Universidade do Minho
Escola de Engenharia

João Ricardo Martins Ramos

Orientation Method for People with Cognitive Disabilities

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Orientation Method for People with Cognitive Disabilities

Doctoral Thesis
Doctoral Degree in Biomedical Engineering

Thesis supervised by
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Professor Doutor José Carlos Ferreira Maia Neves

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STATEMENT OF INTEGRITY

I hereby declare having conducted my thesis with integrity. I confirm that I have not used plagiarism or any form of falsification of results in the process of elaboration of this thesis. I further declare that I have fully acknowledged the Code of Ethical Conduct of the University of Minho.

Full Name: João Ricardo Martins Ramos

Signature: ______________________

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> Walking with a friend in the dark is better than walking alone in the light.
>
> — Helen Keller

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Resumo

Pessoas com incapacidade (física ou cognitiva) representam uma pequena percentagem da população de um país. No entanto, os custos de saúde inerentes a este grupo de pessoas são habitualmente elevados quando comparados com uma pessoa normal. Assim, é necessário encontrar soluções que ajudem no dia a dia destas pessoas. Aquando do diagnóstico de perdas cognitivas, se tal já não tiver ocorrido, o paciente pode ser impedido de viver sozinho e a presença de um cuidador poderá ser necessária. De forma a diminuir esta invasão de privacidade e permitir uma vida independente do paciente na sua própria casa é necessária adaptar a mesma ao conceito de casa inteligente, a qual permite que o cuidador aceda de forma remota e verifique o estado do utilizador. Porém, a casa inteligente não permite a monitorização do utilizador quando este se encontra no exterior. Assim, de forma a manter-se seguro, este pode tornar-se um prisioneiro da sua própria habitação.

Para que a pessoa com perdas cognitiva tenha uma normal interação com a sociedade surge a necessidade de um sistema de orientação adaptável ao exterior e que esteja em conformidade com este grupo de utilizadores. Se se considerarem os dois principais sistemas operativos para dispositivos móveis (*i.e.*, iOS e Android) existe um grande número de aplicações que guiam o utilizador até ao destino pretendido utilizando GPS. Porém, existem muito poucas que sejam adequadas para pessoas com incapacidade. Por outro lado, para além da capacidade de orientação, existe uma outra característica deveras significativa do ponto de vista do cuidador, a capacidade de localização que lhe permite o acesso de forma remota à localização do utilizador final. Esta característica é vital uma vez que os métodos tradicionais de orientação são realmente dispen-

diosos, levando os cuidadores a acompanhar os pacientes durante as suas deslocações. Desta forma, tanto o tempo como os recursos despendidos durante a aprendizagem são desperdiçados.

Vários autores desenvolveram sistemas de orientação adaptados tendo em consideração as características e especificidades do utilizador. A principal preocupação centrava-se na interface do utilizador, uma vez que consideravam que os sistemas disponíveis eram demasiado complexos para serem utilizados por este tipo de indivíduos.

O sistema desenvolvido (*i.e.*, CogHelper) tem uma interface adaptada ao utilizador, a qual utiliza realidade aumentada para concretizar o processo de orientação. O sistema possui também a capacidade de localização em tempo real onde o(s) cuidador(es) podem monitorizar o utilizador final. O nosso principal objectivo não recaiu sobre a interface do utilizador, uma vez que esta já tinha sido previamente estudada, mas na forma como a informação era fornecida ao utilizador. Desta forma, o caminho selecionado para guiar o utilizador é adaptado às suas preferências. De forma a prevenir possíveis erros durante o percurso, o sistema calcula possíveis pontos nos quais o utilizador pode tomar uma decisão errada, e alertá-lo de forma a manter-se no caminho correto. Estas características baseiam-se num módulo de *pattern mining* (para fornecer o caminho adaptado) e numa abordagem de computação especulativa (para antecipar possíveis erros do utilizador).

Abstract

People with disabilities (physical or cognitive) represent a small percentage of a country population. However, the health costs are usually higher when compared to an ordinary person. Thus, one should seek solutions to help the day life of such group of people. When diagnosed with cognitive disabilities the patient may be prevented to live alone and a caregiver may be needed. To avoid this privacy invasion and enable the patient to live independently in his home, there is the need to adapt it to the concept of smart house, which enables the caregiver to remotely access and check the user status. However, the smart house is not able to monitor the user when he goes outside its premises. Thus, in order to keep the user safe, he may become a prisoner of his own home.

To engage people with cognitive disabilities in a normal interaction with the surrounding environment there is the need of a portable orientation system that works outdoors and is adapted to this audience. If one look over the two main operative systems for mobile devices (*i.e.*, iOS and Android) there is a huge number of applications that guides the user through GPS to the intended destination. However, there are just a few adapted to people with disabilities. Besides the orientation feature there is also another important one from the perspective of the caregivers, *i.e.*, a localization feature which allows these second type of users to remotely access the main user location. This is specially important since traditional methods are very expensive, and due to this lack of information caregivers tend to be all the time with the patient during his journey. Thus, the effort and resources spent to teach the user are wasted.

Different authors had developed adapted orientation systems considering the user specificit-

ies and characteristics. Their main concern was the user interface, since they considered that available systems were too complex to be used by these group of people.

The system that was developed (*i.e.*, CogHelper) has an adapted interface, which uses augmented reality to provide the orientation to the user. It has also a real-time localization feature where caregivers may know the user location. Our focus was not on the user interface, since it was already studied, but on how to provide the necessary information to the user. Thus, the path followed by the user is adapted to his preferences. In order to avoid mistakes during the traveling path, the system may calculate possible locations in which the user takes the wrong turn and alert him to keep on the correct path. These features are based on a pattern mining module (to provide the preferred path) and on a speculative computation approach (to anticipate possible user mistakes).

Contents

Nomenclature

A

AI Artificial Intelligence

ANN Artificial Neural Network

C

CBR Case Based Reasoning

CDC Centers for Disease Control and Prevention

CT Computed Tomography

D

DT Decision Tree

G

GOET Game On Extra Time

GPS Global Positioning System

I

IIoT Industrial Internet of Things

M

MDP Markov Decision Process

R

RO Reality Orientation

S

SVM Support Vector Machine

T

TBI Traumatic Brain Injury

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Chapter 1

Introduction

One who never asks either knows everything or nothing.

— Malcolm Forbes

Outline

Introduction

Technological evolution is paramount as it occurs in multiple areas, namely in mathematics and healthcare, allowing for either the development of new methodologies for problem solving or the enhancement of the existing ones, both in diagnosis and treatment.

Therefore, these advances allowed significant improvements in the daily lives of the people. On the other hand and as a side effect, people now live longer (the average life expectancy has increased (PORDATA, 2016)) with better health care systems. However, the population growth is not the meaning of health problems. There are several diseases that Medicine has not found yet a solution . In these cases the possible procedure is to retard the disease progress. Cognitive disabilities are a medical condition for which there is not a cure. They may affect different capabilities of a person and the adopted solution by physicians consists in slowing down the progress of the disease.

Once a patient is diagnosed with a cognitive disability, he may loose his independency, total or partially, according to the level of incidence and to the caregiver's decision. Thus, the patient may be relocated or a caregiver (relative or not) may move in to his house. In order to reduce or prevent this loss of independence it may be advantageous to adapt the patient home to the concept of smart house in which there are several embedded devices that may monitor the user and remotely inform the caregiver. However, this alternative does not guarantee the patient safety when he is outside his premises.

The remain of the chapter is organized as follows: Section 1.1 presents the motivation of this work; in Section 1.2 briefly introduces the Cognitive Assistants; Section 1.3 presents the Research Hypothesis, whereas Section 1.4 and Section 1.5 state the aim of the work and the methodology used; finally, Section 1.6 presents the structure of the document.

1.1 Motivation

Orientation systems intend to guide the user when he is outside his premises, playing an important role in assisting them. An associated localization system enables caregivers to know, in real time, the user position. The goal of this work is the development of such a system, increasing the autonomy of both users, *i.e.*, people with cognitive disabilities and their caregivers.

The pathology of cognitive disabilities is not easy to diagnose, and it is considered a complex process to do. Sometimes it becomes impossible to get the conditions for concluding the right diagnosis, a process that is not free of errors. On the other hand, the diagnosis of cognitive disabilities may take into account different attributes, namely (Scherer et al., 2005):

- **Acquired medical condition:** traumatic brain injury, aneurysm, brain cancer, among others;
- **Brain deterioration:** brain deterioration is often associated with progressive diseases such as multiple sclerosis and Alzheimer's disease, besides the age of the brain;
- **Learning and intellectual problems:** they are related to developmental problems such as mental retardation; and
- **Chronic and severe mental disorders:** diseases such as schizophrenia.

The assistance to an individual diagnosed with cognitive disabilities is essential, being more or less pronounced according to the degree of severity associated with the incidence of the disease.

According to Scherer et al. (2005), memory and organization are the two main areas where people with the pathology require assistance. The use of written notes as lists and notebooks proved to be an effective technique in helping to carry out daily tasks. However, the application of this technique requires a plan and a rigorous training process, so the person with this type of disabilities may recall their daily routines and tasks.

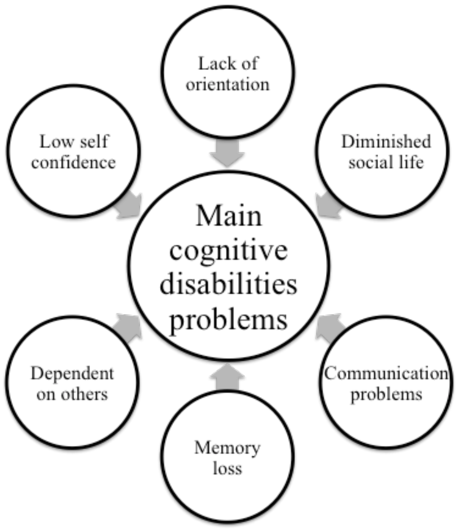


Figure 1.1: Main problems of people with cognitive disabilities.

This technique is very difficult to use in patients with more severe cognitive disabilities, since it requires a huge memory effort for the person with disabilities to remember where he left, for example, the notebook. Whereas the person is able to find the notebook, it is necessary that he had the ability to constantly verify the tasks that should happen in a certain moment. When this ability is compromised, it is necessary for a caregiver to remember to consult the notebook, leaving the patient dependent on his aid.

The main problems/difficulties that a person with cognitive disabilities may suffer are presented in Fig. 1.1. These difficulties may be more or less difficult to overcome, depending on the degree of incidence of the disease.

1.1.1 Cognitive Disabilities

A person with cognitive disabilities is defined as an individual who has more difficulties in one or more types of mental tasks, when compared to an ordinary one (American Psychiatric Association, 1994). Self-care, communication and orientation are examples of the diminished capacities. The severity of the disease may vary from mild to extreme and according to it the patient may need different types of care. When facing mild cognitive disabilities they may not be detected and the patient may be completely autonomous and independent. However, when severe or extreme cognitive disabilities are diagnosed there is the need of a caregiver (relative or not). In this case the loss of independency is inevitable since the patient needs constant help. For moderate cognitive disabilities the patient may need assistance but only in certain activities of his day life. Nevertheless, his interaction with the environment may be diminished since the ability to travel between two locations may be compromised and the caregiver may prevent the patient from going out alone.

1.1.2 Assistive Technologies

Assistive technologies help users with disabilities (*e.g.*, physical, sensory, or intellectual) to perform tasks that were difficult or even impossible to do. Concerning the cognitive disabilities there is a more specific assistive technology named cognitive assistants. These devices intend to help the user with his diminished capacities. Under the orientation topic (a common diminished capacity) the existence of such devices enable the autonomous traveling of people with cognitive disabilities. Through this system the user could autonomously travel between two different locations. Therefore, his independency is increased and the caregiver could also develop other activities without neglecting the provided care/assistance to the patient.

There is several research work that tackle this problem through applications developed for mobile devices. However, the described solutions in the literature are essentially concerned with the user guidance and the application interface. They lack of a localization system that allows caregivers to be aware, and in real time, of the user location.

1.2 Cognitive Assistants

Cognitive assistant is a piece of software that assists the user. This aid may happen in different contexts and may be used by every type of people. Thus a cognitive assistant is able to "*augment the human intelligence*" (Engelbart, 1962), to help or assist in the decision making processes.

Indeed, despite the assistance to a normal user, these systems are very important to people with disabilities, once they may help in handwashing (Mihailidis et al., 2008) or in supporting people with dementia living at home (Wherton and Monk, 2008), just to name a few.

With the advent of desktop computers, came the search for alternatives to the pen and paper, so other solutions to the problem may be proposed. Studies show that a person with problems in retaining new memories, still may use a word processor or other application after a long period of time.

Over time, the computers have been becoming lighter and more portable, mainly due to physical reduction of the components that make it, thus its overall size has decreased. The first applications that were developed in order to replace the pen and the paper consisted in simple programmed reminders, which activated an alarm at a certain occasion, avoiding oversights in carrying out the tasks.

To help people with cognitive disabilities to perform time management, Ripley (2009) describes various applications that have been developed since the year 1996. These applications have methods to insert, edit and remove reminders on devices with more or less advanced technologies. However, since 2007, new applications have been developed that are intended to assist people with cognitive disabilities during their travel. These memory assistants recall the correct route, so the user may reach the intended destination.

People with cognitive disabilities often suffer from a lack of spatial orientation. This situation causes, in general, a privation of their autonomy, since the patient is unable to leave his home alone. Thus, this person becomes a prisoner of his own home. Another solution adopted by caregivers is to reallocate the person with cognitive disabilities to a nursing home or the caregiver moves to the patient's home. Either of these solutions always causes a loss of independence.

Liu et al. (2009b) developed an automatic orientation system for people with cognitive disabilities when traveling in an outdoor environment. The route is displayed to the user by presenting successive images and text messages to help him during the traveling path.

The exterior orientation is an important factor to increase the quality of life of people with cognitive disabilities, since it stimulates a bigger social interaction and encourages an active participation in society, making these people more autonomous.

When a person with cognitive disabilities goes outside there is a constant concern about his location by the caregiver. Thus, to know the position in which the person with cognitive disabilities is, it is necessary that the caregiver call him. In this situation there is the risk of the person with disabilities not knowing his location. In order to make such people more independent is important that these applications have real time tracking systems, so the caregiver may view the current position of the user.

1.2.1 Social Challenge

Over the last years, the medical progress allowed an earlier diagnosis for several diseases, which may allow to start the treatment in the beginning of the pathology. This development increased the life quality of the population since more pathologies could be treated and some chronic conditions may be controlled through medication. However, despite this progress, there are some diseases that remain without a cure or do not have an efficient treatment through medication. When there may not be a medical solution, it is possible to assist the person through technology aiding him in some tasks enabling a continuous accompaniment.

The continuous monitoring of a person with cognitive disabilities is important. However, the physical presence of a caregiver may inhibit the patient and let him enter in an intellectual slouch due to the small brain activity. According to the incidence level of the cognitive disability it may be possible to avoid the total physical dependency of the patient from his caregiver. The technological development enables an independent and normal life of the patient, since caregivers may know the current health condition of the person through remote accessed devices (e.g., smart house). Thus, there is the creation of an Ambient Assisted Living (Costa et al., 2007), which should consider the software engineering best practices described by Preuveneers and Novais (2012).

A current problem under analysis is the need to spatially orientate people with cognitive disabilities. Besides the technological interest in the creation and development of applications or systems with orientation methods, there is a strong social motivation. The goal of researchers and companies is to find or develop solutions that improve the life quality of people with cognitive disabilities since, from a medical perspective, there is very little to do. These patients should be accompanied and actively participate in the surrounding society. The developed technologies must be accessible to people with the above mentioned difficulties and, at the same time, they should integrate caregivers in order to enable a non-presential aid, being alerted whenever there may be something wrong with the patient.

To a person with this dependency level is very important to encourage the performing of tasks without the physical aid provided by caregivers, stimulating the brain activity. The technology intended to these people has a double goal by providing an increase of the independency of patients and caregivers. Over the time the patient may feel more independent and integrated in the society.

1.2.2 Technological Challenge

Technologies with the integration of GPS modules, accelerometers, cameras, magnetic sensors have been used over the last years. The low price of this hardware enabled the access of this technology to ordinary people, and consequently the development of applications and systems could be made using limited resources.

The search for new technologies and the development of innovative applications are the main technologic goal. The purpose of this project is the creation and development of an orientation and localization system for people with cognitive disabilities. Due to the user characteristics, the orientation method should adapt the path to the user preferences as well as the prompting level, preventing the user of making a mistake by alerting him in advance. Different authors have addressed the orientation issue (Carmien et al., 2005; Liu et al., 2010), however they were mainly focused in the user interface, i.e., on how the information should be displayed to the user in order to provide the orientation method. Liu et al. (2010) used static pictures which may not always be in the user perspective, compromising the identification of the landmark and consequently the orientation. To surpass this flaw this project uses an augmented reality interface, so the user has a perspective of the reality with an overlaid arrow.

A different technological aspect is the possibility to add more complexity to the application according to the user adaptation level. At an initial stage the user has only access to the contacts (destinations points) considered as favorites like home and office. Then, at a second stage and according to the user interaction with the app, the caregiver may allow him to have access to more options like regular contacts (not considered favorites) and at a final stage the user may be able to manually introduce the intended location.

Caregivers represent an important target for this system since they need to virtually follow the person with cognitive disabilities, so both users may have a bigger independence level. The caregiver may check, in the map and in real time, the traveling path that is being followed by the user. Despite the interest of the technological goals there is the need to consider the social impact that these type of applications may have in the quotidian of people with these difficulties. An aspect that must be considered is the intrusion that the use of the system may have in the user, which may cause stress and limit the usage of such system. Thus, in order to maximize its usability it should be less intrusive as possible (Novais and Carneiro, 2016).

1.3 Research Hypothesis

When looking at a specific topic, a literature review is an essential process. This process has the propose of establishing the bounds for the investigation problem. A detail review of the literature enables the analysis on how researchers formulated their research questions and define their own philosophies. Thus, it is possible to obtain a precise vision on the current state of the art and start looking for new lines of investigation (Saunders et al., 2009).

Defining the research question(s) is a very important step in one's research since this is a statement that enquires the objectives/goals of the project. Through this statement the researcher may illustrate what is being pursued.

The research question under analysis may be put forward in the form:

> *Considering a context aware system; is it possible to improve a Human Orientation Procedure of people with cognitive disabilities using a Learning Algorithm?*

Through this project it is intended to develop an orientation system taking in consideration the limitations of a person with cognitive disabilities. Through a context aware system it is possible to gather information about the user, like stress or attention deficit, and use this information to provide the orientation. The path may also be adjusted to the user profile and to his current condition. Thus, the system may orientate the user through a longer but preferred path, if the user is not fatigued, and through the shortest one otherwise. Using the gathered information a learning algorithm will anticipate user mistakes and alert him before taking the wrong decisions. This kind of system may also adjust the alerts to each user. Thus, the orientation system adjusts to the user and not vice-versa.

1.4 Work Aim

Before starting a work it is important to define which are the goals in order to understand, at the end of the job, if the work as successfully done and the initial defined goals were achieved. In a general sense and in a summarized form, the goal of this work is to define and implement a platform to guide a person with cognitive disabilities and to remotely locate him to the caregiver, *i.e.*, the system must be able to guide the user by adapting the path to his preferences and by intelligently triggering alerts to keep the user on the right track.

The specific goals that will be addressed in order to pursue the global objective of this thesis are defined as:

- ▷ Identify and analyze the requirements of an orientation and localization systems for people with cognitive disabilities and for the supporting community;
- ▷ Analyze the current state of the art of such type of orientation methods and identify possible deficiencies in those systems;
- ▷ Define the requirements in order to develop a system that overcomes the highlighted flaws of current guiding systems;
- ▷ Development of the system architecture that support the integration of multiple applications;
- ▷ Draw an archetype of the platform;
- ▷ Define the structure of the modules that support trajectory data mining and the reasoning method for guiding the person with cognitive disabilities;
- ▷ Develop of the previously defined modules; and
- ▷ Validate the developed archetype and platform in different scenarios.

1.5 Research Methodology

The combined areas of technology and health are in constant development. This work follows the Action-Research methodology for problem solving (Avison et al., 1999, 2001). Through this research method it is possible to combine research and practice, *i.e.*, after experiment the developed theories, the researcher have to reflect on its effects and its implications. Under this methodology there are cycles of activities, *i.e.*, this is an iterative method in which each iteration includes a problem diagnosis, an action intervention and a reflection of that intervention in order to learn and adjust the formulated theory.

Through this research method it is possible to emphasize existing projects and check what is necessary to improve or develop. Some of these undeveloped features are pointed out as immediate necessities. It is intended to solve an existing problem related to orientation and localization of people with cognitive disabilities.

In the health arena, researchers try to suppress human failures (like cognitive disabilities) conciliating technology and human beings. The active investigation method is used when there is the need to solve a specific problem either by implementing new systems or by developing existing ones. Initially a state of the art review of the theme will be conducted, which involves literature and technology. Then the collected data will be analyzed and a report produced. Next, available resources will be object of study and its possibles failures/disadvantages evaluated. After this step, a proposal will put forward and the possibilities to solve the previous highlighted problems is weighted.

This research method may be divided into six phases, which are depicted below:

1. Problem definition and state of the art review: in this phase it is defined the problem and what are its causes. A hypothesis is formulated and a plan specifying its solution is developed.

2. Constant review of the state of the art: this step needs to be a constant during the project in order to keep the researcher updated with the last developments of projects related to his research.

3. Model design and construction: using the information gathered in phases 1 and 2 it is possible to start the designing process, which allows the building of a model considering the available information. Therefore, the formulated hypothesis may be confirmed.

4. Implementation and experimentation: in this phase a prototype is conceived, which con-

tains the specified features, components and behaviors. Through the prototype is possible to check if the goals were met.

5. Analysis, validation of results and conclusions: the analysis of results and their validation are used to verify if the proposed implementation is in accordance with the expected goals, and enables to derive the conclusions of the developed work.

6. Results dissemination: results and conclusions derived in the previous steps should be disseminated in journals, conferences, among others, in order to acknowledge the scientific community of the resulting advances and research results.

1.6 Document Structure

This thesis is divided into five chapters as follows. Chapter 1, the current one, outlines the motivation; the cognitive assistants, which includes its social and technological challenges; research hypothesis and the aims of the work as well as the methodology used to achieve them. Chapter 2 defines the cognitive disabilities and how they are diagnosed. In this chapter it is also included the different types of cognitive disabilities and the barriers/obstacles that a person with such disabilities may be confronted with. Chapter 3 describes the reasoning methods that could be used in our system. This chapter ends with a discussion stating the advantages and disadvantages of each. Chapter 4 includes the main papers that were published during this PhD process. Finally, Chapter 5 draws the conclusions of this research work. The goals defined in Section 1.4 are revised and the major contributions are outlined. This chapter ends with future research and with some final remarks.

Chapter 2

Cognitive Disabilities

Hearing is one of the body's five senses. But listening is an art.

— Frank Tyger

Outline

Cognitive Disabilities

A cognitive disability is a medical condition and may affect several capabilities of a person like communication and orientation. The diagnostic may not be an easy task to do by the physician since this medical condition may be present under different forms (*e.g.*, stroke, alzheimer, among others) with different levels of incidence (varying from mild to extreme).

A detailed definition of cognitive disabilities is presented on Section 2.1. Section 2.2 explains how the diagnostic is made and the different types of cognitive disabilities are defined on Section 2.3. This Chapter ends with the main barriers/obstacles that a person with cognitive disabilities has to face (Section 2.4).

2.1 Definition

According to the Diagnostic and Statistical Manual for Mental Disorders (DSM-IV) (American Psychiatric Association, 1994), a cognitive disability is a medical condition associated to an individual who has more difficulties in one or more types of mental tasks, when compared to an ordinary one. These tasks include self-care, communication, orientation, use of community resources, functional academic skills, work, leisure, health, and safety, among others.

To a better classification, cognitive disabilities are usually divided into four phases, namely mild, moderate, severe and extreme (see Figure 2.1). The majority of diagnostics that are done are for mild cognitive disabilities (about 80%). About 14% are related to moderate to severe ones.

In the cases of severe and extreme conditions, it is mandatory a continuous assistance to the patient in almost every aspect of his daily life. Any chance of autonomous and independent life is excluded. In a less severe stage, like moderate cognitive disabilities, the patient may live independently, but there is still needed a remote or physical accompaniment. In the less severe stage (mild cognitive disabilities) the diagnostic may not be conclusive, since these disabilities may not be detected and the patient may have an autonomous life.

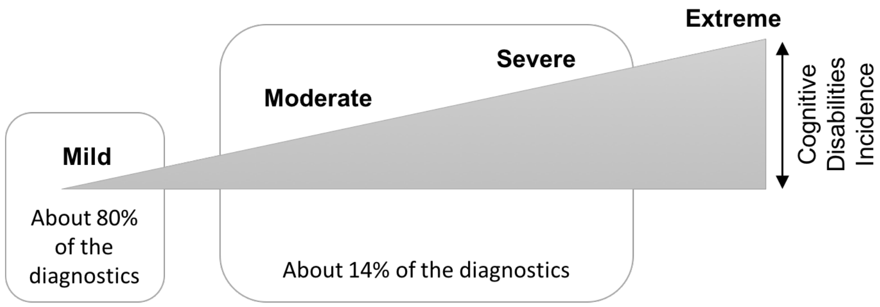


Figure 2.1: Cognitive disabilities classification.

Cognitive disabilities that are related to mental retardation correspond to a specific group of diseases like Down's syndrome, cerebral palsy, autism, birth defect and genetic disorder. However, the concept of cognitive disabilities does not only refer to mental retardation, but includes traumatic brain injury, stroke, Alzheimer and developmental disability, among others.

2.2 Diagnostic

The diagnostic of cognitive disabilities is not an easy task since it is necessary to attest some principles. The main criteria or the most frequently observed is the intellectual function, which is compromised in the presence of cognitive disabilities. A person with this disability has more difficulties in accomplish one or more types of mental tasks (Schalock et al., 2010).

When one undertakes a diagnosis, one may consider functional or clinical cognitive disabilities. The latter are designated by their technical name (*e.g.* Down's syndrome, cerebral palsy or autism), and usually coexist with the functional. This group includes memorization deficit, attention deficit, mathematical comprehension deficit, just to name a few (Webaim, 2007). The categorization of cognitive disabilities into functional or clinical ones creates a distance from a medical perspective. When observing these disabilities from a functional perspective it is possible to ignore the causes of the disease, and to pay more attention to the resulting challenges due to capacity decreasing.

This division in the diagnostic is very useful to those that intend to analyze the needs of people with cognitive disabilities under a practical and technologic perspective. To a professional that wants to develop an application to assist the daily life of a person with cognitive disabilities, it becomes easier to have the knowledge about the functional disabilities (*e.g.* memorization deficit) than to know the clinical disabilities like cerebral palsy. In this case the software expert will have to interiorize all the barriers that may occur when some condition is present.

2.3 Types of Cognitive Disabilities

The degree of incidence of cognitive disabilities may vary from mild to extreme. Although belonging to the same type of disabilities (cognitive disabilities) there are several characteristics like traumatic brain injury, birth defect or mental retardation. The latter also includes other types like cerebral palsy and the Down's syndrome.

2.3.1 Stroke

Strokes are a common cause for invalidity, being the third most common cause of death. However, this disease holds unknown for the general public, *i.e.*, recently some researches indicate that populations do not correctly understand the definition of stroke, ignoring that this happens in the brain (Lindley, 2008).

Interpreting the occurrence of a stroke may be a very difficult task, inclusive to specialized people like doctors and nurses. This is due to the fact that there are many variants associated to the disease, and there are other diseases that are seamless to a stroke.

In general terms it can be stated that a stroke occurs when there is an interruption in the blood supply to the brain, causing part of this to stop working. The occurrence of a stroke triggers some typical symptoms that vary from rapid death to a small loss of sensation on one side of the body.

For a quick memorization of symptoms there is the acronym FAST (Lindley, 2008), which means Facial weakness (the person can no longer smile), Arm weakness (the patient can not raise both arms simultaneously), Speech problems (the person has difficulties in pronouncing the words - aphasia, making it difficult for others to understand his speech) and Test all three symptoms, *i.e.*, the last letter of the acronym indicates that the three previous symptoms should be checked. The existence of these symptoms is an indicative to initiate medical care. A rapid assistance to the person who suffers a stroke is extremely important, once it may reduce the consequences that come from this situation. The patient usually does not feel a strong headache, but if this happens it indicates that the stroke was due to a cerebral haemorrhage.

The occurrence of a stroke may be due to two main causes that may occur in the same way, which is why it is not easy to distinguish between them. About 85% of the occurrence of a stroke is due to a blockage or occlusion of the blood supply to the brain and normally occurs due to a blood clot. These clots may form along a blood vessel or be transported through it, being formed elsewhere. This case is called embolism. The blockade in the blood supply is originated due to the death of brain tissue (cerebral infarction). The second major cause of stroke (about 15%) is due to leakage or rupture of the cerebral artery and has the name of cerebral haemorrhage.

The brain, being a living tissue, needs a constant supply of oxygen and nutrients. When this flow is interrupted or reduced, cells may die. The central core of the brain is damaged in a few minutes while the more peripheral areas can survive up to a few hours.

A patient that survives a stroke will probably suffer from cognitive disabilities such as memory loss, difficulty to make a flowed speech, to read and to process information. In addition to cognitive disabilities, the patient may suffer from physical limitations, having more difficulty to perform mechanical tasks. The severity of the losses that may occur depends on the severity of the stroke and on the time that the patient has to wait for medical assistance.

2.3.2 Alzheimer

Alzheimer's disease was initially studied by Dr. Alois Alzheimer when, in late 1901, a lady of 51 years was admitted to a psychiatric hospital. During four years and until her death, Dr. Alzheimer followed this patient. After her death the doctor had access to her brain tissue and noted the existence of a progressive destruction (Agronin, 2007).

This form of dementia is characterized by a slow and progressive loss of cognitive and behavioral functions, culminating in a vegetative state. Although the pathological characteristics of the disease are presented earlier, clinical signs of Alzheimer have a later manifestation in the life of the person (Budson and Kowall, 2011). The clinical symptoms associated with this disease include memory loss, but the patient also has a decrease in other capabilities like communication and spatial capacities (sense of space/distance).

Neuropathological markers make the clinical detection of Alzheimer. The more distinct markers are the amyloid plaques and neurofibrillary tangles which, at an initially stage, appear in medial temporal limbic structures and spread, at a later stage, to the neurocortex (Budson and Kowall, 2011), which causes the brain destruction and death (Fig. 2.2).

The initial symptoms usually arise after the age of 65 (National Institute on Aging, 2011), and are generally manifested by memory loss, since sensory and motor disorders usually appear later (Budson and Kowall, 2011). From the occurrence of the first symptom until the patient's

Figure 2.2: Alzheimer - healthy brain on the left and strong brain destruction on the right (retrieved from `https://www.nia.nih.gov/alzheimers/scientific-images`, 06-2013).

death there may be several years, depending on the age of the patient. When a person has more than 80 years it may take up to 3 or 4 years to his death. When the patient is younger he may live 10 or more years.

This pathology has not a cure yet, so doctors make use of medication to lower its progress. During the life period of patients diagnosed with Alzheimer, it may be considered three stages designated by mild (or initial), moderate and severe (or advanced) (National Institute on Aging, 2012).

Small losses of memory and personality changes are the earliest symptoms that occur in the first stage of Alzheimer's. In addition, the patient may be unable to remember recent events, which include the name of people or objects. The capacity to solve a simple mathematical problem may be compromised. There may also be other diminished capabilities like organization and planning. The creation of a list of tasks (or activities) or a shopping list may become complex.

The progression to the next stage involves the accentuation of symptoms at the current stage, which may show up other symptoms that had not been detected yet. Thus, in the intermediate stage, memory loss is intensified and it becomes more common for people to be confused. At this stage it generally appear incontinence problems and a caregiver may be needed to assist the patient in everyday tasks such as dressing. The difficulty in recognizing family and friends is emphasized, as well as the identification of dates, *i.e.*, to know what is the day of the week, the name of the current month, among others. At this stage it is necessary to constantly monitor the patient, *i.e.*, it is not recommended to leave him alone, because his judgment may be impaired, causing him to ambulate.

In the extreme case of Alzheimer's, the last stage, which culminates with the death of the person, it is necessary to assist the patient in all tasks, both in daily life and in basic survival needs. The non-recognition of family members becomes vulgar and it may arise difficulties in walking or sitting (National Institute on Aging, 2012).

2.3.3 Mental retardation

Verifying three criteria performs the diagnosis of mental retardation. The most frequently observed is the intellectual function that is presented below average (criterion A). There is also present a significant limitation in at least two of the following areas (criterion B), namely communication, orientation, use of community resources or home life, among others. To ensure this cognitive disability diagnosis, it has to be done before the patient be 18 years old (Criterion C).

The classification of mental retardation may be performed using the notion of intelligence quotient (IQ). For the lowest level of mental retardation, IQ may vary from a minimum of 50-55 to a maximum of 70. The moderate category comprises values from 35-40 to 50-55. Severe losses include patients with an IQ between 20-25 and 35-40. For an IQ below 20-25 cognitive losses are considered extremes (American Psychiatric Association, 1994).

The lowest degree of incidence of this disease represents approximately 85% of the diagnosed patients. This group of people is categorized as educable, *i.e.*, they may develop social and communication skills in the preschool years (at the age of 5 years old). On the other hand, patients in this category may not have the typical symptoms of the disease until adolescence, having no reduction in their sensory and motor skills. These individuals are able to live independently or with little supervision and are able to perform a job with supervision.

At the next level, which constitutes about 10% of this population, individuals are able to develop their communication skills during childhood. Educational programs developed for patients with mild mental retardation are also beneficial to this group, since their training allows them to develop social and labour skills. Thus, people with moderate metal retardation are able to develop a professional activity in a supervised environment, being able to travel alone between certain known locations.

Between 3 and 4% of the individuals diagnosed with mental retardation have a severe degree of incidence. In this group, patients usually do not develop their speech capacities, being uncommunicative by this method. However, during the first years of life, and with proper training, these people are able to learn how to speak and can develop capacities for self-care. Generally, these individuals are well adapted to community life with constant supervision (*e.g.* by relatives). However, it may be necessary to have more specialized training, *i.e.*, the patient has another type of disability which needs special care (American Psychiatric Association, 1994).

The last and most severe degree of incidence of mental retardation includes 1-2% of this population, which present neurological problems. Contrary to the other degrees of incidence, individuals included in this category have a considerable decrease in sensory and motor functions, and require very specialized training in order to try to develop some type of communication skills.

If it is not possible to make a diagnosis of mental retardation, but there is a strong evidence of its presence, the patient may be placed in a separate group considered of mental retardation whose degree of incidence is not specified. This situation may arise when the doctor is trying to, for example, diagnose children and adolescents who do not allow the realization of tests (American Psychiatric Association, 1994).

2.3.4 Traumatic brain injury

When a head injury results in the attainment of brain damage, it is a sign that a Traumatic Brain Injury (TBI) occurred. The main reasons that lead to this head trauma are a collision, a blow, or other type of violent impact to the head. This may occur, for example, in traffic accidents, fights, falls, among others. TBI may occur when the head hits suddenly and violently a certain object as in a car accident, or when an object, which had perforated the skull, hits the brain tissue.

The extension of the injuries (damage) determine the degree of the TBI, which may be considered mild, moderate or severe (National Institute of Neurological Disorders and Stroke, 2012). The Centers for Disease Control and Prevention (CDC) (Centers for Disease Control and Prevention, 2012) show that most of the TBI occurrences are concussions or other forms of mild trauma.

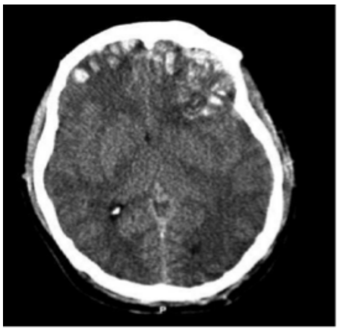
A significant number of people, about 1.7 million per year, suffers from TBI, which contribute to a significant number of deaths or permanent disabilities (Centers for Disease Control and

Prevention, 2012). Approximately 35.2% of TBI are caused by falls, which is the main cause of its occurrence. The second most significant cause is accidents involving motor vehicles and covers approximately 17.3% of the cases of TBI.

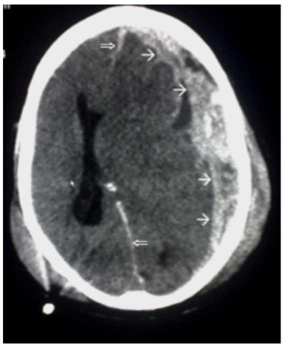
The consequences of TBI vary from person to person and there is no way to predict them. They may appear in a period of days or even weeks after the accident. In this type of trauma the sensory, emotional and reflection capacities may be seriously compromised.

Because these are damages that are unlikely to be reversed, when health professionals watch the person that suffers a TBI, they try to stabilize him in an attempt to prevent deeper damages. The most commonly used imaging techniques to do a better diagnosis and prognosis of a patient who suffered a TBI are X-rays (detection of bone fractures and spinal instability) and computed tomography (CT).

Distinct diagnoses of CT are shown in Fig. 2.3a, which shows concussions, bleeding, hematoma and fracture, and in Fig. 2.3b, which presents a hematoma and midline shift.



(a) Concussions, bleeding in the hemispheres, subdural hematoma and skull fracture (retrieved from Rehman et al. (2008)).



(b) Subdural hematoma (single arrows) and midline shift (double arrows).

Figure 2.3: Different observations in TCs.

To remove or repair the hematomas derived, for example, by the rupture of blood vessels or the damage of brain tissue (concussion) about half of the patients are subjected to surgery after the trauma.

The disabilities resulting from TBI include cognitive problems such as memory loss, deficit in sensory processing, communication problems such as the difficulty in understanding, and the presence of mental or behavioural disorders such as personality changes (National Institute of Neurological Disorders and Stroke, 2012). These disabilities may vary according to the severity of the TBI.

2.4 Barriers/obstacles

A cognitive disability is a medical condition in which the degree of incidence varies considerably. Thus, in a set of people with the same diagnosis, there are several special needs that are specific to each element. The empirical knowledge indicates that cognitive stimulus in this group of people decreases the progress of the disease, *i.e.*, does not allow, in case of Alzheimer's disease, that the degree of incidence increase rapidly. It is considered, therefore, that the absence of cognitive activity accelerates the process. This empirical knowledge has been scientifically explored in order to demonstrate the benefits of stimulation, assessing the effectiveness and impact of this intervention.

In late 1950, the hospitals at the United States materialized the insight of Reality Orientation (RO) in order to combat the main symptoms from the advanced age of the person or from cognitive disabilities, such as disorientation and confusion. The RO was designed to engage the caregiver in the therapeutic process. However, due to the rigid form of application, the RO has become increasingly less used (Woods et al., 2012). RO had, however, a positive effect and, for this reason, it is considered a prototype approach to cognitive stimulation.

Through a set of activities that involve the use of thought and memory, like the discussion of current and past events (*e.g.* recent news, topics of interest), word games, puzzles, music, among others, is possible to cognitively stimulate a person. Using these techniques, the stimulus becomes an interesting activity from which the patient can enjoy. This type of activity can also be done in small groups. To ensure a proper application of the stimulus it is necessary the presence of professionals in group sessions of 4 to 5 people, which have a duration of 45 minutes, and take place twice a week. In order to maximize the effect of this cognitive stimulation it is important that this stimulus continues outside the group sessions and, for this reason, the caregiver becomes a fundamental component of support (Woods et al., 2012).

In addition to the group sessions, it is important to continually perform cognitive stimulation to increase the chances of improving the health of the patient. The use of features of the environment as signposts, allows for stability in the process of stimulation. The set of all these incentives combined with the cognitive ability of the patient, has been very positive.

People with dementia who are subject to this type of stimulation, according to the analyses made, suffer an attenuation in the progression of their clinical condition, which is reflected in an improvement in their life quality. So, they achieve a better interaction and communication with the society in which they are inserted. According to the trials, this intervention is not appropriate for patients in later stages of dementia (Woods et al., 2012).

In the last years, after the reduction of the use of RO, it has been revived the discussion on this topic and its benefits, *i.e.*, there is an awareness that the lack of brain activity can accelerate (or not prevent) the cognitive decline, which can occur in elderly or in people suffering from dementia. In addition to the strategies previously designated, it is now dedicated special attention to cognitive assistants and new assistance strategies derived from the unique characteristics of each person.

Due to the indiscriminate use of various terms to describe cognitive stimulation (*e.g.* training, stimulation or rehabilitation) it is necessary to clarify each one in order to do a proper evaluation of the plan of care for each patient. The cognitive stimulation consists in performing a set of activities with the aim of improving the cognitive and social functions. This is often done in small groups of people. The cognitive training involves the execution of a set of predetermined tasks. There are different levels for each task, so it is possible to further customize the patient support. Finally, cognitive rehabilitation is a task performed between the patient and his therapist, and may involve patient's relatives. In this situation were identified several goals that are intended to be achieved by the patient, improving his performance on tasks of his daily life (Woods et al., 2012).

In studies dating from 2000 it is shown that these cognitive stimulation programs have very positive effects in people suffering from dementia, improving their quality of life and communication capabilities.

Contrarily to a person without health or physical problems, people with cognitive disabilities or people with mobility restrictions may experience various strains. The use of the computer for entertainment or for learning should be available to these people but, for example, the current Web pages now available may be too complex.

Therefore there is a need to establish how it could be possible to turn the Internet into something that may be used by anyone, particularly by people with certain types of pathologies, such as cognitive disabilities. The work presented in (Hoehl and Lewis, 2011) wishes to determine a feasible way for presenting the information provided in the various Web sites. A fast, simple and direct information display becomes a factor of preference by this group of people.

Currently there is not a tool intended to simplify the Web pages, and for this reason it is necessary to define other strategies that enable the reduction of the content. The development of mobile technologies turned the traditional mobile phones (whose goal was to make phone calls) into small portable computers (smartphones). These allow for a quick and mobile access to the Internet, but due to the small size of the screen (compared to the display of a computer), the content presented has to be synthesized (Hoehl and Lewis, 2011).

So, one could try to display a Web page that is designed to be viewed on a mobile device on a computer. A considerable decrease in the content can thereby benefit those with certain types of problems (cognitive and/or physical). The study of this way of displaying information has sometimes been ignored, giving preference to the opposite task, *i.e.*, view content on a mobile device intended to be presented on a computer.

The data presented in (Hoehl and Lewis, 2011) indicates that the content aimed for mobile devices suffers, on average, a reduction of 50%. Thus, unnecessary information is removed, which can sometimes distract the user (*e.g.*, advertisements and interactive elements).

The benefits of applying the method described above are visible, *i.e.*, the content of a Web page is simpler and is more accessible to a greater number of people.

During the last years and due to the numerous needs teaching methods presented some changes. Thus, the traditional slate was replaced by the blackboard, which was substituted by the various technological developments, which culminated in the current interactive board. There is a change in the resources used for the transmission of knowledge that, in addition to the introduction of new technologies, use another type of resources. Educational games have proven the benefits of these new technologies, since the user can learn more information while is having fun (Lanyi and Brown, 2010). On the other hand, the application of computer games in education provides a better learning environment, since the student (user) is able to instantly receive comments on the current state of his learning.

The GOET (Game On Extra Time) project (Lanyi and Brown, 2010) was developed based on these recent methods of teaching. With the use of developed interactive and teaching games, is possible to help people with cognitive and/or sensory disabilities to develop various activities. Getting and keeping a job are two examples of these activities. There are also contemplated other actions like how to prepare the user for the job, manage monetary amounts and travel independently. This type of application is very beneficial and useful in today's society, since virtual reality games are very popular.

To create applications taking into consideration the end-user, it is necessary to apply certain features in the design in order to maximize the usability and accessibility. The cognitive and/or physical limitations of the user can be minimized since the cognitive processing is reduced to the minimum. This reduction can be achieved through alternatives to the written text, such as pictures, animations and sounds (Lanyi and Brown, 2010).

As previously mentioned, educational games offer a good alternative to traditional teaching methods, and encourage the learning process. However, this type of games is intended for a younger population (primary and high school). For an older population there is another type of game designated by persuasive game.

Being an audio-visual and interactive method, persuasive games can have a greater effectiveness in learning, since it is possible to repeat a subject many times as necessary. Each of the generated situations can be customized according to the special characteristics of each person. The use of real-time feedback on the performance of the user can also serve as a primary motivator of learning (Lanyi and Brown, 2010).

The development of didactic applications or persuasive games becomes a very complex task due to the characteristics of the various users. Thus, special education has new methods like multimedia and audio-visual techniques to motivate the users in getting better results in learning. This topic has been having a greater attention in the literature. Researchers want a universal design for the applications, so everyone can use them.

The concept of one-size fits all has, in the last years, fallen into disuse, especially when one wants to develop applications for people with cognitive disabilities or physical limitations. There has been an investment in applications that allow its customization according to user preferences.

The orientation systems do not leave this topic out of analysis, and researchers try to identify which are the aspects that best apply to this group of users. In (Liu et al., 2009a, 2010) it has been identified various preferences like the use of images (landmarks) to orientate the user. These landmarks may have overlaid arrows to minimize the cognitive effort required to identify the path to follow. However, there are users who prefer to receive the information through audio messages (*e.g.*, people with visual impairment) or others who reject this method and prefer text messages (*e.g.*, people with hearing impairment). For this reason, a system that allows the creation and modification of the user preferences becomes imperative, since some users may not use a rigid system.

We have been developing a prototype that tries to overcome the obstacles and the barriers previously highlighted like the presence of interactive elements and advertisement or the concept one size fits all. The initial prototype described in (Ramos et al., 2012) have been enhanced with more functionalities, which are described in detail in (Ramos et al., 2013, 2014a). The system allows the modification of a set of preferences so the person with cognitive disabilities may adapt and use the prototype more easily. In order to let the system adjust to the user preferences our latest developments are focused on a Speculative Computation module, which guarantees that the user is travelling in the correct path alerting him otherwise (Ramos et al., 2014b).

2.5 Summary

Cognitive disabilities are medical conditions that may not be easy to detect and/or diagnose. Thus, if these are mild they may not be detected. If the patient does not cooperate during the diagnosis, it may not be possible to define its level of incidence. Due to the specificity of the medical condition of each patient it is common to distinguish the functional and the clinical diagnosis.

There are different types of cognitive disabilities and after defining the type of disability it is necessary to state its level of incidence and which characteristics of the person are affected. Thus, in the case of, for example, a traumatic brain injury and with the same level of incidence, a person may have his speech more affected while another one may have the memory more compromised.

Indeed, for a developer the functional diagnostic may be more appealing, since he may have to create or to enhance existing applications for this target (people with disabilities) since most of the existing software is not adapted. Thus, there are still some barriers that needs to be overcome in order to enable a person to use applications or to view web pages more easily (without distractive elements).

Chapter 3

Reasoning Methods

You can overcome anything if you don't bellyache.

— Bernard M. Baruch

Outline

Reasoning Methods

We will start looking at the Industrial Internet of Things (IIoT), which is a network of physical objects, systems, platforms and applications that contain embedded technology to communicate and share intelligence with each other, the external environment and with people. Its availability and affordability depends not only on the emergence of new methodologies for problem solving, but also of sensors, processors and other technologies that facilitate the capture and access to real-time information, including reasoning and planning methods, which are the areas that we intend to address in this work.

For example, in robotics the goal is to let an agent (or robot) to serve the purpose of, by itself, and attending to the environment, move an object from one place to another. On the one hand these decisions must be taken on-the-fly and the sensory data may not be always available. Indeed, the robot moves under an uncompleted (data/information/knowledge) scenario. On the other hand new data obtained from the sensors is all the time obtained and used to update the robot (or agent) belief state (Russell and Norvig, 2003; Hertzberg and Chatila, 2008). Under these frameworks and in order to develop an autonomous agent, there are multiple ways to treat default data, information or knowledge, which are key factors in the process of enabling an agent to learn and to plan its actions. Despite the dealing with incomplete information there another metric that should be considered that is the quality of the available information (Analide et al., 2006).

Orientation methods, both indoor and outdoor, represent an important progress on assistive technology. These are very rigorous methods (thus, they may not tolerate faults and correctly respond to the user stimulus) and give an extreme significance to the used interfaces. These must be, simultaneously, simple and complete, i.e., they have to show/provide available features/functionalities in an easy way so the person with disabilities may use the application without feeling confused or losing his confidence on these systems. Although these orientation methods have a significant impact in the user quality of live, using complex technologies and various types of hardware (like sensors and GPS), they lack on reasoning methods. These methods allied to

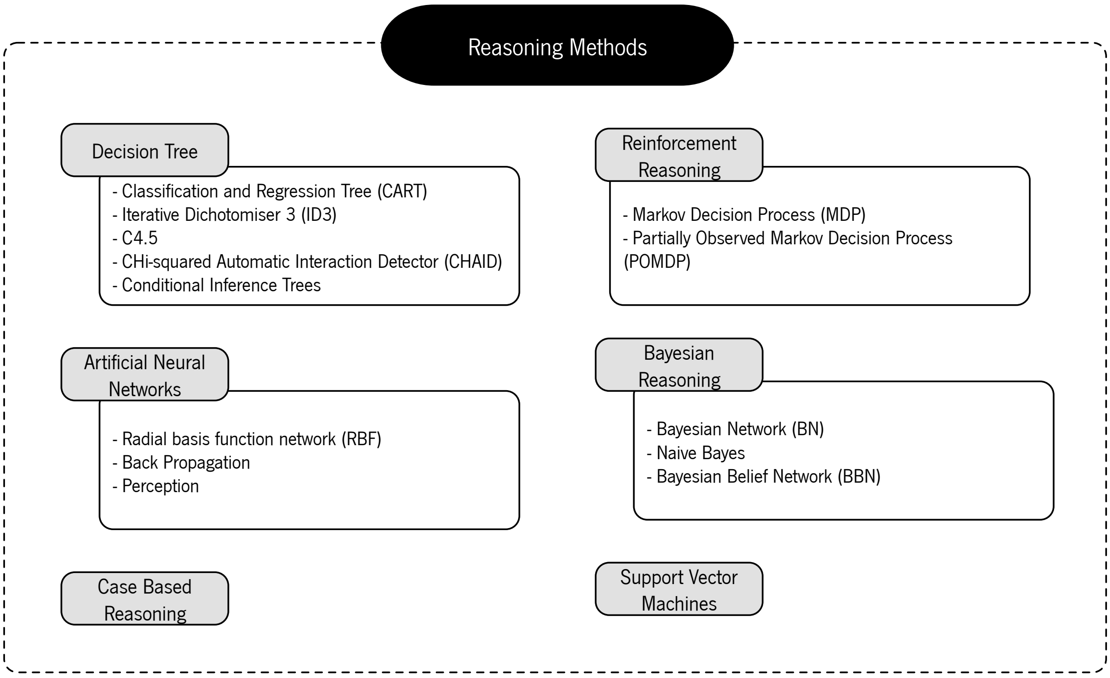


Figure 3.1: Reasoning Methods

the most recent technology create extremely promising systems in assistive technology, since they conciliate the fast technological progress with artificial intelligence based systems. These systems allow a "humanization" of the technology, enabling it to learn each user necessities.

With this section we do not intend to provide an exhaustive description of all reasoning methods (since there are too many) but a description of a small set of them. The selected methods are, in our opinion, the ones that best comply with the current study. Some of the selected methods may come in different forms like bayesian learning, which may be used as a bayesian network, a naive bayes, or a bayesian belief network. Fig. 3.1 depicts some of these reasoning methods and some of the forms in which they may be used. In the next sections a description of these reasoning methods is provided.

Reinforcement Learning (Section 3.5) is an unsupervised learning method where the goal is to enable, for example, a robot to learn by sensing the environment. The goal here is to get the best sequence of actions weighted by a reward function. In Case Based Reasoning (Section 3.6) the agent tries to classify and act based on his knowledge base (the agent finds a similar situation and tries to apply it or an adapted one to the new scenario). In Speculative Computation (Section 3.7) whenever there is incomplete information, the system uses a pre-established default value and continues the execution of the active task (the system does not compute a possible value for the missing data). When the missing information is returned the computation is revised and the default value may be updated. This method enables the system to have the capacity to anticipate a situation and adapt to it more rapidly, i.e., perceive the user next action and act quickly to notice any unusual and potentially dangerous or difficult circumstance. Other reasoning methods may be used or adapted like a Decision Tree Learning (Section 3.1), Artificial Neural Networks (Section 3.2). Support Vector Machines are presented in section 3.3 while the Bayesian Networks are described in Section 3.4.

3.1 Decision Tree

Decision Trees (DT) are used in different arenas and for different purposes. Using the available data, a decision tree may be used, for example, as predictive modelling in statistics, machine learning, pattern recognition or data mining (Rokach and Maimon, 2005). According to Safavian and Landgrebe (1991) a decision tree is able to turn a complex decision making process into a set of simple tasks, which are of easy interpretation. This capacity to reduce the complexity of the tasks enables the creation of a visual and explicit depiction of its makings.

A decision tree has a node called root, which contains all the class labels. This node has no entering edges. All remaining nodes have exactly one entering edge. There may be some nodes without any exit edge, which denote its leaves (or terminal nodes). The remaining nodes are internal ones. When traveling from the root node to another node (internal or leaf) there is only an unique path.

Decision tree learning, as a Data Mining approach to knowledge extraction and learning, are used in order to create prediction models based on set of input variables (Dahan et al., 2014).

This is a supervised learning method that recursively creates a partition of the instance space (Rokach and Maimon, 2005). This process intends to create subsets from the original one (i.e., the data), based on an attribute value test, which simplifies the data analysis. Each subset is subsequently divided until the current subset has the same value of the target variable, or when iterating one more time does not add more value to the predictions.

Like any other learning methods, decision tree learning method has its advantages and disadvantages. Indeed, this method presents huge volumes of data in a simple format, making it easy to understand and interpret (e.g., it is possible to skip the normalization data process before using this method, either by removing empty/blank values, or by using both numerical and categorical data as input to the decision tree).

However, this learning technique is know to be NP-hard under the aspects of optimality (e.g., in order to find the minimal decision tree). If one is using a binary tree then finding the minimum decision tree is NP-complete, which potentiate the use of heuristics as an alternative to the present technique.

3.2 Artificial Neural Networks

An Artificial Neural Network (ANN) stands for a computational tool to model complex problems. Resembling the human brain, this tool is inspired in biological neural networks (Basheer and Hajmeer, 2000; Jain et al., 1996), i.e., when developing this modeling process researchers were inspired by the central nervous systems (e.g., the brain) and tried to create a tool that works like it.

ANNs are used to solve a variety of problems in different contexts as pattern recognition, prediction, optimization, associative memory, or control (Jain et al., 1996). These problems are generally complex and have a large number of inputs.

ANNs may be seen as structures of interconnected processing elements called artificial neurons, which are capable to process and represent knowledge (Basheer and Hajmeer, 2000). According to Jain et al. (1996) ANNs have features that are not present in modern parallel computers, like massive parallelism (enabling a fast processing and hardware failure-tolerance), learning and adaptivity ability (enabling the system to change its internal structure), generalization (enabling the system to use and model unlearned data), among others.

Using an ANN is possible to learn and generalize from experience. Through these networks it is possible to get accurate solutions for imprecisely formulated problems. This capability is specially important in problems that are only understood by experimental observations.

3.3 Support Vector Machines

The data classification is a common and important task in today's life. Medical diagnosis are made based on the classification of microarray gene expression profiles (Noble, 2006). To automate this process of data classification there are computer algorithms that learn though examples in order to label new data, called Support Vector Machines (SVMs). SVMs have become a popular tool for data mining tasks like classification, regression, and handwritten digits recognition (Noble, 2006; Bennett and Campbell, 2000), among others.

To use a SVM as a classification method, there is a procedure that is divided in two phases. The initial phase is a training step in which the SVM is loaded with cases that are marked as belonging to a given category. In the second phase the trained algorithm of the SVM builds a model that is able to label new data, assigning it to the correct category.

Each element used by the algorithm of a SVM is called an instance, and is composed by a target value (i.e., the class label), as well as a set of attributes (i.e., features or observed variables). For the training phase each instance that is used is complete, i.e., has its attributes and the target value. The goal of the algorithm is to predict the target value for a new instance that have only its input data. For the algorithm execution it may be required a data transformation in order to be used by the SVM learning algorithm (e.g., each data instance must be represented as a vector of real numbers). Thus, a categorical attribute have to be converted into numeric data (Hsu et al., 2008).

The SVM learning algorithm creates a hyperplane in order to create a separation between the values under classification. This separation may be a dot (i.e., the target values may be put on a line, and a dot creates the difference between the values), a line, or it may be a more dimensional separation. The simplest SVM algorithm handles binary classification problems, thus a new vector is classified as belonging to one of the two classes. It is possible to extend this classification to more than two classifiers by training the algorithm under a one-versus-all classifiers perspective. This means that instead of labeling the new data as 'A' or 'B', the algorithm tries to answer the binary questions: "Is it A?", "Is it B?", and so on (Noble, 2006). This approach as revealed to be quite effective for some type of problems (e.g., cancer classification).

3.4 Bayesian Networks

Bayesian networks are a method that is able to model uncertain and complex domains. They provide a theoretical framework for dealing with reasoning under uncertainty, which is a major issue in Artificial Intelligence. Having the capacity to deal with incomplete and unreliable information, Bayesian Networks have been applied to a variety of problems, like text analysis, or medical diagnosis (Uusitalo, 2007).

A Bayesian Network may be seen as a graphical approach to problem solving that denotes causal relationships in a given domain (Holmes and Jain, 2008). Each node of the graph represents a variable and directed links form arcs between them. Each node may have one or multiple probability distributions according to the number of incoming links (parents). If a node has no parents, it has an unique probability distribution, else it has one for each parent. Thus, nodes that do not have any connection between them represent variables that are made or granted on certain terms.

The uncertainty level is set by a probability distribution. Indeed, when the knowledge present in a network with respect to a given variable increases, its uncertainty diminishes. This probability distribution is an advantage when one is using Bayesian networks since it allows a better estimation of the risks and uncertainties, comparing to models that use only a nominal value (Uusitalo, 2007).

The Bayes theorem (defined by Rev. Thomas Bayes) is used to determine the nodes probability distribution in a Bayesian network. Using conditional probabilities it is possible to calculate and update a distribution value, since they specify the one's degree of belief in a given proposition, assuming that there are other propositions that are true. Without a prior attention to the values of these distributions of probability the value of the current proposition has no meaning at all (Niedermayer, 2008).

Through the use of the Bayes theorem it is possible to calculate the probability distribution of a node given the value of its parents, but also to calculate the distribution probability of a parent node given the value of its children (Uusitalo, 2007). Thus, one may calculate the probability distribution of the consequences given its causes or may deduce the probabilities of different causes given the consequences.

Bayesian networks have several advantages over traditional methods in respect to causal relationships. As previously stated it is possible to clearly identify the relations between the nodes and identify those that are independent (i.e., there is not any path between the nodes). If the graph is optimized then every node may have a maximum of k parents and the algorithmic routines required may run in linear time, instead of running in an exponential one (Niedermayer, 2008). However, Bayesian networks have their limitations. The prior knowledge that is used in the inference process will dictate the quality of the network. Indeed, the results of the Bayesian networks may be invalid if the prior beliefs are not reliable (e.g., may be excessively optimistic or pessimistic) (Niedermayer, 2008). On the other hand, a data discretization process may be on place, since Bayesian networks do not deal well with continuous variables (Uusitalo, 2007).

3.5 Reinforcement Learning

Reinforcement learning is an unsupervised learning method, which relies on a reward function that returns a value after an action is done. Thus, instead of getting a set of actions to perform under a given scenario the agent has to learn by himself if an action had a positive or negative impact on the scenario (Russell and Norvig, 2003). By acting in the environment the agent may learn the best policy, i.e., determine the best sequence of actions to achieve the goal. According to Hertzberg and Chatila (2008) the formal framework of reinforcement learning is the same as the framework for Markov Decision Process (MDP) in which there is a set of states to define the state of the environment and the agent is able to perform actions (available from a set of possible actions). The agent intends to get the sequence of actions (policy) that enables him to accomplish his goal (e.g., travel between two different locations).

MDP's are an example of reinforcement learning and are widely used in areas like robotics, automated control and artificial intelligence. When a problem is formulated as an MDP, there are some algorithms that may be chosen to solve it. A MDP is a discrete time stochastic control process (Littman et al., 1995), and have four components, namely a set of states, a set of actions, the actions effects (i.e., the state-transitions), and their outcomes.

- ▷ **State:** a state defines the current status of the world. An action do something on the world by changing its state.
- ▷ **Action:** each action denotes a possible alternative of acting on the world, changing its current state.
- ▷ **State-transition:** specifies the effects (the changes on the world) of executing an action. This effects are dependent on the current state of the world, since the same action may have different effects. Its effects may follow a probabilistic distribution, which let us to specify a set of resulting states and their associated probability of ocurrence.

▷ **Immediate reward:** this is a measure that specifies the reward of taking a specific action.

The goal in a MDP is to map the elements of a state set to the actions that may be performed on them in order to maximize a likely reward, i.e., the policy (Littman et al., 1995). This is an iterative process and the number of iterations are consistent with the horizon to reach a solution to the problem, where each reward is a consequence of the previous ones.

At a given iteration the MDP is in a s state and the decision maker may choose from a set of available actions to go to the next one, changing the current state of the process to s', then returning to the decision maker the corresponding reward $R_a(s, s')$. The probability of the current state s evolve to a new state s' is influenced by the action a that is taken, which is according to the state-transition function $P_a(s, s')$.

Whenever the current state of the world cannot be fully determined (i.e., with complete reliability) by the user (i.e., the decision maker) then we are facing a generalization of a Markov decision process, which is entitled Partially Observable Markov Decision Process (POMDP). The user uses the information obtained from previous iterations (e.g., moves and observations) in order to be able to estimate the current process state. Thus, the user have to maintain a probability distribution over the possible states set based on the values from previous ones.

A POMDP is applied in areas like robotic navigation, machine maintenance, and planning under uncertainty, in general. This methodology for problem solving was initially used in operational research. Later, in the 80s and 90s, the POMDP was used by the Artificial Intelligence community with the goal of get an optimal solution for complex planning problems under uncertainty (Chong et al., 2009).

Like a MDP the POMDP is formed by a set of states, a set of possible moves, a state-transition law (which specifies the next state distribution when a move is taken at a current state) and a reward function that specify the reward received when an action is taken. Despite these similarities, a POMDP has two more components:

▷ **Possible actions:** set that stands for the space under scrutiny.

▷ **Observation law:** identify the observations distribution when an action is carried out at a given state (be aware that in POMDP the user do not have a direct observation of the world current state).

The goal of a POMDP is to find the optimal action for each possible belief (the agent can not directly observe the world and the current state is given by an observation law) over the states. The optimal action is the one that maximizes or minimizes the reward or the costs. Find a sequence of optimal actions is the same as finding the best solution of a POMDP.

Partially observed Markov decision processes are used in the Artificial Intelligence scientific field, namely in machine learning (e.g., reinforcement learning), robot navigation (Kaelbling et al., 1998), healthcare (Bennett and Hauser, 2013), and assistive technology (e.g., assisting people with dementia in hand washing (Hoey et al., 2007)). However, applying a MDP or a POMDP is a very challenging task due to the data-intensive evaluation process to get the transition model (i.e., how the belief states evolve over the time, and how the observation model is set).

3.6 Case Based Reasoning

In one's life time we are faced to many different problems that may need an answer, which may be based on the solutions of past ones. One may recall a past event similar to the new one, and adapt its results to the present. A different reasoning process may be put in place, enabling one to assess what went wrong in the past occasion in order to avoid the same mistakes. In computer science this type of action stands for a different methodology for problem solving, different from the ones referred to above, and named Case Based Reasoning (CBR). Indeed, this methodology is sometimes considered as pervasive, namely with respect to human problem solving acts.

In CBR the reasoner uses old cases to understand and solve new ones. In terms of this undertaking the theorem prover may adapt an old solution, use an old one to explain the new, use an old case to critique the solution of the new one, or to reason on a previous case in order to explain the new one.

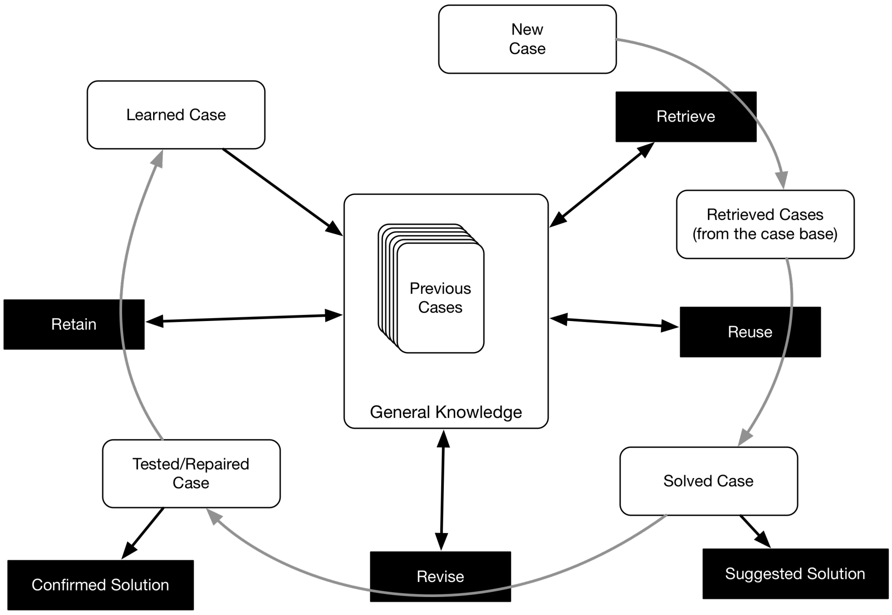


Figure 3.2: The Case Based Reasoning cycle

On the other hand, and according to Kolodner (1992), the quality of a solution relies on:

- ▷ the past experiences;
- ▷ the ability to understand the new experiences in terms of the old ones;
- ▷ the capacity to adapt an old case to the new one; and
- ▷ the capacity to evaluate a solution.

According to the intended use of CBR, it may be classified as interpretative or problem solving (Lopez and Plaza, 1997). Under the former classification, the goal is to determine if a new case should be considered identical to an old one, based on its similarities and differences. In the latter, the goal is to get a solution to the new case according to an adaptation of a previous one.

The cycle for problem solving in CBR (Figure 3.2) consists of "4 R's":

- ▷ **Retrieve:** retrieving cases that are relevant and similar to the new one from the knowledge base. Recalling a past case is considered an indexing problem since it is necessary to find a case instance that is closer to the new one. This process is the core of CBR;
- ▷ **Reuse:** selecting a set of the best cases from the retrieved cases in order to derive a solution. At this stage the theorem prover may have to adapt a recalled case by changing some of its attributes;
- ▷ **Revise:** the theorem prover evaluates the acquire solution, making sure that unrealistic solutions are not considered; and
- ▷ **Retain:** the new solutions (in terms of successful and failed attempts) are stored in the knowledge base, enabling the theorem prover to propose new solutions based on successful attempts, and to avoid potential failures by recalling ineffective ones.

According to Kolodner (1992), CBR stands for a problem solving methodology either to reasoning or learning. Being able to keep a past case solution, the theorem prover may recall a past one and adapt it, so the past case could resemble the new one. Over the time the CBR gives better answers due to the growing number of cases saved in the knowledge base, or case base. Thus, when recalling an old case that is similar to a new one, old mistakes may be avoided. The learning feature of a CBR system is obtained by the cumulation of saved solutions and through the assignment of indexes to them. The better the indexes, the better and similar the recalled cases.

3.7 Speculative Computation

The procedure initially presented by Kakas et al. (1998) on abduction in logic programming was the starting point for the theory of Speculative Computation and Abduction. This procedure was later extended by Satoh et al. (2000). However, the first experiments/studies on speculative computation are dated from 1985. These consider optimistic transaction in databases, three-phase transition in systems with fault-tolerance capacities, efficient execution mechanisms for functional programming (Burton, 1985), and parallel logic programming (Gregory, 1993). These works were the basis of the development of multi-agent systems that use Speculative Computation (Hosobe et al., 2007).

Speculative computation has as its purpose or objective to persist in the execution of a given program, even when some information is missing. Indeed, the hidden information is temporarily replaced by a default one, and when such information is received, the computation is revised. If the execution branch that is using the default one is consistent with the new one, the computational process continues. When the information that is being received stands for something of a different type (i.e., with respect to the default one), then the engaged branch is discontinued, and another one is resumed/started.

Each branch (process) is represented by a tuple $\langle GS, OD, IA, ANS \rangle$:

- ▷ GS - Goal Set: set of extended literals to prove, which express the current status of an alternative computation;
- ▷ OD - Outside Defaults: set of askable literals and represents the assumed information about the outside world during the process;
- ▷ IA - Inside Assumptions: set of negative literals or abducibles, which contains the values that are assumed during the process;
- ▷ ANS - set of instantiations of variables in the initial query.

The set of default values are obtained previously, and are used whenever needed. For our propose (i.e., with respect to an user with cognitive disabilities) it is essential that the system be able to anticipate the user movements, being therefore ready to alert him when some miscalculations occur by its part. This reasoning method is described in detail in Section 4.3.

3.8 Discussion

There are multiple types of reasoning methods that may come under the Artificial Intelligence (AI) scientific field (Figure 3.3). Each has it own attributes (with advantages and drawbacks) and, according to the environmental context, different methods may be applied. However, despite this knowledge there may be some other reasoning methods (news or existent) that have never been applied to a given situation (depending on the context), although they may suit better to it.

With the aim of guiding the user with cognitive disabilities and adapting the path to his preferences it is possible to consider different approaches to sense the environment and the context in which the user is. With this purpose it is important to refer that the selected reasoning method should have a prediction ability, should not need the user feedback (the reasoning method should select an action without questioning the user), or should be able to run when there is some missing information.

Decision Tree Learning (Section 3.1) is a method with predictive abilities through knowledge extraction and learning. However, the Decision Tree has to be fed with a set of input values. Thus an initial supervised phase is necessary in order to enable this reasoning method to autonomously classify future inputs. Considering the context under discussion (guidance) this learning algorithm have this drawback since when the user is using the system for the first time there is not any information about the user to feed the decision tree.

Figure 3.3: Comparison between different reasoning methods

Features / Reasoning methods	Complexity	Fault Tolerance	Learning Mechanism	Reward/Feedback	Input
Decision Tree Learning	NP-hard	✗	Supervised		✓
Artificial Neural Networks	High processing and HDD space	✓	Unsupervised		✓
Support Vector Machines		✓	Supervised		✓
Bayesian Networks		✓			✓
Markov Decision Process		✓	Unsupervised	Reward function	✗
Case Based Reasoning		✓	Supervised	User Feedback	Knowledge Base
Speculative Computation		✓	Unsupervised	✗	Default Values

Inspired on biological systems, Artificial Neural Networks (Section 3.2) are able to model complex systems. Through massive parallelism by using high processing levels, these networks are able to learn and adapt. They also have a fault tolerance feature, thus when there is some missing information the artificial neural networks are able to keep the computation. With respect to the guidance context, this networks present the fault tolerance advantage, however one needs to train the network in order to obtain better results. This and the necessity for high processing power and memory space become a big drawback since, despite learning with new data, these networks need to have some user information (which may not be present when running the application for the first time).

Data classification task may be automated by a computer algorithm named Support Vector Machine (Section 3.3). After a training phase the Support Vector Machine algorithm receives new data and labels it according to the previous training phase. Although this method has a predictive feature it has to be previously trained. Thus, considering the content under analysis it means that the system must have user information before being used for the first time.

Based on Bayes theorem, a Bayesian Network (Section 3.4) is able to reason under incomplete information scenarios, i.e., this method is able to reason under uncertainty. A Bayesian Network establishes causal relations between its nodes through a probability distribution. Thus, given an input value this reasoning method calculates possible outcomes with the respective probability. Applying this method to the guiding context it have its advantages since it could predict the user next movement, i.e., it could calculate the probability of the user turn into a wrong direction in a given corner. However, there is still the need for previous user information in order to train the network and reason under uncertainty scenarios.

Having proven its advantages in fields like robotic navigation and planning under uncertainty, the Partially Observed Markov Decision Process (Section 3.5) has being successfully applied in an orientation system for people with cognitive disabilities (Liu et al., 2009a). A POMDP is able to select the next action (whose information should be presented to the user) and, based on a reward function, evaluate if that action produced a positive or negative impact on the user. However, in a initial step this process was incorporated by a naive model, in which it is assumed that the options will be correctly followed 100% of the time. With the usage of the system the POMDP evolves and better adapts to future actions.

Case Based Reasoning (Section 3.6) is a method that resembles the human thinking method: when facing a problem the user recalls similar situations and adapts the previously used solutions to the new one. Past experiences may be used through some adaptation to the new situation or to know what should not be done in order to avoid negative outcomes. This reasoning method needs a knowledge base from which a previous case is retrieved and adapt. After reusing, there is the need to evaluate the acquired solution before saving it to the knowledge base. This evaluation may be dependent on the user feedback. Thus, in our context there is the need to avoid (the maximum) number of used inputs (or feedbacks), which makes this reasoning method hard to apply.

Speculative Computation (Section 3.7) has the ability to deal with incomplete information, i.e., when the missing data is received the information is processed, the computation is revised and the system keeps executing the orientation guidelines. Indeed, the system is previously loaded with a set of default values, such as information about the travel path (e.g., which directions should the user take, what are the turns that should be done) and information about possible missing turns (e.g., locations in which the user may take the wrong direction and get lost). These values are obtained from a Trajectory Data Mining module, which is described in detail in Section 4.5. Whenever there is a scenario based on incomplete information the framework uses the default value and keeps the execution of the program. Thus, the system does not go under an idle state and when the information is received, the execution is revised. Another aspect that must be referred to is concerned with a process of movement anticipation due to its ability to continue the execution when there is some missing informartion, i.e., at any moment the system is able to predict the user acts, and therefore to prevent user wrongdoings, since it is in an advanced stage of execution.

This reasoning method has never been used, as far as we know, in a system intended to guide a user with cognitive disabilities. However, for the presented reasons we have chosen to implement the speculative framework in the orientation system, as these features were not found in other systems. However, the speculative computation framework uses a set of default values which are obtained from external sources like a trajectory data mining (e.g., OPTICS algorithm (Ankerst et al., 1999), see Section 4.5).

In order to clarify the differences (advantages and drawbacks) of the previously described reasoning methods the main feature that should be considered in order to develop a system for guiding an user with cognitive disabilities are summarized in Figure 3.3.

Chapter 4

Publications Composing the PhD Thesis

Our greatest weakness lies in giving up. The most certain way to succeed is always to try just one more time.

— Thomas Edison

Outline

Publications Composing the PhD Thesis

During the development of this work we have combined research and practice by applying the Action-Research methodology. Thus, after researching and knowledge gathering, a system was set accordingly to the defined goals. Then the developed work were revised in order to catch possible implementation errors.

This iterative process was validated through several publications in journals and conferences under this area of knowledge. This outside validation is crucial since it allows the gathering of feedback from new perspectives (*e.g.*, from the reviewers), from direct scientific questions (*e.g.*, in conferences) and through questions about the viability of the project. Thus, this enabled a continuous and more active development of the project.

The remainder of this chapter includes the main publications of this project. Each section includes a small description of the paper stating the conference or journal in which it was published and if it is an extended version of another paper. For a better understanding of the development of this PhD thesis the papers are presented according to the following logical order: initially, it is presented the state of the art considering the orientation of people with disabilities and a first overview of our system is done (Section 4.1). Then a first prototype of the system is shown in Section 4.2 in which caregivers may remotely have access to the position of the person with cognitive disabilities and the orientation is performed using the shortest path through an augmented reality interface. The system keeps evolving and a Speculative Computation is introduced and developed (Sections 4.3 and 4.4). As this module is matured, the method to obtain the default values for it is studied and structured. Finally, Section 4.5 presents the final version of the speculative computation model and a discussion on the advantages and disadvantages of this reasoning method. A compariton is also included between this and other reasoning methods, having in attention the context for which the CogHelper system is being developed.

4.1 Orientation System for People with Cognitive Disabilities

This paper presents the state of the art with relation to the process of orientation that targets people with cognitive disabilities. An introduction to the system that is being developed is included, stating some of its main features/goals. Details about this publication are given below.

Publication Details	
Title	Orientation System for People with Cognitive Disabilities
Authors	Ramos, J. and Anacleto, R. and Costa, A. and Novais, P. and Figueiredo, L. and Almeida, A.
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Orientation System for People with Cognitive Disabilities

João Ramos, Ricardo Anacleto, Ângelo Costa, Paulo Novais, Lino Figueiredo, and Ana Almeida

Abstract. In health care there has been a growing interest and investment in new tools to have a constant monitoring of patients. The increasing of average life expectation and, consequently, the costs in health care due to elderly population are the motivation for this investment. However, health monitoring is not only important to elderly people, it can be also applied to people with cognitive disabilities. In this article we present some systems, which try to support these persons on doing their day-to-day activities and how it can improve their life quality. Also, we present an idea to a project that tries to help the persons with cognitive disabilities by providing assistance in geo-guidance and keep their caregivers aware of their location.

Keywords: Cognitive disabilities, mobile communication, localization, persons tracking, ambient intelligence.

1 Introduction

Due to technological advancements the average life expectancy has been increased. The number of elderly people is increasing thus, the populations are getting older. The elderly population requires, among others, more health care, which in some cases involves the existence of a caregiver (family or not). If this caregiver cannot assist the elderly person at home, then the elderly person is forced to move to a family member's or nursing home.

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Any of the options described above involves loss of independence by the person who requires health care (elderly). In order to maintain an independent life, smart homes are considered a good alternative [13]. Besides elderly, smart houses can be also used by people with cognitive disabilities. Several intelligent devices embedded in home environment can provide assistance to the resident, monitoring his movements and his health 24 hours a day [15, 4].

Smart houses besides being physically versatile are also user friendly, *i.e.*, perform their functions without bother, be inconvenient or restrict user movements [4]. Its goal is therefore to provide comfort and pleasure to the person.

Smart house's are developed based on the concept of Ambient Intelligence (AmI). This concept was firstly introduced by Information Society Technologies Advisory Group (ISTAG) [11]. In a simple way, AmI can be defined as the combination of ubiquitous computing with adaptive user interfaces [8]. The goal of AmI is to develop sensitive environments that are responsive to the presence of humans. To achieve this goal it is necessary to integrate these environments with ubiquitous computing [13].

Since 1988 the interest and the attention on how assisted technologies can improve the functional needs of people with cognitive disabilities has grown. The development of several projects related to this technology has increased the level of interest and the public awareness to the usage of assisted technology by people with cognitive disabilities and how technology can improve their lives [2].

Like an ordinary person, individuals with cognitive disabilities leave their homes, but once outside, the security and automated actions of their smart houses are inviable. In the last years, the interest and technology improvement has turned people's attention to assisted technology outside home and not only inside.

The integration of technology in day-to-day human life allows an interaction between the system and the person who uses it. In order to totally achieve the concept of AmI, it is necessary to turn the implicit communication (that prevails today) into explicit. In this way, concepts such as ubiquitous computing and invisible computing arise [14, 7]. The interaction should no longer be a simple use of interfaces, becoming more interactive, recognizing humans presence, adaptive and responding to the needs, habits, gestures or emotions shown by the residents.

Nowadays, AmI is integrated in smart houses, which contains several automated devices that may be remotely controlled by the user. Their main goal is to provide comfort, energy saving and security to the residents. This can be achieved by domestic tasks automatization [15].

New developed devices have to be easy to use, lightweight, small and resistant. If these conditions are not verified there is a high probability that the device will not be used for a long time. The person with cognitive disabilities will lose the interest and, therefore, will not use it.

In section 2 we present in detail some of the work developed in this area. In section 3 we describe our propose for a system that tries to help people with cognitive disabilities. Finally, at section 4 we make a brief conclusion of this paper.

2 State of the Art

Dawe, in [9, 10], presents how people with cognitive disabilities interact and communicate using a cell phone. They keep in touch with other persons, family and caregiver with this device. Dawe shows that many of assisted devices are acquired, but are not successfully adapted to the needs of people with cognitive disabilities. This failure may come from complex utilization and handling.

The developed application has simple interfaces loaded with pictures that act like buttons to perform or receive calls, and has a voice memo which alerts the mobile user for an incoming activity. It was also developed a time-based reminder that is activated at a certain time. This reminder is based on daily calls that parents use to remind the person with cognitive disabilities what he had to do next.

Dawe has stimulated the participation of cognitive disability people in the application development, where it was concluded that the system is useful to improve their capability to interact with other persons.

Carmien *et al.* [5] developed a system to support people with cognitive disabilities to travel using public transportation. They studied several techniques that caregivers and people with cognitive disabilities use to travel, for example, from home to school. The simplest way is using a standard bus map and then create a personal map with the important routes colored (figure 1 a)). In addition to routes, significant landmarks are also marked on the map. Moreover, each person with the cognitive disability has a group of time cards (figure 1 b)). These cards, according to the authors, are used if that person wants to go, for example, to the shopping center. The person with cognitive disabilities finds the correct card which has information about the bus route and schedule.

After this analysis they developed a system architecture where the person with cognitive disabilities just has to use a PDA, instead of the map and time cards. This architecture has several goals, the first is to give assistance to the mobile user, sending just-in-time information for many tasks, including destination and information about the correct bus. The second is, when the user needs, start a communication

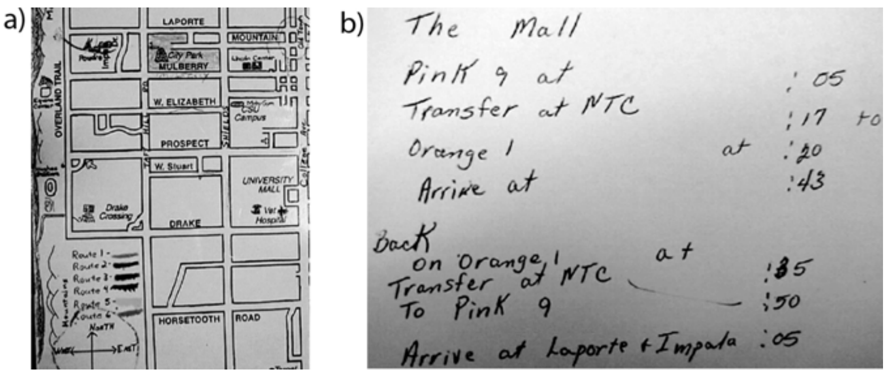

Fig. 1 Traditional artifacts personalized during training [5] - a) Personal colored map; b) Time cards

between him and the caregiver. Finally, the system supplies a safety functionality if something goes wrong.

Based on this architecture, Carmien *et al.* developed a prototype which can be seen on figure 2. On the figure left side it is presented a menu with possible destination options, while the figure on the right side shows bus position on real-time. The buses on the street are equipped with GPS and send wirelessly their position to a server. Bus agents have access to this information and update bus position on the map. When the user selects the destination the system calculates the routes based on the buses GPS information.

There are Mobility Agents that detect if the user has boarded the correct bus. In case of missing the bus or taking the wrong bus, these agents use heuristics to correct the situation.

The goal of this prototype is to give to the mobile device the capability to generate visual and audio prompts caused by real-world events. With this device people with cognitive disabilities can use the public transportation system without getting lost, or taking the wrong bus.

The Personal Travel Assistant prototype was based on mobility agents. These agents are those who really help people with cognitive disabilities to travel using public transportation system. Although traveling from one place to another is an important task in people's life, this usually represents a sub-activity of their day. To implement a broader prompting system the authors developed MAPS - Memory Aiding Prompting System.

The creation of scripts by the caregivers is possible due to an end-user programming tool. With this tool caregivers can create several scripts according to the activities that mobile user wants or needs to do. These scripts have audio-visual stimulation to keep the attention of the mobile user (person with cognitive disabilities).

Recently, Chu *et al.* [6] developed an assistance system that has an interactive activity recognition and prompting. The model has a learning process that adapts the prompting system to each user, helping in their daily activities. The schedule is then, if necessary, revised as many times as the user needs.

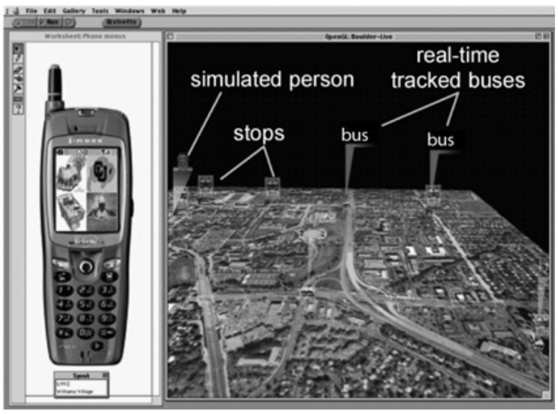

Fig. 2 Prototype showing a prompting device (on left) and a real-time bus system (on right)[5]

Fig. 3 Proposed System Demonstration

The developed system use data from sensors (*e.g.*, IR motion sensors, RFID touch sensors) to determine the user's state. When the system is uncertain of the user state then it queries the user to know what he or she is doing. In order to avoid constant interruptions from questions or prompts, Chu *et al.* proposed a selective-inquiry rule. This interrupts the user only when trying to reduce the uncertainty.

3 System Description

In the previous sections we have shown that a mobile device (*e.g.*, cell phone or smartphone) can be very useful in the day life of people with cognitive disabilities. For instance, caregivers use it to communicate and to know the current location of the person who they are taking care .

We propose a system that tries to support people with cognitive disabilities and to keep their caregivers more unconcerned.

This project consists on an orientation system to help people with cognitive disabilities, turning them more independent. This orientation system consists on a mobile application, which presents, along the user travel path, several landmarks (pictures) to help him to know which direction he must take next, as we demonstrate on figure 3. In the case that a picture is not available, then an arrow will appear indicating the correct path. During an activity or a travel the user will receive, if necessary, prompts indicating several types of information. This information is given just-in-time and includes directions (*e.g.*, turn left) or reminders to keep the user's attention in the present action.

These directions are given by the localization system, which retrieves the person's location and verifies if the person is performing the correct travel path.

If, for some reason, there is an emergency or the user gets lost then he only has to press a simple panic button in the smartphone home screen. When activated it initiates a call and/or sends a SMS to the caregiver with the current user location.

We will develop a web and another Android application to the caregiver be aware, in real-time, of the actions of the person with cognitive disabilities (*e.g.*, where he is going or what is doing).

This system will be developed for Android Operating System and it will use mobile device GPS module to retrieve user outdoor location. However, indoors or in a more dense environment (big cities with tall buildings, dense forests, etc) GPS does not work or does not provide satisfactory accuracy. So, we have a problem, in indoor environments the proposal of only use GPS to retrieve location, does not work. To suppress this limitation we will integrate GPS with an Inertial Navigation System (INS) presented on [3]. Using this type of localization system the user is not context dependent (*e.g.*, smart homes - like we have seen earlier).

The main goal of this localization system is to retrieve location in indoor environments without using a structured environment and in a non-intrusive way. It consists on several sensors (Body Sensors Units) integrated on person's clothes and shoes, spread over the person's lower limbs. These units are connected to a Body Central Unit (BCU), which receives the sensors data and handles the location estimation, to then send it to the user's mobile device. One problem is that INS can have a big drift, due to sensor's thermal changes, which leaves to error accumulations and to poor location estimations. However, we are implementing a probabilistic algorithm that learns the person walking behaviors to, in real-time, correct the sensors data.

In figure 4, we present the framework for our system. People with cognitive disabilities must have a smartphone with Android Operating System and a GPS module. Also, they can have the INS that we have presented before, which connects with the smartphone through a Bluetooth connection, giving to it the actual user location (both indoor and outdoor). This INS includes some sensors, like accelerometers, gyroscopes, force and pressure sensors. With user current location, the smartphone will process the necessary data to present, to the user, the correct landmark for his location in order to assist user's orientation.

Besides showing this information, the mobile application sends (every 5 minutes or 200 meters), over the Internet, the current user location to the system server. Thus, the server must be able to communicate in a standard way, supporting SOAP [1] and OAUTH [12]. It will have a database and decision engines that, for instance, send a message to the caregiver if the sensor platform detects an user emergency.

Finally, the caregivers can connect to the server, through the web or the mobile application to retrieve the person with cognitive disabilities current location. Also, an agent platform, that work with general web information, is used to obtain a landmark image that is needed and is not already stored in the smartphone.

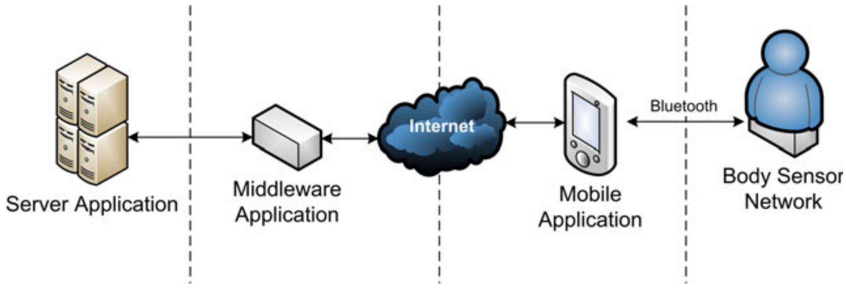

Fig. 4 Framework

4 Conclusion

Nowadays assisted technology is being increasingly used to improve the life of people with cognitive disabilities. There are several studies that analyze these people needs, presenting what is done and what needs to be done to improve their life quality.

There are several systems that assist the life of the residents of smart houses, but once outside the security and automated actions of the smart houses are not available. This is a problem to people with cognitive disabilities because they cannot be completely independent and need a caregiver.

Some authors tried to solve this issue by developing many types of applications that help people with cognitive disabilities, for example, to assist people using public transportation system, but traveling is not the only task that these people perform. It represents a sub-task (sub-activity) that needs to be accomplished in order to do an entire activity. For this reason it was developed a prompting system to assist people with cognitive disabilities and turn them more independent.

In this paper we have presented a system that tries to make these people even more independent and keep caregivers more unconcerned. The goal of our system is to provide an orientation system that works both indoor and outdoor in a non-structured environment. By the other hand we try to develop a monitoring system that gives to the caregiver, in real-time, the current location of the person with cognitive disabilities.

With this system and an INS module people with cognitive disabilities location can be known even when the GPS of the smart phone is not available. This system allows caregivers to always know the current location of the person with cognitive disabilities. This location is updated on the server in a pre-established interval of time. An agent platform that works on mobile devices is used to send a message when the agent detects an user emergency.

The system is currently in a development stage and we expect to do real tests with people in the near future.

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4.2 Interactive Guiding and Localization Platform

The paper presented in this section was published in a journal as an extended version of Ramos et al. (2013). Here, an initial prototype is presented where the focus was on the user interface (which used augmented reality) and on the localization factor. More details about the paper and the journal are given below.

Publication Details	
Title	Interactive Guiding and Localization Platform
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Type	Journal
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Interactive Guiding and Localization Platform

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ABSTRACT

Technology is now part of everyone's life, being widespread and present in the most innocuous objects, making people able to benefit from several technological solutions that only a few years ago were impossible to be implemented. For instance, the smartphone is one example of this type of technology. Usually, this device is equipped with several sensors and a GPS module, which may be used as an orientation system when it carries the right features. The current trend is providing advanced applications to the common public, excluding some fringes of the population, like the people with cognitive disabilities. Thus, everyday technology can be used for helping on several tasks, becoming an interactive terminal, aware of the user conditions. There may be orientation applications that are too complex to be used by people with cognitive disabilities. Therefore, the main goal of this work is to build and implement an orientation method that may be used by people with mild cognitive disabilities and provides several tools to the caregivers. Furthermore, the system is linked to external services like iGenda so the user is stimulated to go outside and increase his/her social participation or not to miss an appointment. The developed system is also a localization system, enabling caregivers to know in real-time the location of the person with cognitive disabilities. Allowing the user to have an independent life.

Keywords: Cognitive Disabilities, Mobile Communication, Localization, Orientation, Person Tracking, Ambient Intelligence.

Mathematics Subject Classification (MSC) : 68U35, 68T01, 68T20
Computing Classification System (CCS) : I.2.0, I.2.1, I.2.11

1 Introduction

A new paradigm has resulted from aged populations (United Nations, Department of Economic and Social Affairs, 2011; Instituto Nacional de Estatística, 2012), this type of population is very costly to the countries' social security systems, and to take care of them facilities like nursing homes or services like caregivers are needed. The use of these alternatives implies the loss of independence of the elderly, some forcing them to leave their house while others may let the person to stay in his/her house with a caregiver, which may be a relative or not, exponentially increasing the costs to the user.

This loss of independence may be overcome by using the concept of smart houses (Sadri, 2007). Besides being physically versatile, the smart house do not restrict the user movements (Augusto and Mccullagh, 2007). The objective of this technology is to provide comfort and safety to the user. It may also monitor the user health through embedded devices in the environment. These devices may allow a remote access to the obtained information by a physician or other caregiver (Augusto and Mccullagh, 2007; Carneiro, Novais, Costa, Gomes, Neves, Tscheligi, De Ruyter, Markopoulus, Wichert, Mirlacher, Meschterjakov and Reitberger, 2009; Stefanov, Bien and Bang, 2004; Tapia, Alonso, Paz, Zato and la Prieta, 2011). A smart house is a good alternative to keep the user independence, but it has a drawback: the user may only be monitored when he/she is inside the house. This disadvantage may limit the person's independence, being constricted to the house boundaries, and relying in external services or people for the additional tasks, since the person may not be able or medically allowed to go outside alone.

The capacity to improve the functional needs of people with cognitive disabilities has increased the interest and the attention on assisted technologies since 1988 (Alper and Raharinirina, 2006). The development of some projects in this field has increased the awareness of the general public to the usefulness of assisted technology on the life of people with cognitive disabilities and how their life quality could be improved.

The developments made so far are very significative and were not exclusive to the development of new devices, covering other areas like Health. In this field new diagnostic techniques have been created/discovered and some existing ones have been enhanced. Thereby the well-being of people has grown. However, despite all the progress, there are some diseases that still do not have a cure like Alzheimer, Down's syndrome, among others. According to the severity of the cognitive disabilities the person may have a normal life (when the disability is mild) or may need help in every task of the day (when the disability is severe), not being able to live alone.

Although smart houses are now available to people in need, they lack in mobility, thus, not being an answer to people that are physically able to leave the house. Thereby researchers have been developing new ways to assist people with cognitive disabilities when they are outside, so they may have a normal life and actively participate in the society (Cesta, Cortellessa, Giuliani, Iocchi, Leone, Nardi, Pecora, Rasconi, Scopelliti and Tiberio, 2004; Pellegrino, Bonino and Corno, 2006; Mulvenna, Bergvall-KaŁreborn, Wallace, Galbraith and Martin, 2010). To accommodate the users conditions a set of requirements must be met, thus, the devices developed to assist these people must be easy-to-use, small, lightweight and resistant, so the person may easily use and carry them, otherwise the user may lost the interest and may not use it (Dawe, 2006; Dawe, 2007; Novais, Costa, Carneiro and Neves, 2010).

In (Ramos, Anacleto, Novais, Figueiredo, Almeida and Neves, 2013) we describe our system and present an archetype. Our developments provide an orientation method for people with mild cognitive disabilities so they may go outside and travel by themselves without getting lost. The system also enables the caregivers to know in real-time the current location of the person with cognitive disabilities. Thereby, the independence of the caregiver is also increased since he/she may do another activity without neglecting the provided care.

Section 2 presents in detail some of the work developed by other authors in this area. In

Section 3 is described in detail the proposed system including all its features and the link to external services like iGenda (Costa, Castillo, Novais, Fernández-Caballero and Simoes, 2012). Finally, at Section 4, a brief reflection about this work is presented including future lines of development.

2 Related Work

Dawe (2005) started her research by analyzing the usability challenges and the user needs of a handled remote communication system for people with cognitive disabilities. Through 20 semi-structured interviews the author found three major aspects when developing and adopting new technologies to assist people with cognitive disabilities. The first finding was that the adoption of assistive technologies, besides involving several caregivers, is a staged process. The second finding was that caregivers believe that technology has potential to increase the independence and the social interaction of this people. Lastly the author found that there are some barriers in the adoption of new technologies like the complexity when the user is setting up the device.

Also in (Dawe, 2006; Dawe, 2007), it is shown how useful a simple cell phone could be to a person with cognitive disabilities and how this device could improve the life quality. Through this device the user could interact and communicate with other people like family, caregivers or friends. This project was successful, thus providing it's feasibility.

Based on the conducted research the author developed an application, as seen in Figure 1, that has simple interfaces with several pictures that act like buttons, which could start or receive calls. The application also have a voice memo to alert the user for incoming activities and a programmed remainder.

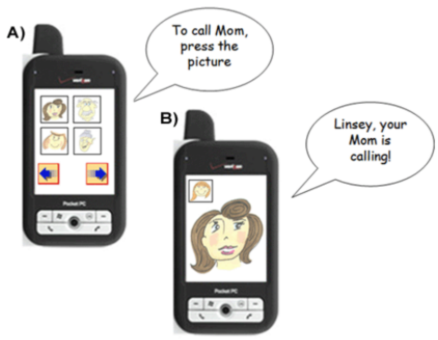

Figure 1: Simple user interface developed in (Dawe, 2007): A) making a call; B) receiving a call

In order to stimulate the user and to create an application that fullfils the user needs, people with cognitive disabilities have participated in the development of the application. The author concluded that the system improved the interaction of the users with the surrounding society.

In (Carmien, Dawe, Fischer, Gorman, Kintsch and Sullivan, 2005) the authors developed a system that helps people with cognitive disabilities to travel by themselves using public transportation, namely the bus. Before developing the system, the authors studied the traditional techniques used by these people to travel, using routes like home to school/office. Using a standard bus map each user creates its own map by coloring the important routes (Figure 2a)) and highlighting significant landmarks. To increase the number of possible destinations each user has a set of time cards (Figure 2b)). This cards were used to travel to other destinations like the shopping center or a friend house. The paper cards have information about the bus route and the schedule.

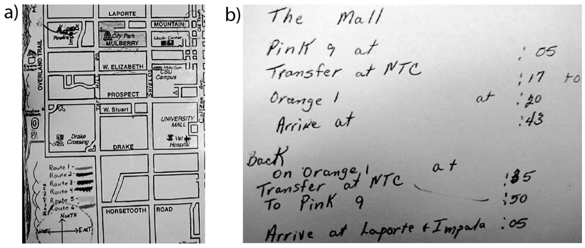

Figure 2: Traditional artifacts personalized during training (Carmien et al., 2005): a) Personal colored map; b) Time cards

The architecture was developed after the first analysis. In this system the time cards and maps, that were initially used by the user, were replaced by a PDA. This project has two main goals: assist the mobile user through just-in-time information for several tasks, which includes information related to the travel path (the route that the user should do and the bus that should be used); create a communication channel between the user and the caregiver.
The developed prototype, based on this architecture, is presented in Figure 3. After the selection of the destination in the application menu (left side of the figure) by the user, the system calculates the route based on the information stored in the server. This information includes the real-time position of the bus (visible on the right side of the figure), which is given by a GPS module installed on the bus and is sent wirelessly to the server.
This prototype enables the user to travel using the public transportation system without getting lost or taking the wrong bus. The mobile device has the capability to generate visual and audio prompts whenever is necessary to keep the user in the right path.
Carmien et al. (2005) also developed a second prototype, which did not need a supporting structure. Using the developed tool, the caregivers could create several scripts taking into account the user needs or the activities that should be carried out by him/her. In order to keep the attention of the mobile user the scripts have audio and/or visual stimulation.
Liu, Hile, Borriello, Kautz, Brown, Harniss and Johnson (2009) developed an orientation system for people with cognitive disabilities. The authors tested the prototype in people with cerebral encephalopathy, traumatic brain injury and Down's syndrome. During the tests the user could freely use the prototype, being remotely controlled. Thus the user could walk and explore all system functionalities without being disturbed.
Before developing the prototype to do the outdoor orientation of the user, the authors studied how to orientate the user indoor. An example of a orientation project can be found in the work (Tapia, Paz, Pinzón, Bajo, Alonso and Corchado, 2012).

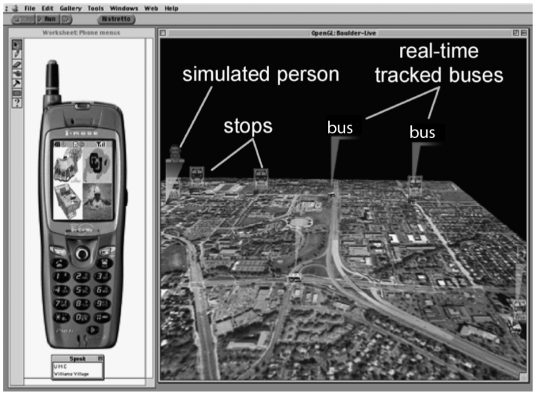

Figure 3: Prototype showing a prompting device (on left) and a real-time bus system (on right) (Carmien et al., 2005)

After the first study, Liu, Hile, Borriello, Kautz, Brown, Harniss and Johnson (2009) tried to identify which features could be extrapolated to the outdoor system, like the combination of pictures with overlaid arrows, audio and text messages (Figure 4).

Figure 4: Sample pictures used in the interface (Liu et al., 2009)

When the user is outside the orientation is a more complex task since the environment is more dynamic. There is traffic, other people passing by, noise, which may distract the user. In another study the authors examined the usability of landmarks in the orientation process. They concluded that a near landmark should be used instead of a landmark outside the user view (*e.g.*, behind a tall building) and the image shown to the user should be in the same perspective of the user so he/she could more easily identify the mark. If this considerations were not taken, the picture may be harder to associate to the real landmark and the orientation system may fail.

An assistance system with interactive activity recognition and prompting was developed by Chu, Song, Kautz and Levinson (2011). Through a hierarchical partially-observed Markov

decision process the system may learn and adapt the user interface to each user and help him/her in his/hers daily activities. The data needed to determine the user's state is obtained from sensors like IR (infrared) motion sensors and RFID (radio frequency identification) touch sensors. The system queries the user for additional information when the sensors are unable to retrieve the user state.
A more recent project is being developed by Fraunnhover Portugal (2012) and the goal is to orientate elder people or people in early stages of dementia. To indicate the path the system shows an arrow that rotates like a compass, showing information about the street where he/she currently is and the selected destination (Figure 5).

Figure 5: Interface for the orientation of AlzNav application (Fraunnhover Portugal, 2012)

Besides these functionalities the system allows the establishment of a perimeter in which the user may freely walk without alerting the caregivers. To know the current location of the user the caregiver may send a text message to the server, receiving the information.

3 System Description

Nowadays, due to the technology progress and the reduction of production costs, almost every person has a smartphone. This device may have applications installed according to the user needs, helping him/her in tasks of his/her life. However these applications are not specifically developed for people with disabilities, so not everyone may benefit from all device capacities.
This work describes a system that is specially being developed for people with mild cognitive disabilities. The system intends to help not only the user (person with disabilities) but also his/her caregiver. The main goal of the project is the development of an application that helps the user travelling between two locations without getting lost. Due to the typical user profile the application must be simple, not requiring a significant cognitive effort. The system has a localization capability which allows the caregiver to be aware of the current user location without being physically present. This feature allows the caregiver to develop another activity

without neglecting the user.
A simplified framework of the system is presented in Figure 6, which is divided in four major parts according to its destinated user/application: the mobile application for the person with cognitive disabilities (named *Cognitive Helper Mobile Solution*, Section 3.1), two applications for the caregiver (*Caregiver Applications - Mobile and Web*, Section 3.2), external services that could be coupled to the system (*External Services*, Section 3.3) and the server.

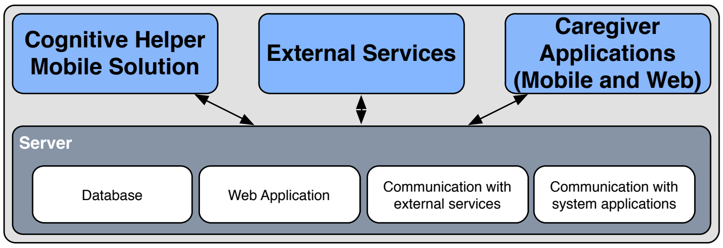

Figure 6: Simplified framework of the system

The server is composed by four modules. The database stores all the data needed to the correct operation of the system like usernames, locations, points of interest (destinations), among others. The web application used by caregivers is stored in the server and is accessed whenever the caregiver uses the application in his/hers computer. There are two types of communication layers according to whom the system needs to communicate with. Thus the system has a communication model to connect with external applications like iGenda and another communication model that connects the server with the system applications.

3.1 Cognitive Helper Mobile Application

With the use of mobile devices with a high processing power means that what was usually done by fixed computers can now be done by a device that fits in a pocket. This has lead to the development of the Body Area Network (BAN) concept (Jain, 2011; Micallef, Grech, Brincat, Traver and Monto, 2008; Wolf and Saadaoui, 2007), which instead relying on fixed sensors and a home environment, it uses mobile devices and sensors, creating a portable monitoring sphere. Using this concept as a starting point, the person with cognitive disabilities (also named user) has access to an application developed to operate on Android Operative System. This application has two main objectives: the first is to orientate the user so he/she may travel between two locations without getting lost and the second is to provide a localization service so the caregivers know the current location of the user.
On Figure 7 is presented the detailed framework of this application. The framework is divided in three parts. On the left it is the *Localization Layer*, which has the methods used to get the user position. This may be done through the GPS module of the device and by a coarse location from the network. This information is used to learn the user frequent paths and after the GPS has a locked location the orientation process may start, since the system needs the user location to calculate the path to the selected destination.

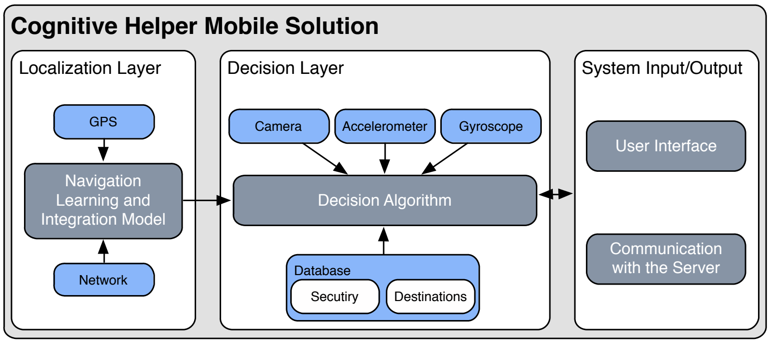

Figure 7: Detailed framework of the mobile application for people with cognitive disabilities

The orientation of the user is done through augmented reality (Figure 8). This specific environment uses the device's camera and several sensors like the accelerometer and the gyroscope. These sensors are needed to get the direction in which the user is pointing the device. These three elements allow the augmented reality environment and let the application to know where the user is facing. If the user is correctly oriented with the path then a green arrow appears indicating the correct direction. If the user is a wrong path a red cross is showed to the user. Using this environment (augmented reality) it is possible to guide the user, ensuring that he/she is moving correctly.

Figure 8: Orientation system using augmented reality

The *Decision Algorithm* (at the center in Figure 7) is the one responsible for this last task. To guarantee that the user is in the correct path this module may generate warnings stimulating the user, but if the user is going in the wrong direction this module generates audio and/or visual alerts. If the system detects that the user is confused, *e.g.* the user is shaking to much the device or is going forwards and backwards in a constricted area, it creates alerts and may send an email, sms or start a call between the user and the caregiver.

The interaction between the user and the application is done through the interface (right part in Figure 7). The interface presents to the user the information about the route and allows him/her to select the intended destination. This selection is done through menus and options. According to the destination stored in the database the user may choose a starred destination (those used more frequently like home and school or office) or generic locations like the mall. Since this information is private it is necessary to be securely store it in the database guaranteeing that only a set of predetermined users have access to it.

In addition to the *User Interface*, the input/output of the application is composed by a *Communication Model* which is responsible for establishing the connections between the application and the server. Through this module the application may update the user destinations, update his/her current position, receive or send messages to the caregiver and receive information from external services that are linked to the server.

If the caregiver notices that the user is capable to use the application correctly, it is possible to allow him/her to choose a destination that is not present in the database (manual insertion). This extra option allows the user not to be limited to the destinations previously created by the caregiver.

3.2 Caregiver Applications

Caregivers have access to two different platforms with similar functionalities: a mobile application for Android Operative System and a Web application. The main goal of both applications is to inform the caregiver about the current location of the user. These applications also show the current guiding process or the accomplished paths done by the user. Through these applications the caregiver receives the alerts triggered by the user application and the caregiver may also send short messages to the user. The Web application has more functionalities where it is possible to edit some preferences like create/update/remove user destinations.

The framework of these applications is presented in Figure 9 and is divided according to the application type. On the left there are the modules related to the mobile application and on the right those related to the Web application. The difference between them is that the web application is composed by one more module than the mobile application (*User Preferences*). Both applications communicate with the server through a *Communication Layer* to transmit different types of information: caregiver's personal information (password, username, name, among others), user data (location points, name, destinations stored in the database), and information from the external services.

Through the *Caregiver Alerts/Notifications* module the caregiver may receive the alerts or notifications generated by the application of the person with cognitive disabilities. These alerts/notifications may inform the caregiver that the user has started a new path or may alert the caregiver indicating that the user is lost.

Create User Notifications enables the caregiver to send simple messages to the user. This feature allows an easier and fast communication between caregivers and users, since the answer may be *Yes* or *No*. This feature may be useful when the caregiver wants to know if the user is well or to enquire about small tasks, *e.g.* the caregiver is watching the traveling path

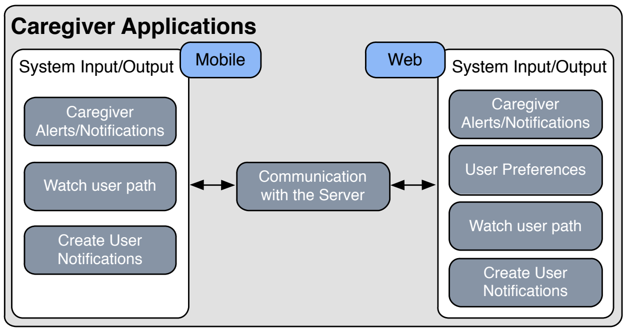

Figure 9: Detailed framework of the caregiver applications

and sees that the user is passing by a grocery and asks if he/she wants to buy fruit. Instead of calling and pausing the navigation, this feature enables a fast answer without interfering with the person routing.

Figure 10 represents the module that allows the caregiver to watch the travelling path of the person with cognitive disabilities. Figure 10a) shows the android application in which the path was already done by the user. Figure 10b) represents the Web application, showing a travel path that is being done (the line is updated when the user changes his/hers position). A specific marker indicates the start and ending point of the route.

Figure 10: Localization system - a) Android application; b) Web Application

One of the functions of the caregiver is the creation of destination points (through *User Preferences*) that may be used by the person with cognitive disabilities. This function is only available in the Web application and the creation of a point may be done by directly selecting it on the map or by searching a location through its address and, if necessary, adjust the point on the map. Besides this task, the caregiver may also specify if the destination point is starred (more used destination) or is a normal one.

3.3 External Services

One of the aims was to provide the system architecture with the resources required to integrate the resultant applications in an AAL environment. Displayed in the Figure 6 the system is already prepared to receive and send information, using a secure communication tunnel. Allowing the connection to external services is beneficial to the localization system as well as to the system that is going to be connected. The previously referred iGenda was used to prove the feasibility of the External Services.
The iGenda project (Costa, Novais, Corchado and Neves, 2011) consists in an intelligent scheduler and time manager designed for cognitive impaired people. The iGenda architecture is composed of a server and mobile/desktop client. The platform logic is set in the server as the client displays only the relevant information and serves as a communication platform between the users. Unlike the CogHelper the caregivers are users as well, being the only difference the set of permissions that the caregiver has over the user profile. In the Figure 11 it is showed an overview of the iGenda architecture.

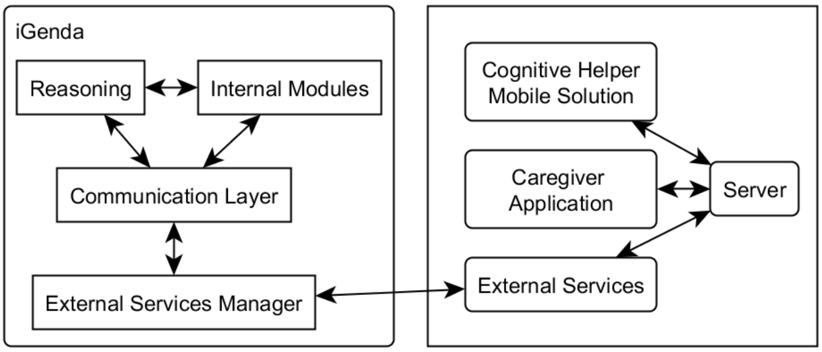

Figure 11: Overview of the iGenda architecture

The objective of the integration of the CogHelper with the iGenda is to provide the users with extra features, and at the same time improving the automation process. One can easily grasp the intentions of joining an localization and augmented reality guiding system with an intelligent scheduler. So, the main aim is releasing the user of the destination selection action and allowing the system to verify if there is any task that requires the user leaving his house and automatically present a visual/audio warning of the pending task as well as starting the guiding process with the directions to the destination.
Although is seems a fairly simple task to select a destination between a list of favorite destinations, to a cognitive impaired person this task is very perilous, as they may be unable to recollect the association between the task and the location of this task, or even worst, being confused and select an erroneous location.
Thus in terms of the mobile platform, the iGenda continuous monitoring establishes the visual interfaces and the communication systems, thus, being the primary application. This business logic is established according to the following work flow: the mobile system warns the user of any incoming task, if the task requires the user to leave his house the guiding system will be

activated showing the path to the task location; if the user wants to leave his house he/she has to willingly open the guiding application and select the destination. Due to the users cognitive impairment conditionings, the CogHelper will be inactive, securing the user of improper operation, like selecting a random destination. Providing security to the user is of the utmost importance, so, interfaces, actions and buttons were carefully planned to be as simple and safe as possible. Moreover, some actions are stricly defined, leaving few to none options to the user, providing a controlled environment, hence, these options can only be edited by the user's caregiver.

In terms of the architecture, the CogHelper and the iGenda are clearly separated, the motive of this approach is the application logic of each project and the development process. They communicate using web services, structured by a WSDL standard and HTTP protocol. The security resides in a 2-step user verification, while the communication process is done recurring to high level data description. As an example the content of a message between the iGenda and the CogHelper is represented in the following example, after establishing the secure communication:


```
{
 "event" : {
           "user" : "Jack Higgins",
           "description" : "Buy groceries",
           "Lat" : "41.0509605",
           "Lon" : "-8.4342343",
           "Location" : "Street of London, 31, PT"
           }
}
```


The message is represented in common JSON format. This approach was due to keep the compatibility between all platforms involved. In it is described an event, in this case going to the grocery, providing digital information, such as the latitude and longitude, and human readable information. The human readable information is the visual representation sent both to the user and the caregiver, thus easier to provide an early detection of the user intents.

Being the iGenda an interactive scheduling system it has the ability of receiving events and schedule them according to their importance. The importance is provided by a set of internal rules that establish the relation between the sender role and importance to the user, and the urgency that the sender established in the event. To better illustrate the hierarchic process we have the following examples: if is the user's personal physician the system assumes the maximum importance to every event that he schedules, even if the physician marks the event with low importance, whereas if is a user's friend that schedules an event it will not surpass any physician or medical-related event. For instance, the user's friend has scheduled a match of tennis Tuesday with the importance level of "1" (ultra-high), being this friend a particularly important one the iGenda has scheduled internally this event with an importance of "9", meaning that any other event that is more important can replace this event. Furthermore, in case there is a overlapping of events, the rescheduling process of the iGenda is able to move the event, asking to each user his consent, deleting the event if it is unable to do it so.

Finally, the iGenda platform is also able to receive high-level information, processing different type of incoming commands. Therefore, in conjugation with the CogHelper the iGenda is able to reschedule events or re-route the user to other events. This is useful for elderly people as their locomotion is limited or unforeseen circumstances happen. As an example, the user can be late to an event, due to perform several stop along the route, the CogHelper can communicate the TOA (Time Of Arrival) to the iGenda an the iGenda can verify the lateness of the user and perform two actions: notify the other users involved in the event, or re-route the user to the following event. The action that the iGenda performs is dictated by the importance of the event and the TOA relative to the event duration. It is clear that if the event has a duration of 40 minutes and the user is going to be late 30 minutes the event may as well be cancelled and redirect the user to his home or to other event. Although these rules are quite strict their are able to be reconfigured to better attend to the user requests or conditionings, like most of the iGenda configurations.

4 Conclusion and Future Work

One problem that arises when a person with cognitive disabilities leaves his/her house alone is the lack of orientation, thus the risk of getting lost is very high.
State of the art projects present user-centered guiding systems, however, caregivers are not attended, being the user information unknown to them.
This project innovations are guiding the user through augmented reality, surpassing the limitation of using static pictures or the need to interpret the direction given by a compass. Besides, the caregivers may know in real time the location of the user. To further increase the system features it is possible to connect with external services, like the iGenda.
Currently, the system is at its final stage. The core of the CogHelper is already developed, providing the localization and guidance features. The user mobile platform and the web platform have reached a mature stage, and are ready to be used in field tests. The iGenda is a completed projected, thus fully mature and able to be integrated with the CogHelper. Our most recent developments are in the integration stage and the route calculation.
Although the communication layer and the external modules layer are part of the core, they are object of continuous development, thus, with every new module a wrapper and interpreter have to be developed to support the full integration. Furthermore, being most of the possible communication in a high-level format, the coordination between the ontologies is critical, implementing an answer to every request.
In terms of routes and warnings, now the system is using the standard Android protocols and the Android Maps. This assures full compatibility between the different user devices and the Operating System version. But, our aim is to provide personalized warnings, and implement smart routes, being in the roadmap the development of a routes engine, mobile-side and server-side.
Lastly, in the upcoming work we plan to do field tests with users, being able to receive feedback from them, polishing the application towards the elderly and cognitive impaired users, and, to reason upon the legal implications of this system and adapt it to the current privacy and data

protection legal requirements.

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4.3 Speculative Orientation and Tracking System

The publication titled *Speculative Orientation and Tracking System* is an extended version of Ramos et al. (2014b). The main goals pass to introduce the model for the Speculative Computation, which enables the system to predict possible user wrongdoings and alert him in advance.

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Speculative Orientation and Tracking System

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ABSTRACT

The current progresses at the intersection of computer science and health care have the potential of greatly improving the living conditions of people with disabilities by removing obstacles that impair the normal unfolding of their everyday lives. Assistive technologies, as an application of scientific knowledge, aim to help users with their diminished capacities and, usually, imply a small adaptation from individuals so that they can use the devices that convey assistive functionalities. One of the most commonly diminished capabilities is that of spatial orientation. This is mirrored by several research works whose goal is to help human beings to travel between locations. Once set up, most of the systems featured in these research works requires changes in the configurations to be made manually in order to achieve a better adjustment to the user. In order to overcome this drawback, the work presented herein features a framework of Speculative Computation to set up the computation of the next step of a user using default values. The consequence of the application of the framework is a faster reaction to user stimuli, which may result in issuing warnings when he is likely to choose the wrong direction.

Keywords: Cognitive disabilities, Mobile application, Guidance, Person tracking, Ambient intelligence, Logic programming.

2000 Mathematics Subject Classification: 68N17, 68T27.

1 Introduction

Technology plays an important role in peoples lives in so many different domains such as business, education, communication, social relationships, and so on. With this ever increasing penetration of technology in everyday life, it was only a matter of time until the development of mainstream technology started having an impact in the lives of people with disabilities. The technology developed specifically for the purpose of improving the lives of people with diminished capacities received the designation of assistive technology. The concept was first legally established in the United States in 1988, by the Technology-Related Assistance for Individuals with Disabilities Act, also referred to as Tech Act. This act was extended in 1998 by the Assistive Technology Act (Alper and Raharinirina, 2006; Scherer, Hart, Kirsch and Schulthesis, 2005). In it, it is stated that "assistive technology is any item, piece of equipment, or product system. . . that is used to increase, maintain, or improve functional capabilities of individuals with disabilities". Passing this act was the first step in seeking to disseminate assistive technologies and provide them to people with disabilities. Indeed, since the first form of the act was passed, the attention towards this kind of technology has been increasing, which led, up until now, to the development of devices to be embedded in a home environment, in order to assist users and monitor their activities, movements, and health on a daily basis (Stefanov, Bien and Bang, 2004).

The existence of these smart home environments, also called smarthouses (Sadri, 2007), minimizes the loss of independence from users with disabilities. This technology also enables caregivers and physicians to have access to information collected from the environment (Carneiro, Novais, Costa, Gomes, Neves, Tscheligi, De Ruyter, Markopoulus, Wichert, Mirlacher, Meschterjakov and Reitberger, 2009), which, in turn, leads to letting the user (*e.g.*, an elder or a person with cognitive disabilities) stay at home longer with increased independence, rather than resorting to admission to a health care institution. However, users can only benefit from the advantages of smarthouses indoors. So, it is necessary to develop means through which people with disabilities can have an active role in the outside world, participate in their community, and feel perfectly integrated in society.

The focus of this work is placed on people with cognitive disabilities. According to the Diagnostic and Statistical Manual for Mental Disorders (Spitzer, Gibbon, Skodol and First, 1994), cognitive disabilities are a medical condition in which individuals have more difficulties in performing mental tasks. These tasks include self-care, communication, use of community resources, work, leisure, and so on. There is a classification for cognitive disabilities according to their severity, which includes the following phases: mild, moderate, severe, and extreme. The main criterion for a diagnosis is the extent to which the mental functions of an individual are compromised, which is also related to the cause of the disabilities. They can be brought about by events such as strokes, Alzheimers disease, mental handicaps, and traumatic brain injuries.

Orientation is one of the mental tasks that are most affected in people with cognitive disabilities. If someone is unable to go to where activities take place, it becomes impossible to participate, which may cause a greater social isolation and bring about, or accentuate, feelings of depression. To address this issue, researchers have been working on new ways of using the available technology to increase the outdoor independence of users, namely in helping them to travel alone between locations. In order to accompany users in their everyday lives, the developed systems have to be available in devices that users can carry around, they have to be small, lightweight, and resistant (Dawe, 2006; Dawe, 2007). These physical features can be found in modern smartphones and tablets, which serve has the support for many of the research works now in progress. At the same time, the interfaces provided by these systems play an important role in their acceptance (Dawe, 2006; Dawe, 2007; Friedman and Bryen, 2007). They have to deliver all the important functionalities, yet be simple enough to allow people with cognitive disabilities to easily use them. Any distractive element should be removed and the instructions should be provided in simple texts.

After analysing the current state of the art in the area of orientation systems for people with cognitive disabilities and identifying the limitations of current systems, a system (Ramos, Anacleto, Costa, Novais, Figueiredo and Almeida, 2012) was developed for the purpose of guiding the user to different locations using simple interfaces, with the possibility of his caregiver monitoring his movements. This increases the freedom of both parts. The user can travel alone while the caregiver is engaged in other activities. The differentiating factor, when compared to other existing systems, is that this system learns the most frequent behaviours of a user and analyses his activity patterns in order to generate default values for Speculative Computation. In sensible decision points, when a user has to choose a direction to follow, Speculative Computation provides a way of managing the lack of real information by providing a tentative computation for the path the user should follow, based on the extracted defaults. This tentative computation can be used to issue warnings in order to alert the user in the event of his following the wrong direction.

This paper is organized as follows. Section 2 contains the main related work on orientation systems for people with cognitive disabilities and reasoning under incomplete information in the context of assistive technologies. The criterion used to gather the current research works was that the orientation systems should be hosted by smartphones. Section 4 provides a description of the system in development, with its latest improvements. The framework for Speculative Computation is formulated in section 5. Finally, conclusions are drawn and future work considerations are made in section 6.

2 Related Work

The work presented herein focuses on orientation systems and ways of anticipating the next step of a user in the event that he makes a mistake in his path and a warning has to be issued. In the current orientation systems aimed for people with cognitive disabilities, this kind of safeguard has not been extensively explored. To demonstrate this, the following subsections provide related work on the topics of orientation systems and reasoning under incomplete information.

2.1 Orientation Systems

The technological development experienced in recent years increased the availability of small, portable, handheld devices with high processing power. Nowadays, purchasing a smartphone is within reach of most people. These devices are capable of running applications with various purposes, but one of particular interest for the theme of this work is that of orientation. The incorporation of a Global Positioning System (GPS) module in a smartphone made possible the development of navigation applications. However, these applications serve a general purpose, they were not developed to be used by people with cognitive disabilities. Recognizing the importance of orientation for people with disabilities and the pivotal role smartphones could have in the development of cognitive assistants, researchers started the development of systems fit for the characteristics of these individuals.

The work of (Carmien, Dawe, Fischer, Gorman, Kintsch and Sullivan, 2005) features a system that enables a user to travel between locations using a public transportation system (*e.g.*, the bus). They devised an interface that enabled caregivers to create lists of activities that should be carried out by people with cognitive disabilities. The role of their system is to deliver those tasks in a simple and comprehensible way while assisting the user in his travels. As such, the components of the system include: a personal travel assistant that uses real-time GPS data from the bus fleet to deliver just-in-time prompts to the user; a mobile prompting client and a prompting script configuration tool for caregivers; and a monitoring system that collects real-time task status from the mobile client and alerts the support community of potential problems.

Liu, Hile, Borriello, Kautz, Brown, Harniss and Johnson 2009 make use of static images with overlaid arrows, audio messages, and text messages in their prototype for guiding a user. The applicability of the system was tested with several real-world scenarios. The underlying principle of this work is to find models to produce tailored pedestrian wayfinding directions for people with cognitive impairment. They developed a framework based on a Markov Decision Process (MDP), which enables the representation of user preferences as costs in a network. Another feature is the use of recognizable landmarks near the user to facilitate guidance.

AlzNav (Fraunnhover Portugal, 2012) is an orientation system developed by Fraunhofer Portugal. Its functionalities include monitoring and alerts, navigation, call for help, and call for a taxi. The application runs on an Android device, and its interface is very simple. Its main focus is to to make the interpretation of the content seen on the screen easy. The direction a user should take is shown using an arrow that works as a compass, spinning around according to the direction the user sets on the mobile device. Along with the arrow, the user also sees the distance he must travel in that direction. The application also sends updates about the situation of the user to the caregiver through SMSs.

These are some of the most important works in the area of orientation systems for people with cognitive disabilities. At the level of the orientation method, i.e. the way in which orientation is presented to the user, the available systems either use static images or a compass-like display. Technologies such as augmented reality have not been explored enough in this domain. Augmented reality can increase the interactivity of applications and facilitate the understanding of instructions. The prompts of the applications assist the interpretation of the information provided by the orientation method and are normally audio and visual. Most of the existing systems work with a predetermined route, being useful only to take a user from a specific point A to a specific point B. There are only a few works that analyse the frequent behaviours of users to try to infer his route, recognize activities, or issue reminders if something is deviating from its normal course.

In previous work (Ramos et al., 2012; Ramos, Anacleto, Novais, Figueiredo, Almeida and Neves, 2013; Ramos, Costa, Novais and Neves, 2014; Ramos, Satoh, Novais and Neves, 2014), we have presented a functional prototype of an orientation and localization system. It is delivered through and Android application that makes use of augmented reality to guide the user along his route. It also enables the caregiver to know the location of the user in real time.

With the purpose of enhancing the guiding experience, a framework of Speculative Computation was devised. With the tentative computation based on default values, it is possible to generate the next step forward before it materializes. This feature can be used as the core of an alert system. The remaining content of this paper explains how this framework was integrated in the orientation system and describes the modifications and adjustments made to the system in order to accommodate it.

3 Reasoning Under Incomplete Information

The issue of incomplete information in orientation systems has not been widely explored. In such systems, it would be advantageous to explore patterns of user behaviour in order to know frequent habits of an individual so as to provide him a better guidance. This has a particular application in people with cognitive disabilities. Given their diminished cognitive capacity, they are prone to errors when following instructions, which makes it easy for them to get lost. As such, identifying the critical points of a route, where an individual is most likely to choose the wrong path, would allow a system to issue warnings in order to avoid the situation. There are, however, some difficulties with this. Given the complexity that travelling routes may have, it is significantly difficult to analyse them and extract patterns. Moreover, there is a need for a reasoning model that accommodates these patterns and structures reasoning with them.
One of such reasoning models is the Markov Decision Process (MDP) (Littman, Dean and Kaelbling, 1995), a discrete time stochastic control process with four components: a set of states, which represent the current status of the world; a set of actions, which represent possible alternatives to act; a set of state transitions, representing the effects of the actions; and a set of immediate rewards, specifying the reward after taking an action. The objective of MDPs is to map the elements of a state to the possible actions one may take so as to maximize the immediate reward after taking the action. For cases in which the state of the world cannot be fully grasped, *i.e.*, when there is incomplete information, there is a special type of MDP, called the Partially Observable Markov Decision Process (POMDP) (Chong, Kreucher and Hero, 2009). In it, an agent uses information from previous iterations in order to estimate the current process state, based on a probability distribution over the possible states. POMDPs were initially developed in the 1980s by the artificial intelligence community has a way of searching for near optimal solutions for complex planning problems under uncertainty. POMDPs have been used in artificial intelligence for robot navigation (Kaelbling, Littman and Cassandra, 1998), healthcare (Bennett and Hauser, 2013), and assistive technology (*e.g.*, assisting people with dementia in hand washing (Hoey, Bertoldi, Poupart and Mihailidis, 2007)). The drawbacks associated with both MDPs and POMDPs is that they require data-intensive estimation steps to get accurate estimation models and their is quite complex.
Another reasoning model is Case-based Reasoning (CBR) (Kolodner, 1992). CBR models are based on recalling past experiences which are similar to the current one and using the solution of those past experiences in the new situation. Another form of putting the problem would be to recall things that went wrong in past experiences and avoid repeating the same mistakes. The advantage of this approach is that it resembles human reasoning in problem solving.

The effectiveness of a CBR system depends highly on the experiences of the reasoner, its ability to understand the new experiences in terms of the old ones, its capacity to adapt an old case to the new one, and its capacity to evaluate a solution. Depending on the particular objective of the CBR implementation, *i.e.*, whether the new situation should be considered identical to an old one based on its similarities and differences or the goal is to get a solution for the new case based on the adaptation of a previous one, the type of CBR used can be classified as interpretative CBR or problem solving CBR (Lopez and Plaza, 1997). It is a cyclic process consisting of four phases: retrieval of past cases; reusing a set of best past cases; revising the solutions in order to avoid poor ones; and retaining new solutions. CBR has been widely applied in clinical decision making in problems of planning and knowledge management for patients with Alzheimer's disease (Corchado, Bajo and Abraham, 2008), in diagnosis and classification of stress-related disorders (Begum, Ahmed, Funk, Xiong and Von Schéele, 2009), and other applications in the field of assistive technologies. As far as this research goes there are no significant examples of CBR applied to orientation systems. The drawbacks of CBR are related with the great number of cases and the large processing time it takes to find similar cases in the case-base.

The final model exposed in this section, and the object of study of this work, is Speculative Computation. Speculative Computation was derived from Default Reasoning and Abductive Logic Programming. It was first presented in Satoh et al. (Satoh, Inoue, Iwanuma and Sakama, 2000) as a method for problem solving in multi-agent systems when the communication between agents is not ensured. Speculative Computation deals with incomplete information by resorting to a set of default ground literals which represent the information being exchanged. Based on these defaults, tentative computations are made. When the information arrives from the system components, the computations are revised and their consistency is checked against it. Based on this, some processes are started and others are removed. The initial setting for which Speculative Computation was presented was that of a master-slave multi-agent system where only the master performs Speculative Computation and the abducibles assume the form of ground literals. Speculative Computation will be explained in more detail in the subsequent sections of this paper.

The search for reasoning models was conducted by taking into consideration the domain of application of this work. As such, only models applied in situations that resemble the context presented herein were considered.

4 System Description

The aim of the CogHelper system is to help people with cognitive disabilities as well as their caregivers, through a lightweight application . Its main purpose is to assist the user in moving between two locations without getting lost. In order to help the caregiver in his tasks, the system also has tracking functionalities which allow the caregiver to locate the user at any time.

The system was devised for outdoor use and its architecture can be seen in Figure 1. It is composed of server-side components, such as the Database and the Agency for the Integration

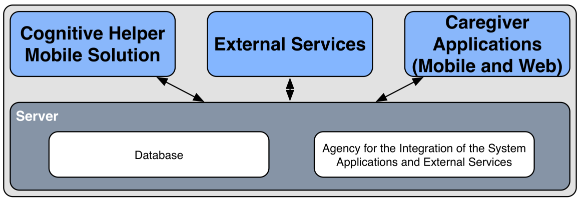

Figure 1: Architecture of the CogHelper System.

of System Applications and External Services Modules, and client side components, such as the Cognitive Helper Mobile Solution, the External Services, and the Caregiver Applications. All the services are connected to the Server, making it the core of the system. The Database Module contains all the information necessary for the system to accomplish its tasks. This information includes usernames, locations, and points of interest. As for the Agency for Integration of System Applications and External Services Module, it provides the facilities to communicate with both internal and external services.
The component of the system aimed specifically for people with cognitive disabilities to use is the Cognitive Helper Mobile Solution which encompasses three layers, displayed in Figure 2. It was developed for Android OS and its main functionality is orientation, enabling the user to travel independently without getting lost. The first layer is the Localization Layer which has methods for getting the current location of the user. This is done using either the GPS of the mobile device or the network through a coarse location. With the information of user location, it is possible to determine the frequent paths of the user. As for the Decision Layer, it provides warnings in order to ensure that the user travels in the right direction. It does so through a Decision Algorithm which crosses data from the camera, accelerometer, and the magnetic sensor with information about the destination and the correct path.
The directions are given through an augmented reality Interface such as the one depicted in Figure 3. The system keeps the caregiver informed of the steps of the user through e-mails and short messages. If the system detects that the user is disorientated or confused through his shaking the device too much or by going forwards and backwards in the same restricted area, the system automatically makes a phone call to the caregiver. The third and last layer

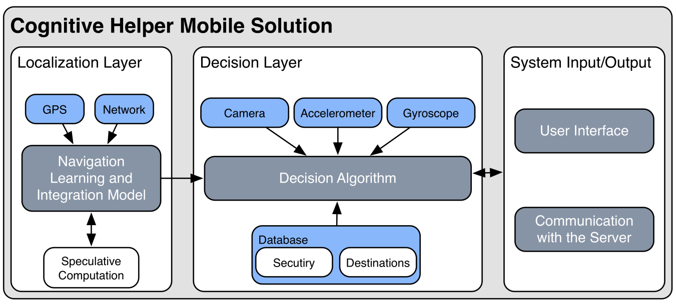

Figure 2: Information layers of the Cognitive Helper Mobile Solution.

Figure 3: Augmented reality interface of the CogHelper Mobile Application for users with cognitive disabilities.

is the System Input/Output. It features a User Interface and a communication module whose function is to pass on the information between the server and the user. Such information may include the update of user destinations, the update of the current location, and so forth.
There are two applications for caregivers, a mobile application for Android OS and a Web application. Their main goal is to inform the caregiver about the current location and state of the user. Despite this, there are some differences between the two. While the Web application is more complex, enabling the caregiver to add, edit or remove user preferences,(*e.g.* destination points), the mobile application is simpler in terms of the functionalities it provides, focusing more on monitoring tasks.
To improve the features of the system, Speculative Computation was included in the mobile application for people with cognitive disabilities under the Localization Layer, since it needs information about the current location of the user, provided by the GPS device or by the network.

5 A Speculative System for Users with Cognitive Disabilities

The procedure initially presented by (Kakas, Kowalski and Toni, 1998) on abduction in logic programming was a starting point for the theory of Speculative Computation and Abduction. This theory was an extension of (Kakas et al., 1998) procedure made by Satoh (Satoh et al., 2000). Under this theory the computation of a given action/task continues when facing an incomplete information scenario. Applying this theory means that the computation does not stop (or does not suspend) when there is a lack of information. Using a default value the computation continues and tries to generate a tentative solution for the problem. Whenever the missing information is received, the current computation is re-examined in order to verify if the default value is consistent with the real one.
During the execution of the speculative framework the computation may change between two phases, Process Reduction Phase and Fact Arrival Phase. During the normal execution the process is in the former phase changing temporally to the latter one when a value is returned. Thus, the Fact Arrival Phase is considered an interruption phase.

In this section we define the framework of Speculative Computation that is used and present a case to show the execution of the framework.

5.1 Framework of Speculative Computation

To develop an orientation method for people with cognitive disabilities using Speculative Computation is necessary to define a framework (designed by SF_{OM}) according to the tuple $\langle \Sigma, \mathcal{E}, \Delta, \mathcal{A}, \mathcal{P}, \mathcal{I} \rangle$, which consists of five sets. The first element of the tuple (Σ) represents a finite set of constants, which contains each system module. The set represented by $\mathcal{E}$ includes the predicates called external predicates. When Q is a literal belonging to an external predicate and S is the identifier of the information source, $Q@S$ is called an askable literal. We define $\sim(Q@S)$ as $(\sim Q)@S$.
Default values are assumed whenever the information is incomplete. They are included in the set represented by Δ (default answer set). This is a set of ground askable literals which satisfies the following condition: Δ does not contain at the same time $p(t_1, \ldots, t_n)@S$ and $\sim p(t_1, \ldots, t_n)@S$. $\mathcal{A}$ is the set of abducible predicates. Q is called abducible when it is a literal with an abducible predicate.
The set of rules ($\mathcal{P}$) that the program is going to execute are in the form:

- $H \leftarrow B_1, B_2, \ldots, B_n$ where H is a positive ordinary literal and each of $B_1, \ldots, B_n$ is an ordinary literal, an askable literal or an abducible literal; and
- H is the non-empty head of the rule (named $head(R)$) in which R is the rule of the form $H \leftarrow B_1, \ldots, B_n$. The body of the rule is represented by $B_1, \ldots, B_n$ (named $body(R)$) and may be replaced by the boolean value true.

The last set, denoted by $\mathcal{I}$, contains the integrity constraints, which do not allow contradictions during the execution of the speculative framework. The integrity constraints are in the form $\perp \leftarrow B_1, \ldots, B_n$ where $\perp$ is the symbol for the contradiction. $B_1, \ldots, B_n$ are ordinary literals, askable literals or abducibles. At least one of $B_1, \ldots, B_n$ must be an askable literal or an abducible.
An askable literal may have two different meanings, namely:

- An askable literal $Q@S$ in a rule $R \in P$ represents a question that is asked to a system module S;
- An askable literal in Δ denotes a default true value ($true$ or $false$), *i.e.*, $p(t_1, \ldots, t_n)@S \in \Delta$, $p(t1, \ldots, tn)@S$ is usually true for a question to a system module S, and $\sim p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is generally false for a question to a system module S.

In the logic program given below the literal $path(a, b)$ denotes that there is a physical connection between the locations a and b, thus the user may travel between them. The literal $show\_next\_point$ is used to indicate that the system must show the next location to which the user should travel. This location may be an intermediate point or the final destination. Whenever the user travels in the wrong direction the literal $show\_user\_warning$ is activated indicating to the system that it must alert the user. In the set of the external predicates there are the predicates $user\_travel(a, b)$ (which says that the user will travel from location a to location b) and $included(a)$ (to indicate if a location a is part of the route). These external predicates ask information from sources gps_sensor and $recognizer$, respectively. The former verifies if the user is travelling from point A to B. The latter checks if point B is included in the set of valid locations. The framework of Speculative Computation that is given below ensures that the user is travelling in the correct path and assesses the need for issuing alerts when he misses a turning point. This framework is given in terms of the following logic programming suite.

- $\Sigma = \{gps\_sensor, recognizer\}$
- $\mathcal{E} = \{user\_travel, included\}$
- $\Delta = \{user\_travel(1, 3)@gps\_sensor, \sim user\_travel(1, 2)@gps\_sensor,$
  $user\_travel(3, 4)@gps\_sensor, user\_travel(4, 3)@gps\_sensor,$
  $user\_travel(3, 2)@gps\_sensor,$
  $included(1)@recognizer, included(2)@recognizer,$
  $included(3)@recognizer, \sim included(4)@recognizer$
- $\mathcal{A} = \{show\_next\_point, show\_user\_warning\}$
- $\mathcal{P}$ is a mark of the following set of rules:

$$guide(A, A) \leftarrow .$$

$$guide(A, B) \leftarrow path(A, F), show\_next\_point(F), user\_travel(A, F)@gps\_sensor, guide(F, B).$$

$$guide(A, B) \leftarrow path(A, F), user\_travel(A, F)@gps\_sensor, show\_user\_warning(F), guide(F, B).$$

$$path(1, 2) \leftarrow .$$

$$path(1, 3) \leftarrow .$$

$$path(3, 4) \leftarrow .$$

$$path(3, 2) \leftarrow .$$

$$path(4, 3) \leftarrow .$$

- $\mathcal{I}$ denotes the following set of integrity constraint or invariants:

$$\bot \leftarrow show\_next\_point(F), \sim included(F)@recognizer.$$

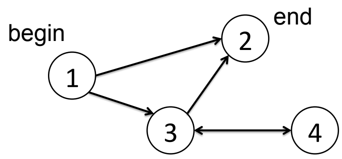

Figure 4: Possible ways to travel between locations 1 and 2.

$$
\begin{aligned}
&\bot \leftarrow \\
&\quad show\_user\_warning(F), \\
&\quad included(F)@recognizer.
\end{aligned}
$$

The two invariants included in set $\mathcal{I}$ ensure that the system does not show a warning when the user travels in the correct path and that it does not show a location that is not valid (is not part of the route) as the next travelling point.
In the setting depicted above the system assumes as default that the user will travel between locations 1 and 2 through an intermediate location 3. Figure 4 presents the possible paths that may be done by the user.

5.2 Preliminary Definitions

To be able to create a proof procedure for the previously described frame-work there is the need of defining some concepts.

Definition 5.1. The tuple $\langle GS, OD, IA, ANS\rangle$ represents a process in which GS (Goal Set) is a set of extended literals to prove. These literals express the current status of an alternative computation; Outside Defaults (OD) is the set of askable literals and represents the assumed information about the outside world during the process; the set of negative literals or abducibles is named Inside Assumptions (IA) and contains the values that are assumed during the process; finally, the set ANS is the set of instantiations of variables in the initial query.

Definition 5.2. PS (Process Set) is a set of processes. AAQ is a set of askable literals that have already been asked. The Current Belief State (CBS) is the set of askable literals.

The set of processes PS expresses all the alternative computations considered. AAQ ensures that redundant questions are not made to the sensors. The current status of the outside world is expressed through the CBS. During the execution of the framework there are different types of process, which is important to define: active processes and suspended processes.

Definition 5.3. Let $\langle GS, OD, IA, ANS\rangle$ be a process and CBS be a current belief state. A process is active with respect to CBS if $OD \subseteq CBS$. A process is suspended with respect to CBS otherwise.

The previous definition states that an active process is a process in which the outside defaults are consistent with the current belief state.

5.3 Process Reduction Phase

During this phase a process may suffer some changes. In the next description a changed PS, AAQ and CBS are defined as $NewPS$, $NewAAQ$ and $NewCBS$.

Initial Step: Let GS be an initial goal set. The tuple $\langle GS, \emptyset, \emptyset, ANS\rangle$ is given to the proof procedure where ANS is a set of variables in GS. That is, $PS = \{\langle GS, \emptyset, \emptyset, ANS\rangle\}$. Let $AAQ = \emptyset$ and $CBS = \Delta$.

Iteration Step: Do the following:

- ▷ **Case 1:** If there is an active process $\langle \emptyset, OD, IA, ANS\rangle$ with respect to CBS in PS, terminate the process by returning outside defaults OD, inside assumptions IA, and instantiation for variables ANS.
- ▷ **Case 2:** If there is no active process, terminate the process by reporting a failure of the goal;
- ▷ **Case 3:** Select an active process $\langle GS, OD, IA, ANS\rangle$ with respect to CBS from PS and select an extended literal L in GS. Let $PS' = PS - \{\langle GS, OD, IA, ANS\rangle\}$ and $GS' = GS - \{L\}$. For the selected extended literal L, do the following:
  - – **Case 3.1:** If L is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle (\{body(R)\} \bigcup GS')\theta, OD, IA, ANS\theta\rangle | \exists R \in \mathcal{P}$ and $\exists$most general unifier (mgu) θ so that $head(R)\theta = L\theta$.
  - – **Case 3.2:** If L is a ground negative ordinary literal or a ground abducible then:
    - ∗ **Case 3.2.1:** If $L \in IA$ then $NewPS = PS' \bigcup \{\langle GS', OD, IA, ANS\rangle\}$.
    - ∗ **Case 3.2.2:** If $\overline{L} \in IA$ then $NewPS = PS'$.
    - ∗ **Case 3.2.3:** If $L \notin IA$ then $NewPS = PS' \bigcup \{\langle NewGS, OD, IA \bigcup \{L\}, ANS\rangle\}$ where $NewGS = \{fail(BS) | BS \in resolvent(L, \mathcal{P} \bigcup \mathcal{I})\} \bigcup GS'$ and $resolvent(L, T)$ is defined as follows:
      - · If L is a groung negative ordinary literal, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_k\theta\} | H \leftarrow L_1, \ldots, L_k \in T$ so that $\overline{L} = H\theta$ by a ground substitution $\theta\}$
      - · If L is a ground abducible, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_{i-1}\theta, L_{i+1}\theta, \ldots, L_k\theta\} | \bot \leftarrow L_1, \ldots, L_k \in T$ so that $L = L_i\theta$ by a ground substitution $\theta\}$.
  - – **Case 3.3:** If L is $fail(BS)$, then
    - ∗ If $BS = \emptyset$, $NewPS = PS'$;
    - ∗ IF $BS \neq \emptyset$, then do the following:
      1. (1) Select B from BS and let $BS' = BS - \{B\}$.
      2. (2) **Case 3.3.1:** If B is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle NewGS \bigcup GS', OD, IA, ANS\rangle\}$ where $NewGS = \{fail((\{body(R)\} \bigcup BS')\theta | \exists R \in \mathcal{P}$ and $\exists$mgu θ so that $head(R)\theta = B\theta\}$
      Case 3.3.2: If B is a ground negative ordinary literal or a ground askable literal or an abducible, $NewPS = PS' \bigcup \{\langle \{fail(BS')\} \bigcup GS', OD, IA, ANS\rangle\} \bigcup \{\langle \{\overline{B}\} \bigcup GS', OD, IA, ANS\rangle\}$.

– **Case 3.4:** If L is a ground askable literal, $Q@S$, then do the following:
  (1) If $L \notin AAQ$ and $\overline{L} \notin AAQ$, then send the question Q to the slave agent S and $NewAAQ = AAQ \bigcup \{L\}$.
  (2) If $\overline{L} \in OD$ then $NewPS = PS'$ else $NewPS = PS' \bigcup \{\langle GS', OD \bigcup \{L\}, IA, ANS\rangle\}$.

5.4 Fact Arrival Phase

During the process reduction phase it is asked information to the information sources. Whenever this information is returned from the source the current belief state is revised according to it. Supposing that an answer Q is returned from a sensor S. Let $L = Q@S$. After finishing a step of the process reduction phase, do the following:

- If $\overline{L} \in CBS$, then $NewCBS = CBS - \{\overline{L}\} \bigcup \{L\}$
- Else if $L \notin CBS$, then $NewCBS = CBS \bigcup \{L\}$.

Some askable literals might not be included in the initial belief set. Thus, if there is a process that is using such askable literal or their complements, they are suspended until the answer arrives.

5.5 Execution Example

An execution example of the program introduced in Section 5.1 is presented bellow. For the process reduction, the following strategy is used:

▷ When a positive literal is reduced, new processes are created along according to the rule order in the program, which are unifiable with the positive literal;

▷ A newly created or newly resumed process and the most left literal is always selected.

In the next execution trace for $guide(1, 2)$ the selected literal is underlined in the selected active process. AAQ and CBS are only shown when a change occurs.
During the next execution trace the user travels between locations 1 and 2 through intermediate location 3 and takes the wrong direction towards location 4. At this stage the system alerts the user and guides him to the correct path.

①

$$
\begin{aligned}
PS &= \{\langle\{\underline{guide(1,2)}\},\ \emptyset,\ \emptyset\rangle\}\\
AAQ &= \emptyset\\
CBS &= \{user\_travel(1,3)@gps\_sensor, \sim user\_travel(1,2)@gps\_sensor,\\
&\quad user\_travel(3,4)@gps\_sensor, user\_travel(4,3)@gps\_sensor,\\
&\quad user\_travel(3,2)@gps\_sensor, included(1)@recognizer,\\
&\quad included(2)@recognizer, included(3)@recognizer,\\
&\quad \sim included(4)@recognizer
\end{aligned}
$$

② By case 3.1

$$
\begin{aligned}
PS = \{&\langle\{\underline{path(1,F)},\ show\_next\_point(F),\ user\_travel(1,F)@gps\_sensor,\ guide(F,2)\},\ \emptyset,\ \emptyset\rangle,\\
&\langle\{path(1,F),\ user\_travel(1,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\},\ \emptyset,\ \emptyset\rangle\}
\end{aligned}
$$

③ By case 3.1

$PS = \{\langle\{\underline{show\_next\_point(2)},\ user\_travel(1,2)@gps\_sensor,\ guide(2,2)\},\ \emptyset,\ \emptyset\rangle,$
$\langle\{show\_next\_point(3),\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle,\ P_1{}^1\ \}$

At step 3 the system starts to check if it is possible to use the path between locations 1 and 2 to guide the user.

④ By case 3.2.3

$PS = \{\langle\{\underline{fail(\sim included(2)@recognizer)},\ user\_travel(1,2)@gps\_sensor,\ guide(2,2)\},\ \emptyset,$
$\{show\_next\_point(2)\}\rangle,$
$P_2{}^2\ ,\ P_1\}$

⑤ By case 3.3.2

$PS = \{\langle\{\underline{fail(\emptyset)},\ user\_travel(1,2)@gps\_sensor,\ guide(2,2)\},\ \emptyset,\ \{show\_next\_point(2)\}\rangle,$
$\langle\{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ guide(2,2)\},\ \emptyset,$
$\{show\_next\_point(2)\}\rangle,$
$P_2,\ P_1\}$

⑥ By case 3.3

$PS = \{\langle\{\underline{included(2)@recognizer},\ user\_travel(1,2)@gps\_sensor,\ guide(2,2)\},\ \emptyset,$
$\{show\_next\_point(2)\}\rangle,$
$P_2,\ P_1\}$

⑦ By case 3.4

$included(2)$ is asked to the $recognizer$

$PS = \{\langle\{\underline{user\_travel(1,2)@gps\_sensor},\ guide(2,2)\},\ \{included(2)@recognizer\},$
$\{show\_next\_point(2)\}\rangle,$
$P_2,\ P_1\}$

$AAQ = \{included(2)@recognizer\}$

⑧ By case 3.4

$user\_travel(1,2)$ is asked to the gps_sensor

$PS = \{\langle\{guide(2,2)\},\ \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor\},$
$\{show\_next\_point(2)\}\rangle,$
$P_2,\ P_1\}$

$AAQ = \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor\}$

At this stage, since the system does not have an answer for the question $user\_travel(1,2)@gps\_sensor$, it uses the default $false$ value and suspends the computation of this branch. The system begins the same process for a new branch that uses a path between locations 1 and 3.

⑨

$PS = \{\langle\{\underline{show\_next\_point(3)},\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle$
$P_1,\ P_3{}^3\ \}$

⑩ By case 3.2.3

$PS = \{\langle\{\underline{fail(\sim included(3)@recognizer)},\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset,$
$\{show\_next\_point(3)\}\rangle$
$P_1,\ P_3\}$

[1] $P_1 = \langle\{path(1,F),\ user\_travel(1,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\},\ \emptyset,\ \emptyset\rangle$

[2] $P_2 = \langle\{show\_next\_point(3),\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle$

[3] $P_3 = \langle\{guide(2,2)\},\ \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor\},\ \{show\_next\_point(2)\}\rangle$

11 By case 3.3.2

$$\begin{aligned} PS = \{ & \langle\{\underline{fail(\emptyset)},\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset,\ \{show\_next\_point(3)\}\rangle, \\ & \langle\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset, \\ & \{show\_next\_point(3)\}\rangle, \\ & P_1,\ P_3\} \end{aligned}$$

12 By case 3.3

$$\begin{aligned} PS = \{ & \langle\{\underline{included(3)@recognizer},\ user\_travel(1,3)@gps\_sensor,\ guide(3,2)\},\ \emptyset, \\ & \{show\_next\_point(3)\}\rangle, \\ & P_1,\ P_3\} \end{aligned}$$

13 By case 3.4

$included(3)$ is asked to the $recognizer$

$$\begin{aligned} PS = \{ & \langle\{\underline{user\_travel(1,3)@gps\_sensor},\ guide(3,2)\},\ \{included(3)@recognizer\}, \\ & \{show\_next\_point(3)\}\rangle, \\ & P_1,\ P_3\} \\ AAQ = \{ & included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ included(3)@recognizer\} \end{aligned}$$

14 By case 3.4

$user\_travel(1,3)$ is asked to the gps_sensor

$$\begin{aligned} PS = \{ & \langle\{guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\}, \\ & \{show\_next\_point(3)\}\rangle, \\ & P_1,\ P_3\} \\ AAQ = \{ & included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\} \end{aligned}$$

The execution of the program assumed, at this stage, that the user is travelling from 1 to 3. Then, it suspends this branch and resumes the branche that is used to alert the user whenever needed.

15

$$\begin{aligned} PS = \{ & \langle\{path(1,F),\ user\_travel(1,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\},\ \emptyset,\ \emptyset\rangle, \\ & P_3,\ P_4\ ^{4}\ \} \end{aligned}$$

16 By case 3.1

$$\begin{aligned} PS = \{ & \langle\{\underline{user\_travel(1,2)@gps\_sensor},\ show\_user\_warning(2),\ guide(2,2)\},\ \emptyset,\ \emptyset\rangle, \\ & \langle\{user\_travel(1,3)@gps\_sensor,\ show\_user\_warning(3),\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle \\ & P_3,\ P_4\} \end{aligned}$$

17 By case 3.4

$$\begin{aligned} PS = \{ & \langle\{\underline{show\_user\_warning(2)},\ guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor\},\ \emptyset\rangle, \\ & P_5\ ^{5}\ ,\ P_3,\ P_4\} \end{aligned}$$

18 By case 3.2.3

$$\begin{aligned} PS = \{ & \langle\{\underline{fail(included(2)@recognizer)},\ guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor\}, \\ & \{show\_user\_warning(2)\}\rangle, \\ & P_5,\ P_3,\ P_4\} \end{aligned}$$

19 By case 3.3.2

$$\begin{aligned} PS = \{ & \langle\{\underline{fail(\emptyset)},\ guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor\},\ \{show\_user\_warning(2)\}\rangle, \\ & \langle\{\sim included(2)@recognizer,\ guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor\}, \\ & \{show\_user\_warning(2)\}\rangle \\ & P_5,\ P_3,\ P_4\} \end{aligned}$$

---

[4] $P_4 = \langle\{guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$

[5] $P_5 = \langle\{user\_travel(1,3)@gps\_sensor,\ show\_user\_warning(3),\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle$

20 By case 3.3

$$PS = \{\langle\{\underline{\sim included(2)@recognizer},\ guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor\},\ \{show\_user\_warning(2)\}\rangle\ P_5,\ P_3,\ P_4\}$$

21 By case 3.4

$$PS = \{\langle\{guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor,\ \sim included(2)@recognizer\},\ \{show\_user\_warning(2)\}\rangle\ \langle\{\underline{user\_travel(1,3)@gps\_sensor},\ show\_user\_warning(3),\ guide(3,2)\},\ \emptyset,\ \emptyset\rangle\ P_3,\ P_4\}$$

22 By case 3.4

$$PS = \{\langle\{\underline{show\_user\_warning(3)},\ guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor\},\ \emptyset\rangle\ P_3,\ P_4,\ P_6\}$$ [6]

23 By case 3.2.3

$$PS = \{\langle\{\underline{fail(included(3)@recognizer)},\ guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor\},\ \{show\_user\_warning(3)\}\rangle\ P_3,\ P_4,\ P_6\}$$

24 By case 3.3.2

$$PS = \{\langle\{\underline{fail(\emptyset)},\ guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor\},\ \{show\_user\_warning(3)\}\rangle\ \langle\{\sim included(3)@recognizer,\ guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor\},\ \{show\_user\_warning(3)\}\rangle\ P_3,\ P_4,\ P_6\}$$

25 By case 3.3

$$PS = \{\langle\{\underline{\sim included(3)@recognizer},\ guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor\},\ \{show\_user\_warning(3)\}\rangle\ P_3,\ P_4,\ P_6\}$$

26 By case 3.4

$$PS = \{\langle\{guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor,\ \sim included(3)@recognizer\},\ \{show\_user\_warning(3)\}\rangle\ P_3,\ P_4,\ P_6\}$$

Since locations 2 and 3 are valid, the two branches that are used to alert the user are suspended. The integrity contraints show that the system does not alert the user when he is travelling in the correct path and this is shown in these previous steps.

27

$user\_travel(1,3)$ is returned from gps_sensor

nothing changes

From this point on the execution will do the same as in step 1: guide the user from the intermediate location 3 to the final location 2. It starts by finding a possible path to the destination and tries to show if the location is valid or alerts the user if not. For each possible location two new branches are derived from the current one.

28

$$PS = \{\langle\{\underline{guide(3,2)}\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle\ P_3,\ P_6,\ P_7\}$$ [7]

[6] $P_6 = \langle\{guide(2,2)\},\ \{user\_travel(1,2)@gps\_sensor,\ \sim included(2)@recognizer\},\ \{show\_user\_warning(2)\}\rangle$

[7] $P_7 = \langle\{guide(3,2)\},\ \{user\_travel(1,3)@gps\_sensor,\ \sim included(3)@recognizer\},\ \{show\_user\_warning(3)\}\rangle$

29 By case 3.1

$PS = \{\langle\{\underline{path(3,F)},\ show\_next\_point(F),\ user\_travel(3,F)@gps\_sensor,\ guide(F,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
$\langle\{path(3,F),\ user\_travel(3,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
$P_3,\ P_6,\ P_7\}$

30 By case 3.1

$PS = \{\langle\{\underline{show\_next\_point(2)},\ user\_travel(3,2)@gps\_sensor,\ guide(2,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
$\langle\{show\_next\_point(4),\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
P_8[8]$,\ P_3,\ P_6,\ P_7\}$

31 By case 3.2.3

$PS = \{\langle\{\underline{fail(\sim included(2)@recognizer)},\ user\_travel(3,2)@gps\_sensor,\ guide(2,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_next\_point(2)\}\rangle$
P_9[9]$,\ P_8,\ P_3,\ P_6,\ P_7\}$

32 By case 3.3.2

$PS = \{\langle\{\underline{fail(\emptyset)},\ user\_travel(3,2)@gps\_sensor,\ guide(2,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_next\_point(2)\}\rangle$
$\langle\{included(2)@recognizer,\ user\_travel(3,2)@gps\_sensor,\ guide(2,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_next\_point(2)\}\rangle$
$P_9,\ P_8,\ P_3,\ P_6,\ P_7\}$

33 By case 3.3

$PS = \{\langle\{\underline{included(2)@recognizer},\ user\_travel(3,2)@gps\_sensor,\ guide(2,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_next\_point(2)\}\rangle$
$P_9,\ P_8,\ P_3,\ P_6,\ P_7\}$

34 By case 3.4

$PS = \{\langle\{\underline{user\_travel(3,2)@gps\_sensor},\ guide(2,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ included(2)@recognizer\},\ \{show\_next\_point(3),$
$show\_next\_point(2)\}\rangle$
$P_9,\ P_8,\ P_3,\ P_6,\ P_7\}$

35 By case 3.4

$user\_travel(3,2)$ is asked to the gps_sensor

$PS = \{\langle\{\underline{guide(2,2)}\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,$
$included(2)@recognizer,\ user\_travel(3,2)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_next\_point(2)\}\rangle$
$P_9,\ P_8,\ P_3,\ P_6,\ P_7\}$

$AAQ = \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,2)@gps\_sensor\}$

[8] $P_8 = \langle\{path(3,F),\ user\_travel(3,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\},$ $\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$

[9] $P_9 = \langle\{show\_next\_point(4),\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer,$ $user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$

36 By case 3.1

$$\begin{aligned} PS \; = \; & \{\langle \emptyset,\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ included(2)@recognizer, \\ & user\_travel(3,2)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_next\_point(2)\}\rangle \\ & \langle\{\underline{show\_next\_point(4)},\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle \\ & P_8,\ P_3,\ P_6,\ P_7\} \end{aligned}$$

After step 36 the execution trace finds the total path to travel, however there are other branches that may be computed. Thus, the system verifies if the unfinished branch is viable to be computed. In this case it computes over the path that connects location 3 and location 4.

37 By case 3.2.3

$$\begin{aligned} PS \; = \; & \{\langle\{\underline{fail(\sim included(4)@recognizer)},\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\}, \\ & \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3), \\ & show\_next\_point(4)\}\rangle \\ & P_8,\ P_3,\ P_6,\ P_7,\ P_{10}{}^{10}\} \end{aligned}$$

38 By case 3.3.2

$$\begin{aligned} PS \; = \; & \{\langle\{\underline{fail(\emptyset)},\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_next\_point(4)\}\rangle \\ & \langle\{included(4)@recognizer,\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_next\_point(4)\}\rangle \\ & P_8,\ P_3,\ P_6,\ P_7,\ P_{10}\} \end{aligned}$$

39 By case 3.3

$$\begin{aligned} PS \; = \; & \{\langle\{\underline{included(4)@recognizer},\ user\_travel(3,4)@gps\_sensor,\ guide(4,2)\}, \\ & \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3), \\ & show\_next\_point(4)\}\rangle \\ & P_8,\ P_3,\ P_6,\ P_7,\ P_{10}\} \end{aligned}$$

The current computed branch is suspended since the default value for $included(4)$ is $false$, *i.e.*, location 4 is not a valid location and the program must not show this location as a location to travel to. The current branch is suspended and the branch suspended on step 29 is resumed.

40 By case 3.4

$included(4)$ is asked to the $recognizer$

$$\begin{aligned} PS \; = \; & \{\langle\{user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor,\ included(4)@recognizer\},\ \{show\_next\_point(3), \\ & show\_next\_point(4)\}\rangle \\ & \langle\{\underline{path(3,F)},\ user\_travel(3,F)@gps\_sensor,\ show\_user\_warning(F),\ guide(F,2)\}, \\ & \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle \\ & P_3,\ P_6,\ P_7,\ P_{10}\} \\ AAQ \; = \; & \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor,\ user\_travel(3,2)@gps\_sensor,\ included(4)@recognizer\} \end{aligned}$$

41 By case 3.1

$$\begin{aligned} PS \; = \; & \{\langle\{\underline{user\_travel(3,4)@gps\_sensor},\ show\_user\_warning(4),\ guide(4,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle \\ & \langle\{user\_travel(3,2)@gps\_sensor,\ show\_user\_warning(2),\ guide(3,2)\},\ \{included(3)@recognizer, \\ & user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle \\ & P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}{}^{11}\} \end{aligned}$$

[10] $P_{10} = \langle \emptyset,\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ included(2)@recognizer,\ user\_travel(3,2)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_next\_point(2)\}\rangle$

$user\_travel(3,4)$ is asked to the gps_sensor

$PS = \{\langle\{\underline{show\_user\_warning(4)},\ guide(4,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
P_{12}[12]$,\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

43 By case 3.2.3

$PS = \{\langle\{\underline{fail(included(4)@recognizer)},\ guide(4,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_user\_warning(4)\}\rangle$
$P_{12},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

44 By case 3.3.2

$PS = \{\langle\{\underline{fail(\emptyset)},\ guide(4,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,$
$user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$
$\langle\{\sim included(4)@recognizer,\ guide(4,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_user\_warning(4)\}\rangle$
$P_{12},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

45 By case 3.3

$PS = \{\langle\{\underline{\sim included(4)@recognizer},\ guide(4,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),$
$show\_user\_warning(4)\}\rangle$
$P_{12},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

Using default values the system detects that the user may travel towards location 4. This location is not a valid one so the system alerts the user and guides him to the correct path.

46 By case 3.4

$\sim included(4)$ is asked to the $recognizer$

$PS = \{\langle\{guide(4,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,$
$user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),$
$show\_user\_warning(4)\}\rangle$
$\langle\{\underline{user\_travel(3,2)@gps\_sensor},\ show\_user\_warning(2),\ guide(3,2)\},$
$\{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
$P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

Before deriving new branches from $guide(4,2)$ the system resumes another branch that verifies if an alert show be sent to the user if he travels towards location 2.

47 By case 3.4

$PS = \{\langle\{\underline{show\_user\_warning(2)},\ guide(3,2)\},\ \{included(3)@recognizer,$
$user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$
P_{13}[13]$,\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

[11] $P_{11} = \langle\{user\_travel(3,4)@gps\_sensor,\ guide(4,2)\},\ \{included(3)@recognizer,$ $user\_travel(1,3)@gps\_sensor,\ included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_next\_point(4)\}\rangle$

[12] $P_{12} = \langle\{user\_travel(3,2)@gps\_sensor,\ show\_user\_warning(2),\ guide(3,2)\},\ \{included(3)@recognizer,$ $user\_travel(1,3)@gps\_sensor\},\ \{show\_next\_point(3)\}\rangle$

[13] $P_{13} = \langle\{guide(4,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,$ $user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$

48 By case 3.2.3

$PS = \{\langle\{\underline{fail(included(2)@recognizer)},\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle\ P_{13},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

49 By case 3.3.2

$PS = \{\langle\{\underline{fail(\emptyset)},\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle$
$\langle\{\sim included(2)@recognizer,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle\ P_{13},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

50 By case 3.3

$PS = \{\langle\{\underline{\sim included(2)@recognizer},\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle\ P_{13},\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

Since location 2 is a valid location the current branch is suspended and the one resumed in step 46 is resumed, deriving two more branches.

51 By case 3.4

$PS = \{\langle\{guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(2)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle$
$\langle\{\underline{guide(4,2)}\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11}\}$

52

$\sim user\_travel(3,4)$ is returned from $recognizer$

$CBS = \{user\_travel(1,3)@gps\_sensor, \sim user\_travel(1,2)@gps\_sensor, \sim user\_travel(3,4)@gps\_sensor, user\_travel(4,3)@gps\_sensor, user\_travel(3,2)@gps\_sensor, included(1)@recognizer, included(2)@recognizer, included(3)@recognizer, \sim included(4)@recognizer$

53 By case 3.1

$PS = \{\langle\{\underline{show\_next\_point(3)},\ user\_travel(4,3)@gps\_sensor,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}$[14]$\}$

54 By case 3.2.3

$PS = \{\langle\{\underline{fail(\sim included(3)@recognizer)},\ user\_travel(4,3)@gps\_sensor,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle\ P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}\}$

[14] $P_{14} = \langle\{guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(2)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(2)\}\rangle$

55 By case 3.3.2

$$PS = \{\langle\{\underline{fail(\emptyset)},\ user\_travel(4,3)@gps\_sensor,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$$
$$\langle\{included(3)@recognizer,\ user\_travel(4,3)@gps\_sensor,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$$
$$P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}\}$$

56 By case 3.3

$$PS = \{\langle\{\underline{included(3)@recognizer},\ user\_travel(4,3)@gps\_sensor,\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$$
$$P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}\}$$

57 By case 3.4

$$PS = \{\langle\{\underline{user\_travel(4,3)@gps\_sensor},\ guide(3,2)\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$$
$$P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}\}$$

58 By case 3.4

$user\_travel(4,3)$ is asked to the gps_sensor

$$PS = \{\langle\{\underline{guide(3,2)}\},\ \{included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,4)@gps\_sensor,\ \sim included(4)@recognizer\},\ \{show\_next\_point(3),\ show\_user\_warning(4)\}\rangle$$
$$P_3,\ P_6,\ P_7,\ P_{10},\ P_{11},\ P_{14}\}$$
$$AAQ = \{included(2)@recognizer,\ user\_travel(1,2)@gps\_sensor,\ included(3)@recognizer,\ user\_travel(1,3)@gps\_sensor,\ user\_travel(3,2)@gps\_sensor,\ included(4)@recognizer,\ user\_travel(4,3)@gps\_sensor\}$$

At this stage the system will derive four new branches: two for location 2 and two for 4. As the system knows that the user is not going in the direction of location 4, both branches will be suspended. The only branch that will continue the computation is the one that points to location 2 as the next point to travel. These processes are not shown in detailed steps due to the extension of the proof procedure and they will be similar to the steps from step 28 onwards. For the previous execution the framework starts with the objective of guiding the user between the starting location 1 and the ending 2. At an initial step it tries to find a path between location 1 and the destination. According to Figure 4 there are two possibilities, which are locations 2 (the goal) and 3. The system starts processing 2 branches for each next possible location: one branch of the pair lets the execution continue if the next location is valid (*i.e.*, is included in the valid locations set) and the user is travelling to it; the other branch represents the case in which the location is not valid and the user is travelling towards it. In the former the system keeps guiding the user to the next point (since he is travelling in the correct path) whereas in the latter the system alerts the user, informing him about his mistake and guides him to the correct path. Any branch that tries to execute an alternative combination of the previously described situations is suspended since it is not valid (*e.g.*, alert the user when the next location is valid). During the execution of a branch the program may query the information source. While this information is not returned the program continues its execution, so branches which queried for

$user\_travel(1,2)@gps\_sensor$ are paused (since the default value is negative). The only branch that continues the computation is the one that assumes the default value $user\_travel(1,3)@gps\_sensor$. Whenever an answer is returned from the information source the computation is revised. The current branch may be paused and a previously paused one may be resumed. The system continues to start, pause, and resume branches during the entire processing until the destination point is reached.

Besides not knowing an answer, the system continues the computation using Speculative Computation. This situation occurs at different steps in which a default value is assumed.

At Step 9, $show\_next\_point(3)$ is assumed and the integrity constraints are checked. Thus, it is ensured that there is no contradiction by checking if $\sim included(3)@recognizer$ is not derived. In this step an ordinary abduction is performed. When an answer is returned and confirms the default value, nothing changes.

In situations like the previous one the Speculative Computation is in an advanced stage of the computation and it does not have to be revised.

The previous execution trace represents a computation example and it has not been implemented. Its purpose is to check if it is possible to formalize the orientation problem through Speculative Computation. According to the proof, applying Speculative Computation is expressive and adequate.

6 Conclusions

Orientation may be a serious problem for people with cognitive disabilities. Some may even be prevented by caregivers to go out their homes by themselves due to the risk of getting lost. In order to minimize this risk and increase the autonomy of people researchers have been developing orientation methods for people with cognitive disabilities, so that they may travel alone and be remotely monitored.

Our orientation system used augmented reality, surpassing limitations of different systems that use static pictures with overlayered arrows or other symbols, or of systems that resemble a compass in which the user needs to interpret and understand the direction. On the other hand, our system enables caregivers to know, in real time, the current location of the person with cognitive disabilities on a map. In order to increase the effectiveness of the system, it is possible to connect it to external services expanding its features.

To increase the system responsiveness and enable it to be ready for a possible error situation before it happens (predictive feature) it was envisioned a suite for speculative computation having in mind the public that will use our system.

Applying the framework of Speculative Computation enables the system to deal with incomplete information. Instead of pausing the computation and wait for a value to calculate the correct path to follow, the framework uses a default value and keeps the computation running. When the missing data is returned the computation is revised. If the returned value is coherent with the default one then the computation is in an advanced stage of execution. However, if the returned value is contradictory with the default then the computed branch is suspended and another may be started or resumed.

The Speculative Computation framework lets the system be in a constant execution stage. Instead of pausing the computation and be in an idle state. Thus, the system may have a predictive feature since it may be ready to alert the user before he turns in the wrong direction. Lastly, the Speculative Computation framework does not compute the set of default values, *i.e.*, it just uses the values that compose the set. The method for the detection of user behaviour patterns is independent of the framework, but Speculative Computation can be used in combination with it, providing a structured reasoning framework capable of coping with missing information. Future work includes analysing behaviour extraction methods, specific for the problem of orientation, which can be useful for the extraction of default values.
The detection of frequent trajectory patterns had been studied in (Giannotti, Nanni, Pinelli and Pedreschi, 2007; Monreale, Pinelli and Trasarti, 2009; Lee, Chen and Ip, 2009). In these studies the authors use different location acquisition methods (*e.g.*, GPS and GSM networks) to gather the user location. The detection of patterns is the result of a data mining process in which different algorithms are applied. Knowing the user preferences (frequent trajectories) our system may use this information to create a route that better adapts to the user characterists. Thus, the path used to guide the user may not be the shortest one, but the one that the user knows better.

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4.4 An Alert Mechanism for Orientation Systems based on Speculative Computation

The conference proceeding article *An Alert Mechanism for Orientation system based on Speculative Computation* presents a more solid version for the model used in the Speculative Computation process. It also sets how we intended to get the default values for it, considering that the path should be adapted to the user through a pattern mining feature.

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An Alert Mechanism for Orientation Systems based on Speculative Computation

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***Abstract*—The role of assistive technologies is to help users with diminished capabilities in the fulfillment of their everyday tasks. One of such tasks is orientation. It is crucial for the autonomy of an individual and, at the same time, it is one of the most challenging tasks for an individual with cognitive disabilities. Existing solutions that tackle this problem are mostly concerned with guidance, tracking and the display of information. However, there is a dimension that has not been the object of concern in existing projects, the prediction of user actions. This work presents a Speculative Module for an orientation system that is used to alert the user for potential mistakes in his path, anticipating possible shifts in the wrong direction in critical points of the route. With this module, it becomes possible to issue warnings to the user and increase his attention so as to avoid a deviation from the correct path.**

I. Introduction

The term cognitive disability is used to represent the condition of an individual who has difficulties in one or more types of mental tasks, when compared to ordinary people, according to [1]. Causes may include traumatic brain injury, stroke, Alzheimer's and developmental disability, among others. One can distinguish four phases of cognitive disabilities: mild, moderate, severe and extreme. While individuals in the severe or extreme phases need continuous assistance with every aspect of their everyday lives, people in the mild or moderate phases are capable of leading an independent life, requiring assistance only in certain activities. One of the mental tasks that is greatly affected is orientation. It is, at the same time, something that is vital for the autonomy of a person. As such, there is a clear necessity for technologies that increase the independence of individuals with cognitive disabilities outdoors. These technologies can be materialized in orientation systems that assist the user during his travels and compensate for his diminished orientation capabilities. Using these orientation/way finding systems the user may be guided from his current location to a predefined destination. The current approaches to this include systems that are focused exclusively on guidance, display of information and communication with a caregiver or a support community [2], [3], [4]. However, it would also be useful to anticipate the actions of the user and provide alerts when he is expected to make a wrong turn in his path. Through different alerts it would be possible to indicate to the user that he is approaching a critical point in his route, in which experience shows that he normally makes a mistake.

This work proposes an orientation system endowed with such a feature. Besides guidance, an intuitive display of information, and a tracking suite for caregivers (previously disclosed in [5]), the system has a mechanism based on Speculative Computation that issues alerts to the user if he reaches a point in his path where it is likely for him to make a mistake. As such, the main contributions of this work are: i) a method for the generation of default values regarding the habits of the user when following a route; ii) the integration of these defaults in a framework for Speculative Computation with constraint processing; and iii) a module for an orientation system that analyses a route and issues alerts to the user, increasing his level of attention.

This paper is organized as follows. Section II presents related work on orientation systems for people with cognitive disabilities. Section III provides a brief description of the orientation system that hosts the Speculative Module. The Speculative Module and the framework for Speculative Computation are described and formulated in Section IV. Finally, conclusions are drawn and future work considerations are made in Section V.

II. Related Work

There are a few research projects that focus on the development of orientation systems for people with cognitive disabilities. However, they lack the kind of predictive capability that would allow them to anticipate the actions of users and employ preemptive measures to avoid them, in the event that they are undesirable.

With the recognition that smartphones could play a pivotal role in the development of orientation systems for individuals with cognitive disabilities [6], researchers started to focus on these handheld devices as the ideal vehicles for conveying guidance. An example of this is the work in [2] which provides an application that enables a user to travel between locations using a public transportation system such as a bus. This is possible through a precompiled list of instructions, created by a caregiver, and delivered through a smartphone. As the user moves around, a personal travel assistant uses the GPS module to deliver the next set of instructions. As such, this system is

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mostly focused on providing an appropriate support for both the user and the caregiver.

Worries with the way in which information is displayed to users were behind the work in [6]. In their system, static images with overlaid arrows, audio messages, and text messages are used to guide a user. The objective is to find a tailored way of providing directions to individuals with cognitive disabilities. To achieve this, the preferences of users are modeled in a Markov Decision Process (MDP) [7]. Another feature is the use of recognizable landmarks near the user to facilitate guidance.

Fraunhofer Portugal also develops work in this area with their AlzNav orientation system [4]. The objective of the system is to make the interpretation of on-screen instructions as easy as possible. The direction that a user should take is shown by an arrow that works as a compass, spinning around as the user spins his phone. Along with the compass information, the user also sees on the screen the distance he should travel in a certain direction. Moreover, the system provides updates about the situation of the user to the caregiver through SMSs.

Although the existing approaches tackle some of the most important aspects of orientation for individuals with cognitive disabilities, it is still possible to find aspects in which they are lacking. Predicting the steps of users would provide an advantage. By making use of usage patterns, it becomes possible to identify critical points in the routes that are usually taken by the user. A critical point may be defined as a point where something usually goes wrong, or, in this specific case, where a user starts going in the wrong direction. Then, if the system is capable of predicting where this will happen, it can issue alerts to the user and reinforce the right path. This is the kind of feature that is proposed in the present work. The objective is to develop an orientation system that adapts to the user and tries to maximize user autonomy by minimizing the risk of getting lost.

III. System Description

The CogHelper System has the aim of guiding the user (person with cognitive disabilities) by adapting not only the level of prompting (indicating wether the user is traveling in the correct or wrong path) but also adjusting the guiding path to user preferences. This goal is complemented by a secondary objective of providing a tracking system for caregivers, which allows the caregiver to locate the user at any time.

The orientation method provided is devised for outdoor and the system architecture is shown in Figure 1. The architecture may be divided in four main modules: the server-side components (such as the database and the agency for the integration of the system applications and external services); the client-side applications (such as Cognitive Helper Mobile Solution and Caregiver Applications); and the external services, which allow the integration of CogHelper with other systems or other applications. The core of the system is the server since all the services are connected to it. The database module stores all the information necessary for the correct execution of the system (like usernames, locations and points of interest) and the remaining module provides the facilities for the communication between the server and the services (both internal and external).

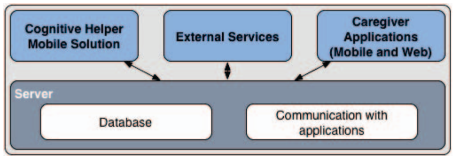

Fig. 1. Architecture of CogHelper System

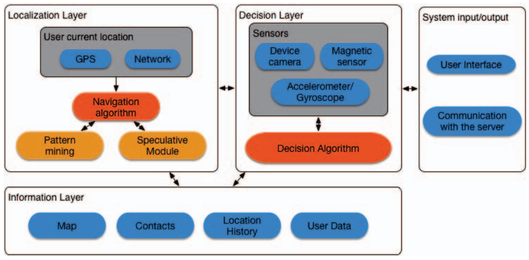

Fig. 2. Information layers of the CogHelper Module for People with Cognitive Disabilities

The component of the system that is specifically aimed at people with cognitive disabilities is the Cognitive Helper Mobile Solution (depicted in Figure 2), which consists of four layers. This component was developed for Android OS and its main functionality is to guide the user, enabling him to travel outside alone without getting lost. The Localization Layer has the methods that enable the system to get current location of the user, which may be done through the GPS of the mobile device or through the network (giving a coarse location). With this information the Navigation Algorithm is able to use the pattern mining module (responsible for getting the path that best fits the needs of the user) and the Speculative Module (which ensures that the user is traveling in the right path and alerts him before he takes a wrong turn). The Decision Algorithm (Decision Layer) uses information from the device camera, magnetic sensor and accelerometer to get the device orientation and ensure that the user is correctly oriented within the path.

The directions and alerts are given through an augmented reality interface. This interface module is included in the System Input/Output Layer, which is also includes a communication module. The latter is responsible for passing the information between the server and the user application. User destination updates, user current location updates, and so forth are some of the messages exchanged by these services. The last Layer depicted in Figure 2 (Information Layer) is used as a local database for storing information about the map, user contacts, his location history and other data associated with the user.

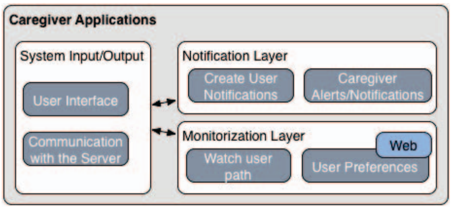

Fig. 3. Information layers of the CogHelper Module for Caregivers

Caregivers may use two different applications, a mobile application for Android OS and a Web application. Despite being developed for different platforms, these two applications have the same goal, provide a monitoring platform for the caregiver to check the current position of the user without having to be physically present. However there are some differences between the two. As depicted in Figure 3 the difference resides in the User Preferences module that is only present in the Web application. This module is responsible for adding, editing and removing user preferences such as destination points. This feature makes the Web application more complex. The Watch User Path module allows the caregiver to know the current location of the user. Inside the Notification Layer there are two modules that generate and receive alerts from and to the user application. The third Layer (System Input/Output) has the User Interface, which enables the user to interact with the application and shows the necessary information to the user. The other module ensures the communication with the server.

IV. A Speculative Module for Users with Cognitive Disabilities

The objective of the Speculative Module is to predict the next step of the user of the orientation system and manipulate that prediction in order to determine if an alert/warning should be issued. The whole procedure is controlled by Speculative Computation, acting as an interface between the instructions for the correct path (encoded as rules in the framework), the predictions about user transitions from one point to another in the path (encoded as default values), and the real information about these transitions that arrive from the other modules of the system. The Speculative Module has two main components, the framework of Speculative Computation and the method for the Generation of Default Values.

A. Framework of Speculative Computation

Speculative Computation as a reasoning framework was initially presented in [8] for problem solving in multi-agent systems when the communication between agents is not ensured. The Speculative Computation part of the Speculative Module is based on a logic programming framework that uses abductive reasoning [9]. As such, it includes a dynamic belief mechanism about the outside world. A Framework of Speculative Computation for an Orientation Method (SF_{OM}) is a tuple $\langle \Sigma, \mathcal{E}, \Delta, \mathcal{A}, \mathcal{P}, \mathcal{I} \rangle$. The meaning of each element is the following. Σ is a finite set of constants. An element in Σ is a module of the orientation system. $\mathcal{E}$ is a set of predicates called external predicates, representing the decision criteria. When Q is a literal with an external predicate and S is the identifier of a system module, $Q@S$ is called an askable literal. $\sim(Q@S)$ is defined as $(\sim Q)@S$. Default values are assumed whenever the information is incomplete. They are included in the set represented by Δ (default answer set). This is a set of ground askable literals which satisfies the following condition: Δ does not contain at the same time $p(t_1, \ldots, t_n)@S$ and $\sim p(t_1, \ldots, t_n)@S$. $\mathcal{A}$ is the set of abducible predicates. Q is called abducible when it is a literal with an abducible predicate. The set of rules ($\mathcal{P}$) that the program is going to execute are in the form: $H \leftarrow B_1, B_2, \ldots, B_n$ where H is a positive ordinary literal and each of $B_1, \ldots, B_n$ is an ordinary literal, an askable literal or an abducible literal; and H is the non-empty head of the rule (named $head(R)$) in which R is the rule of the form $H \leftarrow B_1, \ldots, B_n$. The body of the rule is represented by $B_1, \ldots, B_n$ (named $body(R)$) and may be replaced by the boolean value true. The last set, denoted by $\mathcal{I}$, contains the integrity constraints, which do not allow contradictions during the execution of the speculative framework. The integrity constraints are in the form $\perp \leftarrow B_1, \ldots, B_n$ where $\perp$ is the symbol for contradiction. $B_1, \ldots, B_n$ are ordinary literals, askable literals or abducibles. At least one of $B_1, \ldots, B_n$ must be an askable literal or an abducible. An askable literal may have two different meanings: an askable literal $Q@S$ in a rule $R \in \mathcal{P}$ represents a question that is asked to a system module S; or an askable literal in Δ denotes a default truth value ($true$ or $false$), i.e., $p(t_1, \ldots, t_n)@S \in \Delta$, $p(t1, \ldots, tn)@S$ is usually true for a question to a system module S, and $\sim p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is generally false for a question to a system module S. The literals in Δ represent the defaults about travel habits of the user in a specific route and the inclusion of locations in that route.

In the logic program given below, which provides a formalization of the example in Figure 4, the literal $path(a, b)$ denotes that there is a physical connection between the locations a and b, thus the user may travel between them. The literal $show\_next\_point$ is used to indicate that the system must show the next location to which the user should travel. This location may be an intermediate point or the final destination. Whenever the user travels in the wrong direction the literal $show\_user\_warning$ is activated indicating to the system that it must alert the user. In the set of external predicates there are the predicates $user\_travel(a, b)$ (which says that the user will travel from location a to location b) and $included(a)$ (to indicate if a location a is part of the route). These external predicates ask information from sources gps_sensor and $recognizer$, respectively. The former verifies if the user is traveling from point A to B. The latter checks if point B is included in the set of valid locations.

The framework of Speculative Computation that is given below ensures that the user is traveling in the correct path and assesses the need for issuing alerts when he may miss a turning

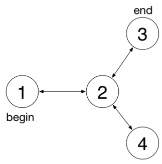

Fig. 4. Possible ways to travel between locations 1 and 3.

point. This framework is given in terms of the following logic program:

- $\Sigma = \{gps\_sensor, recognizer\}$
- $\mathcal{E} = \{user\_travel, included\}$
- $\Delta = \{user\_travel(1,2)@gps\_sensor,$
  $user\_travel(2,4)@gps\_sensor,$
  $\sim user\_travel(4,2)@gps\_sensor,$
  $user\_travel(2,3)@gps\_sensor,$
  $included(1)@recognizer, included(2)@recognizer,$
  $included(3)@recognizer, \sim included(4)@recognizer$
- $\mathcal{A} = \{show\_next\_point, show\_user\_warning\}$
- $\mathcal{P}$ is the following set of rules:
  $guide(A, A) \leftarrow .$
  $guide(A, B) \leftarrow$
  $path(A, F),$
  $show\_next\_point(F),$
  $user\_travel(A, F)@gps\_sensor,$
  $guide(F, B).$
  $guide(A, B) \leftarrow$
  $path(A, F),$
  $user\_travel(A, F)@gps\_sensor,$
  $show\_user\_warning(F),$
  $guide(F, B).$
  $path(1, 2) \leftarrow .$
  $path(2, 4) \leftarrow .$
  $path(2, 3) \leftarrow .$
  $path(4, 2) \leftarrow .$
- $\mathcal{I}$ denotes the following set of integrity constraint or invariants:
  $\bot \leftarrow$
  $show\_next\_point(F),$
  $\sim included(F)@recognizer.$
  $\bot \leftarrow$
  $show\_user\_warning(F),$
  $included(F)@recognizer.$

The two invariants included in set $\mathcal{I}$ ensure that the system does not show an alert when the user travels in the correct path and that it does not show a location that is not valid (is not part of the route) as the next traveling point. In the setting depicted above the framework assumes as default that the user normally travels from 1 to 2, from 2 to 4, and from 2 to 3, but not from 4 to 2. The framework also assumes that 1, 2 and 3 are included in the path, but 4 is not. Figure 4 presents the setting for the decision of whether to show or not a warning. It is a graph representing the path that a user should take. At location 2, there is an alternative path that may take the user to location 4. This is a point where the user may follow the wrong path.

B. Preliminary Definitions

The normal execution of the framework comprises the reduction of a non askable literal into subgoals under the rules in $\mathcal{P}$. Upon the appearance of an askable literal a query is sent to the system modules . When the answers are returned from Σ, they are added to the execution. To be able to create a proof procedure for the previously described framework there is the need for a few definitions:

Definition 1. *The tuple $\langle GS, OD, IA, ANS\rangle$ represents a process in which GS (Goal Set) is a set of extended literals to prove. These literals express the current status of an alternative computation; Outside Defaults (OD) is the set of askable literals and represents the assumed information about the outside world during the process; the set of negative literals or abducibles is named Inside Assumptions (IA) and contains the values that are assumed during the process; finally, the set ANS is the set of instantiations of variables in the initial query.*

Definition 2. *APS is a set of active processes and SPS is a set of suspended processes.*

Definition 3. *AAQ is a set of askable literals that have already been asked. The Current Belief State (CBS) is the set of askable literals.*

The APS expresses the set of processes that are consistent with the CBS and the SPS represents those which are not. AAQ ensures that redundant questions are not made to the sensors. The current status of the outside world is expressed through the CBS. During the execution of the framework there are different types of process, namely active processes and suspended processes.

Definition 4. *Let $\langle GS, OD, IA, ANS\rangle$ be a process and CBS be a current belief state. A process is active with respect to CBS if $OD \subseteq CBS$. A process is suspended with respect to CBS otherwise.*

The previous definitions state that an active process is a process in which the outside defaults are consistent with the current belief state. As such, if a process that states that an alert to the user should be issued is active, it means that the system will perform that action.

C. Process Reduction Phase

During this phase a process may suffer some changes. It represents the normal reduction of literals according to the rules in $\mathcal{P}$, the integrity constraints $\mathcal{I}$, and the CBS. In the following description changed PS, AAQ and CBS are defined as $NewPS$, $NewAAQ$ and $NewCBS$.

Initial Step: Let GS be an initial goal set. The tuple $\langle GS, \emptyset, \emptyset, ANS\rangle$ is given to the proof procedure where ANS is a set of variables in GS. That is, $PS = \{\langle GS, \emptyset, \emptyset, ANS\rangle\}$. Let $AAQ = \emptyset$ and $CBS = \Delta$.

Iteration Step: Do the following:

- **Case 1:** If there is an active process $\langle \emptyset, OD, IA, ANS\rangle$ with respect to CBS in PS, terminate the process by returning outside defaults OD, inside assumptions IA, and instantiation for variables ANS.
- **Case 2:** If there is no active process, terminate the process by reporting a failure of the goal;
- **Case 3:** Select an active process $\langle GS, OD, IA, ANS\rangle$ with respect to CBS from PS and select an extended literal L in GS. Let $PS' = PS - \{\langle GS, OD, IA, ANS\rangle\}$ and $GS' = GS - \{L\}$. For the selected extended literal L, do the following:
  - **Case 3.1:** If L is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle(\{body(R)\} \bigcup GS')\theta, OD, IA, ANS\theta\rangle | \exists R \in \mathcal{P}$ and $\exists$most general

unifier (mgu) θ so that $head(R)\theta = L\theta$.

- **Case 3.2:** If L is a ground negative ordinary literal or a ground abducible then:
  - **Case 3.2.1:** If $L \in IA$ then $NewPS = PS' \bigcup \{\langle GS', OD, IA, ANS\rangle\}$.
  - **Case 3.2.2:** If $\overline{L} \in IA$ then $NewPS = PS'$.
  - **Case 3.2.3:** If $L \notin IA$ then $NewPS = PS' \bigcup \{\langle NewGS, OD, IA \bigcup \{L\}, ANS\rangle\}$ where $NewGS = \{fail(BS) | BS \in resolvent(L, \mathcal{P} \bigcup \mathcal{I})\} \bigcup GS'$ and $resolvent(L, T)$ is defined as follows:
    - If L is a groung negative ordinary literal, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_k\theta\} | H \leftarrow L_1, \ldots, L_k \in T$ so that $\overline{L} = H\theta$ by a ground substitution $\theta\}$
    - If L is a ground abducible, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_{i-1}\theta, L_{i+1}\theta, \ldots, L_k\theta\} | \bot \leftarrow L_1, \ldots, L_k \in T$ so that $L = L_i\theta$ by a ground substitution $\theta\}$.
- **Case 3.3:** If L is $fail(BS)$, then
  - If $BS = \emptyset$, $NewPS = PS'$;
  - IF $BS \neq \emptyset$, then do the following:

  (1) Select B from BS and let $BS' = BS - \{B\}$.
  (2) **Case 3.3.1:** If B is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle NewGS \bigcup GS', OD, IA, ANS\rangle\}$ where $NewGS = \{fail((\{body(R)\} \bigcup BS')\theta | \exists R \in \mathcal{P}$ and $\exists$mgu θ so that $head(R)\theta = B\theta\}$
  Case 3.3.2: If B is a ground negative ordinary literal or a ground askable literal or an abducible, $NewPS = PS' \bigcup \{\langle \{fail(BS')\} \bigcup GS', OD, IA, ANS\rangle\} \bigcup \{\langle \{\overline{B}\} \bigcup GS', OD, IA, ANS\rangle\}$.
- **Case 3.4:** If L is a ground askable literal, $Q@S$, then do the following:

  (1) If $L \notin AAQ$ and $\overline{L} \notin AAQ$, then send the question Q to the slave agent S and $NewAAQ = AAQ \bigcup \{L\}$.
  (2) If $\overline{L} \in OD$ then $NewPS = PS'$ else $NewPS = PS' \bigcup \{\langle GS', OD \bigcup \{L\}, IA, ANS\rangle\}$.

D. Fact Arrival Phase

During the process reduction phase information is asked from the system modules. Whenever this information is returned from the source the current belief state is revised according to it. Supposing that an answer Q is returned from a system module S. Let $L = Q@S$. After finishing a step of the process reduction phase, do the following:

- If $\overline{L} \in CBS$, then $NewCBS = CBS - \{\overline{L}\} \bigcup \{L\}$
- Else if $L \notin CBS$, then $NewCBS = CBS \bigcup \{L\}$.

Some askable literals might not be included in the initial belief set. Thus, if there is a process that is using such askable literal or their complements, they are suspended until the answer arrives.

E. Generation of Default Values

The Framework of Speculative Computation uses the values from the *default answer set* (defined by Δ) whenever it is under a scenario of incomplete information. During the execution of the framework it asks the information source and keeps the execution using the value from this set. The *default answer set* needs to be generated each time the user wants to travel from the location he currently is to the destination selected inside the mobile application. This generation process is very important because its goal is to find a traveling route that is adjusted to the preferences of the user. Instead of guiding the user though the shortest path, it might guide him through a longer, but preferred, path. This set also includes values of possible mistakes that the user may make, reflecting his habits when following that route. They are used in order to alert and prevent him from taking the wrong path.

The generation of the *default values* is a complex process and is dependent on the number of times the person has traveled with the aid of the CogHelper System. If it is the first time the person with cognitive disabilities is using the application, then there is no historic data about him and the generated route will use a shortest path method (*e.g.*, Dijkstra algorithm). If there is historic data available, then all similar routes are retrieved from the database. This set of routes includes those with the same (or approximately) starting point or routes that go through the current starting point to the intended destination, *i.e.*, routes that started elsewhere and, from a given point, become similar to the other routes retrieved from the database.

After this first retrieval step, a pattern mining method is applied [10], [11], [12] to get the best route (the one that best fits user preferences). Figure 5 represents a calculated path using the raw data retrieved from the database in which a pattern mining method has been applied. This example route will be used to guide the user between the points.

To be able to use the resulting route to guide the user it is necessary to remove the error of the raw data. For this normalizing step there are multiple online services like *RoadMatcher*[13], *TrackMatching*[14] and *GraphHopper*[15], to name a few. To use these services, the system sends the route raw points and receives the points without the inherent raw error. This second phase ends with a route like the one presented in Figure 6.

Removing the error from the raw GPS data enables the system to guide the user in a more precise way, however if we use this calculated route for the guiding process it would generate too many assertive messages informing the user to travel small distances, given the density of points. This situation would be distracting to the user since the number of prompts would be exacerbated. Thus, after this process we need to reduce the number of routing points to the minimum. Using the map information from OpenStreetMap, it is possible to get the starting and ending points of a street and get

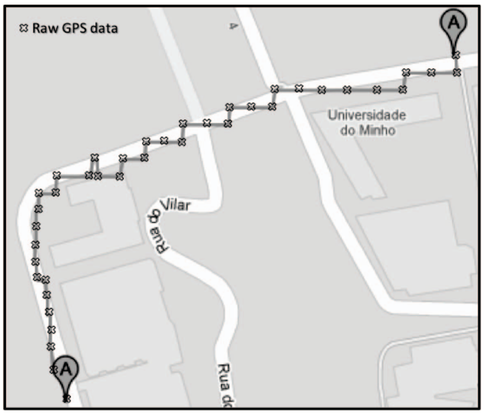

Fig. 5. Route obtained from database raw data and after applying a pattern mining method

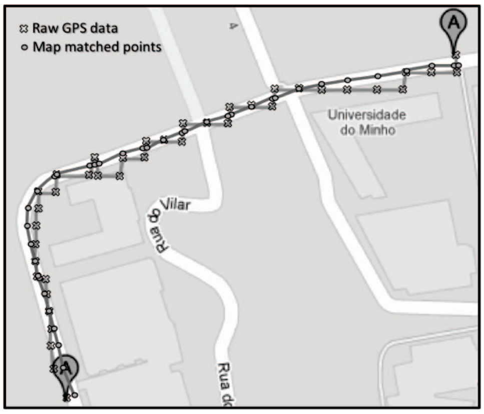

Fig. 6. Route obtained after applying a pattern mining method

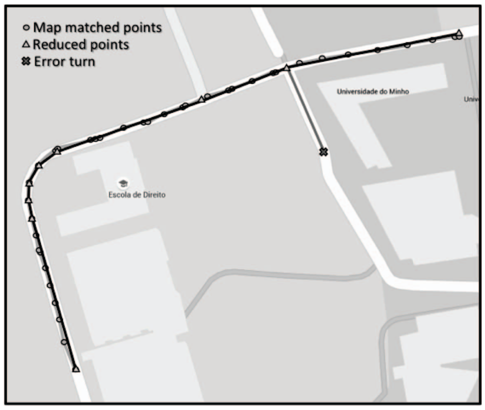

Fig. 7. Route with reduced number of points

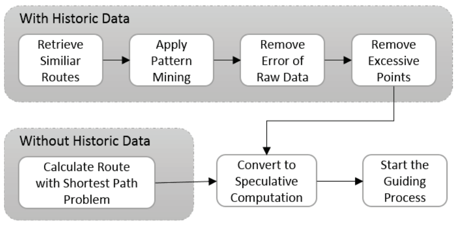

Fig. 8. Generation of default values schema

intersections with other streets. With these points, it becomes possible to guide the user and predict if he is going to take a wrong turn at an intermediate intersection (using historic data from the database). This reduction process is illustrated in Figure 7.

With the reduced route the system may guide the user to the intended destination. However, there is the need to convert the GPS points (latitude and longitude coordinates) so that the framework of Speculative Computation may use this information and create the alerts whenever they are necessary. This data conversion transforms single location points into arcs that connect these points. Thus, if the generated route has 30 valid points (including start, end and intermediate locations) 29 arcs are created. These are used to indicate the next location point that the user should travel to. In order to alert the user we need to create another arc between the error point X (see *error turn* in Figure 7) and an intersection with a valid point. This arc together with the literal $\sim included(X)$ indicates that the user is traveling to a wrong direction and an alert must be shown. The entire process of generating the default values depends on historic data of each user. Note that a user may have historic information about previous interactions with the application, but it may not suit the current guidance because the user may be traveling to a different destination or from a different starting location. Figure 8 shows a schematic of the tasks necessary to get the *default answer set*.

F. Execution Example

An execution example of the Program introduced in Section IV-A is presented below. For the process reduction, when a positive literal is reduced, new processes are created according to the rule order in the program, if the rules are unifiable with the positive literal.

In the next execution example for $guide(1, 3)$ the selected literal is underlined in the selected active process. SPS, AAQ and CBS are only shown when a change occurs. During the following execution trace the user travels between locations 1 and 3 through intermediate location 2 and takes the wrong direction towards location 4. When this occurs the system alerts the user and guides him to the correct path.

①
$APS = \{\langle\{\underline{guide(1,3)}\},\ \emptyset,\ \emptyset\rangle\}$
$AAQ = \emptyset$
$CBS = \{user\_travel(1,2)@gps\_sensor,$
$user\_travel(2,3)@gps\_sensor, user\_travel(2,4)@gps\_sensor,$
$included(1)@recognizer, included(2)@recognizer,$
$included(3)@recognizer, \sim included(4)@recognizer\}$

② By case 3.1
$APS = \{\langle\{\underline{path(1,F)},\ show\_next\_point(F),$
$user\_travel(1,F)@gps\_sensor,\ guide(F,3)\},\ \emptyset,\ \emptyset\rangle,$
$\langle\{\underline{path(1,F)},\ user\_travel(1,F)@gps\_sensor,$
$show\_user\_warning(F),\ guide(F,3)\},\ \emptyset,\ \emptyset\rangle\}$

③ By case 3.1
$APS = \{\langle\{\underline{show\_next\_point(2)},$
$user\_travel(1,2)@gps\_sensor, guide(2,3)\},\ \emptyset,\ \emptyset\rangle,$
$\langle\{user\_travel(1,2)@gps\_sensor,$
$show\_user\_warning(2), guide(2,3)\},\ \emptyset,\ \emptyset\rangle\}$

④ By case 3.2.3, 3.3.2 and 3.3
$APS = \{\langle\{\underline{included(2)@recognizer},$
$user\_travel(1,2)@gps\_sensor, guide(2,3)\}, \emptyset,$
$\{show\_next\_point(2)\}\rangle,$
$\langle\{user\_travel(1,2)@gps\_sensor,$
$show\_user\_warning(2), guide(2,3)\},\ \emptyset,\ \emptyset\rangle\}$

⑤ By case 3.4
$included(2)$ is asked to the $recognizer$
$APS = \{\langle\{\underline{user\_travel(1,2)@gps\_sensor},\ guide(2,3)\},$
$\{included(2)@recognizer\}, \{show\_next\_point(2)\}\rangle,$
$\langle\{\underline{user\_travel(1,2)@gps\_sensor},$
$show\_user\_warning(2), guide(2,3)\},\ \emptyset,\ \emptyset\rangle\}$
$AAQ = \{included(2)@recognizer\}$

To an easier comprehension of this execution example the branch that would check if an alert should be issued when the user travels towards location 2 is omitted since it would become a suspended process.

⑥ By case 3.4
$APS = \{\langle\{\underline{guide(2,3)}\},\ \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle\}$

⑦ By case 3.1
$APS = \{\langle\{\underline{path(2,F)},\ show\_next\_point(F),$
$user\_travel(2,F)@gps\_sensor,\ guide(F,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor\},$
$\{show\_next\_point(2)\}\rangle,$
$\langle\{\underline{path(2,F)}, user\_travel(2,F)@gps\_sensor,$
$show\_user\_warning(F),\ guide(F,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle\}$

⑧ By case 3.1
$APS = \{\langle\{\underline{show\_next\_point(3)},$
$user\_travel(2,3)@gps\_sensor,\ guide(3,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor\},$
$\{show\_next\_point(2)\}\rangle,$
$\langle\{show\_next\_point(4), user\_travel(2,4)@gps\_sensor,$
$guide(4,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle^{P_1},$
$\langle\{user\_travel(2,3)@gps\_sensor, show\_user\_warning(3),$
$guide(3,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle^{P_2}$
$\langle\{user\_travel(2,4)@gps\_sensor, show\_user\_warning(4),$
$guide(4,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle^{P_3}\}$

⑨ By case 3.2.3, 3.3.2 and 3.3
$APS = \{\langle\{\underline{included(3)@recognizer},$
$user\_travel(2,3)@gps\_sensor,\ guide(3,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor\},$
$\{show\_next\_point(2), show\_next\_point(3)\}\rangle,$
$P_1, P_2, P_3\}$

⑩ By case 3.4
$included(3)$ is asked to the $recognizer$
$APS = \{\langle\{\underline{user\_travel(2,3)@gps\_sensor},\ guide(3,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor,$
$included(3)@recognizer\},$
$\{show\_next\_point(2), show\_next\_point(3)\}\rangle,$
$P_1,$
$\langle\{\underline{user\_travel(2,3)@gps\_sensor}, show\_user\_warning(3),$
$guide(3,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle,$
$P_3\}$
$AAQ = \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer\}$

⑪ By case 3.4
$user\_travel(2,3)$ is asked to the gps_sensor
$APS = \{\langle\{\underline{guide(3,3)}\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor\},$
$\{show\_next\_point(2), show\_next\_point(3)\}\rangle^{P_4},$
$P_1,$
$\langle\{\underline{show\_user\_warning(3)},\ guide(3,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor,$
$user\_travel(2,3)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle,$
$P_3\}$
$AAQ = \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor\}$

⑫ By case 3.2.3, 3.3.2 and 3.3
$APS = \{P_4, P_1,$
$\langle\{\underline{\sim included(3)@recognizer},\ guide(3,3)\},$
$\{included(2)@recognizer, user\_travel(1,2)@gps\_sensor,$
$user\_travel(2,3)@gps\_sensor\},$
$\{show\_next\_point(2), show\_user\_warning(3)\}\rangle,$
$P_3\}$

According to what was previously described, the branch represented by P_3 is not shown since the system must not indicate the user to travel towards location 4. Thus, after executing this branch, it will become a suspended process.

⑬ By case 3.4
$included(4)$ is asked to the $recognizer$
$APS = \{P_4,$
$\langle\{\underline{user\_travel(2,4)@gps\_sensor}, show\_user\_warning(4),$
$guide(4,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor\}, \{show\_next\_point(2)\}\rangle\}$
$AAQ = \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor, included(4)@recognizer\}$

⑭ By case 3.4
$user\_travel(2,4)$ is asked to the gps_sensor
$APS = \{P_4,$
$\langle\{\underline{show\_user\_warning(4)}, guide(4,3)\}, \{included(2)@recognizer,$

$user\_travel(1,2)@gps\_sensor, user\_travel(2,4)@gps\_sensor\},$
$\{show\_next\_point(2)\}\rangle\}$
$AAQ = \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor, included(4)@recognizer,$
$user\_travel(2,4)@gps\_sensor\}$

⑮ By case 3.2.3, 3.3.2 and 3.3
$APS = \{P_4,$
$\langle\{\underline{\sim included(4)@recognizer},\ guide(4,3)\},$
$\{\overline{included(2)@recognizer}, user\_travel(1,2)@gps\_sensor,$
$user\_travel(2,4)@gps\_sensor\},$
$\{show\_next\_point(2), show\_user\_warning(4)\}\rangle\}$

⑯ By case 3.4
$APS = \{\langle\{\underline{guide(3,3)}\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor\},$
$\{show\_next\_point(2), show\_next\_point(3)\}\rangle,$
$\langle\{guide(4,3)\}, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, user\_travel(2,4)@gps\_sensor,$
$\sim included(4)@recognizer\},$
$\{show\_next\_point(2), show\_user\_warning(4)\}\rangle^{P_5}\}$

⑰ By case 3.1
$APS = \{\langle\emptyset, \{included(2)@recognizer,$
$user\_travel(1,2)@gps\_sensor, included(3)@recognizer,$
$user\_travel(2,3)@gps\_sensor\},$
$\{show\_next\_point(2), show\_next\_point(3)\}\rangle,$
$P_5\}$

At this stage the system has an active process that will also become suspended since the user is alerted before making the mistake of turning to location 4. When this occurs the execution trace ends since there is no more active processes.

V. Conclusion and Future Work

This work proposes a default generation method which produces predictions for the direction that a user may follow at particular points in his route. The process is based on data from previous runs of the system which are used to identify critical points, such as intersections, where he may make a mistake in his path. The habits of the user at those locations are also assessed in order to determine the direction he usually follows when he is there. These habits will become the default values. Here, Speculative Computation is used as a control mechanism that helps the system determine whether it is necessary to issue an alert or not. The integration of both the Generation of Defaults and Speculative Computation to create a predictive feature for orientation systems is the main contribution of this work. The method for the detection of user orientation patterns is independent of the framework, but Speculative Computation can be used in combination with it, providing a structured reasoning framework. With the general definition of the Generation of Defaults, it becomes necessary to explore different pattern mining techniques in order to determine which is the most appropriate for the problem at hand. Therefore, this will be the object of study in future works.

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4.5 An Orientation Method with Prediction and Anticipation Features

The goal of this publication was to establish the current state of the CogHelper system. Thus, it was considered that the localization feature for caregivers was fully functional; the orientation of the user with disabilities was done using an augmented reality interface, where a speculative computation module is able to anticipate user mistakes and alert him before he takes the wrong path. This publication is an extended version of Ramos et al. (2016).

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An Orientation Method with Prediction and Anticipation Features

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Abstract Nowadays, progress is constant and inherent to a living society. This may occur in different arenas, namely in mathematical evaluation and healthcare. Assistive technologies are a topic under this evolution, being extremely important in helping users with diminished capabilities (physical, sensory, intellectual). These technologies assist people in tasks that were difficult or impossible to execute. A common diminished task is orientation, which is crucial for the user autonomy. The adaptation to such technologies should require the minimum effort possible in order to enable the person to use devices that convey assistive functionalities. There are several solutions that help a human being to travel between two different locations, however their authors are essentially concerned with the guidance method, giving special attention to the user interface. The CogHelper system aims to overcome these systems by applying a framework of Speculative Computation, which adds a prediction feature for the next user movement giving an anticipation ability to the system. Thus, an alert is triggered before the user turn towards an incorrect path. The travelling path is also adjusted to the user preferences through a trajectory mining module.

Keywords: Orientation system, Speculative computation, Trajectory data mining, Localization system.

1 Introduction

Cognitive disability is a broad concept which includes different intellectual or cognitive deficits. These deficits may be present from birth (like birth defect) or may be acquired later (like traumatic brain injury). More precisely, this term is used to define a person who has more difficulties in one or more types of mental tasks when compared to an ordinary person [19]. A disability may be present in several levels of incidence, varying from mild to extreme. An individual with severe or extreme cognitive disabilities needs constant assistance throughout his everyday life whereas a mild to moderate disabled person may be capable of having an independent life, only requiring some assistance in certain activities, which may be provided by a caregiver or a technological system.

Assistive technology aims to increase, maintain or even improve functional capabilities of a person with disabilities [1]. A mental task commonly affected is orientation, which is imperative for an independent life. Thus, it is necessary to have technologies that assist the user during his travel between home and

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office/school. Using an orientation device the user is sufficiently autonomous to travel between his current location to a predefined destination. Current approaches focus essentially on the guidance activity, giving more attention to the information display and to the communication with a caregiver [5, 12, 9]. In order to be capable to correctly use such applications there is the need of a training period in which the person with cognitive disabilities has to lear how to use the application. It has been proven that, despite the type of cognitive loss, a person may learn how to use different types of technology [8].

This work proposes an orientation system for the early stages of cognitive disabilities (mild and moderate) that, besides guiding the user, tries to anticipate possible mistakes. An alert is triggered when the user is expected to make a wrong turn in his path. In order to adapt the system to the user it is also included a trajectory mining feature so it is possible to calculate a path that is preferred by the user (which may not be the shortest one).

This paper is organized as follows. Section 2 presents related work concerning orientation systems for people with cognitive disabilities. Section 3 provides a description of the orientation system giving emphasis to new developments on the Speculative Module and Trajectory Mining Module. The Speculative Module that hosts the framework for Speculative Computation is explained in Section 4. On Section 5 the Trajectory Module used to get a path according to the user's preferences is described. Finally, conclusions are drawn and future work considerations are made in Section 6.

2 Related Work

The technological development of smartphones brought more portability to the user since it became possible to execute applications in small and portable devices. These devices are specially important to people with cognitive disabilities since it is through them that the user may contact his caregiver. In order to execute an application to guide the user, the developers have to pay special attention to the interface [8]. This must be simple to understand and to interact with, otherwise the developed application may have a low acceptance degree due to the necessary cognitive effort to use it.

The works described in [12], [5] and [9] are examples of three different orientation methods for people with cognitive disabilities. In these examples the main goal is to guide a person outdoors from the current location to a predefined destination. The difference between them resides in how this is done, but all are particularly focused on the user interface. Thus, they lack the predictive capabilities which would allow them to anticipate wrong user actions and apply necessary measures to avoid them, and the capability of adjusting the path to user preferences. Despite the importance of such applications to people with cognitive disabilities, this research area has received little attention from the academic and industrial community. Thus, as far as we know, there is not any recent work considering this investigation topic.

With the goal of guiding cognitive disabled people and considering the systems interface, Carmien *et al.* [5] developed an application that enables the user to travel using a public transportation system reducing the effort needed to understand complex transportation maps (Figure 1). On each bus a GPS unit was installed and its coordinates were transmitted to a remote server. Using the information from the server the system would be able to select the bus that the user should take in order to reach the intended destination. While the user is travelling, a personal travel assistant ensures that the user has taken the correct bus, alerting him otherwise.

Liu *et al.* [12] focused their research on the display of instructions (Figure 2). They used static pictures with overlaid arrows (or highlighted areas in an image), audio and/or visual messages to guide the user (Figure 2a). Their objective was finding the best way of providing the directions to the user using either static pictures reflecting user perspectives with landmarks that are easy to find or visual/audio messages whenever an image is not available (Figure 2b). According to the necessary travelling distance the authors discovered that a distant landmark should be more useful since it could be used for a longer time while closer landmarks needed to be replaced more often according to the user movements.

A different approach was used by Fraunhofer Portugal in the AlzNav orientation system [9]. This system used an arrow that resembles a compass to guide the user (Figure 3). This arrow rotates according to the direction in which the mobile device is pointed. Thus, the user has to interpret the information presented on the device's screen. Besides the compass, the user has also information about the street he is and the distance he should travel in the calculated direction. This system has also a monitoring system enabling caregivers to know the current position of the user through a SMS. A "safe area" may also be

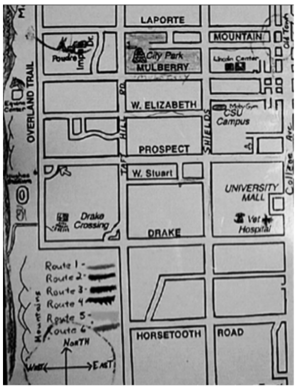


Figure 1: Complex map of the routes of the public transportation system [5]

set by the caregiver in where the user may travel alone and an alert is only triggered when he goes out of it.

The previously presented approaches tackle some important aspects of orientation systems for people with cognitive disabilities. However there are some features that should be considered in order to make the system adaptable to the user and not the other way around. Predicting user steps is a big advantage for this type of system since it is possible to identify critical points in a certain path, i.e., identify points where the user takes the wrong path and alert the user before he makes a mistake. If the system is able to predict when an error will occur, it can issue an alert to the user reinforcing the right path. Another important feature is the ability to adjust the path to the user since he may prefer to travel for a longer but preferred path instead of taking the shortest one. These are the kind of features proposed in this work. The goal is to develop an orientation system that adapts to the user, maximizing his autonomy and consequently his independence.

3 System Description

CogHelper is an ongoing project [17, 15, 16] with two main goals: provide an efficient orientation system for people with cognitive disabilities, considered the main user of the system, and provide a tracking system for caregivers. The former is accomplished through an augmented reality interface so users only need to align the mobile device with the correct travelling path in order to see a green arrow indicating

(a) Different types of landmarks

(b) Different ways to guide the user

Figure 2: Information display using landmarks [12]

Figure 3: Interface for the alignment of the AlzNav application [9].

the right direction. Here, both the prompting level and the travelling path is adjusted according to the user preferences. The latter enables caregivers to know at any time the current position of the person with disabilities.

This orientation system is devised for outdoor and the system architecture is depicted in Fig. 4, which may be separated in the client-side applications and the server-side components. The former includes the *Cognitive Helper Mobile Solution* (described in detail in Section 3.1), the *Caregiver Applications (Mobile and Web)* (described in Section 3.2), and the *External Services*, which allow the integration of CogHelper with other systems or applications, adding more features/functionalities to it. The latter is divided into the database module, which stores all the information necessary for the correct execution of the system (like usernames, locations and points of interest), the web services, and the remaining module enables the communication between the server and the different services.

The orientation method under development is conceived for outdoors which has been fully described in [14]. The core of the system is considered to be fully developed, *i.e.*, both applications for caregivers (mobile and web), the web services (running on the server) needed in order to ensure communications between applications, the database, and finally the mobile application for the person with cognitive disabilities. At this point of the development this application uses augmented reality for the orientation and the selected path is the shortest one (not being adapted to the user as proposed in this paper).

3.1 Application for People with disabilities

The primary target of the CogHelper system is people with cognitive disabilities. Thus, the mobile application intended to this audience is composed by four layers (see Fig. 5), each with specific functions. The *Information Layer* stores the information for the normal execution of the application (like user data and his contacts). In the *Localization Layer* the current user position is retrieved from the GPS module of the device (or from the network) and is used by the *Navigation Algorithm.* To this information is added data gathered from the device sensors, like the camera, magnetic sensor and accelerometer (enabling the system to compute the device's direction), which are used by the decision algorithm to ensure the user is

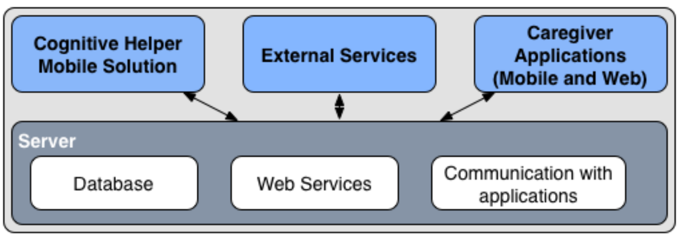


Figure 4: Architecture of CogHelper System

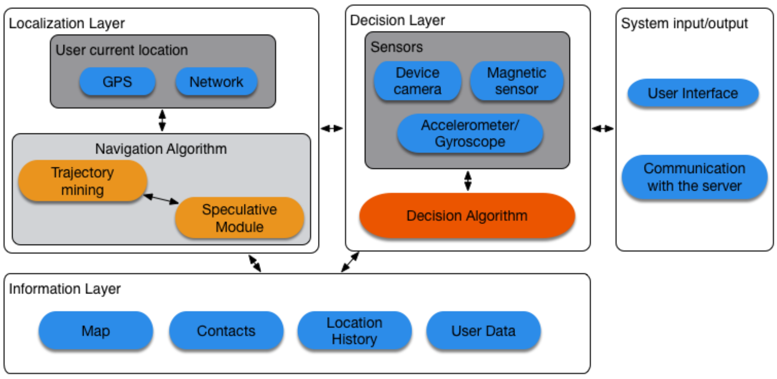


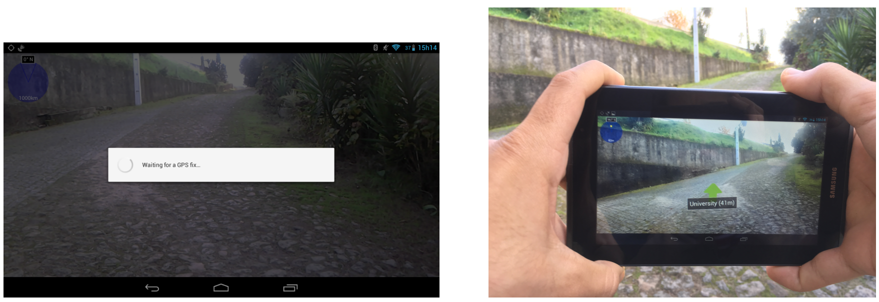
Figure 5: Information layers of the CogHelper Module for People with Cognitive Disabilities

travelling in the correct path (Figure 6). All information is then presented to the user through the user interface (under the *System input/output*). For an easier interpretation of the displayed information, the guiding process has an augmented reality interface so the user just has to orientate the device with the correct travelling path in order to view a green arrow pointing the correct path. When the user goes out of the path (even if he does it intentionally) the systems alerts the caregiver that the user may be lost.

A detailed description of previously cited modules is done in [14, 15]. Being an ongoing project, CogHelper is being improved with new modules in order to give the system an adaptability feature. The *Trajectory mining* and *Speculative Module* components (depicted in Fig. 5) are responsible for the adaptability of the system to the user.

The *Trajectory mining* component generates a path that is preferred by the user (which may not be the shortest one), *i.e.*, the path is calculated according to the preferences of the user (historic data from previous uses of the application). This path is used as input values of the *Speculative Module*, which ensures that the user is travelling in the correct path alerting him otherwise. These modules are described in more detail in Section 5 and Section 4, respectively.

Moreover, one cannot exclude the development of additional features, such as the ones described in [6], in order to detect other user activities, namely fall detection.



(a) Waiting for a GPS signal (b) Informing the path to the user

Figure 6: Orientation method for people with disabilities - Augmented reality interface

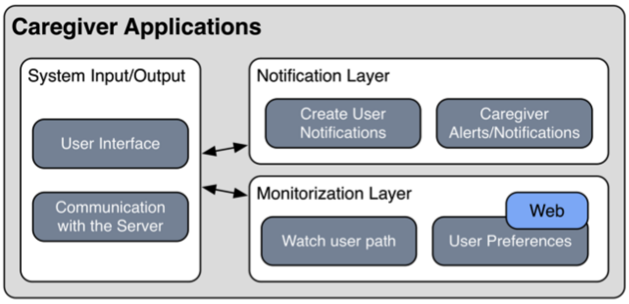


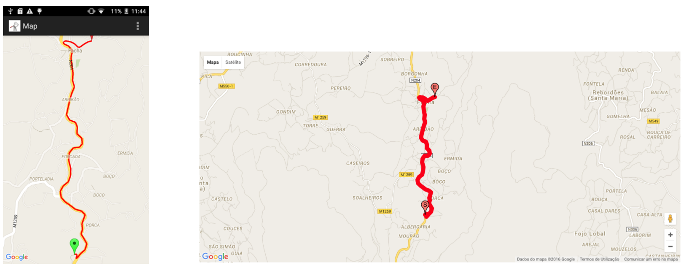
Figure 7: Information layers of the CogHelper Module for Caregivers

3.2 Applications for Caregivers

Caregivers may not be the primary target of CogHelper system but they should not be dismissed. If a caregiver may not know the user status, he may become worried and prevent the user to travel alone and autonomously between two locations. In order to let caregivers be an active part of the orientation system, CogHelper also supports a localization system enabling caregivers to know in real time the current location of the user. This feature enables caregivers to develop a different activity without neglecting the care provided to the user. Indeed, both caregivers and users have their autonomy increased.

There are two different applications intended to caregivers, a mobile application for Android OS and a Web application. Developed for two different platforms, these applications have the same goal: provide a localization system. Indeed, these two applications provide a monitoring platform in which caregivers may remotely check the current position of the user. There is no need for the caregiver to be physically with the user. Despite the shared goal, there are some differences between the two. As shown in Fig. 7 the dissimilarity resides under the *Monitorization Layer* in which the *User Preferences* module is only present in the Web application. Through this module the caregiver may add, edit or remove user preferences such as his destination points or the available options (giving or denying access, for example, to the option for manual insertion of the destination). These additional features make the Web application more complex.

Despite the previously described difference, the architecture of the applications for the caregivers is divided in three layers: *Monitorization Layer*, *Notification Layer* and the *System Input/Output*. The *Watch User Path* module allows the caregiver to remotely have access to the current location of the user. The *Notification Layer* is composed by two modules which receive and generate alerts from and to the user application. The remaining layer is made by the *User Interface*, that enables the caregiver to interact with the applications, and a communication module to exchange information with the server.



(a) Android application

(b) Web application

Figure 8: Localization system for caregivers

On Fig. 8 is depicted an example of a path viewed in the mobile and web applications, respectively. On both examples the starting and ending points are marked with different symbols, enabling an easier identification of these locations. When the user is travelling the ending mark does not appear and the map view is updated to show his current location.

4 Speculative Module for Users with Cognitive Disabilities

The Speculative Module under the mobile application for people with cognitive disabilities has the objective of predicting the next step of the user (when using the orientation system) and use that prediction to set the information that should be displayed to the user (alert/warning or acknowledge messages). The execution of the Speculative Computation resembles an interface between the rules with the instructions for the correct path, the set of default values (predictions about user travels from one location to another, obtained from the trajectory mining module - Section 5), and real information returned by information sources (informing the real journey of the user).

Through the use of this module the system continues its execution using a default value (whenever the real information is missing) or using the real one (returned from the information sources). Thus, the system does not enter an idle state when there is missing information. It tries to generate a tentative solution for the problem, which is revised when the real information is received (to verify if the default value is consistent with the real one). The default values are obtained before the execution of the speculative computation framework from the Trajectory Pattern Mining described in Section 5.

For the execution of the Speculative Computation module the computation changes between its normal execution phase (*Process Reduction Phase*) and temporarily to a revision phase (*Fact Arrival Phase*) to revise the computation according to the received values. The initial information, before execution, represented in the Speculative Computation framework includes:

1. All the possible paths between two points, in the form of connections between intermediary points, as facts in the knowledge base;
2. The transitions between points usually performed by the user as default values;
3. Information of whether a point is included or not in the recommended path as default values;
4. A set of rules that structure the derivation of the path the user is likely to follow given the information during execution and the issuing of alerts/warnings in case of a potential mistake;

At the beginning of the computation, when there is no information regarding the actual position of the user and his transitions between the most relevant points, the defaults are used in the *Process Reduction Phase* to build the most likely path, step by step, and issue the warnings for potential mistakes or acknowledgements of correctly taken steps. A warning is issued whenever a user is likely to take the wrong path, which may happen when the defaults tell the computation that the user will make a transition to a point not included in the correct path. Through *Fact Arrival*, the GPS sensor and a recognizer inform the Speculative Module of the actual transitions of the user and whether the points are indeed part of the correct path or not. If the user actually moves to a point not included in the correct path, the recognizer re-calculates the path to the destination and a point previously out of the correct path may suddenly become part of the new path. *Fact Arrival Phase* is the mechanism through which this information is updated and the tentative paths produced for a user are adjusted and improved.

Items 1, 2, and 3 from the list above are obtained from a Trajectory Mining Module. Item 1 corresponds to the calculation of the possible paths between two points, producing a reduced graph, with only the most relevant points an the connections between them. Item 2 is obtained from the pattern mining of the trajectories usually taken by the user, reflecting his walking habits. Finally, item 3 corresponds to the calculation of the recommended path between the point of origin and the destination, expressed in the form of intermediary points included in the route. It is also stated which points are not included in this route.

The Framework of Speculative Computation in the Orientation Method for people with cognitive disabilities (designed by SF_{OM}) is defined in terms of the signature $\langle \Sigma, \mathcal{E}, \Delta, \mathcal{A}, \mathcal{P}, \mathcal{I} \rangle$ [18], where:

- Σ stands for a finite set of constants (an element of Σ is called a system module);
- $\mathcal{E}$ denotes a set of functions called *external predicates*. When Q is a literal belonging to an external predicate and S is the identifier of the information source, $Q@S$ is called an *askable literal*. We define $\sim$*(Q@S)* as *($\sim$Q)@S*;
- Δ designates the *default answer* set, which is a set of ground askable literals that satisfy the condition: Δ does not contain both $p(t_1, \ldots, t_n)@S$ and $\sim\ p(t_1, \ldots, t_n)@S$ at once;
- $\mathcal{A}$ is a mark of a set of predicates called *abducible predicates*. Q is called *abducible* when it is a literal with an *abducible predicate*;
- $\mathcal{P}$ signals a set of rules of the form:
  - ▷ $H \leftarrow B_1, B_2, \ldots, B_n$ where H is a positive ordinary literal, where each of $B_1, \ldots, B_n$ is an ordinary literal, an askable literal or an abducible; and
  - ▷ H is the head of rule R and is named as *head(R)* (always non-empty), being R the rule of the form $H \leftarrow B_1, \ldots, B_n$; $B_1, \ldots, B_n$ is the body denoted by *body(R)*, that in some situations is substituted by the boolean value *true*.
- $\mathcal{I}$ is a set of integrity constraints of the form:
  - ▷ $\bot \leftarrow B_1, B_2, \ldots, B_n$, where $\bot$ is a contradiction special symbol and B_1, B_2, $\ldots$, B_n is an ordinary literal or an *askable literal* or an *abducible*. However at least one of $B_1, B_2, \ldots, B_n$ is an *askable literal* or an *abducible*.

An *askable literal* may have different meanings, namely:

1. An *askable literal* $Q@S$ in a rule $\mathcal{P}$ stands for a question put to a system module S by OM; and
2. An *askable literal* in Δ denotes a default truth value, either *true* or *false*, i.e., $p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is usually *true* for a question to a system module S, and $\sim p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is generally *false* for a question to a system module S.

As an example, one can consider the graph of Figure 9, in which the objective is for the user to move from node 1 to node 3. From the Trajectory Mining Module it is possible to know that the user usually moves from 1 to 2, from 2 to 3, but also from 3 to 4, from 4 to 5, from 5 to 6, and from 6 to 3. Additionally, it is possible to determine that nodes 1, 2, and 3 are part of the shortest path, while node 4 is obviously not. However, since the user, when in node 2, usually moves to 4, this is identified during *Process Reduction* as a point where a mistake may happen and, as a result, a warning is issued. If, during *Fact Arrival*, it is confirmed the user indeed moves to 4, this node becomes now part of the route and the alternative path including 5 and 6 is selected. Although simple, this example illustrates the role of the Speculative Module in producing instructions for the user and preventing mistakes in his path.

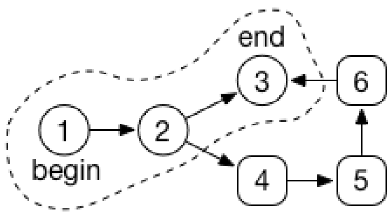


Figure 9: Possible ways to travel between locations 1 and 3.

Below there is a logic program that represents the formalization of the problem depicted in Figure 9 and the situation described above according to the Speculative Computation Framework for Users with Cognitive Disabilities. Its components include: Σ, a representation of existing system modules responsible for providing information; $\mathcal{E}$, the predicates which represent the necessary information to derive the path of the user; Δ is the default answer set and consists in a set of default values; $\mathcal{A}$, a set of abducible predicates; and $\mathcal{P}$ is a logic program with a set of clauses. In the logic program given below the literal $path(a, b)$ denotes that there is a physical connection between the locations a and b, thus the user may travel between them. The literal *show_next_point* is used to indicate that the system must show the next location to which the user should travel. This location may be an intermediate point or the final destination. Whenever the user travels in the wrong direction the literal *show_user_warning* is activated indicating to the system that it must alert the user. In the set $\mathcal{E}$ there are the predicates $user\_travel(a, b)$ (which states that the user will travel from location a to location b) and $included(a)$ (to indicate if a location a is part of the route). The values for these predicates are asked from the information sources *gps_sensor* and *recognizer*, respectively. The former verifies if the user is travelling from point A to B. The latter checks if point B is included in the set of valid locations.

- $\Sigma = \{gps\_sensor, recognizer\}$
- $\mathcal{E} = \{user\_travel, included\}$
- $\Delta = \{user\_travel(1, 2)@gps\_sensor, user\_travel(2, 3)@gps\_sensor,$
  $user\_travel(2, 4)@gps\_sensor, user\_travel(4, 5)@gps\_sensor,$
  $user\_travel(5, 6)@gps\_sensor, user\_travel(6, 3)@gps\_sensor,$
  $included(1)@recognizer, included(2)@recognizer,$
  $included(3)@recognizer, \sim included(4)@recognizer$
  $included(5)@recognizer, included(6)@recognizer,$
- $\mathcal{A} = \{show\_next\_point, show\_user\_warning\}$
- $\mathcal{P}$ is the following set of rules:
  $guide(A, A) \leftarrow .$
  $guide(A, B) \leftarrow$
  $path(A, F),$
  $show\_next\_point(F),$
  $user\_travel(A, F)@gps\_sensor,$
  $guide(F, B).$
  $guide(A, B) \leftarrow$
  $path(A, F),$
  $user\_travel(A, F)@gps\_sensor,$
  $show\_user\_warning(F),$
  $guide(F, B).$
  $path(1, 2) \leftarrow .$
  $path(2, 3) \leftarrow .$
  $path(2, 4) \leftarrow .$
  $path(4, 5) \leftarrow .$
  $path(5, 6) \leftarrow .$
  $path(6, 3) \leftarrow .$
- $\mathcal{I}$ denotes the following set of integrity constraints or invariants:
  $\bot \leftarrow$
  $show\_next\_point(F),$
  $\sim included(F)@recognizer.$
  $\bot \leftarrow$
  $show\_user\_warning(F),$
  $included(F)@recognizer.$

For the Execution of the Speculative Module there are some important definition that must be done. During its execution the Framework is composed by a Process Set (PS), which represents a set of processes (active or suspended); a set of Already Asked Questions (AAQ) containing the askable literals; and the Current Belief State (CBS) is a set of askable literals. PS expresses all the alternative computations that were considered. The AAQ set is used to avoid asking redundant questions to the sensors. CBS is the current belief state and expresses the current status of the outside world.

A process defined as the tuple $\langle GS, OD, IA, ANS\rangle$ in which GS is a set of extended literals and called a Goal Set, expressing the current status of an alternative computation; OD is a set of askable literals called outside defaults, which denote a set of assumed information about the outside world during a computation; IA is a set of negative literals or abducibles called inside assumptions that stand for the values assumed during a computation; and ANS is a set of instantiations of variables in the initial inquiry.

At the beginning of the computation there is only an active process defined as $\langle\{guide(1,3), \emptyset, \emptyset, \emptyset\}\rangle$; AAQ is empty, since any question was asked to the sensors; and CBS is equal to the default values set. According to the definition described in [16] the computation enters in the *Process Reduction Phase*, in which it follows a set of rules in order to derive the next action. This is an iterative process where the set PS and AAQ are changed according to the computation state. After questioning the information source the computation uses default values and keeps its execution. When the information source returns the real value the CBS set is updated (if necessary) and the computation is revised, entering temporarily in the *Fact Arrival Phase*. In this phase, if the assumed default value is in accordance with the received one the computation continues, otherwise it is revised and processes using the default value enter in the suspend mode while suspended ones may be started. Then, the framework goes again to the *Process Reduction Phase* continuing the iterative process until there is no processes to reduce.

5 Trajectory Mining Module

Advances in mobile computation (*e.g.*, smartphones) and in location-acquisition methods (*e.g.*, GPS module) enabled the gathering of massive spatial trajectory data, which, in turn, has raised the interest of researchers in trajectory data mining [21]. According to [7] there are three important attributes when considering Behavioural Pattern Mining: location, trajectory and behaviour. The first attribute considers the extraction of important user locations (like home or office). The second one considers the trajectory modeling through the extraction of regular routes. The last attribute emphasizes the extraction of behavioural patterns. Thus the system may be able to predict the user's destination through his current path. By applying trajectory data mining we may get a preferable user path and use it as input of the previously described module of Speculative Computation.

Through active recording (the user location is logged only when the application is running) it is possible to obtain the position of the user. However there are a few steps that precede the trajectory pattern mining like trajectory data preprocessing and trajectory data management [21].

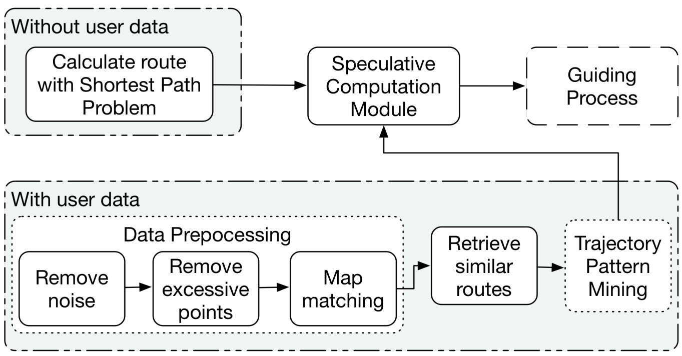
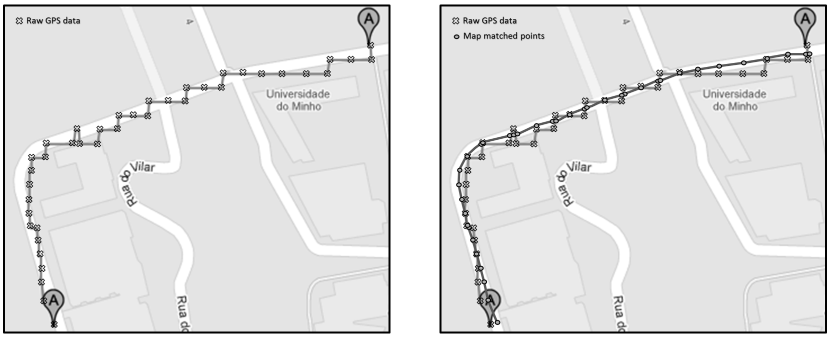


Figure 10: Generation of default values schema

For the mining module operation it is important to consider the existence of user historic data. When the user is using CogHelper for the first time (thus, there isn't any information about his travelling habits) the system calculates the shortest path and uses it as input for the speculative computation module in order to guide the user. When there is available information about the user, the mining module extracts similar routes according to the current user location and the intended destination and use them for the trajectory pattern mining. Ending this process the data is sent to the speculative computation module (as default values) so the system is able to guide the user. Before applying the pattern mining the retrieved data need to be preprocessed. An illustration of this process is presented in Figure 10.

5.1 Data Preprocessing

In a first step (trajectory data preprocessing) it is important to remove the noise from each collected position (Figure 11a is an example of raw data collected during a travel). There may be points that may appear outside the travelled route (due to a bigger GPS error), which should not be considered for the trajectory data mining (Figure 11b). To this step there are several on-line tools with map matching features (in our case we are using GraphHopper Map Matching API [11]). Then, since collected locations represent a large number of samples, it is important to remove excessive data, *i.e.*, points that do not bring useful information like intermediate points in roads without intersections.



(a) Route obtained from database raw data (b) Error removal from raw data

Figure 11: Trajectory data processing

After this process, the remaining data should represent locations on a map that may appear slightly outside the road. Thus, a map matching process is necessary in order to align the collected data with the existing real maps.

Ending this preprocessing stage and before starting the trajectory data mining process, the system has to obtain similar routes (*e.g.*, travel paths with the same destination and a similar starting point). Thus, instead of using all routes for this stage, the system selects the similar routes (or similar route parts) through similarity/distance functions. When, for a user, there is no route for an intended destination the system selects the shortest path.

5.2 Trajectory Mining

Finally, the trajectory data mining may begin. For this process there are different types of pattern mining. The described process may be considered as a standard for the use of trajectory data mining, however there might be some derivations of it. According to its own purposes an author may adapt this standard for his algorithm or system.

In [10] the authors consider a trajectory pattern as a set of individual trajectories which share an identical sequence of visited places. For their trajectory pattern mining in an initial stage the authors try to get a set of regions of interest (which is possible by different approaches) and then the authors try to define the trajectory patterns. Giannotti *et al.* intend to apply their trajectory pattern mining in the analysis of traffic flows. An extension of this work is presented in [13] in which the authors make use of all trajectories saved on the database to construct a predictive model in order to be able to predict the user's (or object's) next move (*e.g.*, predict where the user will be when the GPS module is temporarily unavailable).

A different approach is applied in [2]. Here the aim is to automatically obtain the frequent moves, neglecting the time at which they occur. To the authors a trajectory is an ordered list of stops and moves, *i.e.*, the user moves between two places (considered as stops) in which he stays for a given time interval. For their purpose the authors intend to discover the pattern of moves between two places usually done by the users regardless of the intermediate points (*e.g.*, the streets or roads used). Using this data Alvares *et al.* could obtain answers for questions like the most frequent stops during a period of time, which stops have a duration higher than a predefined threshold, among others.

Chen, in [7], proposed a model in which after the geo-coordinates extraction, a tree-based hierarchy graph is built. Through this the author intends to apply hierarchy density clustering algorithms like OPTICS [20] to find patterns in the recorded data. The OPTICS algorithm [20] has been used for mining people's life pattern using GPS log data. This is an algorithm that tries to find density-based clusters in the spatial data [4]. For this process a distance metric between location points is required in order to group the data into clusters.

Considering the different models and their application our goal is to define the best strategy to apply in CogHelper. According to our research and considering the goal for each method/algorithm, we consider that OPTICS will be the most appropriate for our system.

6 Conclusions and Future Work

This work defines how a trajectory mining method could be used to adapt the path to the user by producing a set of default values. These values are considered to be the predictions for the directions that the user should follow in order to travel between his current location to the intended destination. The trajectory mining module process uses data from previous executions of the system, which are used to obtain the best travelling path (according to user preferences) and critical points, such as intersections in which the user may take the wrong turn. Through this set of default values the Speculative Computation module is used as a mechanism that determines if it is necessary to issue an alert or not. The integration of these two modules are the main contribution of this work. The speculative framework is independent of how the trajectory mining is achieved using the calculated values to ensure the correct travel. A structured reasoning method is provided through the combination of these modules. After preprocessing the data, it is possible to apply different trajectory mining techniques. Our future goal is to determine the most appropriate one for the problem.

In order to better perceive the advantages and disadvantages of CogHelper, a comparison with different systems (presented in Section 2) should be conducted. However this may not be an easy task since CogHelper has an adaptability feature that is not present in other systems. These systems are mainly focused on the user interface (on how the information should be available to the user) and do not adapt the travelling path to user preferences.

As future work, user privacy issues will be considered by taking into account the work developed in [3].

Acknowledgements

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4.6 CogHelper: a Speculative Computation View

A short review and comparison between different reasoning methods is done in this publication. Here we specify why the speculative computation was selected to the detriment of others, like Bayesian networks. Details of the paper, including the journal impact factor are given below.

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CogHelper: a Speculative Computation View

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Abstract

Once a patient is diagnosed (or a caregiver suspects that the patient may have) cognitive disabilities he may loose the state of being autonomous, which may range from partial to total lost of independence, according to the level of incidence. Smart houses may be used as a tentative solution to overcome this situation. However, when one goes outside their premises, this alternative may become unusable. Indeed, due to the decreased orientation ability, caregivers may prevent these people from going out, as they may get lost. Therefore, we are developing a system that guides the user through an augmented reality interface and provides a localization tool for caregivers. The orientation method implements a speculative computation module, thus the system may calculate and anticipate possible user mistakes and issue alerts before he takes the wrong path.

Keywords: *Ambient Intelligence; Cognitive Disabilities; Mobile Communication; Orientation; Person Tracking*

I. Introduction

A cognitive disability is a medical condition that affect different capabilities of a person, like communication and orientation. An adopted solution by physicians may consist in the use of drugs with the goal of slowing the progression of the disease, and give to the patient a better quality of life. Brain stimuli (e.g., in Alzheimers) attenuate the progression of the disease, which is reflected in an improvement of their quality of life. So, attaining a better interaction and communication with the society in which he is inserted. On the other hand, according to the trials, this intervention is not appropriate for patients in later stages of dementia (Woods, Aguirre, Spector, & Orrell, 2012). When the degree of incidence is moderate or severe, the loss of autonomy may be inevitable. The presence of a caregiver may be needed or the patient may be reallocated to a nursing home or to a relative's house. However, embedded devices in the environment may allow the monitoring of the patient, enabling remote access to the collected data by health professionals or caregivers. This alternative does not guarantee safety when he goes outside. Indeed, the lack of orientation is one of the causes for the loss of autonomy by people with mild or moderate cognitive disabilities. To create applications taking into consideration the end-user, it is necessary to consider features in its design in order to maximize its usability and accessibility. The cognitive and/or physical limitations of the user can be minimized since the cognitive processing is reduced to a minimum. This reduction can be achieved through alternatives to written text, such as pictures, animations and sounds (Lanyi & Brown, 2010).

To minimize the loss of independency we are engaged in developing a system that through an augmented reality based interface (in order to diminish the effort needed to understand the displayed information), guides the user when traveling outside its premises. This system has a Speculative Computation unit which may anticipate possible user mistakes and alert him before taking the wrong turn. Our system also has a localization feature in order to keep caregivers aware of the location of the person with disabilities.

This document is organized as follows: Section I introduces the scope of the document. Section II presents the main features on which orientation systems are grounded. Section III describes the system that is under construction. Section IV explains the use of Speculative Computation in one's system. Finally, Section V presents conclusions and future work directions.

II. Orientation Systems

The reduction in the quality of life caused by the lack of spatial orientation was studied in (Liu et al., 2006, 2008), where it is stated that there is a low applicability of orientation systems from an user perspective, i.e., people with diminished cognitive or physical capacities may not use these systems.On the other hand, orientation methods may epitomize an important progress on assistive technology. These are very rigorous methods thus, they may not tolerate faults and correctly respond to user stimuli. As such, existing systems place an ex-

Table 1: *System features covered by exitings projects*

Features		Carmien et al., 2005	Liu, Hile, Borriello, Kautz, et al., 2009	Ramos et al., 2012, 2013	Fraunnhover Portugal, 2012	Patterson, Liao, Fox, & Kautz, 2003	Sadilek & Kautz, 2010
Orientation Method	Images		✓				
	Compass				✓		
	Augmented Reality			✓			
Prompts	Audio	✓	✓	✓/✗	✓		
	Visual	✓	✓	✓/✗	✓		
Context Aware				✗		✓	✓
User Frequent Behaviour				✗		✓	
Real Time Monitoring				✓	✓	✓	✓

treme importance on the used interfaces. They must be, simultaneously, simple and complete, i.e., they have to show/provide available features/functionalities in an easy way, so the person with disabilities may use the application without feeling confused or losing his confidence on these systems. In Table 1 a perspective is given of the system features considered in different ventures. Here, the orientation method is related to the user interface, while prompts considers the type of alerts given to the user. The localization feature (useful for caregivers) is expressed as real time monitoring, i.e., on the fly. As you may see, there are few proposals for guiding the user with cognitive disabilities, and even in those the information is only given through audio and visual (textual) prompts. In Table 1 with a tick (✓) one has the features that were implemented in each project (with a ✗ are marked the features under development in CogHelper). The last two columns of the table present ideas in which the main goal is not the user orientation but his remote monitoring and next movement detection, tasks that are accomplished under a context aware setting.

Although these orientation methods have a significant impact on the user quality of life, and use up to date technologies and different types of hardware (like sensors and GPS), they lack reasoning methods. These methods allied to the most recent technology create extremely promising systems in assistive technology, since they conciliate the fast technological progress with embedded artificial intelligent features. These systems allow for a "humanization" of the technology, enabling it to take into account user necessities. For example, in robotics the goal is to let an agent (or robot) to serve the purpose of moving an object from one place to another, taking the context into consideration. On the one hand, these decisions must be taken on-the-fly, and also in situations where the sensory data may not always be available. Indeed, the robot moves under an incompleted (data/information/knowledge) scenario. On the other hand, new data obtained from the sensors is continuasly streamed to update the belief state of the robot (or agent) (Russell & Norvig, 2003; Hertzberg & Chatila, 2008). Under these framework and in order to develop an autonomous agent-based system, there are multiple ways to treat default data, information or knowledge, which are key factors in the process of enabling an agent to learn and to plan its actions. In Table 2 there are the most prominent reasoning methods (it was not our intention to provide a full description of all reasoning methods available, but to highlight the ones considered more suitable to be applied to the problem under analysis).

Decision Tree Learning is a method with predictive abilities through knowledge extraction and learning (Dahan, Cohen, Rokach, & Maimon, 2014). However, the Decision Tree has to be fed with a set of input values (Rokach & Maimon, 2005). Thus, an initial supervised learning phase is necessary in order to enable this reasoning method to autonomously classify future inputs.

Inspired on biological systems, Artificial Neural Networks (ANNs) are able to model complex problems (Basheer & Hajmeer, 2000; A. K. Jain, Mao, & Mohiuddin, 1996). Through massive parallelism, these networks are able to learn and adapt to future affairs. ANNs are also fault tolerant, i.e., when there is some missing information the ANNs are able to keep the computation.

Data classification may be also automated by Support Vector Machines (Noble, 2006; Bennett & Campbell, 2000). After a training phase, the Support Vector Machine may handle new data and label it, i.e., although this method has a predictive feature, it has to be previously trained.

Based on the Bayes Theorem a Bayesian Network is able to reason under incomplete information scenarios, i.e., this method is able to reason under uncertainty (Uusitalo, 2007). A Bayesian Network establishes causal relations between its nodes through a probability distribution. Thus, given an input value this reasoning method calculates possible outcomes with the respective probability. Applying this method to the guiding context it has its advantages since it could predict the next movement of the user. However, there is still the need for previous user information to be fed to the network in order to train it.

The Partially Observed Markov Decision Process (POMDP) has proven its advantages in fields like robotic navigation and planning under uncertainty. This reasoning method has been successfully applied in orientation systems for people with cognitive disabilities (Liu, Hile, Borriello, Brown, et al., 2009). A POMDP is able to select the next action and, based on a reward function, evaluate if that action produced a positive or negative impact on the user. However, in a initial phase this method starts with a naive approach, in which it is assumed that the options will be correctly followed 100% of the time. With the usage, the POMDP evolves and better adapts to future endheouvers.

Case Based Reasoning is a method that resembles the human thinking method, i.e., when facing a problem the user recalls similar situations and adapts the previously used ones to the new one (Kolodner, 1992). Past experiences may be used through some adaptation to the new situation or to know what should not be done in order to avoid negative outcomes. This reasoning method needs a knowledge base from which a previous case is retrieved and adapted to solve a new problem. Once the reuse phase is over, there is the need of evaluating the acquired solution before saving it back to the knowledge base. This evaluation may be dependent on user feedback.

In one's work it is assumed that Speculative Computation (Satoh, 2005; Kakas, Kowalski, & Toni, 1998) has a more adjusted knowledge representation and reasoning method, as it may anticipate the next movement of the user and provide alerts. This feature may not be found in statistical learning, since this is a pattern recognition method, or in reinforcement learning, since in this method the reward is returned after the action is taken. Speculative Computation has the ability to deal with incomplete information, i.e., when the missing data is received the information is processed, the computation is revised and the system keeps executing the orientation guidelines. Indeed, the system is previously loaded with a set of default values, such as information about the travel paths (e.g., which directions should the user take, what are the turns that should be done), and information about possible missing turns (e.g., locations in which the user may take the wrong direction and get lost). One is faced with a scenario that uses default values and keeps the execution of the program. Thus, the system does not go under an idle state and when the information is received, the execution is revised. Another aspect that must be referred to is related with a process of movement anticipation, i.e., at any moment the system is able to predict the user acts, and therefore to prevent user wrongdoings. This reasoning method has never been used, as far as we know, in a system intended to guide a user with cognitive disabilities. The speculative computation framework uses a set of default values which are obtained from external sources like a trajectory data mining (e.g., OPTICS algorithm (Ankerst, Breunig, Kriegel, & Sander, 1999)).

III. CogHelper - An Orientation System for People with Cognitive Disabilities

Nowadays it is possible to have small devices with huge processing power (e.g., smartphones). This kind of devices brought more portability than those of existing solutions (like laptops), since the user may install and execute several applications according to his/her needs. Indeed, although the old solutions help the user in his tasks, some of these applications may be too complex to be used by people with disabilities, especially by those with cognitive ones.

As a matter of fact, a person may be understood or seen as an adaptive species, since he may take or change a decision/attitude depending on the circumstances. It is at this point that one may look at Ambient Intelligence based techniques to recognize the sit-

Table 2: *Comparison between different reasoning methods*

Reasoning methods \ Features	Complexity	Fault Tolerance	Learning Mechanism	Reward/Feedback	Input
Decision Tree Learning	NP-hard	✗	Supervised		✓
Artificial Neural Networks	High processing	✓	Unsupervised		✓
Support Vector Machines		✓	Supervised		✓
Bayesian Networks		✓			✓
Markov Decision Process		✓	Unsupervised	Reward function	✗
Case Based Reasoning		✓	Supervised	User Feedback	Knowledge Base
Speculative Computation		✓	Unsupervised	✗	Default Values

uation under which the user is placed, that prompt an automatic activation or deactivation of actions that the system should perform, i.e., the identification of the state of affairs should be done tacitly (Moran & Dourish, 2001), without requiring user intervention (e.g., through the use of sensors and other automated methods, it is possible to get the perception of the physical environment where the user is).

Being able to set the user needs the system may adapt by itself to him. For instance, if the system detects that the user is confused or lost, it may put an emphasis on the orientation process, minimizing the risks of a wrong move. It uses data gathered by a context aware framework, which is fed to a system that works in a speculative way, i.e., the system may predict the user movements and adjust its alerts accordingly.

The name of the system is CogHelper and it may help people with cognitive disabilities and their caregivers (Ramos et al., 2013). This system (named CogHelper) is intended to work outdoors, and its structure (Fig. 1) consists of internal services like the application for people with cognitive disabilities (”Cognitive Helper Mobile Solution”, Section i), the application for caregivers (”Caregiver Applications”, Section ii), and the server, as well as external services that let the system use other facilities, like an external reminder. The framework of Speculative Computation is described in detail in Section IV.

The server is the core of the system, since all the other services are connected to it, namely in terms of a database (to store all the data needed to its correct operation, like usernames, locations, points of interest), and a communication module to connect to other internal services, as well as to external ones.

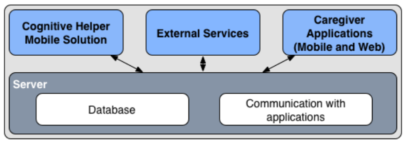


Figure 1: *Simplified Framework of CogHelper.*

The features that are developed and compose the system are summarized at Table 1, with a tick.

i. Application for People with Cognitive Disabilities

With the advent of high processing powered mobile devices, it was possible to overcome a major limitation of smart houses. Instead of having multiple fixed sensors at a home environment, it is possible to develop a portable monitoring bubble using mobile devices and sensors (e.g., over the body or clothes), then leading to a new concept or abstraction, the Body Area Network (BAN) (P. Jain, 2011; MontoÌẠn et al., 2008; Wolf & Saadaoui, 2007).

The system developed so far operates under the Android Operative System, targeting human beings with cognitive disabilities. It is based on the BAN concept. It fulfills two main objectives, i.e., to guide the user and to provide his/her own localization. Not only it enables the user to travel between two locations without getting lost, but also provides a localization system, so caregivers may know in real time the current location of the user.

A detailed framework of the "Cognitive Helper Mobile Solution" is presented in Fig. 2 and consists of a Localization Layer, with methods to get the user location, necessary to let the Navigation system settle the route. The user location may be done trough the GPS module of the mobile device, or by a coarse location from the network. In this layer it is also included a Navigation Algorithm, which is based on a Speculative Computation Framework, described in detail in Section IV, and a Trajectory Mining Module (responsible for obtaining the default values for the speculative computation module). With the information from the user location and the Speculative framework, the system may learn from the frequent paths taken by the user.

Once the destination is selected, using tools like cameras, accelerometers, or magnetic sensors, the route is presented to the user by way of augmented reality (Fig. 3). In other words, one may say that the computational system is able not only to set the direction to where the user must point, but also to present it to him. If the user is pointing to the right direction, a green arrow will appear on the screen, signaling that the chosen track is the correct one. On the other hand, if the user is pointing to the wrong direction, a red cross is displayed. The decision process (at the center in Fig. 2) ensures that the user is moving on the right track, and some notices are brought about to him, whenever necessary. These prompts may be seen as a stimulus to the user to keep himself/herself on the right track, or alert him to take the right decisions. To keep caregivers aware of user movements an email or short message may be also sent to them, i.e., when the user reaches the destination point, passes a control one, or gets lost. Indeed, through an interface (right part in Fig. 2) the user may communicate with the computational system and to set the destination points, namely in terms of starred destinations (e.g., home, school, or office), or generic ones (e.g., the mall). To communicate with the server in order to obtain and send the needed information, the computational system is provided with an Input/Output layer. The information exchanged between the system and the server may include the update of user destinations, the update of his/her current location, or information about the external services that are available.

ii. Applications for Caregivers

To look at and follow the user throughout his/her life time, caregivers have access to two different platforms, namely a mobile application for the Android Operative System (Fig. 5a), and a Web application (Fig. 5b). The former one gives extra degrees of freedom to caregivers, since it may be used everywhere with an Internet tie-in. The detailed framework of these platforms is shown in Fig. 4, and consists of three components, being the extra module exclusive for the Web application, which is pointed out as "Web". On the left it is possible to see the Input/Output layer, which caters for the interaction between the caregiver and the computational system. There is also a Commu-

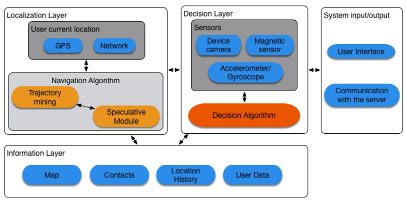


Figure 2: *Detailed framework of the application for people with cognitive disabilities.*

Figure 3: *Orientation system using augmented reality.*

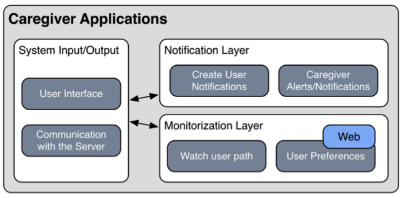
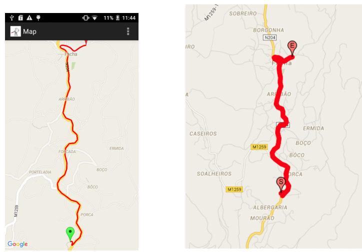


Figure 4: *Detailed framework of the caregivers application.*



(a) *Android application* **(b)** *Web application*

Figure 5: *Localization system for caregivers*

nication Module the communication between the caregiver applications and the server, in order to send and receive requests, like getting the current position of the user.

The Notification Layer is in charge of handling the alerts that come from the user application. These alerts may inform the caregiver that the user is lost or that he reached its destination. The Create User Notification Module enables the caregiver to create notifications to the user, which are no more than small text messages that may include questions of Yes/No answer (e.g., the user may be asked if he needs assistance). Finally, the framework has a Monitoring Layer, which enables the caregivers to be aware of user movements, like knowing his/her current location or the traveling path. The Web application is the only one that has a User Preferences Module, through which the caregiver may edit some preferences of the person with disabilities. This feature includes, for example, the creation of destination points, which may be done by a direct selection on the map or by searching an address. One is also able to state if the destination point is general, or favourite (i.e., more frequently used).

IV. Applying Speculative Computation to an Orientation System

Satoh (Satoh, 2005) extended the procedure of Kakas et al. (Kakas et al., 1998), given rise to the theory of Speculative Computation and Abduction, that is a step forward in handling incomplete information. Instead of having the computational process in an idle state (i.e., waiting for incoming information to continue the computation), it moves ahead by replacing the unknown information by a default one, therefore obtaining a tentative solution for the problem. Whenever the missing data is acquired, the computation process is reexamined. The execution of speculative framework is based on two phases, *Process Reduction Phase* and *Fact Arrival Phase*. The former one stands for the normal execution of the computation process, while the latter denotes an interruption stage. Before starting the execution of the Speculative Computation framework it is necessary to have a bulk of information, holding on to:

1. All the possible paths between the current user location and the intended destination as facts in the knowledge base;
2. The transitions between points usually performed by the user as default values;
3. Information regarding the inclusion of a point in the current recommended traveling path as default values; and
4. A set of rules that structure the execution of the computation regarding the most likely path that the user will follow and the issuing of alerts if a (potencial) mistake happens.

i. The Speculative Computation Framework

The Speculative Computation Framework in the Orientation Method (SF_{OM}) for people with cognitive disabilities is defined in terms of the tuple $\langle \Sigma, \mathcal{E}, \Delta, \mathcal{A}, \mathcal{P}, \mathcal{I} \rangle$ (Satoh, 2005), where:

- Σ stands for a finite set of constants (an element of Σ is called a system module);
- $\mathcal{E}$ denotes a set of functions called *external predicates*. When Q is a literal belonging to an external predicate and S is the identifier of the information source, $Q@S$ is called an *askable literal*. We define *∼(Q@S)* as *(∼Q)@S*;
- Δ is the *default answer* set, which is a set of ground askable literals that satisfy the condition: Δ does not contain both $p(t_1, \ldots, t_n)@S$ and $\sim\ p(t_1, \ldots, t_n)@S$ at once;
- $\mathcal{A}$ is a set of predicates called *abducible predicates*. Q is called *abducible* when it is a literal with an *abducible predicate*;
- $\mathcal{P}$ is a Logic Program (LP) and contains a set of rules in the form:
  - ▷ $p \leftarrow p_1, p_2, \ldots, p_n$ where p is a positive ordinary literal, and each of $p_1, \ldots, p_n$ is an ordinary literal, an askable literal or an abducible; and
  - ▷ p is the head of rule R and is named as *head(P)* (always non-empty), in which R is a rule of the form $p \leftarrow p_1, \ldots, p_n$; where $p_1, \ldots, p_n$ is the body of the rule denoted as *body(P)*, that in some situations is substituted by the boolean value *true*.
- $\mathcal{I}$ is a set of integrity constraints in the form:
  - ▷ $?(p_1, p_2, \ldots, p_n)$, where the symbol "?" denotes "falsity", the p_1, p_2, …, p_n are ordinary literals or *askable literals* or *abducibles*. At least one of $p_1, p_2, \ldots, p_n$ is an *askable literal* or an *abducible*.

An *askable literal* may have different meanings, namely:

1. An *askable literal* $Q@S$ in a rule $\mathcal{P}$ stands for a question put to a system module S; and
2. An *askable literal* in Δ denotes a default truth value, either *true* or *false*, i.e., $p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is usually *true* for a question to a system module S, and $\sim p(t_1, \ldots, t_n)@S \in \Delta$, $p(t_1, \ldots, t_n)@S$ is generally *false* for a question to a system module S.

In the logic program given below *path(a,b)* denotes that it is possible to travel between locations *a* and *b*; *show_next_point* states that the system must show the next location (which may be an intermediate or the final one) to the user; *show_user_warning* indicates that the system must alert the user, given that he is going in the wrong direction; and the default values for the travel path of the user are defined in Δ. *user_travel(a,b)*, says that the user will travel from location *a* to location *b*; *included(a)* is evidence that location *a* is part the route.

To ensure that the user is traveling on the correct track and that he is alerted whenever he is out of it, a supporting structure was specified based on Speculative Computation, in terms of the logic programming suite (LPS):

- ▷ $\Sigma = \{gps\_sensor, recognizer\}$
- ▷ $\mathcal{E} = \{user\_travel, included\}$
- ▷ $\Delta = \{user\_travel(1,2)@gps\_sensor,$
  $user\_travel(2,3)@gps\_sensor,$
  $user\_travel(2,4)@gps\_sensor,$
  $user\_travel(4,5)@gps\_sensor,$
  $user\_travel(5,6)@gps\_sensor,$
  $user\_travel(6,3)@gps\_sensor,$
  $included(1)@recognizer,$
  $included(2)@recognizer,$
  $included(3)@recognizer,$
  $\sim included(4)@recognizer$
  $included(5)@recognizer,$
  $included(6)@recognizer\}$
- ▷ $\mathcal{A} = \{show\_next\_point,$
  $show\_user\_warning\}$
- ▷ $\mathcal{P}$ is the following set of rules:
  $guide(A, A) \leftarrow .$
  $guide(A, B) \leftarrow$

$path(A, F)$,
$show\_next\_point(F)$,
$user\_travel(A, F)@gps\_sensor$,
$guide(F, B)$.

$guide(A, B) \leftarrow$
$path(A, F)$,
$user\_travel(A, F)@gps\_sensor$,
$show\_user\_warning(F)$,
$guide(F, B)$.

$path(1, 2) \leftarrow .$
$path(2, 3) \leftarrow .$
$path(2, 4) \leftarrow .$
$path(4, 5) \leftarrow .$
$path(5, 6) \leftarrow .$
$path(6, 3) \leftarrow .$

▷ $\mathcal{I}$ denotes the following set of integrity constraints or invariants:
$?(show\_next\_point(F), \sim included(F)@recognizer)$.
$?(show\_user\_warning(F), included(F)@recognizer)$.

To ensure program integrity, two invariants were added that state that the system may not show the next route point to the user if it is not part of it, or that the system may not alert the user if he is moving on the right track.

As an example, it is assumed that the user will travel between locations 1 and 3 through intermediate location 2. An elucidation of the possible paths that the user may use are presented in Figure 6.

ii. Preliminary Definitions

There are some aspects of the formal process set above that must be defined in order to translate it into a proof procedure.

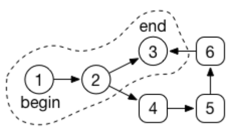


Figure 6: *Possible ways to move among locations 1 and 3.*

Definition 1 *An extended literal is either a literal or an expression of the form $fail(\{l_1, \ldots, l_n\})$ where l_i is a literal. $fail(\{l_1, \ldots, l_n\})$ is used to prove that there is no proof for l_i (Kakas & Mancarella, 1990)* □

Definition 2 *A process is the tuple $\langle GS, OD, IA, ANS \rangle$ in which GS is a set of extended literals and called a Goal Set, expressing the current status of an alternative computation; OD is a set of askable literals called outside defaults, which denote a set of assumed information about the outside world during a computation; IA is a set of negative literals or abducibles called inside assumptions that stand for the values assumed during a computation; and ANS is a set of instantiations of variables in the initial inquiry.* □

Definition 3 *PS is a set of processes. A set of already asked questions AAQ is a set of askable literals. A current belief state CBS is a set of askable literals.* □

The set of processes *PS* expresses all the alternative computations that were considered. The *AAQ* set is used to avoid asking redundant questions to the sensors. *CBS* is the current belief state and expresses the current status of the outside world. It is also important to define an *active process* and a *suspended process*.

Definition 4 *Let $\langle GS, OD, IA, ANS \rangle$ be a process and CBS be a current belief state. A process is active with respect to CBS if $OD \subseteq CBS$. A process is suspended with respect to CBS otherwise.* □

The definition of an active process emphasizes that it is a process whose outside defaults have to be consistent with the current belief state.

iii. Process Reduction Phase

In this phase changes may occur in the process set. In the following description, changed *PS*, *AAQ* and *CBS* are specified as *NewPS*, *NewAAQ* and *NewCBS*; otherwise they stay unchanged.

Initial Step: Let GS be an initial goal set. The tuple $\langle GS, \emptyset, \emptyset, ANS \rangle$ is given to the proof procedure where ANS is a set of variables in GS. That is, $PS = \{\langle GS, \emptyset, \emptyset, ANS \rangle\}$. Let $AAQ = \emptyset$ and $CBS = \Delta$.

Iteration Step: Do the following:

- ▷ **Case 1:** If there is an active process $\langle GS, \emptyset, \emptyset, ANS \rangle$ with respect to CBS in PS, terminate the process by returning outside defaults OD, inside assumptions IA, and instantiation for variables ANS. This case may only be applied on the first iteration step since OD and IA are empty sets;
- ▷ **Case 2:** If there is no active process, terminate the process by reporting a failure of the goal;
- ▷ **Case 3:** Select an active process $\langle GS, OD, IA, ANS \rangle$ with respect to CBS from PS and select an extended literal L in GS. Let $PS' = PS - \{\langle GS, OD, IA, ANS \rangle\}$ and $GS' = GS - \{L\}$. For the selected extended literal L, do the following:
  - **Case 3.1:** If L is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle (\{ body(R)\} \bigcup GS')\theta, OD, IA, ANS\theta \rangle | \exists R \in \mathcal{P}$ and $\exists$most general unifier θ so that $head(R)\theta = L\theta$.
  - **Case 3.2:** If L is a ground negative ordinary literal or a ground abducible then:
    - ∗ **Case 3.2.1:** If $L \in IA$ then $NewPS = PS' \bigcup \{\langle GS', OD, IA, ANS \rangle\}$.
    - ∗ **Case 3.2.2:** If $\overline{L} \in IA$ then $NewPS = PS'$.
    - ∗ **Case 3.2.3:** If $L \notin IA$ then $NewPS = PS' \bigcup \{\langle NewGS, OD, IA, \bigcup\{L\}, ANS \rangle\}$ where $NewGS = \{fail(BS) | BS \in resolvent(\ L, \mathcal{P} \bigcup \mathcal{I})\} \bigcup GS'$ and $resolvent(L, T)$ is defined as follows:
      - · If L is a groung negative ordinary literal, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_k\theta\} | H \leftarrow L_1, \ldots, L_k \in T$ so that $\overline{L} = H\theta$ by a ground substitution $\theta\}$
      - · If L is a ground abducible, $resolvent(L, T) = \{\{L_1\theta, \ldots, L_{i-1}\theta,\ L_{i+1}\theta, \ldots, L_k\theta\} | \bot \leftarrow L_1, \ldots, L_k \in T$ so that $L = L_i\theta$ by a ground substitution $\theta\}$.
  - **Case 3.3:** If L is $fail(BS)$, then
    - ∗ If $BS = \emptyset$, $NewPS = PS'$;
    - ∗ IF $BS \neq \emptyset$, then do the following:
      (1) Select B from BS and let $BS' = BS - \{B\}$.
      (2) **Case 3.3.1:** If B is a positive ordinary literal, $NewPS = PS' \bigcup \{\langle NewGS \bigcup GS', OD, IA, ANS \rangle\}$ where $NewGS = \{fail((\{body(R)\} \bigcup BS')\theta | \exists R \in \mathcal{P}$ and $\exists$MGU θ so that $head(R)\theta = B\theta\}$
      Case 3.3.2: If B is a ground negative ordinary literal or a ground askable literal or an abducible, $NewPS = PS' \bigcup \{\langle \{ fail(BS')\} \bigcup GS', OD, IA,\ ANS \rangle\} \ \bigcup \{\langle \{\overline{B}\} \bigcup GS', OD, IA, ANS \rangle\}$.
  - **Case 3.4:** If L is a ground askable literal, $Q@S$, then do the following:
    (1) If $L \notin AAQ$ and $\overline{L} \notin AAQ$, then send the question Q to the slave agent S and $NewAAQ = AAQ \bigcup \{L\}$.
    (2) If $\overline{L} \in OD$ then $NewPS = PS'$ else $NewPS = PS' \bigcup \{\langle GS', OD \bigcup \{L\}, IA, ANS \rangle\}$.

iv. Fact Arrival Phase

In this phase the current belief state is revised according to the information received from the sensors. Supposing that an answer Q is returned from a sensor S. Let $L = Q@S$. After finishing a step of process reduction, let us do the following:

- If $\overline{L} \in CBS$, then $NewCBS = CBS - \{\overline{L}\} \bigcup \{L\}$
- Else if $L \notin CBS$, then $NewCBS = CBS \bigcup \{L\}$.

There might be some askable literals that are not included in the initial belief set. If this occurs, processes that are using such askable literals and those using their complements are suspended until the answers are returned.

v. Correctness of the Proof Procedure

The correctness of the procedure is guaranteed by stable model semantics (Kakas & Mancarella, 1990). Thus, the following definitions are given for the semantics of the previously described logical program.

Definition 5 *Let T be a set of rules and integrity contraints. The set of ground rules obtained by replacing all the variables in every rule or every integrity contraint T by every ground term is denoted as* $\prod_T$ □.

Definition 6 *Let T be a set of rules and integrity constraints. Let M be a set of ground atoms and* $\prod_T^M$ *be the following program:* $\prod_T^M = \{H \leftarrow B_1, \ldots, B_l | H \leftarrow B_1, \ldots, B_l, \sim A_1, \ldots, \sim A_h. \in \prod_P$ *and* $A_i \notin M$ *for each* $i = 1, \ldots, h.\}$. *Let* $min(\prod_T^M)$ *be the least model of* $\prod_T^M$. *A stable model for a logic program T is M iff* $M = min(\prod_M^T)$ *and* $\bot \notin M$. □

Definition 7 *Let T be a set of rules and integrity constraints, and Θ be a set of ground abducibles.* □

For any process evaluation strategy, when an answer is received with a set of outside defaults and a set of inside assumptions from the proof procedure, the answer is correct with respect to a generalized stable model with respect to inside assumptions and the program. This program is obtained from the original one and the current world belief.

Theorem 1 *Let* $SF_{OM} = \langle \Sigma, \mathcal{E}, \Delta, \mathcal{A}, \mathcal{P}, \mathcal{I} \rangle$ *be a speculative framework where* $\mathcal{P}$ *is a call-consistent logic program whose set of integrity constraints is satisfiable. Let GS be an initial goal set. Suppose that GS is reduced to ∅ when OD is outside defaults. IA are inside assumptions, ANS is the set of variables instantiations in GS, and CBS is the current belief set. Let* GS' *be a goal obtained from GS by replacing all the variables in GS by ANS. Then, there is a generalized stable model* $M(\Theta)$ *for* $\mathcal{P} \bigcup \mathcal{I} \bigcup \mathcal{F}(CBS)$, *such that* $M(\Theta) \models GS'$ *and* $OC \subseteq CBS$ *and* $IA \subseteq \Theta$. □

Proposition 1 *Since* $\mathcal{P}$ *is a call consistent logic program, so is* $\mathcal{P} \bigcup \mathcal{I} \bigcup \mathcal{F}(CBS)$. *Then, an abducible derivation may be constructed (Kakas & Mancarella, 1990) using a set of reduction steps applied to* $\langle GS, \emptyset, \emptyset, ANS' \rangle$ *to* $\langle \emptyset, OD, IA, ANS \rangle$ *where* ANS' *is a set of variables in GS. This derivation is correct for generalized stable model semantics for a call-consistent logic program (Kakas & Mancarella, 1990). Thus,* $M(\Theta) \models GS\theta$ *and* $OD \subseteq \Theta$. □

An execution example of the program introduced in Section i is presented in Appendix A. For the reduction process the following strategy is used:

- ▷ When a positive literal is reduced, new processes are created according to the rule order in the program, which are unifiable with the positive literal;
- ▷ A newly created or newly resumed process and the most left literal is always selected.

In the execution trace in A for $guide(1,3)$ the selected literal is underlined in the active process that was sorted out. *AAQ* and *CBS* are only shown when a change occurs. In order to reduce the execution example and to facilitate its reading and interpretation, the literals have been abbreviated. Thus, *gps_sensor* is represented by *g*, *recognizer* by *r*, *user_travel* by *u*, *included* by *i*, *path* by *p*, *show_next_point* by *snp*, and *show_user_warning* by *suw*.

The program starts with the objective of guiding the user from location 1 to location

3. According to Figure 6 there are two possibilities, i.e., making way through location 2 or through locations 2, 4, 5 and 6. The system starts processing 2 branches for each next possible location: one branch lets the execution continue if the location is valid (i.e., it is included in the possible locations set) and the user is moving towards it, the other stands for the situation in which the location is not valid and the user is moving to it. In the former one the system keeps guiding the user to the next point, whereas in the latter it alerts the user and guides him to the correct track. The execution of an alternative combination of what was previous described is suspended since that move is not valid (e.g., alert the user if the next location is valid).

During the execution of a particular move that may change positions, the information source may be queried. While this information is not returned the program continues its execution, so the moves which are queried $\sim$ *user_travel*$(1, 2)$ @*gps_sensor* are paused (since the default value is negative). The only move that proceeds is the one that assumes the default value *user_travel*$(1, 2)$@*gps_ sensor*. Whenever an answer is returned from the information source the computation is revised. The current move may be paused and a previously paused may be resumed. The system may re-initialize, pause, or resume moves until the destination point is reached.

Instead of suspending the computation due to not knowing the answer to set the next user's movement, Speculative Computation enables the continuity of the computational task, i.e., it sets a default value as the way to have an answer to set the next user's movement and therefore the computational process does not come to an end (e.g., Step 8).

At Step 3, *show_next_point*(2) it is assumed and are checked the integrity constraints. Thus, it is assured that there is no contradiction by checking if $\sim$ *included*(2)@*recognizer* is not derived. In this step an ordinary abduction operation is carried out.

When an answer is returned and it confirms the default value, nothing changes. Thus, in these situations Speculative Computation is in an advanced stage of the computation and it has not to be revised (e.g., Step 11).

At different stages of the computational process a ongoing procedure may have to be suspended once the askable literal is in opposition with the information contained in the *CBS*. For instance, this situation occurred at Step 33.

The execution trace just referred to above denotes a computational process that was not implemented. Its propose is to check if it is possible to set the orientation problem through speculative computation. Indeed, according to the proof procedure referred to above, the application of Speculative Computation is an expressive and adequate option.

V. Conclusions

An active participation in society is vital for people with cognitive disabilities and, having this in mind, numerous scholars have studied and developed various methods to orientate them, both indoors and outdoors. The independent traveling allows the patient to maintain an employment (within their capabilities). The degree of independence for the patient and for the caregiver is increased, since the patient can be remotely controlled, and the caregiver may perform another activity without neglecting the care being provided.

The present orientation systems have to be adapted to the characteristics of the users, i.e., these systems must be easy to operate when the orientation is being performed. If these system specifications are not matched, it may imply a more complex mental activity, leaving the user confused. In this situation the orientation system may become unfeasible.

For people with reduced orientation capabilities there are several projects under consideration. Using these systems, people with cognitive disabilities may have a more active life, reducing the worry of getting lost both indoors and outdoors. Depending on the type of cognitive disability and its degree of incidence, the user can keep a job or perform other activities. However, the user has to learn two types of orientation systems, since a system adapted to the outside world cannot be used indoors or vice versa. The system presented in this work stands for an answer to all these shortcomings, making a moving to provide a better quality of life to disabled people.

Through this work we present an orientation system for people with mild (or moderate) cognitive disabilities that has an anticipation feature, once it alerts the user before he takes the wrong turn. This is achieved by applying a Speculative Computation module, which needs to be loaded by the traveling path before its execution. This specificity enables the independent development of a pattern mining module, so that travel path is adapted to the user (instead of using the shortest one by default). Caregivers are not disregarded and a localization feature was considered. Thus, these users may remotely access the traveling path of the person with disabilities.

A. Execution example of the Speculative Computation Framework

An execution example is given below in which the user is guided from location 1 to location 3. In order to reduce the amount of text in the example, we used the abbreviated form of the elements of each tuple. Thus $u(1,2)@g$ is the askable literal $user\_travel(1,2)@gps\_sensor$; $i(1)@r$ is the literal $included(1)@recognizer$; $p(1,2)$ represents $path(1,2)$; $snp(2)$ is the predicate $show\_next\_point(2)$; and $suw(2)$ represents the predicate $show\_user\_warning$. The sets AAQ and CBS are shown when a change occurs.

1.

$$\begin{aligned} PS &= \{< \{\underline{guide(1,3)}\},\ \emptyset,\ \emptyset >\} \\ AAQ &= \emptyset \\ CBS &= \{u(1,2)@g, u(2,3)@g, u(2,4)@g, u(4,5)@g, \\ &\quad u(5,6)@g, u(6,3)@g, i(1)@r, i(2)@r, \\ &\quad i(3)@r, \sim i(4)@r, i(5)@r, i(6)@r\} \end{aligned}$$

2. By **Case 3.1**

$$\begin{aligned} PS = \{&< \{\underline{p(1,Y)}, snp(Y), u(1,Y)@g, guide(Y,3)\}, \\ &\emptyset, \emptyset >, < \{p(1,Y), u(1,Y)@g, \\ &suw(Y), guide(Y,3)\}, \emptyset, \emptyset >\} \end{aligned}$$

3. By **Case 3.1**

$$\begin{aligned} PS = \{&< \{\underline{snp(2)}, u(1,2)@g, guide(2,3)\}, \emptyset, \emptyset >, \\ &< \{u(1,2)@g, suw(2), guide(2,3)\}, \emptyset, \emptyset >\} \end{aligned}$$

4. By **Case 3.2.3**

$$\begin{aligned} PS = \{&< \{\underline{fail(\{\sim i(2)@r\})}, u(1,2)@g, guide(2,3)\}, \\ &\emptyset, \{snp(2)\} >, P_1{}^1\} \end{aligned}$$

5. By **Case 3.3.2**

$$\begin{aligned} PS = \{&< \{\underline{fail(\emptyset)}, u(1,2)@g, guide(2,3)\}, \emptyset, \{snp(2)\} >, \\ &< \{i(2)@r, u(1,2)@g, guide(2,3)\}, \emptyset, \{snp(2)\} >, \\ &P_1\} \end{aligned}$$

6. By **Case 3.3**

$$\begin{aligned} PS = \{&< \{\underline{i(2)@r}, u(1,2)@g, guide(2,3)\}, \emptyset, \{snp(2)\} >, \\ &P_1\} \end{aligned}$$

7. By **Case 3.4**
$i(2)$ **is asked to the sensor** r

$$\begin{aligned} PS &= \{< \{\underline{u(1,2)@g}, guide(2,3)\}, \{i(2)@r\}, \\ &\quad \{snp(2)\} >, P_1\} \\ AAQ &= \{i(2)@r\} \end{aligned}$$

8. By **Case 3.4**
$u(1,2)$ **is asked to the sensor** g

$$\begin{aligned} PS &= \{< \{\underline{guide(2,3)}\}, \{i(2)@r, u(1,2)@g\}, \\ &\quad \{snp(2)\} >, P_1\} \\ AAQ &= \{i(2)@r, u(1,2)@g\} \end{aligned}$$

9. By **Case 3.1**

$$\begin{aligned} PS = \{&< \{\underline{p(2,Y)}, snp(Y), u(2,Y)@g, guide(Y,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, \\ &< \{p(2,Y), u(2,Y)@g, suw(Y), guide(Y,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, P_1\} \end{aligned}$$

10. By **Case 3.1**

$$\begin{aligned} PS = \{&< \{\underline{snp(3)}, u(2,3)@g, guide(3,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, \\ &< \{snp(4), u(2,4)@g, guide(4,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, \\ &< \{u(2,3)@g, suw(3), guide(3,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, \\ &< \{u(2,4)@g, suw(4), guide(4,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, \\ &P_1\} \end{aligned}$$

11. $u(1,2)$ is returned from g
Nothing changes.

12. By **Case 3.2.3**

$$\begin{aligned} PS = \{&< \{\underline{fail(\{\sim i(3)@r\})}, u(2,3)@g, guide(3,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2), snp(3)\} >, \\ &P_2{}^2, P_3{}^3, P_4{}^4, P_1\} \end{aligned}$$

13. By **Case 3.3.2**

$$\begin{aligned} PS = \{&< \{\underline{fail(\emptyset)}, u(2,3)@g, guide(3,3)\}, \\ &\{i(2)@r, u(1,2)@g\}, \{snp(2), snp(3)\} >, \\ &< \{i(3)@r, u(2,3)@g, guide(3,3)\}, \{i(2)@r, \\ &u(1,2)@g\}, \{snp(2), snp(3)\} >, \\ &P_2, P_3, P_4, P_1\} \end{aligned}$$

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[1] $P_1 =< \{u(1,2)@g, suw(2), guide(2,3)\}, \emptyset, \emptyset >$

[2] $P_2 =< \{snp(4), u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >$

[3] $P_3 =< \{u(2,3)@g, suw(3), guide(3,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >$

[4] $P_3 =< \{u(2,4)@g, suw(4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >$

14. By **Case 3.3**
$PS = \{< \{i(3)@r, u(2,3)@g, guide(3,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2), snp(3)\} >, P_2, P_3, P_4, P_1\}$

15. By **Case 3.4**
$i(3)$ **is asked to the sensor** r
$PS = \{< \{u(2,3)@g, guide(3,3)\}, \{i(2)@r, u(1,2)@g, i(3)@r\}, \{snp(2), snp(3)\} >, P_2, P_3, P_4, P_1\}$
$AAQ = \{i(2)@r, u(1,2)@g, i(3)@r\}$

16. By **Case 3.4**
$u(2,3)$ **is asked to the sensor** g
$PS = \{< \{guide(3,3)\}, \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\}, \{snp(2), snp(3)\} >, P_2, P_3, P_4, P_1\}$
$AAQ = \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\}$

17. By **Case 3.1**
$PS = \{< \emptyset, \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\}, \{snp(2), snp(3)\} >, < \{snp(4), u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, P_3, P_4, P_1\}$

18. By **Case 3.2.3**
$PS = \{< \{fail(\sim i(4)@r), u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2), snp(4)\} >, P_3, P_4, P_1, P_5$[5]$\}$

19. By **Case 3.3.2**
$PS = \{< \{fail(\emptyset), u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2), snp(4)\} >, < \{i(4)@r, u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2), snp(4)\} >, P_3, P_4, P_1, P_5\}$

20. By **Case 3.3**
$PS = \{< \{i(4)@r, u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2), snp(4)\} >, P_3, P_4, P_1, P_5\}$

21. By **Case 3.4**
$i(4)$ **is asked to the sensor** r
$PS = \{< \{u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g, i(4)@r\}, \{snp(2), snp(4)\} >, < \{u(2,3)@g, suw(3), guide(3,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, P_4, P_1, P_5\}$
$AAQ = \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g, i(4)@r\}$

22.
$u(2,3)$ **has already been asked to the sensor** g
$PS = \{< \{suw(3), guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g\}, \{snp(2)\} >, P_4, P_1, P_5, P_6$[6]$\}$

23. By **Case 3.2.3**
$PS = \{< \{fail(i(3)@r), guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g\}, \{snp(2), suw(3)\} >, P_4, P_1, P_5, P_6\}$

[5] $P_5 =< \emptyset, \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\}, \{snp(2), snp(3)\} >$

[6] $P_6 =< \{u(2,4), guide(4,3)\}, \{i(2)@r, u(1,2)@g, i(4)@r\}, \{snp(2), snp(4)\} >$

24. By **Case 3.3.2**
$PS = \{< \{fail(\emptyset), guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g\}, \{snp(2), suw(3)\} >, < \{\sim i(3)@r, guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g\}, \{snp(2), suw(3)\} >, P_4, P_1, P_5, P_6\}$

25. By **Case 3.3**
$PS = \{< \{\sim i(3)@r, guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g\}, \{snp(2), suw(3)\} >, P_4, P_1, P_5, P_6\}$

26.
$i(3)$ **has already been asked to the sensor** r
$PS = \{< \{guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g, \sim i(3)@r\}, \{snp(2), suw(3)\} >, < \{u(2,4)@g, suw(4), guide(4,3)\}, \{i(2)@r, u(1,2)@g\}, \{snp(2)\} >, P_1, P_5, P_6\}$

27. By **Case 3.4**
$u(2,4)$ **is asked to the sensor** g
$PS = \{< \{suw(4), guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g\}, \{snp(2)\} >, P_1, P_5, P_6, P_7$[7]$\}$
$AAQ = \{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\ i(4)@r, u(2,4)@g\}$

...

28. By **Case 3.2.3**
$PS = \{< \{fail(i(4)@r, guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g\}, \{snp(2), suw(4)\} >, P_1, P_5, P_6, P_7\}$

29. By **Case 3.3.2**
$PS = \{< \{fail(\emptyset), guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g\}, \{snp(2), suw(4)\} >, < \{\sim i(4)@r, guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g\}, \{snp(2), suw(4)\} >, P_1, P_5, P_6, P_7\}$

30. By **Case 3.3**
$PS = \{< \{\sim i(4)@r, guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g\}, \{snp(2), suw(4)\} >, P_1, P_5, P_6, P_7\}$

31.
$i(4)$ **has already been asked to the sensor** r
$PS = \{< \{guide(4,3)\}, \{i(2)@r, u(1,2)@g, u(2,4)@g, \sim i(4)@r\}, \{snp(2), suw(4)\} >, P_1, P_5, P_6, P_7\}$

32. $u(2,3)$ is returned from g
Nothing changes.

33. $\sim u(2,4)$ is returned from g
By **Fact Arrival Phase**:
$CBS = \{u(1,2)@g, u(2,3)@g, \sim u(2,4)@g, u(4,5)@g, u(5,6)@g, u(6,3)@g, i(1)@r, i(2)@r, i(3)@r, \sim i(4)@r, i(5)@r, i(6)@r\}$

34.
$\{i(2)@r, u(1,2)@g, i(3)@r, u(2,3)@g\}$ and $\{snp(2), snp(3)\}$
are returned as outside defaults and inside assumptions.

[7] $P_7 =< \{guide(3,3)\}, \{i(2)@r, u(1,2)@g, u(2,3)@g, \sim i(3)@r\}, \{snp(2), suw(3)\} >$

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Chapter 5

Conclusions and Future Work

Think twice before you speak, because your words and influence will plant the seed of either success or failure in the mind of another.
— Napoleon Hill

Outline

Conclusions and Future Work

The technological evolution is constant. Thus, new devices are developed whereas the existing ones are enhanced with new functionalities or became deprecated. This evolution is inherent to the living society and it occurs in several areas, like healthcare and computation. As such, the quality of live of populations has increased over the last years, being one indicator the increasing of the life expectancy.

However, all this progress did not eliminate all diseases, *i.e.*, there are some medical conditions that do not have yet a cure (like Alzheimer), and physicians make use of drugs to try to prevent or slow the progression of the disease. For some conditions the brain stimuli is also beneficial for the patient since it may slow down the progression to a worse stage of the disease.

Cognitive disabilities are medical conditions that may largely vary from person to person. Thus, if one considers two different persons with the same diagnosis it may not mean that they face the same difficulties or have the same necessities. This fact increases the complexity when a programmer tries to develop an application or when manufacturers intend to create a device to help this group of people. The personalization level has to be increased in order to enable the application/device to be better adjusted to the user. When this requisite is not met the device may not be suitable and may be rejected by the user due to the lack of adaptability.

People with cognitive disabilities have to face some obstacles/barriers when trying to use, for example, a service like the Internet. Interactive buttons and ads usually took the user attention over the important information. There are authors who studied the impact of these distracting elements when people with cognitive disabilities try to access on-line information. They conclude that the user have much more difficulties using this service. Another important aspect is that people with cognitive disabilities tend to have their independency reduced since caregivers have their concerns in knowing the current state of the disabled person. This lack of independency may be surpassed by applying the concept of smart house. Thus, the user is remotely monitored by caregivers or physicians while living in a more independent way.

However, this solution has a major drawback: the user may only be monitored and his security may only be guaranteed when he is inside his house. Thus, if the user goes outside all embedded devices may not be able to monitor him. This may turn the user a prisoner of his own home since he may be prevented to go out alone by the caregivers. To overcome this issue and let the person with cognitive disabilities to travel by himself between two location we have been developing CogHelper.

The remain of the chapter is divided as follows: Section 5.1 presents the conclusions of this PhD project considering other orientation systems/methods. This section also includes the contributions and relevant work. Section 5.2 describes new contributions to complement CogHelper. Finally, Section 5.3 ends the document with the final remarks.

5.1 Conclusions

People with cognitive disabilities have more difficulties in one or more mental task when compared to an ordinary person. A commonly affected task is orientation. Thus, developing CogHelper we intended to support this group of people when moving outside home and at the same time improve their independency, since caregivers may remotely have access to their locations and do not need to physically be with the person with disabilities.

Considering as goal the guidance of people with disabilities we have found few projects/systems with this feature. Regarding this fact and considering that these projects were not recent, their main focus was on the user interface. The authors considered that the available software for mobile devices had an interface that was not suitable for this goal. The feature dedicated to the caregivers (remote localization) was only available in one system. We developed CogHelper further and tried to create a system that adapts as much as possible to the user considering his preferences. Indeed, it is able to predict possible user mistakes alerting him before the error becomes a reality. Section 5.1.1 describes in details the contributions of this work.

5.1.1 Contributions

To achieve the goals defined in Section 1.4 (Work Aim), the following contributions were fulfilled:

- ▷ A study of the concept of Cognitive Assistants (see Chapter 1):
  - This allowed to understand how technology could be beneficially used to improve the day-life of people with disabilities. This resulted on the assessment of the social and technological challenges when developing an orientation method for people with cognitive disabilities;
- ▷ A comprehensive study of Cognitive Disabilities (see Chapter 2):
  - This allowed to understand the concept of Cognitive Disabilities (its definition), how the diagnosis are made and how the different types of disabilities are set; and
  - To understand the main barriers/obstacles that these people face in their day-life, which includes their main difficulties and how it may be possible to overcome them;
- ▷ A study of orientation systems and their components (see Chapter 4):
  - This allowed to identify gaps and aspects of existing solutions that could be improved or modified. Additionally, this step resulted in an exhaustive study of the state of the art of the topic, including future developments (see Section 4.1);
- ▷ A study of computer systems/technologies that support the communication between different platforms (see Chapter 4):
  - This allowed the definition of the requirements for our system considering the gaps identified in others and in the necessities of the target audience (see Section 4.2);
- ▷ Development of an archetype platform (see Chapter 4):

  - It allows for the development of a cognitive assistant archetype, which considers the integration of multiple applications (see Section 4.2 and 4.3);

- ▷ Development of CogHelper system (see Chapter 4 and 3):

  - Development of server-side components, which includes the Web services used for the intercommunication of applications (see Section 4.2 and 4.3);
  - Development of a mobile application for Android OS for caregivers with the remote localization feature, which enables caregivers to know the current location of the person with disabilities anywhere (see Section 4.2 and 4.3);
  - Development of a Web application that beside enabling the access to the user location, allows the configuration of other parameters like the available destinations on the application for the person with disabilities (see Section 4.2 and 4.3);
  - Development of a mobile application for the main user of CogHelper to guide him between two locations considering the following:
    * An augmented reality interface in order to reduce the effort needed to understand and follow instructions (see Section 4.3);
    * A reasoning module that uses Speculative Computation to anticipate possible user mistakes (see Section 4.4, 4.6 and 3.7); and
    * Designing of a trajectory mining module to generate the default values used in the speculative module (see Section 4.5).

- ▷ Testing in different fictitious scenarios the developed system:

  - Enabled the validation of the developed work; and
  - Definition of future developments.

5.1.2 Relevant Work

In Chapter 4 we highlighted the main publications considering its scientific projection. During this PhD it has been published a total of 9 international papers, 4 of them in international journals. The full list in given in Sections 5.1.2.1 and 5.1.2.2.

5.1.2.1 Scientific Journals

▷ Ramos, J., Oliveira, T., Satoh, K., Neves, J., & Novais, P. **CogHelper: a Speculative Computation View**. Expert Systems. (submitted)

- **Scimago Journal Factor (2015 - last known)**: 0.496; Q3 - Artificial Intelligence; Q3 - Computational Theory and Mathematics; Q2 - Control and Systems Engineering; Q3 - Theoretical Computer Science
- **JCR Impact Factor (2015 - last known)**: 0.947; Q3 - Computer Science, Artificial Intelligence; Q3 - Computer Science, Theory & Methods

Abstract: Once a patient is diagnosed (or a caregiver suspects that the patient may have) cognitive disabilities he may loose the state of being autonomous, which may range from partial to total lost of independence, according to the level of incidence. Smart houses may be used as a tentative solution to overcome this situation. However, when one goes outside their premises, this alternative may become unusable. Indeed, due to the decreased orientation ability, caregivers may prevent these people from going out, as they may get lost. Therefore, we are developing a system that guides the user through an augmented reality interface and provides a localization tool for caregivers. The orientation method implements a speculative computation module, thus the system may calculate and anticipate possible user mistakes and issue alerts before he takes the wrong path.

▷ Ramos, J., Oliveira, T., Satoh, K., Neves, J., & Novais, P. (2017). **An Orientation Method with Prediction and Anticipation Features**. Iberoamerican Journal of Artificial Intelligence, 20, 82-95.

- **Scimago Journal Factor (2015 - last known)**: 0.108; Q4 - Artificial Intelligence; Q4 - Software

Abstract: Nowadays, progress is constant and inherent to a living society. This may occur in different arenas, namely in mathematical evaluation and healthcare. Assistive technologies are a topic under this evolution, being extremely important in helping users with diminished capabilities (physical, sensory, intellectual). These technologies assist people in tasks that were difficult or impossible to execute. A common diminished task is orientation, which is crucial for the user autonomy. The adaptation to such technologies should require the minimum effort possible in order to enable the person to use devices that convey assistive functionalities. There are several solutions that help a human being to travel between two different locations, however their authors are essentially concerned with the guidance method, giving special attention to the user interface. The CogHelper system aims to overcome these systems by applying a framework of Speculative Computation, which adds a prediction feature for the next user movement giving an anticipation ability to the system. Thus, an alert is triggered before the user turn towards an incorrect path. The travelling path is also adjusted to the user preferences through a trajectory mining module.

▷ Ramos, J., Novais, P., Satoh, K., Oliveira, T., & Neves, J. (2015). **Speculative Orientation and Tracking System**. International Journal of Artificial Intelligence (IJAI), 13(1), 94-119.

- **Scimago Journal Factor (2015)**: 1.209; Q2 - Artificial Intelligence

– **Indexed on** Scopus (Document Type: Article)

Abstract: The current progresses at the intersection of computer science and health care have the potential of greatly improving the living conditions of people with disabilities by removing obstacles that impair the normal unfolding of their everyday lives. Assistive technologies, as an application of scientific knowledge, aim to help users with their diminished capacities and, usually, imply a small adaptation from individuals so that they can use the devices that convey assistive functionalities. One of the most commonly diminished capabilities is that of spatial orientation. This is mirrored by several research works whose goal is to help human beings to travel between locations. Once set up, most of the systems featured in these research works requires changes in the configurations to be made manually in order to achieve a better adjustment to the user. In order to overcome this drawback, the work presented herein features a framework of Speculative Computation to set up the computation of the next step of a user using default values. The consequence of the application of the framework is a faster reaction to user stimuli, which may result in issuing warnings when he is likely to choose the wrong direction.

▷ Ramos, J., Costa, A., Novais, P., & Neves, J. (2014). **Interactive Guiding and Localization Platform**. International Journal of Artificial Intelligence (IJAI), 12(1), 63-78. Retrieved from `http://www.ceser.in/ceserp/index.php/ijai/article/view/2732`

– **Scimago Journal Factor (2014)**: 0.73; Q2 - Artificial Intelligence

– **Indexed on** Scopus (Document Type: Article)

Abstract: Technology is now part of everyone's life, being widespread and present in the most innocuous objects, making people able to benefit from several technological solutions that only a few years ago were impossible to be implemented. For instance, the smartphone

is one example of this type of technology. Usually, this device is equipped with several sensors and a GPS module, which may be used as an orientation system when it carries the right features. The current trend is providing advanced applications to the common public, excluding some fringes of the population, like the people with cognitive disabilities. Thus, everyday technology can be used for helping on several tasks, becoming an interactive terminal, aware of the user conditions. There may be orientation applications that are too complex to be used by people with cognitive disabilities. Therefore, the main goal of this work is to build and implement an orientation method that may be used by people with mild cognitive disabilities and provides several tools to the caregivers. Furthermore, the system is linked to external services like iGenda so the user is stimulated to go outside and increase his/her social participation or not to miss an appointment. The developed system is also a localization system, enabling caregivers to know in real-time the location of the person with cognitive disabilities. Allowing the user to have an independent life.

5.1.2.2 Conference Proceedings

- ▷ Ramos, J., Oliveira, T., Satoh, K., Neves, J., & Novais, P. (2016). **Orientation System Based on Speculative Computation and Trajectory Mining**. In J. Bajo, M. J. Escalona, S. Giroux, P. Hoffa-Dabrowska, V. Julián, P. Novais, N. Sãnchez-Pi, R. Unland, & R. Azambuja-Silveira (Eds.), Highlights of Practical Applications of Scalable Multi-Agent Systems. The PAAMS Collection (Vol. 616, pp. 250-261). Springer International Publishing. `http://doi.org/10.1007/978-3-319-39387-2_21`

  - **Scimago Journal Factor (2015 - Last known)**: 0.149; Q4 - Computer Science (Miscellaneous)
  - **Indexed on** Scopus (Document Type: Conference Paper); ISI Web of Science (Document Type: Proceedings Paper)

Abstract: Assistive technologies help users with disabilities (physical, sensory, intellectual) to perform tasks that were difficult or impossible to execute. Thus, the user autonomy is increased through this technology. Although some adaptation of the user might be needed, the effort should be minimum in order to use devices that convey assistive functionalities. In cognitive disabilities a common diminished capacity is orientation, which is crucial for the autonomy of an individual. There are several research works that tackle this problem, however they are essentially concerned with user guidance and application interface (display of information). The work presented herein aims to overcome these systems through a framework of Speculative Computation, which adds a prediction feature for the next move of the user. With an anticipation feature and a trajectory mining module the user is guided through a preferred path receiving anticipated alerts before a possible shift in the wrong direction.

▷ Ramos, J., Oliveira, T., Novais, P., Neves, J., & Satoh, K. (2015). **An alert mechanism for orientation systems based on Speculative computation**. In Innovations in Intelligent SysTems and Applications (INISTA), 2015 International Symposium on INnovations in Intelligent SysTems and Applications (Vol. 8, pp. 156-163). Madrid: IEEE. `http://doi.org/10.1109/INISTA.2015.7276741`

- **Indexed on** Scopus (Document Type: Conference Paper); ISI Web of Science (Document Type: Proceedings Paper)

Abstract: The role of assistive technologies is to help users with diminished capabilities in the fulfillment of their everyday tasks. One of such tasks is orientation. It is crucial for the autonomy of an individual and, at the same time, it is one of the most challenging tasks for an individual with cognitive disabilities. Existing solutions that tackle this problem are mostly concerned with guidance, tracking and the display of information. However, there is a dimension that has not been the object of concern in existing projects, the prediction

of user actions. This work presents a Speculative Module for an orientation system that is used to alert the user for potential mistakes in his path, anticipating possible shifts in the wrong direction in critical points of the route. With this module, it becomes possible to issue warnings to the user and increase his attention so as to avoid a deviation from the correct path.

▷ Ramos, J., Satoh, K., Novais, P., & Neves, J. (2014). **Modelling an Orientation System based on Speculative Computation**. In S. Omatu, H. Bersini, J. M. Corchado, S. Rodríguez, P. Pawlewski, & E. Bucciarelli (Eds.), Distributed Computing and Artificial Intelligence, 11th International Conference (Vol. 290, pp. 319-326). Springer International Publishing. `http://doi.org/10.1007/978-3-319-07593-8_37`

- **Scimago Journal Factor (2014)**: 0.143; Q4 - Computer Science (Miscellaneous), Q4 - Control and Systems Engineering
- **Indexed on** Scopus (Document Type: Conference Paper); ISI Web of Science (Document Type: Proceedings Paper)

Abstract: Progress is inherent to a living society, which may occur in several different areas (e.g. computation, healthcare) and manners. The present (or now) is the time that is associated with the events perceived directly and in the first time, making, for example, the society to be very inquisitive on assistive technologies and how they may improve the human beings quality of living. This application of scientific knowledge for practical purposes may help the user in his/her diminished capabilities, and, usually, implies a small adaptation on the part of the individual in the use of devices; indeed one of the die down potentials of people with cognitive disabilities is the one of spatial orientation. On the other hand several were the authors that have developed systems to help an human being to travel between two locations. However, once the system is set up the change in the configurations have

to be done manually in order to better adjust the system to the user. In order to go round this drawback, in this work it is presented a framework of speculative computation to set up the computation of the next user step using default values. When the information is obtained the computation is revised. Thus, the system may have a faster reaction to the user stimulus or it may start warning the user before he/she takes the wrong direction.

▷ Ramos, J., Anacleto, R., Novais, P., Figueiredo, L., Almeida, A., & Neves, J. (2013). **Geo-localization System for People with Cognitive Disabilities**. In J. B. Pérez, J. M. C. Rodríguez, J. Fahndrich, P. Mathieu, A. Campbell, M. C. Suarez-Figueroa, A. Ortega, E. Adam, E. Navarro, R. Hermoso, & M. N. Moreno (Eds.), Trends in Practical Applications of Agents and Multiagent Systems (Vol. 221, pp. 59-66). Springer International Publishing. `http://doi.org/10.1007/978-3-319-00563-8_8`

- **Scimago Journal Factor (2013)**: 0.139; Q4 - Computer Science (Miscellaneous), Q4 - Control and Systems Engineering
- **Indexed on** Scopus (Document Type: Conference Paper)

Abstract: Technology is present in almost every simple aspect of the people's daily life. As an instance, let us refer to the smartphone. This device is usually equipped with a GPS module which may be used as an orientation system, if it carries the right functionalities. The problem is that these applications may be complex to operate and may not be within the bounds of everybody. Therefore, the main goal here is to develop an orientation system that may help people with cognitive disabilities in their day-to-day journeys, when the caregivers are absent. On the other hand, to keep paid helpers aware of the current location of the disable people, it will be also considered a localization system. Knowing their current locations, caregivers may engage in others activities without neglecting their prime work, and, at the same time, turning people with cognitive disabilities more independent.

▷ Ramos, J., Anacleto, R., Costa, A., Novais, P., Figueiredo, L., & Almeida, A. (2012). **Orientation System for People with Cognitive Disabilities**. In P. Novais, K. Hallenborg, D. I. Tapia, & J. M. C. Rodríguez (Eds.), Ambient Intelligence - Software and Applications (Vol. 153, pp. 43-50). Springer Berlin Heidelberg. `http://doi.org/10.1007/978-3-642-28783-1_6`

- **Scimago Journal Factor (2012)**: 0.133; Q4 - Computer Science (Miscellaneous), Q4 - Control and Systems Engineering
- **Indexed on** Scopus (Document Type: Conference Paper); ISI Web of Science (Document Type: Proceedings Paper)

Abstract: In health care there has been a growing interest and investment in new tools to have a constant monitoring of patients. The increasing of average life expectation and, consequently, the costs in health care due to elderly population are the motivation for this investment.However, health monitoring is not only important to elderly people, it can be also applied to people with cognitive disabilities. In this article we present some systems, which try to support these persons on doing their day-to-day activities and how it can improve their life quality. Also, we present an idea to a project that tries to help the persons with cognitive disabilities by providing assistance in geo-guidance and keep their caregivers aware of their location.

5.2 Future Work

During the research and the development of this work some issues have arisen. Indeed, they complement the core development of CogHelper and, for that reason, as future work it must be considered:

- ▷ The improvement of the security by encrypting the information exchanged between the different applications/modules of the system;
- ▷ Add more alert mechanisms like vibrate the mobile device to gain the attention of the user;
- ▷ Enable an offline mode, where the user may be guided without having access to the Internet;
- ▷ Reduce the GPS error by predicting the next step considering the user speed and the next point he should be moving to (this enables the application to execute with more precision in tunnels);
- ▷ Add a panic detector in order to alert caregivers more quickly (by analyzing the shaking of the device or if the user is constantly going forward and backwards); and
- ▷ Test the entire system in real scenarios and get the user feedback.

5.3 Final Remarks

During the time spent in this PhD work we have tried to develop a new mechanism to help people and let them to be more independent. This work represents an effort on a area that has sometimes be neglected by companies and other researchers. We have achieve interesting conclusions and draw new lines of investigation to go even further to develop a Cognitive Assistant that can truly adapt to the user needs.

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