicity, all threads had the same IP address but a different port. The communication between the smart devices and the platform was implemented using UDP sockets.

The experiments were performed on a computer with the following specifications: AMD V140 processor at 2.30 GHz, 2 GB RAM, 32-bit Windows 7 Ultimate SP1. The RESTful web services were deployed on the same computer using the Oracle GlassFish Application Server Open Source Edition 3.1.2.2.

3.1. Experiment 1: response time of the device registration process

The objective of this experiment is to measure the response time of the registration process. The devices involved in the experiment varied from 10 to 80 in steps of 10 units. The device and sensor types as well as the number of available sensors were set randomly. We used the device and sensor types reported in Table 2 because they may be the most popular. In addition, the initial battery level (ranging from 1% to 100%) for each device was also set randomly in order to explore a wide variety of scenarios. For each configuration of the platform (reported in Table 2), we conducted 10 independent experiment runs for a total of 80 simulations.

The performance measure is average response time of the registration process.

TABLE 2. EXPERIMENTAL SETTINGS

Number of smart devices	{10, 20, 30, 40, 50, 60, 70, 80}
Device types	{smartband, smartphone, smartwatch}
Sensor types	{gyroscope, accelerometer, microphone, temperature sensor}
Initial battery level	From 1 % to 100 %

3.2. Experiment 2: response time of the sensor data collection process

The objective of this experiment is to measure the response time of the sensor data collection process. The experimental settings were the same as those reported for Experiment 1 (Section 3.1). However, to focus on the sensor data collection process, the discovery and registration of devices were not taken into account. We assumed that these phases had already been completed. The time was measured from the first message exchanged (containing sensor data) between the smart device and the central node to the moment when the smart device ran out of battery.

The performance measure is average response time of the sensor data collection process.

3.3. Experiment 3: energy efficiency

The objective of this experiment is to evaluate the energy-aware data collection mechanism. This experiment involved 50 smart devices. In contrast to Experiments 1 and 2, for this experiment, the devices' initial battery level was set on a random basis ranging from 10% to 15% to avoid unnecessarily long simulation times. In addition, the devices simulated the sensing process for a predefined period of time ranging from 20 s to 100 s in steps of 20 units. The devices and the central node adopted two different data collection mechanisms. The first mechanism collected data adjusting the monitoring rate based on the remaining energy level of the devices (as described in Section 2.1). When the devices had a battery level between 15% and 10%, the monitoring messages were sent every 10 ms, when the battery level was between 9% and 5%, the monitoring rate was set to 20 ms, and when the devices had a battery level between 4% and 1%, the monitoring rate was set to 30 ms. In contrast, the second data collection mechanism had a fixed monitoring rate of 10 ms completely unaware of the energy level of the devices. It should be noted that we chose the devices with the highest battery consumption (among all of the devices reported in Table 1) endowed with a single sensor with the highest level of energy consumption. Finally, for each configuration of the platform, we conducted 10 independent experiment runs for a total of 100 simulations.

The performance measure is average number of devices with a battery level of 0%.

3.4. Experiment 4: energy efficiency

As in Experiment 3, the objective of this experiment is to evaluate the energy-aware data collection mechanism. In this experiment, we selected the device and sensor types (from Table 1) on a random basis. The remaining experimental settings were the same as those reported for Experiment 3 (Section 3.3). The performance measure is the average number of smart devices with a battery level of 0% after a predefined period of time.

4. Results

In this section we analyze the results obtained from the experiments described in Section 3. Error bars included in the simulation results (see Figs. 3, 4, 5, and 6) represent standard deviation from the mean.

Figures 3 and 4 (showing results from experiments 1 and 2, respectively) indicate that both 1) the average response time of the registration process and 2) the average response time of the sensor data collection process increased exponentially as the number of devices increased. It should be noted that both the registration process and the sensor data collection process of smart devices were conducted in

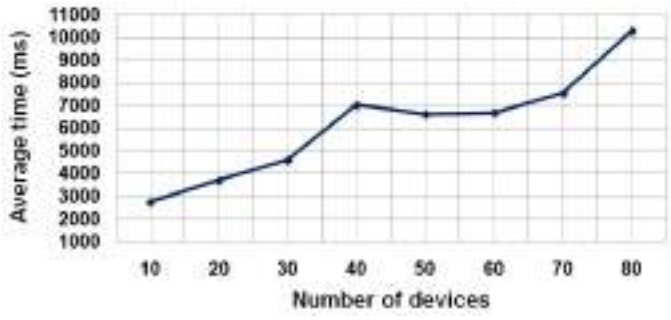

Figure 3. Performance of the registration process

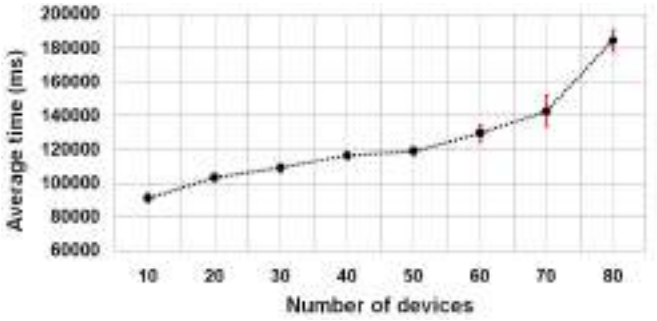

Figure 4. Performance of the sensor data collection process

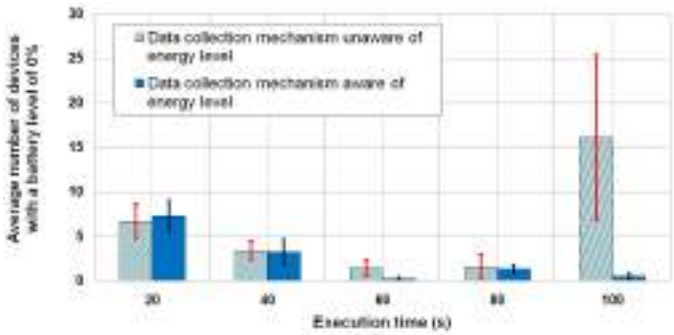

Figure 5. Energy efficiency: average number of devices with a battery level of 0%

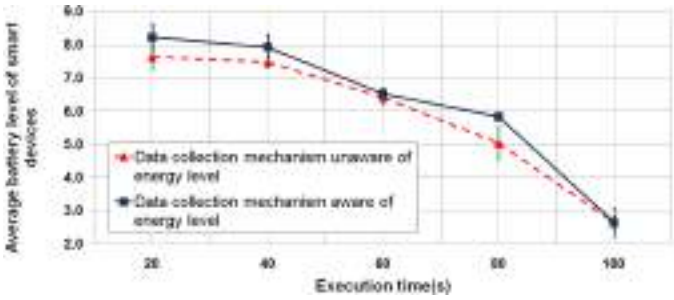

Figure 6. Energy efficiency: average battery level of smart devices

a concurrent manner using a single central node. Contextualizing this scenario, the data collection platform can handle a concurrent workload of up to 80 smart devices deployed in a smart place environment, e.g., an office.

Figures 5 and 6 show results from experiments 3 and 4 about the energy efficiency of the proposed energy-aware data collection platform compared to a data collection platform unaware of the energy consumption of smart devices. Figure 5 shows that, in general, regardless of the execution time, in our platform, there were fewer devices that ran out of battery. In addition, as shown in Figure 6, in all cases, the average battery level of the smart devices deployed in our platform was greater than the average battery level of the smart devices deployed in the data collection platform unaware of energy consumption. This is because smart devices deployed in our platform made dynamic adjustments to the monitoring rates based on their remaining energy level, i.e., as their energy level decreased, their monitoring rate was lower.

5. Related Work

De Souza et al. [10] and Spiess et al. [11] designed SOCRADES, a SOA for interconnecting smart devices with business services. SOCRADES incorporates well-established standards to hide hardware and software heterogeneity (communication is mainly supported by SOAP web services). SOCRADES includes an event-oriented messaging service to deal with the dynamics of an IoT environment where smart devices can join and leave communication groups at any time. SOCRADES' components (e.g., the catalog, monitor, or discovery service) work together to unify composite services.

Katasonov et al. developed UBIWARE [12], an agent-based platform for IoT focused on semantics aspects for interoperability. In addition, an agent-based architecture enables UBIWARE to deal with distributed resources and heterogeneous services. UBIWARE (as a middleware) serves the purpose of establishing the link between IoT devices and web resources.

AgFlow (developed by Zeng et al. [13]) is a platform capable of dynamically composing web services while taking into account quality-of-service criteria such as reputation, execution cost, execution time, availability and reliability. Agflow has three components: web services, service broker, and service composition manager. The service broker provides a directory service using a UDDI registry and is responsible for registering services. The service composition manager interacts with the service broker to locate services (based on a set of requirements) in order to create composite services. It should be noted that whereas Agflow was not specifically designed for IoT settings, the features and capabilities of Agflow can be of use in IoT environments.

Stavropoulos et al. [14] present aWESoME, a service-oriented architecture middleware for intelligent environment systems based on web standards such as WSDL (web service description language). aWESoME is composed of four layers: the *hardware layer* (where smart devices are located at), the *integration layer* (containing device drivers), the *service layer* (containing the description of services) and

the *application layer*, which serves as the system interface. It should be mentioned that aWESoME is provided with energy management APIs. For instance, an API to determine the battery level of sensors. However, such APIs are deployed as a middleware service, they are not incorporated into an energy-aware data collection mechanism.

As in [12], our platform interacts with IoT devices using web service technologies. Unlike De Souza et al. [10], Spiess et al. [11] and Stavropoulos et al. [14] who interconnected smart devices using SOAP web services due to their well-established standards, our platform makes use of RESTful web services, which have less communication overhead than SOAP web services. It should be noted that a myriad of IoT devices may be energy-constrained and that less communication overhead results in fewer bytes transmitted, and as a consequence, less energy consumption. In addition, as done by Zeng et al. [13] who take into account quality-of-service criteria, our platform takes into account the energy consumption of device sensors to collect data by means of deduplicating available sensors and dynamically adjusting the monitoring rate of IoT devices based on their remaining energy.

6. Conclusion

The importance of this work is that by 1) dynamically adjusting monitoring rates based on the remaining battery level of IoT devices and 2) eliminating unnecessary data collection from duplicate sensors, we enable data collection from the IoT to profile users' affective state while taking into account energy constraints. The proposed energy-aware data collection platform makes use of RESTful web services to prevent smart devices from transmitting non-essential data (e.g., SOAP headers) to the central node and the web services in charge of service discovery, registration, and data collection. Empirical results (see Section 4) indicate that our platform can handle a concurrent workload of up to 80 smart devices and that the data collection mechanism helps smart devices in saving energy.

By collecting context information from sensors, this platform lays the foundations of a system designed to identify the causes and changes of users' affective state. In doing so, we aim to enable the use of intervention mechanisms to improve or regulate the affective state of users. Then, our future work will focus on profiling users' affective state and designing an intervention mechanism.

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