AMBIENT INTELLIGENCE: BASIC CONCEPTS AND APPLICATIONS (Keynote Lecture)

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Abstract: Ambient Intelligence is a multi-disciplinary approach which aims to enhance the way environments and people interact with each other. The ultimate goal of the area is to make the places we live and work in more beneficial to us. Smart Homes is one example of such systems but the idea can be also used in relation to hospitals, public transport, factories and other environments.
The achievement of Ambient Intelligence largely depends on the technology deployed (sensors and devices interconnected through networks) as well as on the intelligence of the software used for decision-making. The aims of this article are to describe the characteristics of systems with Ambient Intelligence, to provide examples of their applications and to highlight the challenges that lie ahead, especially for the Software Engineering and Knowledge Engineering communities.

1 Introduction

The steady progress in technology have not only produced a plethora of new devices and spread computing power into various levels of our daily lives, it is also driving a transformation on how society relates to computer science. The miniaturization process in electronics has made available a wide range of small computing devices which can now help us when we wash clothes and dishes, cook our meals, and drive our cars. Inspired on those successful applications which are now embedded in our daily lives many new technological developments are spreading little computing devices everywhere possible (see as an example recent developments on RFID technology (Want, 2004)). Several new devices of that kind are being investigated and produced every year. These developments are being quickly absorbed by the research community (see for example recent reports on (Nugent and Augusto, 2006; Augusto and Shapiro, 2007)) and by several leading companies around the world (see for example (Philips, 2007)).

This richness in technology and computer power has been continuously progressing since the very inception of computer science. First a machine was shared by many highly trained programmers. Then it became possible in many countries around the world that many people, not necessarily with a high level of training, will have access to one PC in an individual basis. Now many people can have access to several computing devices like a PC, a laptop and a PDA at work plus a PC at home and various smaller processing units embedded in electro-domestic appliances. All seems to indicate this trend will continue. Slowly systems are being designed in such a way that people do not need to be a computer specialist to benefit from computing power. This technical possibility is being explored in an area called *Ambient Intelligence* (AmI) where the idea of making computing available to people in a non-intrusive way is at the core of its values. The benefit of an AmI system is measured by how much can give to people whilst minimizing explicit interaction. The aim is to enrich specific places (a room, a building, a car, a street) with computing facilities which can react to people's needs and provide assistance.

Given the evolution of markets and industry people is now more willing to accept technologies participating and shaping their daily life. At the same time there are important driving forces at political level which create a fertile terrain for this to happen. An important example of this is the decentralization of health care and development of health and social care assistive technologies. For various reasons governments and health professionals are departing away from the hospital-centric health care system enabling this shift of care from the secondary care environment to primary care. Subsequently, there is an effort to move away from the traditional concept of patients being admitted into hospitals rather to enable a more flexible system whereby people are cared for closer to home, within their communities. Smart homes are one such example of a technological development which facilitates this trend of bringing the health and social care system to the patient as opposed to bringing the patient into the health system.

The aim of this paper is to describe more specifically the relationship in between AmI and related areas (Section 2), to describe some possible scenarios of application (Section 6), and finally to highlight the technical difficulties and opportunities laying ahead (Section 7) which, in the view of the author, will shape the course of important areas of computer science (Section 8).

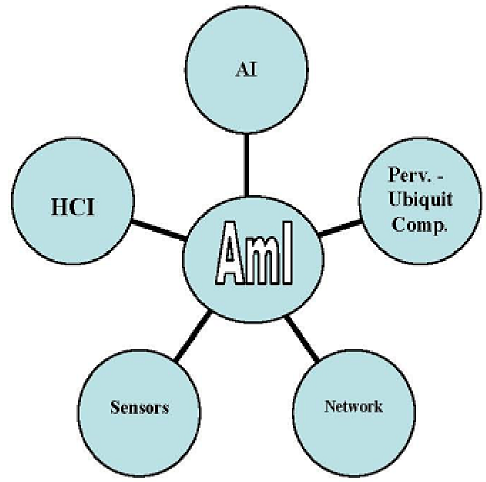

Figure 1: Relationship between AmI and other areas.

2 Ambient Intelligence

"Ambient Intelligence" (AmI) (IST Advisory Group, 2001; Augusto and Cook, 2007) is growing fast as a multi-disciplinary approach which can allow many areas of research to have a significant beneficial influence into our society. The basic idea behind AmI is that by enriching an environment with technology (mainly sensors and devices interconnected through a network), a system can be built to take decisions to benefit the users of that environment based on real-time information gathered and historical data accumulated. AmI has a decisive relationship with many areas in computer science. The relevant areas are depicted in Figure 1.

Here we must add that whilst AmI nourishes from all those areas, it should not be confused with any of those in particular. Networks, sensors, interfaces, ubiquitous or pervasive computing and AI are all relevant but none of them conceptually covers AmI. It is AmI which puts together all these resources to provide flexible and intelligent services to users acting in their environments.

AmI is aligned with the concept of the *"disappearing computer"* (Weiser, 1991; Streitz and Nixon, 2005):

> *"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."*

The notion of a disappearing computer is directly linked to the notion of "Ubiquitous Computing" (Weiser, 1993), or "Pervasive Computing" (Saha and Mukherjee, 2003) as IBM called it later on. Some authors equate "Ubiquitous Computing" and "Pervasive Computing" with "Ambient Intelligence". Here we argue that Ubiquitous and Pervasive systems are different as they emphasize the physical presence and availability of resources and miss a key element: the explicit requirement of *"Intelligence"*. This we think, is the ground of Artificial Intelligence (AI) (Russell and Norvig, 2003) and should not be ignored. Here we refer to AI in a broad sense, encompassing areas like agent-based software and robotics. What matters is that AmI systems provide flexibility, adaptation, anticipation and a sensible interface in the interest of human beings. The same observations can be made about alternatives to *"Ubiquitous"* or *"Pervasive"* like the most recent, and less used, term: *"Everyware"* (Greenfield, 2006).

This paper will be based in a more suitable definition which expands Raffler's (Raffler, 2006) to emphasize Intelligence as a fundamental element of an AmI system:

> *"A digital environment that proactively, but sensibly, supports people in their daily lives."*

In order to be sensible, a system has to be intelligent. That is how a trained assistant, e.g. a nurse, typically behaves. It will help when needed but will restrain to intervene unless is necessary. Being sensible demands recognizing the user, learning or knowing her/his preferences and the capability to exhibit empathy with the user's mood and current overall situation.

Although the term Ambient Intelligence will be used in this article to describe this area of research in Europe, the reader should be aware that similar developments on USA and Canada are usually referred as *"Smart Environments"* or *"Intelligent Environments"*. We keep here the European denomination as it emphasizes the intelligence factor of these systems as opposed to the physical infrastructure.

Important for Ubiquitous/Pervasive computing are the "5Ws" (Who, Where, What, When and Why) principle of design (Brooks, 2003) :

Who: the identification of a user of the system and the role that user plays within the system in relation to other users. This can be extended to identifying other important elements like pets, robots and objects of interest within the environment.

Where: the tracking of the location where a user or an object is geographically located at each moment during the system operation. This can demand a mix of technologies, for example technology that may work well indoors may be useless outdoors and viceversa.

When: the association of activities with time is fundamental to build a realistic picture of a system's dynamic. For example, users, pets and robots living in a house will change location very often and knowing when those changes happened and for how long they lasted are fundamental to the understanding of how an environment is evolving.

What: the recognition of activities and tasks users are performing is fundamental in order to provide appropriate help if required. The multiplicity of possible scenarios that can follow an action makes this very difficult. Spatial and temporal awareness help to achieve task awareness.

Why: the capability to infer and understand intentions and goals behind activities is one of the hardest challenges in the area but with no doubt a fundamental one which allows the system to anticipate needs and serve users in a sensible way.

An important aspect of AmI has to do with interaction. On one side there is a motivation to reduce the human-computer interaction (HCI) (Dix et al., 2003) as the system is supposed to use its intelligence to infer situations and user needs from the recorded activities, as if a passive human assistant were observing activities unfold with the expectation to help when (and only if) required. On the other hand, a diversity of users may need or voluntarily seek direct interaction with the system to indicate preferences, needs, etc. HCI has been an important area of computer science since the inception of computing as an area of study. Today, with so many gadgets incorporating computing power of some sort, HCI continues to thrive as an important area. An example of an attempt to conciliate both worlds as been reported at: (Augusto et al., 2007) where image processing is done locally inside the context where images are gathered and then a text-based summary is used for diagnosis of the situation. This allows the use of a rich source of information whilst at the same time retaining privacy.

3 Smart Homes

An example of an environment enriched with AmI is a "Smart Home". See for example Figure 2 for a depiction of a basic layout and (Cook and Das, 2004; Augusto and Nugent, 2006) for more technical details on how this Smart Homes can operate intelligently.

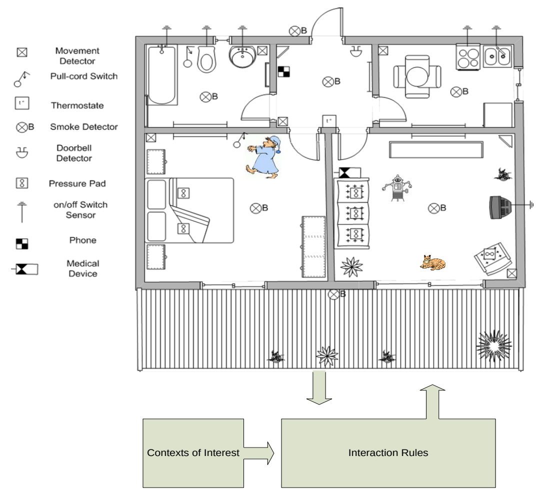

Figure 2: A Smart Home as an AmI instance.

By Smart Home here we understand a house equipped to bring advanced services to its users. Naturally, how smart a house should be to qualify as a Smart Home is, so far, a subjective matter. For example, a room can have a sensor to decide when its occupant is in or out and on that basis keep lights on or off. However, if sensors only rely on movement and no sensor in, say, the door can detect when the person left, then a person reading and keeping the body in a resting position can confuse the system which will leave the room dark. The system will be confusing absence of movement with absence of the person, that inference will certainly not be considered as particularly "bright", despite the lights.

Technology available today is rich. Several artifacts and items in a house can be enriched with sensors to gather information about their use and in some cases even to act independently without human intervention. Some examples of such devices are electrodomestics (e.g., cooker and fridge), household items (e.g., taps, bed and sofa) and temperature handling devices (e.g., air conditioning and radiators). Expected benefits of this technology can be: (a) increased safety (e.g., by monitoring lifestyle patterns or the latest activities and providing assistance when a possibly harmful situation is developing), (b) comfort (e.g., by adjusting temperature automatically), and (c) economy (e.g., controlling the use of lights). There is a plethora of sensing/acting technology, ranging from those that stand alone (e.g., smoke or movement detectors), to those fitted within other objects (e.g., a microwave or a bed), to those that can be worn (e.g., shirts that monitor heart beat). For more about sensors and their applications the reader may like to consider (Want, 2004), and (Nugent and Augusto, 2006).

Recent applications include the use of Smart Homes to provide a safe environment where people with special needs can have a better quality of life. For example, in the case of people at early stages of senile dementia (the most frequent case being elderly people suffering from Alzheimer's disease) the system can be tailored to minimize risks and ensure appropriate care at critical times by monitoring activities, diagnosing interesting situations and advising the carer. There are already many ongoing academic research projects with well established Smart Homes research labs in this area, for example Domus (Pigot et al., 2002), Aware Home (Abowd et al., 2002), MavHome (Cook, 2006), and Gator Tech Smart Home (Helal et al., 2005).

4 Other Environments and Applications for AmI

Other applications are also feasible and relevant and the use of sensors and smart devices can be found in:

- Health-related applications. Hospitals can increase the efficiency of their services by monitoring patients' health and progress by performing automatic analysis of activities in their rooms. They can also increase safety by, for example, only allowing authorized personnel and patients to have access to specific areas and devices.
- Public transportation sector. Public transport can benefit from extra technology including satellite services, GPS-based spatial location, vehicle identification, image processing and other technologies to make transport more fluent and hence more efficient and safe.
- Education services. Education-related institutions may use technology to track students progression on their tasks, frequency of attendance to specific places and health related issues like advising on their diet regarding their habits and the class of intakes they opted for.
- Emergency services. Safety-related services like fire brigades can improve the reaction to a hazard by locating the place more efficiently and also by preparing the way to reach the place in connection with street services. The prison service can also quickly locate a place where a hazard is occurring or is likely to occur and prepare better access to it for security personnel.
- Production-oriented places. Production-centred places like factories can self-organize according to the production/demand ratio of the goods produced. This will demand careful correlation between the collection of data through sensors within the different sections of the production line and the pool of demands via a diagnostic system which can advice the people in charge of the system at a decision-making level.

Well-known leading companies have already invested heavily in the area. For example, Philips (Philips, 2006) has developed Smart Homes for the market including innovative technology on interactive displays. Siemens (Siemens, 2006) has invested in Smart Homes and in factory automation. Nokia (Nokia, 2006) also has developments in the area of communications where the notion of ambience is not necessarily restricted to a house or a building. VTT (VTT, 2006) has developed systems which advise inhabitants of Smart Homes on how to modify their daily behaviour to improve their health.

In the next section we give one step in the direction of identifying some of the important issues and how to consider them explicitly within a system.

5 System Flow

An AmI system can be built in many ways. Mainly they will need sensors and devices to surround occupants of an environment with technology (we can call this an "*e-bubble*") that can provide accurate feedback to the system on the different contexts which are continuously developing. The information collected has to be transmitted by a network and pre-processed by what is called middleware. Finally, in order to make decision-making easier and more beneficial to the occupants of the environment the will have a higher-level layer of reasoning which will accomplish diagnosis and advice or assist other humans which have the final responsibility on the operation of the system. Some elements that may be included are for example an Active Database where the events are collected to record sensors that have been stimulated and a reasoner which will apply spatio-temporal reasoning and other techniques to take decisions (Augusto and Nugent, 2004). A typical information flow for AmI systems is depicted in Figure 3.

As the interactors perform their tasks, some of these tasks will trigger sensors and those in turn will activate the reasoning system. Storing frequency of activities and decisions taken during relevant parts of the system's life time allow the system to learn information which is useful to decision makers, e.g., for

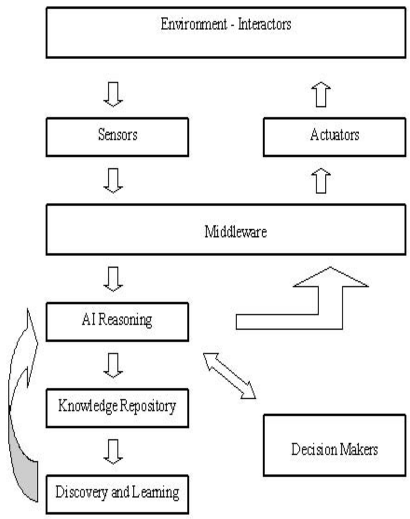

Figure 3: Information flow in AmI systems.

doctors and nurses to decide if a change in the medication of a patient suffering Alzheimer's disease may be needed. It also allows learning which can improve the system itself, e.g., to make interaction rules more personalized and useful for a particular person. For example, peoples' habits in winter are different than in summer in terms of what is the usual time to get up or the time they spend watching TV or sleeping.

Lets examine in the following section what the possible intelligent environments can be. The reader more interested in a formal treatment of AmI concepts is referred to (Augusto, 2007) where some of the following scenarios are formalized with regards to an abstract AmI architecture.

6 AmI Scenarios

AmI systems with the general architecture described in the previous section can be deployed in many possible environments. Below we describe some of these environments in order to better illustrate the scope of the idea.

Scenario 1: An instance of the concept of Ambient Intelligence is a Smart Home. Here an AmI specification may include the following details. The meaningful environment is the house, including the backyard and a portion of the front door as these areas also have sensors. Objects are plants, furniture, and so on. Figure 2 have three interactors depicted and therefore I has three elements: a person in the bedroom, a cat, and a floor cleaning robot in the living room. There are also multiple sensors in S, movement sensors, pull cord switch, smoke detector, doorbell detector, pressure pad, plus switch sensors for taps, a cooker and a TV. In addition, there is a set of actuators, as the taps, cooker and TV also have the capacity to be turned on and off without human assistance. Medical devices can also exhibit autonomous behaviour by making recommendations before and after their usage. Contexts of interest can be “cooker is left on without human presence in the kitchen for more than 10 minutes”, “occupant is still sleeping after 9AM”. Interaction rules specified may consider that “if occupant is in bed and is later than 9AM and contact has been attempted unsuccessfully then carer should be notified”.

Scenario 2: Let us consider a specific room of a hospital as the environment, whit a patient monitored for health and security reasons. Objects in the environment are furniture, medical equipment, specific elements of the room like a toilet and a window. Interactors in this environment will be the patient, relatives and carers (e.g., nurses and doctors). Sensors can be movement sensors and wrist band detectors for identifying who is entering or leaving the room and who is approaching specific areas like a window or the toilet. Actuators can be microphones within the toilet to interact with the patient in an emergency. Contexts of interest can be “the patient has entered the toilet and has not returned after 20 minutes” or “frail patient left the room”. Interaction rules specified in IR can consider, for example, that “if patient is leaving the room and status indicates that this is not allowed for this particular patient then nurses should be notified”.

Scenario 3: Assume a central underground coordination station is equipped with location sensors to track the location of each unit in real-time. Based on the time needed to connect two locations with sensors, the system can also predict the speed of each unit. Examples of objects in this environment are tracks and stations. Interactors are trains, drivers and command centre officers. Sensors are used for identification purposes based on ID signals sent from the train. Other signals can be sent as well, e.g., emergency status. Actuators will be signals coordinating the flow of trains and messages that can be delivered to each unit in order to regulate their speed and the time they have to spend at a stop. Contexts of interest can be “delays” or “stopped train”. One interaction rule can be “if line blocked ahead and there are intermediate stops describe the situation to passengers”.

Scenario 4: Lets assume a school where students are monitored to best advise on balancing their learning experience. The objects within a classroom or play ground are tables and other available elements. The interactors are students and teachers. The sensors will identify who is using what scientific kit and that in turn will allow monitoring of how long students are involved with a particular experiment. Actuators can be recommendations delivered to wristwatch-like personalized displays. Contexts of interest can be "student has been with a single experimentation kit for too long" or "student has not engaged in active experimentation". The first context will trigger a rule "if student has been interacting with one single kit for more than 20 minutes advise the student to try the next experiment available" whilst the second one can send a message to a tutor, such as "if student S has not engaged for more than 5 minutes with an experiment then tutor has to encourage and guide S".

Scenario 5: When a fire brigade has to act then the environment can be a city or a neighborhood. Streets can be equipped with sensors to measure passage of traffic within the areas through which the fire brigade truck might go through in order to reach the place where the emergency is located. Objects here will be streets and street junctions. Interactors will be cars. Actuators can be traffic lights as they can help speed the fire brigade through. A context will be a fire occurring at peak time with a number of alternative streets to be used. An interaction rule can be "if all streets are busy, use traffic lights to hold traffic back from the vital passage to be used".

Scenario 6: If a production line is the environment then different sensors can track the flow of items at critical bottlenecks in the system and the system can compare the current flow with a desired benchmark. Decision makers can then take decisions on how to proceed and how to react to the arrival of new materials and to upcoming demands. Different parts of the plant can be de/activated accordingly. Similarly, sensors can provide useful information on places where there has been a problem and the section has stopped production, requiring a deviation in flow. Objects here are transportation belts and elements being manufactured whilst actuators are the different mechanisms dis/allowing the flow of elements at particular places. A context can be "a piece of system requiring maintenance" and a related interaction rule can be "if section A becomes unavailable then redirect the flow of objects through alternative paths".

7 Are we there yet...?

A variety of technology that can be deployed and distributed along different environments is being produced. People and organizations are opening to this transformation. Computing, after five decades of unrelenting growth, is in the position to offer systems that will permeate people's daily life as never before.

However, this branch of science has already experienced the pain caused by rushed expectations. Remember AI in the 60s and the AI winter? And then Software Engineering had its ups and downs as well. Despite good success in achieving techniques (ACM-Pnueli, 1996) and tools (ACM-SPIN, 2001) to increase the reliability of software, major disasters occur from time to time with disastrous consequences for people and companies counted in deaths, injured and multi-millon losses.

Given that in AmI systems people is the main beneficiary (but also mainly affected when the system does not deliver as expected) previous lessons learnt should be considered carefully and enough preparation should be done before widespread use occur.

Looking backwards to how systems have been developed and witnessing the commercial success of faulty systems driven be effective marketing, it is quite likely that systems will be developed unsystematically and deployed prematurely. AmI systems are different to previous one and need different methods and tools to flourish.

8 Conclusions

In this chapter, we have reviewed the notion of Ambient Intelligence and associated emerging areas within computer science. We highlighted that an essential component of the area is the distribution of technology intelligently orchestrated to allow an environment to benefit its users. We illustrated the concept by describing briefly a number of different areas of possible application. We expanded in what currently is the driving force of AmI: Smart Homes.

Although the area is very new it has attracted significant attention, sometimes under different names like "intelligent ubiquitous systems" or "intelligent environments". An indication of this is that there is a good number (rapidly increasing) of scientific events, books published, commercial exhibitions and governmental projects being launched every year.

AmI has a strong emphasis on forcing computing to make an effort to reach and serve humans. This may sound the obvious expectation from computing systems but the reality is that so far humans have to do the effort to specialize themselves in order to enjoy the advantages of computing. It is expected that enforcing this requirement at the core of the area will constitute a major driving force and a turning point in the history of computer science. The technological infrastructure seems to be continuously evolving in that direction, and there is a fruitful atmosphere on all sides involved: normal users/consumers of technology, technology generators, technology providers and governmental institutions, that this paradigm shift is needed and feasible.

Still, achieving that capability is far from easy and certainly is not readily available at the moment. The short history of computer science is full of problems which turned to be harder than expected and there is plenty of examples of important systems that crashed. The very fact that makes AmI systems strong can be also their more serious weakness. If humans are put at the centre of the system and made more dependant on the technological environment (we called this an e-bubble), reliability on that e-bubble will be at the level of safety critical systems.

Since these systems are autonomous and proactive, predictability and reliability should not be underestimated if we want the environments where we live and work to be helpful and safe.

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