Ambient Intelligence – a State of the Art from Artificial Intelligence perspective

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Abstract. Ambient Intelligence (AmI) deals with a new world where computing devices are spread everywhere (ubiquity), allowing the human being to interact in physical world environments in an intelligent and unobtrusive way. These environments should be aware of the needs of people, customizing requirements and forecasting behaviours. AmI environments may be so diverse, such as homes, offices, meeting rooms, schools, hospitals, control centers, transports, touristic attractions, stores, sport installations, music devices, etc. In the aims of Ambient Intelligence, research envisages to include more intelligence in the AmI environments, allowing a better support to the human being and the access to the essential knowledge to make better decisions when interacting with these environments. This paper can be seen as a State of the Art of Ambient Intelligence, according to an Artificial Intelligence (AI) perspective. We will define Ambient Intelligence; refer some of their prototype and systems; and to analyze how the main Artificial Intelligence areas can be applied.

Keywords: Ambient Intelligence, Artificial Intelligence, Ubiquitous Computing, Context Awareness.

1 Introduction

The European Commission's IST Advisory Group (ISTAG) has introduced the concept of Ambient Intelligence (AmI) [1,2]. ISTAG believes that it is necessary to take a holistic view of Ambient Intelligence, considering not just the technology, but the whole of the innovation supply-chain from science to end-user, and also the various features of the academic, industrial and administrative environment that facilitate or hinder realisation of the AmI vision [3]. Due to the great amount of technologies involved in the Ambient Intelligence concept we may find several works that appeared even before the ISTAG vision pointing in the direction of Ambient Intelligence trends. Other concepts have some overlapping with Ambient Intelligence, namely Ubiquitous Computing, Pervasive Computing, Context Awareness and Embedded Systems.

The concept of Ubiquitous Computing (UbiComp) was introduced by Mark Weiser during his tenure as Chief Technologist of the Palo Alto Research Center (PARC) [4]. Ubiquitous Computing means that we have access to computing devices anywhere in

an integrated and coherent way. Ubiquitous Computing was mainly driven by Communications and Computing devices scientific communities but now is involving other research areas. Ambient Intelligence differs from Ubiquitous Computing because sometimes the environment where Ambient Intelligence is considered is simply local. For instance we can imagine a meeting room equipped with Ambient Intelligence but without any ubiquity. However, as ubiquity is an important issue, there is a natural trend to consider it in AmI. In the same example referred before it is quite common that meeting participants fail in attending the meeting because they are travelling to another city or country, contacting partners and doing business. To minimize the negative impacts of these absences, Ambient Intelligence must consider ubiquity, so meeting participants that are abroad may have mobile devices, like PDAs or notebooks, and be aware of the meeting development and interact with the meeting participants, a kind of telepresence in the meeting. Another difference is that Ambient Intelligence makes more emphasis on intelligence than Ubiquitous Computing.

A concept that sometimes is seen as a synonymous of Ubiquitous Computing is Pervasive Computing. According Teresa Dillon, Ubiquitous Computing is best considered as the underlying framework, the embedded systems, networks and displays which are invisible and everywhere, allowing us to 'plug-and-play' devices and tools, On the other hand, Pervasive Computing, is related with all the physical parts of our lives; mobile phone, hand-held computer or smart jacket [5].

Context Awareness means that the system has conscience about the current situation we are dealing with. An example is the automatic detection of the current situation in a Control Centre. Are we in presence of a normal situation or are we dealing with a critical situation , or even an emergency? In this Control Centre the intelligent alarm processor will exhibit different outputs according the identified situation [6]. Automobile Industry is also investing in Context Aware systems, like near-accident detection. Human-Computer Interaction scientific community is paying lots of attention to Context Awareness. Context Awareness is one of the most desired concepts to include in Ambient Intelligence, the identification of the context is important for deciding to act in an intelligent way. However, sometimes the AmI final users do not want this high level of intelligence available in the system.

Embedded Systems mean that electronic and computing devices are embedded in current objects or goods. Today goods like cars are equipped with microprocessors; the same is true for washing machines, refrigerators, toys etc. Embedded Systems community is more driven by electronics and automation scientific communities. Current efforts go in the direction to include electronic and computing devices in the most usual and simple objects we use, like furniture, mirrors etc. Ambient Intelligence differs from Embedded Systems since computing devices may be clearly visible in AmI scenarios. However, there is a clear trend to involve more embedded systems in Ambient Intelligence.

The Encyclopedia of Artificial Intelligence refers the concept of Ambient Intelligence [7] and notice that in the past AI community centred the attention in the hardware (40’s and 50’s), in the computer (60’s), in the network (70’s and 80’s) and in the Web

(90's till now). However, it starts to be clear that Intelligence must be provided to our daily-used environments. We are aware of the push in the direction of Intelligent Homes, Intelligent Vehicles, Intelligent Transportation Systems, Intelligent Manufacturing Systems, even Intelligent Cities. This is the reason why Ambient Intelligence concept is so important nowadays [7].

Ambient Intelligence is not possible without Artificial Intelligence. On the other hand, AI researchers must be aware of the need to integrate their techniques with other scientific communities techniques (Automation, Computer Graphics, Communications, etc). Ambient Intelligence is a tremendous challenge, needing the better effort of different scientific communities.

In which concerns AI almost all research areas can contribute for the Ambient Intelligence effort. In section 2 we will explain how areas like Machine Learning, Computational Intelligence, Planning, Natural Language, Knowledge Representation, Computer Vision, Intelligent Robotics, Incomplete and Uncertain Reasoning and Multi-Agent Systems can be used in the Ambient Intelligent challenge.

Section 3 will be dedicated to some Ambient Intelligence real-world prototypes and systems.Finally, in section 4 we try to establish some conclusions and further directions.

2 How Artificial Intelligence can contribute for the Ambient Intelligence challenge

Recently Ambient Intelligence is receiving a significant attention from Artificial Intelligence Community. We may refer the Ambient Intelligence Workshops organized by Juan Augusto and Daniel Shapiro at ECAI'2006 (European Conference on Artificial Intelligence) and IJCAI'2007 (International Joint Conference on Artificial Intelligence) and the Special Issue on Ambient Intelligence, coordinated by Carlos Ramos, Juan Augusto and Daniel Shapiro to appear in the March/April'2008 issue of the IEEE Intelligent Systems magazine.

In this section we will analyze the possible contributions of AI community for the Ambient Intelligence effort.

2.1 Knowledge Representation

Knowledge Representation is one of the most important areas in the AI field. After the bad times of AI in the 60's it started to be clear that knowledge is too important for the success of Intelligent Systems. AI reborn at the beginning of the 70's was due to the success of some Knowledge-based Systems, like MYCIN [8] or AUTHORIZER's ASSISTANT [9]. Expert Systems achieved a tremendous success in areas like Medicine, Industry, and Business. During the 90's with the strong devel-

opment of the Internet and the born of WWW the human being was faced with a critical problem; information achieved huge dimensions and the mapping between information and knowledge was pointed as urgent. AI community started to pay attention to Ontologies and Semantic Web. New areas like Information Retrieval and Text Mining appeared.

The early experience in Intelligent Systems development show us that intelligence is not possible without knowledge. However, little attention has been paid to Knowledge Representation in most of the Ambient Intelligence projects.

2.2 Machine Learning

Machine Learning received attention from the AI community since the beginning. The building of the first artificial neural models and hardware, with the Walter Pitts and Warren McCullock work [10] and Marvin Minsky and Dean Edmonds SNARC system are in the origin of AI. Neural Networks have obtained a great success, namely after the 70's, being applied in many real-world problems, namely in classification. Other techniques have been used with success, using more high-level descriptions, like Inductive Learning, Case-based Reasoning, and Decision Trees based methods.

During the 80's the term Data Mining started to be used. Many people from Databases area preferred to use this term to refer to the Machine Learning techniques (together with some Statistics methods like K-means) in the overall Knowledge Discovery effort. Data Mining is seen just like a phase in Knowledge Discovery (selection, cleaning and pre-processing are phases before Data Mining, while interpretation and evaluation are phases after Data Mining). At the end of the 90's Business Intelligence appeared as a buzzword in Information Systems, covering Data Mining and Knowledge Discovery, but also Warehouses, Enterprise Resource Planning, Client Relationship Management among others.

Nowadays, Machine Learning is widely used, so it is expectable that Ambient Intelligence will need to handle this kind of technology. One aspect very important for AmI is the need to learn from user observation. Several systems understand user commands, but they are not so intelligent to avoid things that the user does not wish to do. The use of basic Machine Learning methods will allow learning from the user observation, making AmI systems more acceptable for users.

2.3 Computational Intelligence

On the last years Computational Intelligence community is very active, claiming for a great success in real world problems. Sometimes this community is involved in the AI field, sometimes appears as an alternative to symbolic AI and more close to Operations Research. Computational Intelligence involves many pattern recognition and optimization oriented methods, like Neural Networks, Genetic Algorithms, Ant Colo-

nies, Particle Swarm Intelligence, Taboo Search, Simulated Annealing, Fuzzy Logic and even Agents. These methods are oriented for specific problems, suffering from tuning, i.e. parameter selection and values choice is crucial for the success of these methods.

Considering that Ambient Intelligence environments will support the possible choices of the human being we may expect that Computational Intelligence will be placed in AmI systems.

2.4 Planning

Planning is the activity by means it is possible to solve a problem in which the solution has the format of a plan. AI Planning studies all the aspects relative to general planning. Allen Newell's General Problem Solver system has defined some important aspects for Planning, however the first system exclusively dedicated to AI Planning was STRIPS. The first Planning systems were dedicated to Blocks World, however, namely after the 80's, real-world problems were treated by AI involving several types of constraints (e.g. resources, time). Plans can be established before the plan execution (off-line) or during the execution (on-line). They can be deliberative (we plan and execute what was planned without considering non-expected events) or reactively (we react to stimulus in a much more basic way), or hybrid (combining the best of deliberative and reactive policies).

Planning is studied in many other areas. In Robotics it is important the Trajectory Plan for robot arms movements or for mobile robots movements, collision avoidance are the main aspect to deal with, and the problem is much more a geometric reasoning problem, different from most AI symbolic reasoning planners. Assembly Planning is another very important area, while having some analogy with Blocks World problems, the geometry is also important here. Manufacturing Systems deal with Planning, in this area the attention is given to plan how products will be manufactured (Process Planning) and produced (Production Planning, that is more a scheduling problem) or even how the layout of the factories will be done (Layout Planning). Planning is studied in many other disciplines, so we listen terms like Treatment Planning in Medicine, Enterprise Resource Planning in Information Systems, and Restoration Planning in Power Systems.

Planning is one of the activities more related with intelligence. It is quite difficult to convince someone that a system is intelligent without the ability to plan how to solve problems. In this way Ambient Intelligence environments will need to support planning in order to give intelligent advices for the users. A clear example is found in Transportation area, inside vehicles where intelligent driving systems will help drivers; and on the road, where route planning will consider many constraints related with traffic, time, and cost.

2.5 Incompleteness and Uncertainty

Real-world problems are affected with incompleteness and uncertainty. Generally we deal with information, some part of this information is correct, some part may be incorrect, and some part is missing. The question is how to proceed with an elaborated reasoning process dealing with these information problems. Many techniques have been used (e.g. Bayesian Networks, Fuzzy Logic, Rough Sets) to handle the problem.

Since AmI environments are real, we are sure that Incompleteness and Uncertainty will be present there, and users expect support from these environments even if these problems exist.

2.6 Speech Recognition and Natural Language

The most common way human beings use to interact is by means of language, by voice or written. So it is clear that this kind of interaction is also expectable in the environments with Ambient Intelligence. Speech Recognition and Natural Language are different and complementary problems, using different techniques.

In Speech Recognition an electric signal is obtained by means of a microphone. The basic problem is the identification of phonemes in this signal, so it is more a signal processing and pattern recognition work. Joining phonemes and identifying words is the next activity. Several Speech Recognition systems are available and can be used with more or less success, depending how the user speaks.

The input of Natural Language is a written sequence, resulting from a speech recognition system or obtained from a keyboard, or even from a written document. The objective of Natural Language is to understand this input. First, it is necessary to do a Syntax analysis, after this Semantics is important. This is a difficult task, namely because some sentences are ambiguous, like the well known “the boy saw the man in the hill with the telescope” (Who was in the hill? Who has the telescope?). If this ambiguity is observed in just one sentence, the problem is much more complex in texts, because the understanding of one sentence depends on the understanding of previous sentences, or posterior sentences, or even from the user knowledge. Knowledge Representation plays an important role in Natural Language. Automatic Translation Systems are one of the most studied areas of Natural Language. Recently there is a trend to use Statistics-based Translation, while being fast and more easy to implement, the results are not good. So, today the combination between statistics approaches and knowledge-oriented approaches is being experimented.

2.7 Computer Vision

Vision is the richest sensorial input of the human being. So, the ability to automate the vision is very important. Basically, Computer Vision is a geometric reasoning problem. Computer Vision comprises many areas, like Image Acquisition, Image

Processing, Object Recognition (2D and 3D), Scene Analysis, and Image Flow Analysis.

Computer Vision can be used in different situations in Ambient Intelligence. In Intelligent Transportation Systems it can be used to identify traffic problems on the roads, or in intelligent driving assistance to identify patterns or the approaching to another vehicle. Computer Vision can be used to identify human being gestures used to control the environment equipment or expressions of the human being face to identify the emotional state of somebody.

2.8 Robotics

Robots are widely used in Manufacturing, in this kind of environment Robotics can be viewed according to the automation approach. However, there is a close connection between Robotics and Artificial Intelligence, namely where the attention is to give more focus to all intelligent aspects of the created robots. This resulted in what was called previously Intelligent Robotics and received more recently a new vision, referred as Cognitive Robotics.

Ambient Intelligent environments, like home, can benefit of intelligent robots. This is especially true when persons live alone, are elder people, or have health problems. The creation of intelligent robots, able to perform several tasks or just to act as companion elements is very important. The problem is that it is easy to create robots operating very well in specific tasks, but it is too complex to create robots with the flexibility to do different tasks as the human being. This limitation is more related with physical constraints.

2.9 Multi-Agent Systems

In the beginning of the 80's AI community started with a new area, Distributed Artificial Intelligence (DAI), combining AI with Distributed Computing. From DAI emerged the Intelligent Agents and Multi-Agent Systems Paradigms. Agents are expected to support several features, like sensing capabilities, autonomy, reactive and proactive reasoning, social abilities, and learning, among others. Multi-Agent Systems emphasize the social abilities, like communication, cooperation, conflict resolution, negotiation, argumentation, and emotion. Rapidly, Multi-Agent Systems started to be the main paradigm in AI. After the World Wide Web boom in the 90's Agents received even more attention.

Multi-Agent Systems are especially good in modeling real-world and social systems, where problems are solved in a concurrent and cooperative way without the need to obtain optimal solutions (e.g. in traffic or manufacturing).

In Ambient Intelligence environments, Agents are a good way to model meaningful entities, like rooms, cars or even persons.

3 Ambient Intelligence Prototypes and Systems

Here we will analyze some examples of Ambient Intelligence prototypes and systems, divided by the area of application.

3.1 AmI at Home

Domotics is a consolidated area of activity. After the first experiences using Domotics at homes there was a trend to refer the Intelligent Home concept. However, Domotics is too centred in the automation, giving to the user the capability to control the house devices from everywhere. We are still far from the real Ambient Intelligence in homes, at least at the commercial level.

Several organizations are doing extended experiences to achieve the Intelligent Home concept. Some examples are HomeLab from Philips, MIT House_n, Georgia Tech Aware Home, Microsoft Concept Home, and e2 Home from Electrolux and Ericsson. **Fig. 1** illustrates a personal health coach detecting the use of a toothbrush and playing cartoon to make brushing enjoyable for children, an example from HomeLab.

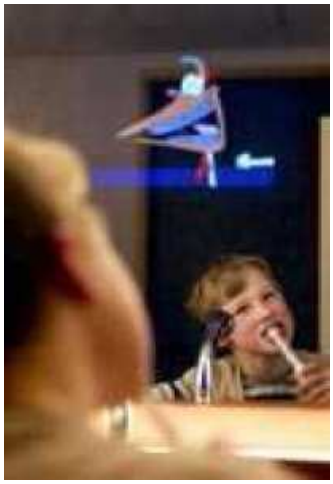

Fig. 1. Entertainment in the bathroom mirror, from Philips HomeLab

3.2 AmI in Vehicles and Transports

Since the first experiences with NAVLAB 1 [11], Carnegie Mellon University has developed several prototypes for Autonomous Vehicle Driving and Assistance. The last one, NAVLAB 11, is an autonomous Jeep. Most of the car industry companies are doing research in the area of Intelligent Vehicles for several tasks like car parking assistance or pre-collision detection.

Another example of AmI application is related with Transports, namely in connection with Intelligent Transportation Systems (ITS). The ITS Joint Program of the US Department of Transportation identified several areas of applications, namely: arterial management; freeway management; transit management; incident management; emergence management; electronic payment; traveler information; information management; crash prevention and safety; roadway operations and management; road weather management; commercial vehicle operations; and intermodal freight. In all these application areas Ambient Intelligence can be used.

3.3 AmI in Elderly and Health Care

Several studies point to the aging of population during the next decades. While being a good result of increasing of life expectation, this also implies some problems. The percentage of population with health problems will increase and it will be very difficult to Hospitals to maintain all patients. Our society is faced with the responsibility to care for these people in the best possible social and economical ways. So, there is a clear interest to create Ambient Intelligence devices and environments allowing the patients to be followed in their own homes or during their day-by-day life.

The medical control support devices may be embedded in clothes, like T-shirts, collecting vital-sign information from sensors (blood pressure, temperature, etc). Patients will be monitored at long distance. The surrounding environment, for example the patient home, may be aware of the results from the clinical data and even perform emergency calls to order an ambulance service.

For instance, we may refer the IST Vivago® system (IST International Security Technology Oy, Helsinki, Finland), an active social alarm system, which combines intelligent social alarms with continuous remote monitoring of the user's activity profile [12].

3.4 AmI in Tourism and Cultural Heritage

Tourism and Cultural Heritage are good application areas for Ambient Intelligence. Tourism is a growing industry. In the past tourists were satisfied with pre-defined tours, equal for all the people. However there is a trend in the customization and the same tour can be conceived to adapt to tourists according their preferences.

Immersive tour post is an example of such experience [13]. MEGA is an user-friend virtual-guide to assist visitors in the Parco Archeologico della Valle del Temple in Agrigento, an archaeological area with ancient Greek temples in Agrigento, located in Sicily, Italy [14]. DALICA has been used for constructing and updating the user profile of visitors of Villa Adriana in Tivoli, near Rome, Italy [15].

3.5 AmI at Work

The human being spends considerable time in working places like offices, meeting rooms, manufacturing plants, control centres, etc.

SPARSE is a project initially created for helping Power Systems Control Centre Operators in the diagnosis and restoration of incidents [6]. It is a good example of context awareness since the developed system is aware of the on-going situation, acting in different ways according the normal or critical situation of the power system. This system is evolving for an Ambient Intelligence framework applied to Control Centres.

Decision Making is one of the most important activities of the human being. Nowadays decisions imply to consider many different points of view, so decisions are commonly taken by formal or informal groups of persons. Groups exchange ideas or engage in a process of argumentation and counter-argumentation, negotiate, cooperate, collaborate or even discuss techniques and/or methodologies for problem solving. Group Decision Making is a social activity in which the discussion and results consider a combination of rational and emotional aspects. ArgEmotionAgents is a project in the area of the application of Ambient Intelligence in the group argumentation and decision support considering emotional aspects and running in the Laboratory of Ambient Intelligence for Decision Support (LAID), seen in **Fig. 2** [16], a kind of Intelligent Decision Room. This work has also a part involving ubiquity support.

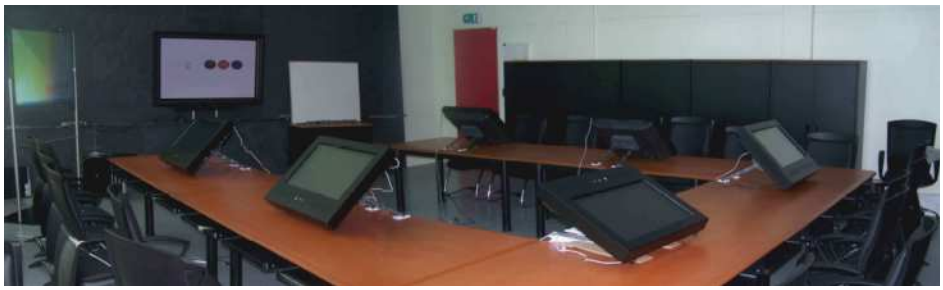

Fig. 2. Ambient Intelligence for Decision Support, LAID Laboratory

3.6 AmI in Sports

Sports involve high-level athletes and many more practitioners for hobby of free-time occupancy. Many sports are done without any help of the associated devices, opening here a clear opportunity for Ambient Intelligence to create sports assistance devices and environments.

FlyMaster NAV+ is a free-flight on-board pilot Assistant (e.g. gliding, hangliding, paragliding), using the FlyMaster F1 module with access to GPS and sensorial information. FlyMaster Avionics S.A., a spin-off, was created to commercialize these products (see **Fig. 3**).

Fig. 3. FlyMaster Pilot Assistant device, from FlyMaster Avionics S.A.

4 CONCLUSIONS

This article presents the state of the art in which concerns Ambient Intelligence field. After the history of the concept, we established some related concepts definitions, like Ubiquitous and Pervasive Computing, Embedded Systems, Context Awareness. Applications of Ambient Intelligence are presented. We identified several Artificial Intelligence areas important for achieving the Ambient Intelligence concept, namely Knowledge Representation, Machine Learning, Computational Intelligence, Planning, Multi-Agent Systems, Natural Language, Speech Recognition and Computer Vision, Robotics, Incompleteness and Uncertainty.

Ambient Intelligence deals with a futuristic notion for our lives. Most of the practical experiences concerning Ambient Intelligence are still in a very incipient phase, due to the recent existence of this concept. Today, it is not clear the separation between the computer and the environments. Most Ambient Intelligence prototypes involve computers, notebooks, PDAs, interactive displays, keyboards, mouses, pointers. However, for new generations things will be more transparent, and environments with Ambient Intelligence will be more widely accepted. Ambient Intelligence in vehicles and in traffic and travel control, in health and elderly care, in tourism and cultural heritage, at home and at work, will be a reality soon. There is a long way to follow in order to achieve the Ambient Intelligence concept, however, in the future, this concept will be referred as one of the landmarks in the Artificial Intelligence development.

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