Past, Present and Future of Ambient Intelligence and Smart Environments

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Summary. We are gradually making a transition to a new era where computers become truly intertwined with our daily lives. Up to not so long ago, we were able to know clearly where computers were and in which way they affected our lives. This has been gradually blurred and now computing devices of various types are all around us, embedded in different objects we interact with and in that way they influence our lives. There are indications that this trend is irreversible and that computing and society will now interact with each other in far richer ways than before, to the point that computing will become transparent to humans and still intrinsically involved in our daily living. This paper provides a brief overview of the evolution of these fields, describes some of the current developments, and points at some of the immediate challenges that researchers in these area face.

1 The Past

For centuries humans have witnessed scientific and technological leaps that changed the lives of their generation, and those to come, forever. We are no exception. In fact so much of those advances are occurring now, in a more or less unperceived way. Slowly and silently technology is becoming interwoven in our lives in the form of a variety of devices which are starting to be used by people of all ages.

The technological advances in miniaturization of microprocessors (Figure 1) have made possible a significant development for Ambient Intelligence. Computing power is now embedded in many different objects like home appliances (e.g., programmable washing machines, microwave ovens, robotic hovering machines, and robotic mowers), they travel with us outside the home (e.g., mobile phones and PDAs), and they help guide us to and from our home (e.g., car suspension and fuel consumption and GPS navigation). Computers that require reduced power and that are tailored to accomplish very specific tasks are gradually spreading through almost every level of our society.

This widespread availability of resources forms the technological layer for the realization of Ambient Intelligence. Having the necessary technology is not enough for an area of science to flourish. Previous experiences of people with computers over recent decades have created an interesting context where people's expectations of these systems are growing and their fear of using them has decreased. Concomitantly with this difference in the way society perceives technology there is also a change in the way services are handled. 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.

For example, the South Eastern Health & Social Care Trust of Northern Ireland has established a Connected Health project intended to support to approximately 1,000 by 2011 in the community. In the arena of telecare the programme includes the fitting of sensors into private and social housing. The programme is intended to help maintain elderly and vulnerable people stay as safe as possible in their home. In addition, it is intended to increase their level of autonomy, independence and health status particularly if they have a long-term chronic condition, which can be significantly detrimental to their lifestyle.

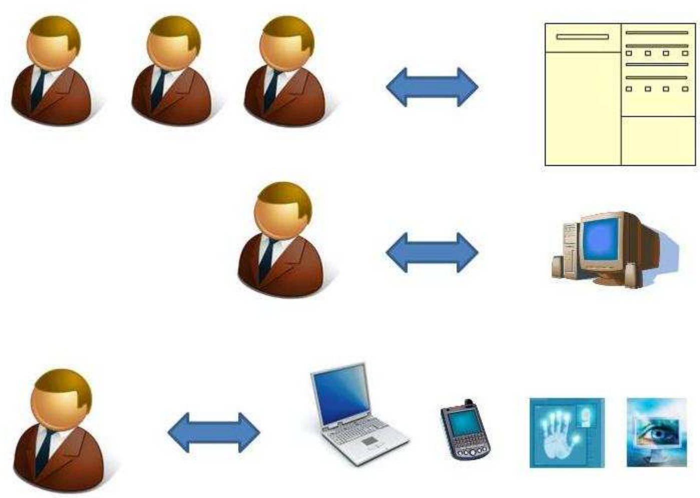

Fig. 1. Historical evolution and shift on availability of computing power per person.

Developments, competencies and drivers are converging at the same time in history and all of the necessary components are in place; that is the need to distribute technology around us, the will to change the way our society interacts with technology, the available technological knowledge and all the elements to satisfy the demand are converging.

2 The Present

The areas of Ambient Intelligence and Smart Environments are being defined naturally as work in the area progresses and on demand by everyday life problems and real applications. Although Ambient Intelligence [19, 12, 42] and Smart Environments [17] are strongly related, we can distinguish them by going back to the old "mind/brain" metaphor used in AI. The first one is more concerned with the specific techniques to make an environment behave intelligently whilst the second one is more related with the intelligent interconnection of resources and their collective behavior. Both overlap hugely and share many common objectives and it is difficult to tell apart one from the other. These areas gradually evolved in the last decades, motivated by seminal work conducted at Xerox Labs under the paradigm of the *disappearing computer* [47]:

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

This concept indicated the possibility for some technology to become fully integrated in everyday life and at the same time emphasized the degree of transparency of a technology as a measure of the success for that technology on being fully adopted by society.

This developments evolved into the areas of ubiquitous and pervasive computing which in turn were complemented by other pre-existing areas of computing (for example artificial intelligence, HCI, etc.) to create areas with consistent goals which emphasize different aspects of the resulting systems.

2.1 Definition

Ambient Intelligence can be defined as follows:

> "A digital environment that supports people in their daily lives by assisting them in a sensible way." [6]

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.

2.2 A Multi-disciplinary Area

Ambient Intelligence and Smart Environments systems nourish from many well established areas of computing and engineering. It also mixes with many other professions through their many application domains, e.g., health and social care. Figure 2 highlights some of those technological and scientific pillars.

2.3 Basic Architecture

Systems for Ambient Intelligence can be organized in various ways but some features are to be found in all those architectures. Little effort has been directed towards identifying what all AmI systems have in common and on studying these systems as a new category of artificial entities. This section aims at rectifying that by providing both a view of a system from the point of view of a basic system architecture and then a complementary view from the point of view of information flow. A complementary explanation can be found in [6].

What are the essential components of an AmI system? Basically an AmI system has a real environment and occupants that interact with that environment in some typical way for that combination environment/occupants.

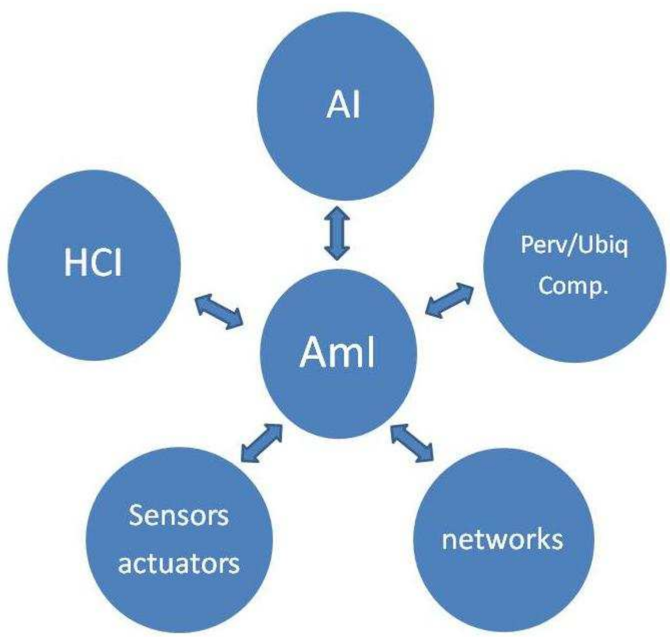

Fig. 2. Interaction in between AmI and other disciplines

Hence we can define an AmI system as follows:

$$AmISystem = \langle E, IC, I \rangle$$

such that:

$$\underbrace{\text{E}}_{Environment} \qquad \underbrace{\overset{\longrightarrow}{\underset{\longleftarrow}{\text{IC}}}}_{\substack{Interaction \\ Constraints}} \qquad \underbrace{\text{I}}_{Interactors}$$

such that:

E: is the Environment. For example, a house, a hospital, a factory, a street, a city, an airplane, an airport, a train, or a bus station.

IC: is a set of Interaction Constraints. It specify the possible ways in which elements of E and I can interact with each other. Some elements that can be typically further specified here are $\langle S, A, C, IR \rangle$ where:

> S is a set of sensors, A is a set of actuators, C is a set of contexts of interest and IR is a set of Interaction Rules. Sensors capture information from the environment. Actuators allow the system to act upon and influence the environment. The set of contexts of interest distinguish those situations where we expect the system to act. The set of interaction rules establishes the protocol on how the system put all the previous elements together to make decisions and trigger actions.

I: is a set of Interactors (usually beneficiaries, it can be people, pets or robots). They can interact with the system in various ways, IR should capture the ways this interaction is conducted.

The definition above tell us of the essential elements, they can be further refined to any arbitrary level of detail and instantiated to the specific details of different application domains. Still it is more declarative in nature stating what is important rather than how it all works. Figure 3 highlights the flow of information and how the different components of an AmI system interact with each other gathering information from the real world, understanding it, taking decisions and using those decisions to interact with the real world again.

Sensors, Actuators, and Middleware

A distinctive feature of the systems we are addressing in this article is that they are immersed in the real, physical, world. As such they have to interact directly with an environment. These systems have to gather information of that environment in real-time through sensing devices and after some reasoning they usually have to act.

Given the importance of sensing/actuating devices this area for research and development is very actively pursuing the production of new sensing devices or the expansion of the capabilities of current devices. There are nowadays sensors that can detect wide range of situations and measure a variety of substances.

The most widely known is probably infrared sensors that can detect movement as it has become fairly common to have anti-burglar alarms which are based in that technology. The possibility to identify objects or individuals is one of the most popular sensing options [46, 26]. They combine an ID tag and a tag reader which can detect the ID tag based on proximity. Other sensors allow can detect weight, the presence chemicals, gases, humidity, brightness or temperature. Other devices can read physiological data like blood pressure or blood sugar levels which can then be used for healthcare. More details on these technological options can be found in [20, 48, 35, 45].

Sensors can be physically connected to a network or wireless [41], each option with advantages and disadvantages, for example, the first ones are more reliable but the second ones offer a more flexible architecture.

Sensors and actuators bring their own problems for system implementation. First there is a cost associated. Then, all of them are, to different degrees, unreliable [11]. There are problems of compatibility between sensors

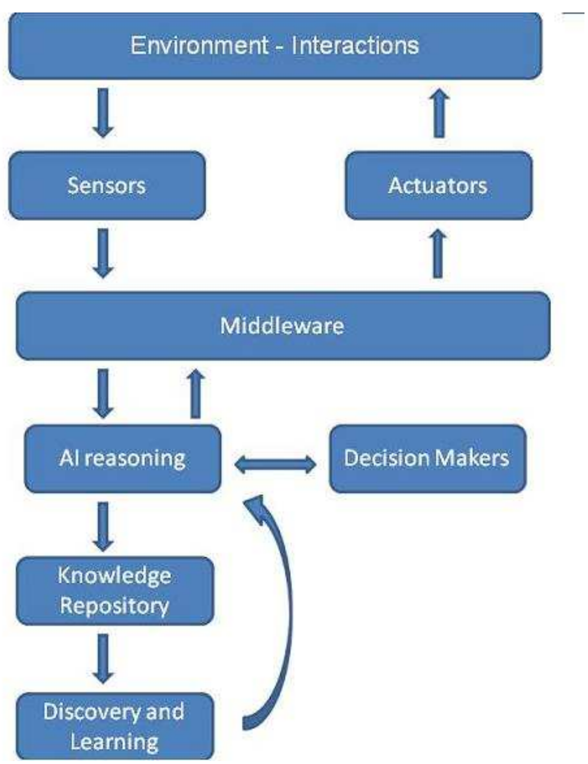

Fig. 3. Generic Architecture for AmI-SmE systems

produced by different manufacturer and they require substantial maintenance effort. And in any case they can generate vast amounts of data that has to be somehow stored, filtered, merged and interpreted [14, 29].

Important European projects have been devoted to the development of efficient middleware that can provide a viable architecture to interconnect sensors (see for example, Amigo and Persona).

Artificial Intelligence

One of the most exciting technical aspects of a system exhibiting Ambient Intelligence is the capability to act autonomously in the benefit of humans. This implies both a hard challenge and a tremendous responsibility. We will focus on the former and will address the latter in another section.

There are several aspects that will have a strong influence in the intelligence a system can exhibit:

- Learning and Activity Recognition: it means the system is capable to analyze the vast amount of data produced by sensor triggering and out of that it and can make sense of the events that happen in a particular environment. It means the system should be able to group together events as recorded by the sensors into conceptual clusters. For example, from the movement and RFID sensors installed in the kitchen and in other objects like cups, kettles, cupboard, water taps, etc. the system identifies that a person is preparing coffee, which in term is part of making breakfast, etc. [49, 13].
- Context-awareness: all Ambient Intelligence systems take place in an environment. What we do in this area is to smarten up the environment deploying hardware and software that links the environment with a computing system which is supposed to operate in the interest of a human or group of humans. To operate successfully such systems must understand the context [23] and the evolution of that context, i.e. its dynamics [7].
- Reasoning: cognitive inference is essential for the system to infer whether it has to act or not and what action(s) should be taken. A variety of methods exist here, ranging from systems which are more rule-based [7] to those based in biologically inspired models [33].
- Multiagents: have an important role in providing a flexible paradigm to model the different levels of autonomy and dependency that each component can have in a Smart Environment [18]. One problem so far which is preventing full exploitation of the multiagent technology is that what has been used so far is merely forcing the diverse needs of AmI-SmE systems to pass through the sieve of traditional agents. More effort has to be put on developing the type of multiagent architectures that are needed to develop AmI-SmE sytems (for an attempt in that direction see [10]).
- Robots: provide a valuable tool both as an interface and as an actuator within a smart environment. Robots can provide an element of socialization [22]. They can also be disguised in the way of a tool that users can

benefit from like an intelligent wheelchair which can help navigate a house to users with mobility challenges [31].

Human-Computer Interaction

Weiser's initial vision was very emphatic on the requirement that technology only will be successful if it becomes adopted to the extent of not being noticed, very much the way we use a fridge or a washing machine nowadays. Humans should be able to use devices in a way that does not demand vast amounts of training and specialization. Needles to say most of what it is on offer today in the areas of AmI and SmE fall short in this aspect. It is also fair to say that there is a significant part of the community which is doing interesting progress and is working extremely hard to achieve this aim.

Gesture recognition [40], gaze tracking [28], facial expression recognition [39], emotion recognition [37], and spoken dialogue [32], either isolated or combined to form multi-modal interfaces [5], are some of a range of options becoming available to facilitate communication between humans and the system in a natural way [3].

Images also help assess a situation where safety can be compromised. The Wireless Sensor Networks Lab at Stanford University uses a network of video cameras to infer a sequence of body postures and hence detect possible hazards like a fall [27].

2.4 Applications

The range of possible applications for Ambient Intelligence and Smart Environments is vast and we can look at the future of the area with expectation and hope that it will bring to everyday life a range of available solutions. Here we list some emerging applications driven by the demand of users, companies and governmental organizations:

- 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 [38]. They can also increase safety by, for example, only allowing authorized personnel and patients to have access to specific areas and devices. Health can be decentralized and made accessible at home through telecare and telehealth services in what it is commonly termed Ambient Assisted Living.
- 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 create smart classrooms where the modes of learning are enhanced [44].

- 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. Companies can use RFID sensors to tag different products and track them along the production and commercialization processes. This allows identifying the product path from production to consumer and helps improving the process by providing valuable information for the company on how to react to favourable demand and unusual events like products that become unsuitable for sale [46]. Smart offices has been also the centre of attention and some interesting proposals aim at equipping offices with ways to assist their employees to perform their tasks more efficiently [30].

2.5 Social Implications

By the very definition of the fields of Ambient Intelligence and Smart Environments these systems are created to be immersed in a place where they will affect people's lives directly. Whether it is students in a classroom, people at home, pedestrians in a street or shoppers in a mall, their lives will be influenced by the technology deployed in those places. If the system works ideally, their life will be improved. The problem is that a computing system rarely works ideally and in this domain, given the complexity of the environment, see some of the challenges listed in later sections, it is even more unlikely the system will work ideally. Hence there is scope for disappointment [21, 25].

Privacy

Take video cameras as an example. They can be used to monitor streets so that street crime can be detected as soon as possible. They can also be used in a shopping centre to know more about shoppers' preferences. They can be used in smart homes to detect situations where somebody can be at risk [27, 4], which is an extremely valuable safety net for anyone who is in a vulnerable position. For example, for elderly living alone, children with learning disabilities, public transport safety at night, people on their own after and surgery, etc.

Cameras are such a rich media. They can facilitate so much information which is relevant for the implementation of an intelligent environment. Still, leaving technical difficulties aside, like achieving understanding of what is captured by one or more cameras, they are fiercely resisted by users and researchers.

To illustrate the point think about extreme situations like having a camera in your own bathroom or bedroom at home. Sure there are many other situations where cameras can be used and indeed are being used. What is acceptable or not acceptable to share changes enormously with cultural values and the situation. Some users are happy to give up some degree of privacy in return for increased safety; some will never allow a camera recording their daily life activities.

Safety

Sensors record information about our daily activities and there is technology that can mine the recorded data to extract patterns of behaviour. The idea being that negative behaviours can be indentified and discouraged and positive ones encouraged and reinforced.

What happens when all that private information fall in the wrong hands? There have been many incidents where sensitive digital information from governments and military forces around the world has been forgotten in the pen drive, CD or laptop in an airport or train. How many unwanted calls do you get per week because a company (e.g., bank or electronics shop you bought something in instalments) stored your personal details in a PC and the company that do back-ups sells the information (most probably without the company's knowledge) to SPAM maker companies?

It is not unlikely then that the same can happen to sensitive private data about our habits and illnesses can be accessible to groups of people who are eager to take profit of that knowledge. Users will become more and more aware of this and extra measures have to be provided to bring peace of mind to the market. If the market is label as unsafe by the users then all those involved will lose a fantastic opportunity to benefit society.

3 The Future

The literature of the area is prolific and there is a growing body of research and developments reported in the recent technical literature (see for example: [24, 2, 8, 1]).

Still we cannot claim these developments are being massively taken by society, there are some success stories in various areas and parts of the world but the systems produced are still too unreliable, expensive and difficult to use as to be embraced by society. So what are the current bottlenecks for the area preventing further progress?

3.1 Emotional and Social Intelligence

Cognitive intelligence is a hard goal in its own right and the area has a good deal of work ahead to provide robust and intelligent systems. Equally hard and still not so deeply investigated is the element of emotional intelligence.

This is to some extent a less logical and predictable side of humans, it has to do with anger, fears, desires, pleasure, etc.

A system that is supposed to "... support people in their daily lives by assisting them in a sensible way" has to be aware of the user's preferences and has to know when is the right time to approach her/him and in which way, as well as to realize when it is better to stay silent. Think about a system that offers you help each 5 minutes over the whole day, or remind you of all the things you have listed as interesting but you do not have currently in the house or recommend you to have a box of chocolate when you are trying to lose weight.

Let us assume we accept that a system that can exhibit a level of subtle behaviour is what we need and let us do a little exercise to think how we can achieve that. How can we sense when the user is angry? Will it be because is shouting or cursing? Is it meaningful that the person is slamming doors?

Understanding all the subtle semantics of a dialogue to the extent to infer a particular state of mind is the terrain of spoken dialogue and natural language understanding, which still is a challenging area in computing. Detecting other states of mind like feeling tired, hungry, happy, or depressed can provide equally hard challenges.

3.2 Scaling Up From One To Many Users

Many current systems can provide some level of acceptable service in the case of one single user, for example the literature abounds on smart homes to support independent living which are based in the assumption only one person is the permanent resident in the house, or at least the only one that the house have to take care of.

When multiple occupants share the space and the house have some degree of responsibility for more than one of them then things are even harder. Funny examples are known where systems were not prepared for the complexity of a user having a pet wondering around the house triggering sensors here and there. Consider for example a family living under the same roof and a system that tries to provide services for all them. Choosing a T.V. program may be a situation of conflict, should the system stay away from such domestic rows or should it have a duty to advise and mediate? How the system should react when there are irreconcilable positions?

3.3 User Acceptance!

At the end of the day if these technologies want to be accepted and be as pervasive as a fridge or a washing machine are nowadays, then they have to achieve overall satisfaction. This will involve delivering adequate and reliable services which are judged to be good value for money.

Currently there are not standards or accepted measures of quality. The diversity of areas involved and the diversity of potential applications conspire against this. Still it is important for the area to achieve maturity that some sort of benchmark is agreed. See the Darmstadt Challenge [9] as an example of a step in this direction. Another interesting avenue is the possibility to provide users with the option to program the behaviour of the system [34, 15, 43, 16].

4 Conclusions

The last section may have emphasized what the area is still missing and the hardship of working in a field which has ambitious practical aims. However, it is not all that gloomy. The same reasons used to say there is no guarantee of success can be used to argue there is no proof that the aims are unachievable. There are already good success stories and developments are gradually starting to appear in the form of smart homes, smart cars, smart classrooms, smart offices, etc. ([36]).

Patience and sustained work will be needed to extend the technical frontiers of this area bit by bit. To what extent these technologies will be taken by society it is to be discovered, meanwhile the potential benefits are such that it is worth trying. Researchers and developers should remember at all times that users are at the centre and that technology should be built for them.

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