UDC 004.81

Ambient Intelligence: Concepts and Applications

Juan Carlos Augusto and Paul McCullagh

School of Computer Science and Mathematics
University of Ulster at Jordanstown BT37 0QB
United Kingdom
{jc.augusto, pj.mccullagh}@ulster.ac.uk

Abstract. Ambient Intelligence aims to enhance the way people interact with their environment to promote safety and to enrich their lives. A Smart Home is one such system but the idea extends 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. In particular we address system specification and verification for the former and knowledge acquisition from the vast amount of data collected for the latter.

1. Introduction

The steady progress in technology has not only produced a plethora of new devices and devolved computing power into many aspects of our daily lives; it is also driving a transformation on how society relates to Computer Science. The miniaturization process in electronics has already made available a wide range of embedded computing devices which can now help us when we wash clothes and dishes, cook our meals, and drive our cars. Inspired by those successful applications technological developments, such Radio-Frequency Identification (RFID) technology [1], which can be used to identify, locate and track tagged items or people, in association with personal area networking protocols may be enablers to deliver ubiquitous computing to all aspects of our lives. These research developments [2, 3] are rapidly exploited by global enterprises, see for example [4], through the process of knowledge transfer, promoting 'globalization' of technology.

This growth in technology and computing power has been continuously progressing since the very inception of Computer Science, and is exemplified by Moore's Law [5], which accurately predicted the doubling of the number of transistors on integrated circuits every 18 months. Consider the historical perspective. Initially a large mainframe machine was shared by many highly trained programmers located in a secure environment restricted to specialist researchers. The computer then became an essential tool for many non-scientific academic disciplines, exemplified by departmental mini computers. As cost fell and power and storage increased, the computer was embraced by industry, hospitals, and governments. More recently office workers, not necessarily with a high level of training, gained access to a personal computer on the desktop. Nowadays in the developed world, most people have access to an array of mobile computing devices including laptop, mobile phone, personal data assistant (PDA) and interact with processing units embedded in electro-domestic appliances, such as DVD players, television set-top boxes, cookers and microwave ovens. Visionary opinion indicates that the trend for accelerating device sophistication, driven by intelligent sensors and smaller and more powerful processing elements will continue [6] for the next 10-20 years.

However it is possible to recognize a paradigm shift. Systems are being designed in such a way that people do not need to be a computer specialist to benefit from computing power, and indeed intuitive graphical interfaces have been augmented by voice interaction [7], and multi-modal interfaces where virtual objects (in a virtual world) can be moved by 'hand' using an enriched glove. Gaming has adapted to provide a wireless and more intuitive interface. Protocols such as Bluetooth and Zigbee have removed the need for physical connection. 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, minimizing explicit interaction is at the core of its values. The aim is to enrich specific places (room, building, car, street) with computing facilities which can react to peoples' needs and provide assistance.

People are now more willing to accept technologies participating and shaping their daily life. Today's teenagers are part of the "Net" Generation, brought up within a world of computers, mobile phones and the Internet with little fear of technology and in fact embracing the latest electronic hi-tech advances. At the same time there are important socio-economic and political driving forces. An important example of this is the move towards decentralization of health care and development of health and social care assistive technologies for independent living. The electronic health (e-Health) paradigm [8] moves the citizen away from the hospital-centric health care system, hastening this shift of care from the secondary and tertiary care environments to primary care. Subsequently, there is an effort to move away from the traditional concept of patients being admitted into hospitals (which are potentially dangerous places due to the potential for cross-infection) 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.

Leading companies have already invested heavily in research and development in the area. For example, Philips [9] has developed Smart

Homes for the market including innovative technology on interactive displays. Siemens [10] has invested in Smart Homes and in factory automation. Nokia [11] also has developments in the area of communications where the notion of ambience is not necessarily restricted to a house or a building, but provides ubiquitous connectivity. VTT [12] has developed systems which advise inhabitants of Smart Homes on how to modify their daily behaviour to improve their health, and hence promotes a culture of ‘wellbeing’ rather than disease treatment.

The aim of this paper is to describe the scope of AmI, in particular the relationship in between AmI and related areas (Section 2), to provide a case study for the Smart Home (Section 3), and to address other environments (Section 4) where AmI will undoubtedly have future impact. We illustrate (Section 5) the flow of information in a general AmI system and this permits a description of further scenarios of application (Section 6), it allows us to highlight the technical difficulties and opportunities laying ahead (Section 7), possible solutions using software verification (Section 8), and to provide a final analysis on the likely course of these important areas of Computer Science (Section 9).

2. Ambient Intelligence

Ambient Intelligence (AmI) [13, 14] is growing fast as a multi-disciplinary topic of interest 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 inherits aspects of many cognate areas of Computer Science, see Figure 1, but should not be confused with any of those in particular.

Networks, Sensors, Human Computer Interfaces (HCI), Pervasive Ubiquitous Computing and Artificial Intelligence (AI) are all relevant and inter-related but none of them conceptually covers the full scope of AmI. Ambient Intelligence 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”* [15, 16]:

“The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.” M. Weiser, [15]

The disappearing computer is directly linked to the notion of *Ubiquitous Computing* [17], or *Pervasive Computing* [18], a label coined by IBM, or more recently *Everyware* [19]. These definitions emphasize the physical presence of systems and availability of resources but miss a key element: the explicit requirement of *Intelligence*, the basis of AI [20]. AI is used 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 users. Here we expand Raffler's definition [21] to emphasize Intelligence as a fundamental element of an AmI system:

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

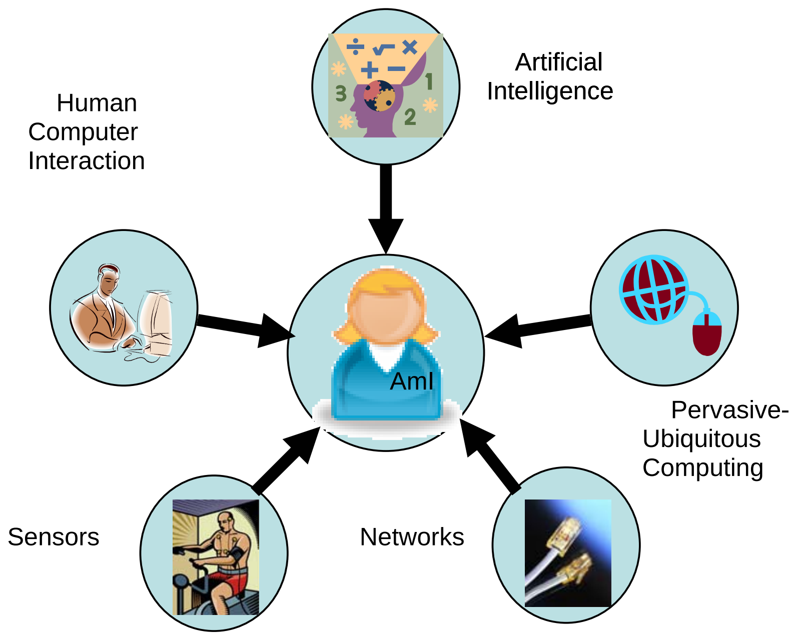

Fig. 1: Relation in between AmI and other areas in Computing Science

In order to be sensible, a system has to be intelligent. That is how a trained assistant, e.g. a nurse or personal assistant, typically behaves; proactively helping when needed but exercising restraint if 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 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 to as *Smart Environments* or *Intelligent Environments*. We retain the European denomination as it emphasizes the intelligence factor of these systems as opposed to the physical infrastructure.

Of Importance for AmI are the "5Ws" (Who, Where, What, When and Why) principle of design [22]:

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 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 vice-versa.

When: the association of activities with time is required to build a realistic picture of a system's dynamic. For example, users, pets and robots living in a house will change location often change location 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 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 [23] 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 was 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 and needs. Today, with so many gadgets incorporating computing power of some sort, HCI continues to thrive as an important area of study.

3. Smart Home

A prominent example of an environment enriched with AmI is a *Smart Home*, that is a house equipped to bring advanced services to its users. To gain an understanding of the state-of-the-art devices and services provided in a Smart Home see [26]. Naturally, how smart a house should be to qualify as a Smart Home is 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 then a person reading in a resting position can confuse the system which will leave the room dark. The system will be misinterpreting absence of movement with absence of the person. Further context is thus required. For example the person has left the room, as detected by a door switch.

Figure 2 depicts the basic layout of a house which can operate intelligently [24, 25]. To the occupant the house should provide the normally expected homely environment, and should in no way resemble a laboratory. However, 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.

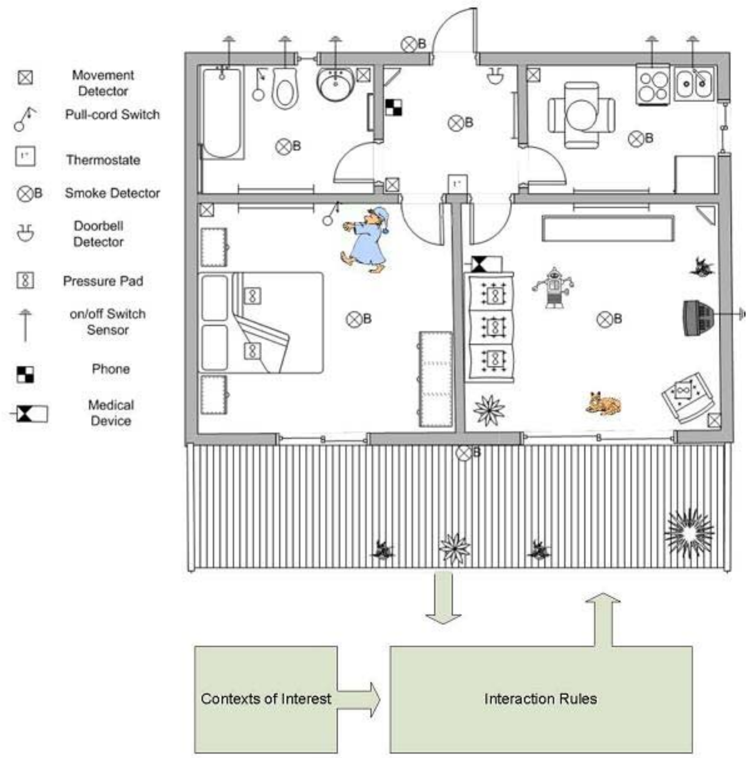

Fig. 2: A generic layout of a 'Smart Home' enriched with sensors and devices

The figure depicts movement sensors (Passive Infra Red detectors), a pull-chord switch, a thermostat, a smoke detector, a doorbell indicator, pressure pads, on-off switch detectors, a phone for external contact and a medical device (e.g. blood pressure monitor, or heart monitor). Some examples of enriched devices are electro-domestics (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 potentially 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 devices that stand alone (e.g., smoke or movement detectors), to those fitted within other objects (e.g., a microwave controller or a bed occupancy sensor), to those that can be worn (e.g., shirts manufactured with electrodes that monitor heart beat, and potentially detect unsafe conditions). Also indicated in Figure 2 is the ‘invisible’ intelligent support network which deduces ‘Contexts of Interest’ from the sensed environment and provides support to the occupant via actuators using ‘Interaction Rules’. This provides the ambient intelligence to the Smart Home. Thus for example, if the bath is at an inappropriate temperature or if water is left running for an inappropriate length of time, the Smart Home can intervene to assist the occupant.

Recent applications include the use of Smart Homes to provide a safe environment where people with special needs can enjoy 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 possibly advising the carer when intervention is required. This is a further example of AmI, whereby a message can be generated automatically and sent to carer (who may live remotely) by appropriate technology, such as mobile phone or digital television, the carer’s environment of course having sensed the most appropriate delivery channel. There are many ongoing academic research projects with well established Smart Home research labs in this area, for example Domus [27], Aware Home [28], MavHome [29], and Gator Tech Smart Home [30].

A potential drawback of existing Smart Homes technology is the need for the user to wear sensor devices, e.g. for position sensing and fall detection. This is contrary to the notion of AmI, which places the emphasis on the enriched environment to act intelligently and provides significant technological challenges for researchers. For example, in an attempt to facilitate more intelligent unfettered assistance to an occupant, images may be gathered, processed and then a text-based summary used for diagnosis of the situation [31], e.g. to provide position information or to detect a fall. This allows the use of a rich source of information whilst at the same time reducing explicit HCI requirements.

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 and reduce cross-infection by, for example, only allowing authorized personnel and patients to gain access to specific areas and devices.

Public transportation sector. Efficient flow of traffic can benefit from extra technology including Global Position Satellite (GPS)-based spatial location estimation (known as 'sat-nav') to make transport more fluent and hence more efficient and safe. Of course this approach also facilitates vehicle tracking, raising freedom of movement and privacy issues in the citizen. Indeed satellite tracking may eventually form the basis of congestion charging and road pricing. Currently this is achieved in restricted zones using cameras and vehicle identification with image processing software. London has led the world in this area with a £10 billion, five-year investment programme [26]. As the ambient technology advances with satellite tracking systems fitted to all cars, many congested cities may follow the London model, but without the huge infrastructure investment. Automated license plate identification for car tax payment and speed restrictions are part of today's transport environment, sensed by an ever-increasing network of roadside cameras.

Education services. Universities and higher education institutions use smart card technology to permit access to computing and library facilities, car parks, dining halls and lecture rooms. The same technology may be used to monitor attendance, and track students' progression on their modules,

Emergency services. Safety-related services like ambulance and fire brigades can improve their reaction time to an incident by accurate GPS based location and by expediting the route by automating traffic signals in their favour. The prison and police service can quickly locate a place where a hazard is occurring and prepare better access to it for security personnel.

Production-oriented places. Production-centred 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.

Public Surveillance The widespread deployment of CCTV cameras provides monitoring of potentially dangerous public places. City centers, underground stations and public transport can all benefit for increased surveillance. Until recently this was a completely passive process, often used to gather evidence of wrong-doing, but limited in terms of crime prevention. As video becomes automatically analysed and interpreted by computer this will extend AmI to the high street.

The next section identifies some important aspects of an AmI architecture so that a system can support the level of services described above.

5. System Flow

An AmI system can be built in many ways. Typically it needs sensors and devices to surround occupants of an environment (interactors) with technology (we can call this an "*e-bubble*"). The technology can provide accurate data to the system on the different contexts which are continuously developing. The data collected is transmitted by a network and pre-processed by middleware, which collates and harmonises data from different devices. In order to make decision-making easier and more beneficial to the occupants of the environment the system will have a higher level layer of reasoning which will accomplish diagnosis and advise or assist humans with responsibility for intervention.

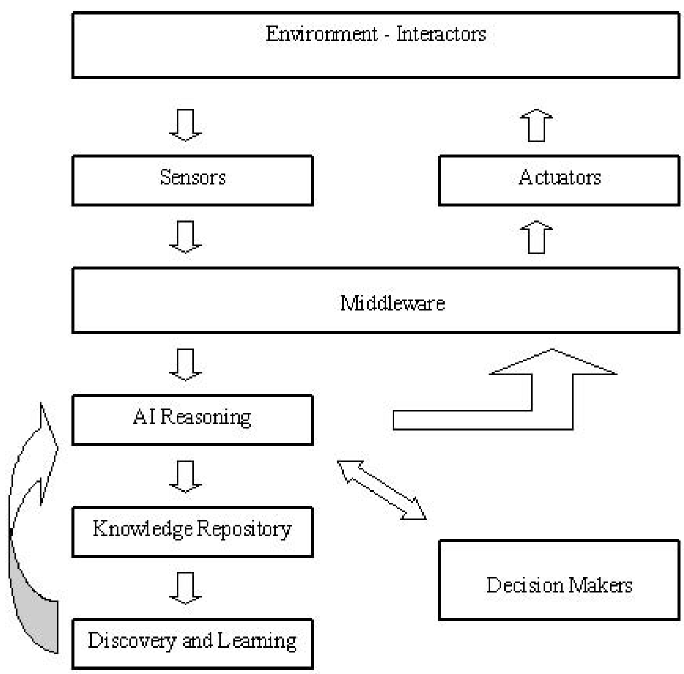

Fig. 3: Flow of information and general architecture of an AmI system.

Elements that may be included in the high level 'Decision Making' process are a 'Knowledge Repository' where the events are collected and an 'AI Reasoner' which will apply for example spatio-temporal reasoning to take decisions [32]. For example, a decision could be to perform some action in the environment and this is enabled via 'Actuators'. Knowledge discovery and machine learning techniques learn from the acquired information in order to update the AI Reasoner in the light of experience of the system. A typical information flow for AmI systems is depicted in Figure 3.

6. Flow of Information in 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: Smart Home. The AmI specification may include 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 has three interactors depicted and therefore has three elements: a person in the bedroom, a cat, and a floor cleaning robot in the living room. There are also 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. 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: Hospital room, where a patient is 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/speakers 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 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: Underground station 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: School, where students are monitored 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 has not engaged for more than 5 minutes with an experiment then tutor has to encourage and guide the student”.

Scenario 5: Fire Brigade has to act then the environment. 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: Production Line. 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”.

Scenario 7: Public Surveillance. Sensors are enriched CCTV cameras on street or on transport, monitored by security guards. Interactors are law abiding citizens and potential muggers. A context can be “if a person is attacked, provide an alarm, issue a verbal warning in-situ to deter attacker and activate a rescue from the nearest police station or security guard”. Bi-directional voice channels can be used. Of course AmI requires that the sensing, decision making and actuator are automated. In future this can be achieved with image and sound processing, reasoning for the identification of an emergency situation and text-to-speech warnings delivered to the offender.

7. Are we there yet…?

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

However, it is necessary to proceed with caution. Computing has already experienced the pain caused by rushed expectations, resulting in hype, disappoint and sometimes disaster. Despite success in achieving techniques [34] and tools [35] to increase the reliability of software, disasters have occurred from time to time with negative consequences for people and companies counted multi-million dollar losses.

For example consider the explosion of Arianne-5 rocket due to a bug in the navigation system which cost $7billion. The cause of the failure was a software error in the inertial reference system. Specifically a 64 bit floating point number relating to the horizontal velocity of the rocket with respect to the platform was converted to a 16 bit signed integer and thus the conversion failed [36]. Worse still, failure in computer systems can result in lost lives e.g. failed hospital information systems [37]. The Institute of Medicine [38] recommended that healthcare professionals focusing on patient safety should increase their understanding of how information technology could be applied to deliver safer care. This recommendation was made as part of the approach to reducing errors in the delivery of care leading to the death of as many as 98,000 US citizens annually. According to Schrekner, "*Advances in software engineering include the growth of requirements engineering (focused on the gathering, documentation, and analysis of user requirements), user-interface design (focused on the design and construction of intuitive and safe user interfaces), and usability engineering (focused on the study of ease of use and suitability for purpose). In addition to an improved software engineering paradigm, others have identified the need for better embedded medical device user interfaces to reduce errors*" [39].

Connecting for Health, the largest ever computing project in the UK (and possibly Europe) aims to implement electronic health records systems, a backbone network for ubiquitous access to emergency information anywhere in England, and infrastructure of eletronic data interchange including picture archive and communication system (PACS). In addition it will permit patient booking of hospital appointments, and will integrate health and social care by 2010. This will bring a culture change to healthcare delivery and help to deliver health records and expertise 'anytime/anywhere', which should provide huge benefits to the citizen. Health providers in many other countries are eagerly anticipating the outcome. However, despite billions of pounds of investment, and input from preeminent IT developers and suppliers, due to the enoromus complexity of healthcare (standardization issues, coding, interpretation, security, confidentiality and digital peristence), elements of the project are behind schedule. Users of the new systems are understandably concerned at the step change which will require re-skilling in the updated software and systems. A report of the British Computer Society Health Informatics Forum stated [40], "IT enables change, is sometimes a catalyst for change, but it is not an end in itself. This misconception has been a prime cause of large scale IT project failure since computers first became common place." This may be another lesson to learn as we embrace AmI systems, where the change will be significant.

It is important that safety critical AmI systems are thoroughly tested to reduce the potential for error and are accepted by users. Also it is crucial to recognise the paradigm shift as not simply one of technological change. Given that in AmI systems the person is the main beneficiary (but is also affected when the system does not deliver as expected) lessons learnt should be considered carefully and enough preparation should be done before widespread use can occur. Looking back to how systems have been developed and witnessing the commercial success of under-developed systems driven by effective marketing, it is possible that systems will be developed unsystematically and deployed prematurely. AmI systems need different methods and tools to flourish.

8. A Possible Way Ahead

Software Engineering has provided Computer Science with important methods and tools to increase reliability in software and computing systems. The reader can find a good summary on these advances in [41]. These tools can be used to model some aspects of an AmI system and make its behaviour a bit more predictable.

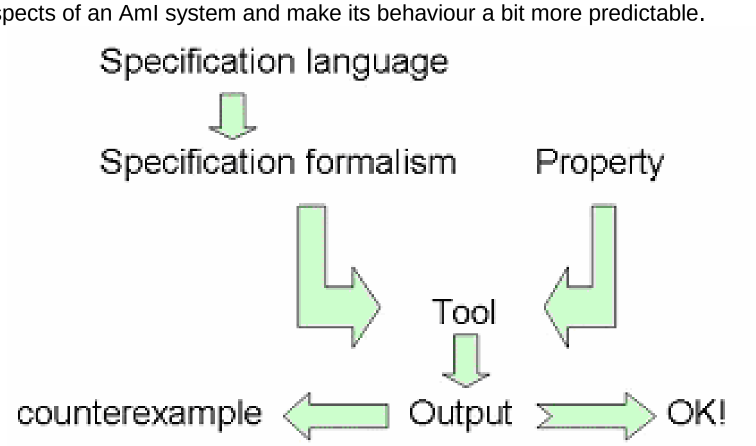

Fig. 4: Typical verification cycle

Methods and tools for verification are usually applied following a standard procedure, see Figure 4 for a global view of the typical process that is usually followed (this is fairly standard and independent of the verification technique and tool used).

First a system is specified in some notation with a clear syntax and semantics, often with the help of a tool. Then the behavioral properties that are relevant in that system are expressed in a language (usually different from the one used to characterize the system) which will also have precise syntax and semantics. Then a tool helps to analyze if the relevant behavioral properties are present in the specified system or not. As a result of that analysis the tool may be able to either prove that the property holds with regards to the system specified or to provide a counter-example showing that is not the case.

Notice we say “with regards to the system specified” because a) on one side not all the details of the implementation can be represented so a conscious choice has to be made on abstracting some specific meaningful features of the system under study and b) mistakes can be made in modeling those selected features of the implementation which have been selected. So there will be usually a gap between the system being implemented and the model of the system which is being used for the analysis. The reader is referred to [42] for an up-to-date treatment of a proposed software development process which centers on alignment between model and implementation and to [43] for recent developments on possible direct verification of the implementation (real code verification).

Take as an example UPPAAL [44] which is a freely accessible tool to model and rigorously verify real-time systems. In real-time systems the duration of events are of fundamental importance for the successful implementation of the system. For example, an airport will be such a system. The delays a passenger experiences before boarding an aircraft and taking off, the time a flight is kept waiting before given permission to land, the time a passenger has to wait to retrieve his/her luggage once they have landed are all very relevant to keep the system safe and efficient and therefore to the customer satisfaction.

UPPAAL allows the modeling of a system as a network of automata and then the verification of behavioral properties written in a fragment of TCTL (Timed Computation Tree Logic, see [41] for more details). An automaton is a mathematical model for a finite state machine which moves through a series of states according to a transition function. The transition may depend on inputs from the environment. TCTL is one language that can be used to express behavioral properties which should be verified. We provide further down a brief explanation of TCTL and its use to express and prove behavioural properties.

We leave the examination of several technical details and recommend the interested reader to consult [41, 44] as the focus of this article is on the analysis of AmI systems and not on the technical difficulties of formal verification. Therefore the text below is of a descriptive nature and aimed to illustrate the potential contributions of tools available which will provide a better context for a final speculative analysis of what else can be done to help the development of AmI systems.

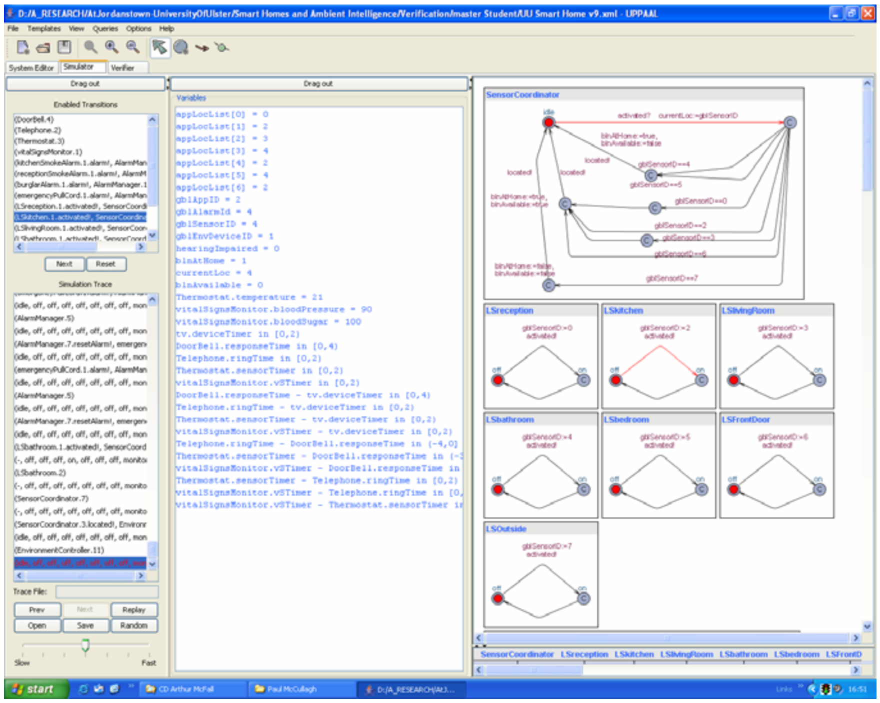

Fig 5: General overview of Smart Home System

In our recurring scenario the system to be modeled is a Smart House for which we provided a basic layout and explanation of components in Section 3. The model shown below was developed in [45].

The interface in between UPPAAL and the use of the verification system is focused mainly on three panels: (a) the specification panel is where the automata can be drawn and several elements can be defined (e.g., clocks, Boolean variables and channels), (b) the simulation panel is where the behaviour of the system can be explored through different simulation modes which will show possible evolutions as the system evolves through different states and (c) the verification panel, where behavioural properties can be verified. We are not providing details on how to define a system in UPPAAL, but rather provide a description of a specification for a Smart Home system below and latter on will address the verification stage.

The simulation panel is shown in Figure 5 subdivided into three areas: in the left hand side column the different components are listed together with their data definitions, in the center column the current values for states, variables and clocks are listed and in the right hand side column the different components of the system being modeled as automata are shown.

Figure 6 includes a sensor coordinator (top leftmost automata) that will detect if the house occupant is at home and if so, in which room. The middle level shows various individual sensors which can detect movement and send a signal to the sensor coordinator. There are sensors for all rooms in the house (kitchen, living, bedroom, bathroom, and reception hall). There is also a sensor to detect if the front door is open or not and a sensor to detect if the person has left the house.

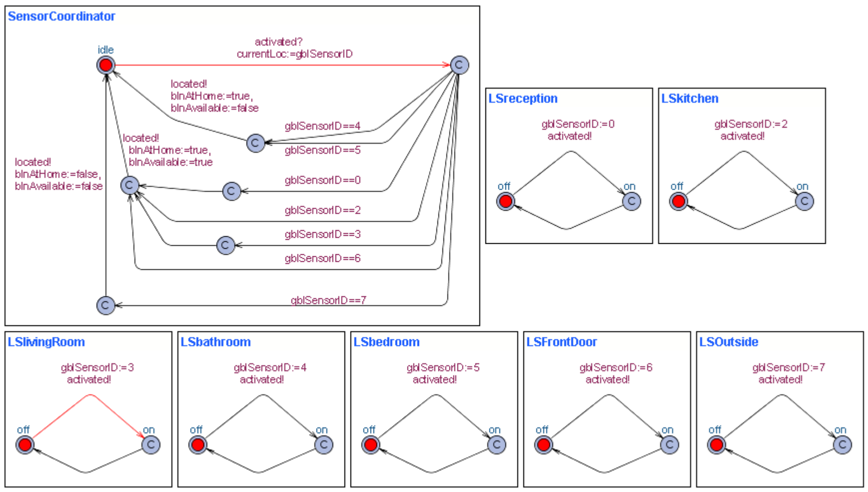

Fig 6: Automata illustrating sensor coordinator (top left) and movement sensors

Figure 7 shows the television manager which will monitor the usage, not with regards to content of the viewed program but to detect if the set has been left unattended for too long, as defined by some predetermined criterion.

Figure 8 shows the alarm manager (top left side corner) which will be continuously monitoring and will react when any of a set of alarms is triggered. Within the house there are several alarms of various types. The system here represented considers smoke alarms in the kitchen and in the reception hall. There is also a burglar alarm which is activated when someone opens an external door or a window during the time when the alarm is primed. An emergency pull cord can be activated by the occupant of the house to call the attention of carers if, say, the person does not feel well or has fallen in an area where the pull cord can be reached.

Different alarms are identified by different identification codes (AlarmID) and these in turn will lead to different handling procedures. For example, identification codes 1 and 2 correspond to smoke alarms and that is why the model goes through a state "contactFireBrigade" if those are detected. When the identification code is 3 then the alarm was raised by the burglar alarm and the model will reach a state "contactSecurity". If the identification code is between 4 to 7 then the alarm was raised by either the emergency pull cord, the telephone manager, the doorbell manager, or a device reading vital signs (these last three to be explained further down) and the model will reach a state "contactNurse" as they are health-related emergencies.

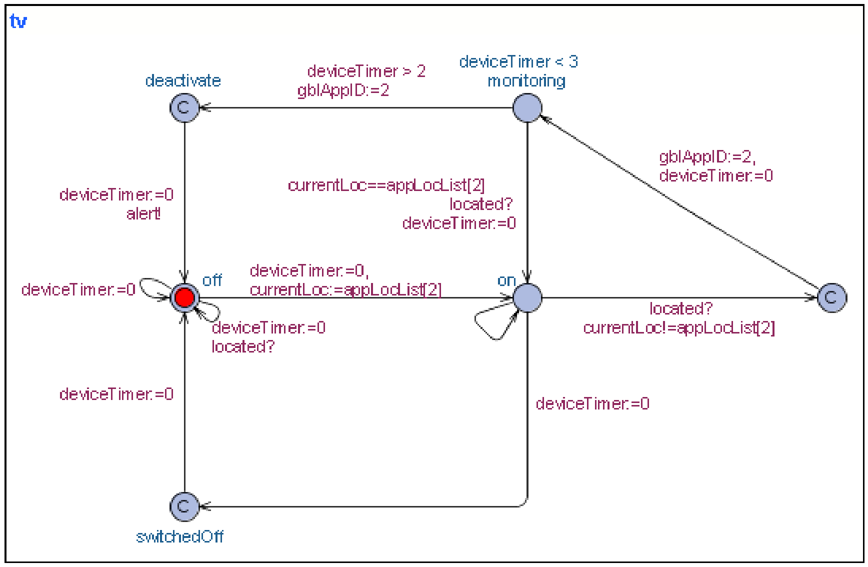

Fig 7: Automaton illustrating the television controller

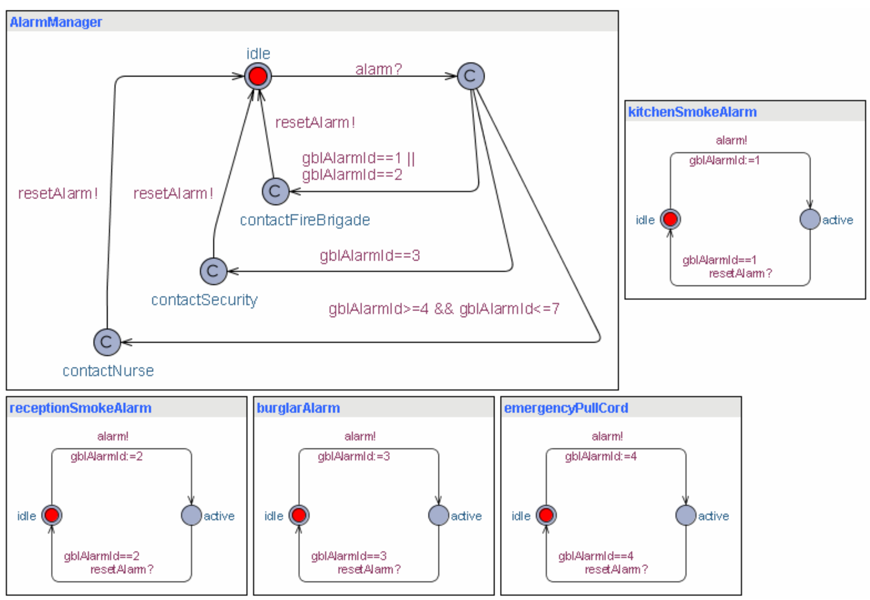

Fig 8: Automata illustrating alarm manager

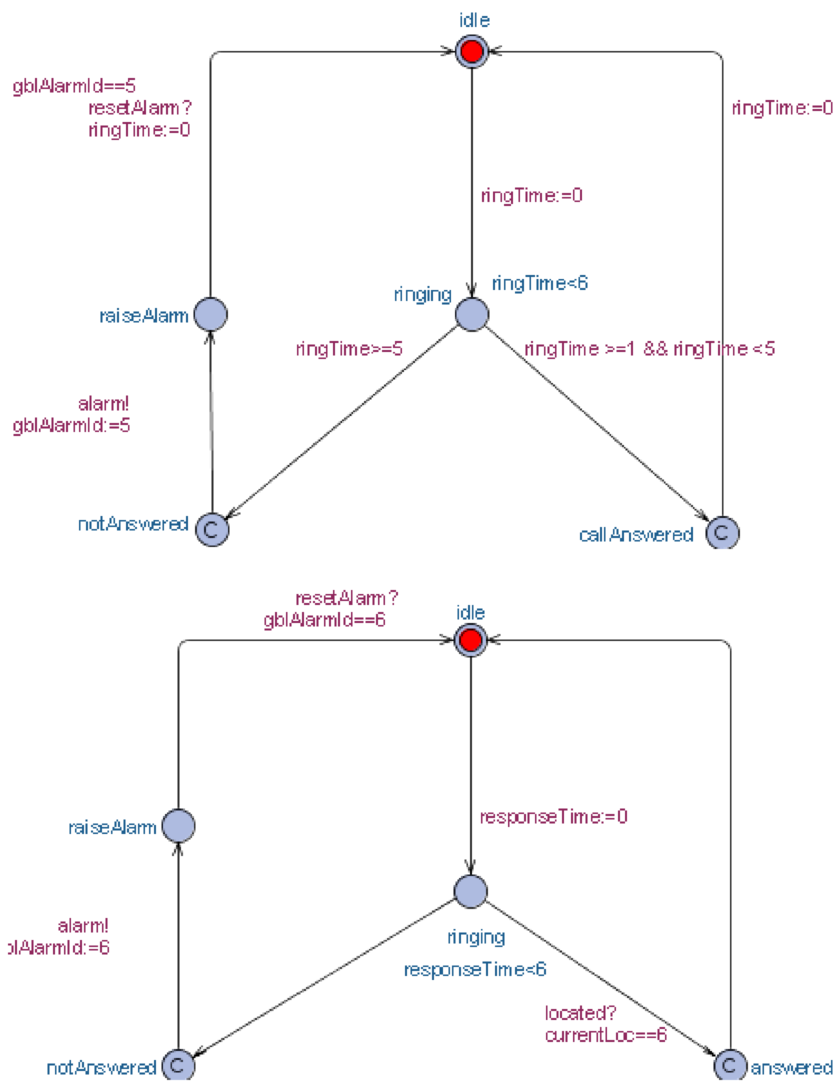

Fig 9: Automaton for Smart Home specification illustrating managers for telephone (top) and doorbell (bottom)

Figure 9 shows a door bell manager which will detect if the front door is open or closed. This manager also takes into account the time elapsed since someone rang the doorbell because if the occupant is at home but nobody goes to the front door to respond to the call, it may be inferred that the occupant is unwell. Some Smart Home systems may decide to contact a designated carer in these circumstances. A telephone manager which will detect phone use and perform response time monitoring in a similar way outlined for the doorbell manager is shown in the lower half of the figure.

Figure 10 shows specifications for radiators, air conditioner and thermostat. They start and stop the heating and air conditioning system and are regulated by the thermostat which checks the temperature periodically ensuring temperature is within reasonable levels (10 and 20 degrees in this example). If the temperature falls below 10 degrees the thermostat will detect that as 'low' which will lead to the heating being started. If the temperature rises above 20 degrees the thermostat will detect that as 'high' which will lead to the air conditioning being started. If temperature is within the desirable range then both air conditioned and heating are off.

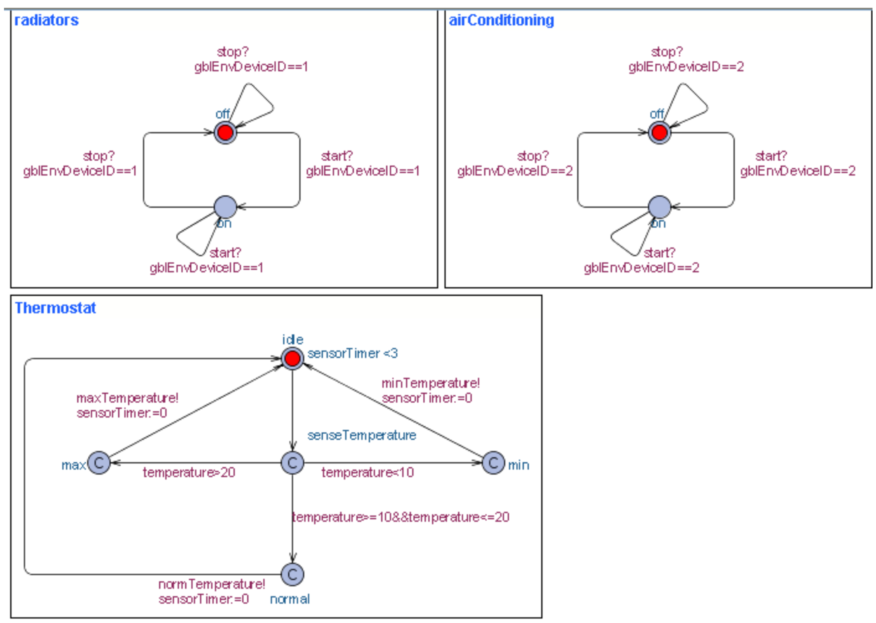

Fig 10: Automata for Smart Home specification including radiator, air-conditioning and thermostat behaviour specification

The temperature system manager which provides modeling for an environment controller can orchestrate the components described in Figure 9 and ensure that whenever the thermostat reaches appropriate levels the heating and air conditioning system are started or stopped to keep the ambient temperature at comfortable levels.

How the environment controller reacts is also conditioned by the presence or absence of the occupant in the house. In this model of the system, the heating and air conditioning systems are only operational if the occupant is at home.

Of course many of these aspects can be modeled differently as determined by user requirements, and environmental variables such as seasonal variation. This is only one possible model for such a system.

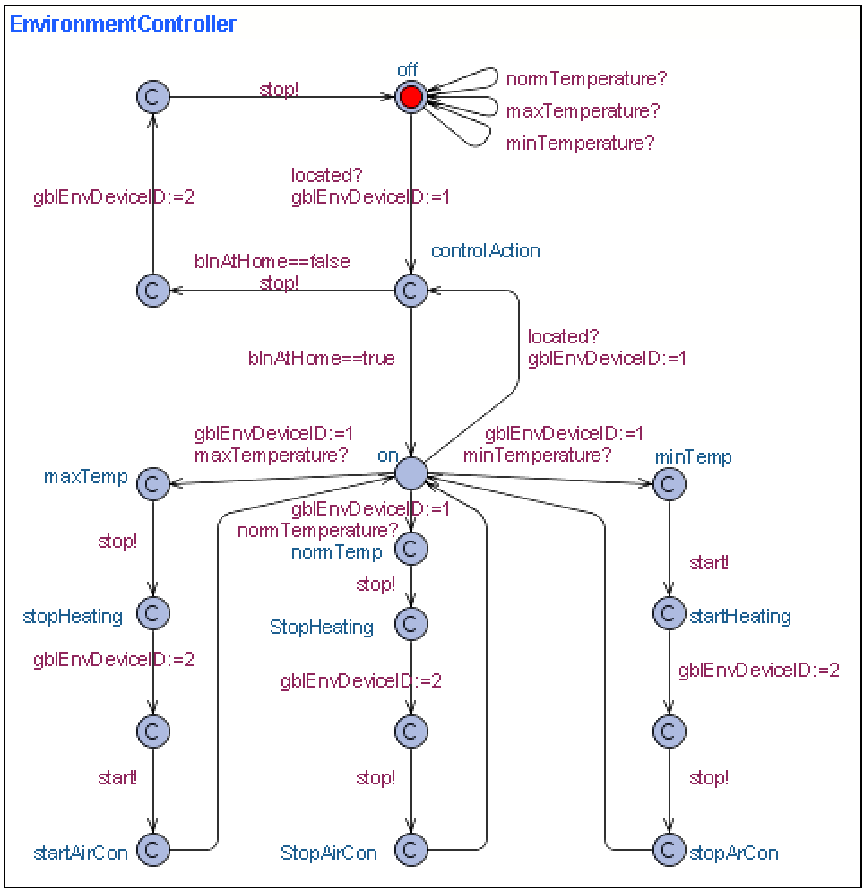

Fig 11: Automaton for environment control

The remaining automata at Figure 12 provide vital signs monitoring. In this case for blood pressure and blood sugar but other vital signs can be modeled in similar ways.

If any of the monitored parameters fall below/above the minimum/maximum thresholds set up as desirable (defined as constants in the definition panel provided by UPPAAL) then this model states that the vital signs monitoring unit should issue an alarm (identification code 7) which will be handled by the alarm monitoring system described in Figure 8. That, as we explained, will cause the model to reach a state where a warning is issued to a carer (possibly a nurse) who is acting on behalf of the healthcare organization that takes care of the occupant's health.

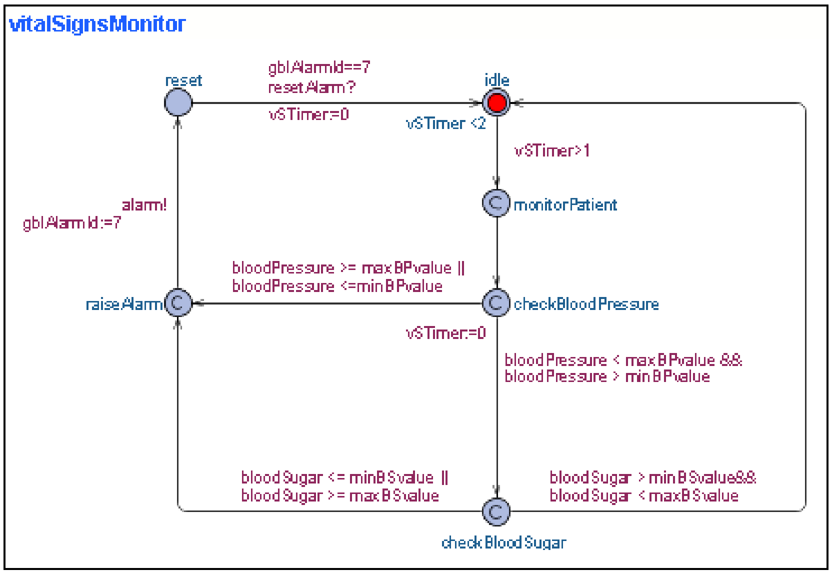

Fig 12: Automaton for environment control and physiological monitoring (blood pressure and blood glucose)

With a model of the system we can proceed to consider the behavioral properties of interest. The expected methodology to be followed will be to formalize previously established requirements for the modeled system. Below we provide some examples of properties. We do not claim full coverage by any means and the purpose is to illustrate possible uses of the formal machinery available.

The language to specify properties which is used in the UPPAAL verification system, TCTL, includes symbols that can refer to possible computations according to which choices are selected at any point where more than one option is available. Symbols "E" (there is a path …), "A" (at all paths …), "<>" (at some state in this path…), and "[]" (at all states in this path…) are combined in such a way that a path operator (E and A) is always followed by a temporal operator (<> or []). For example, if condition P is a Boolean expression then "E<>P" and "E<> A[] P" will be valid sentences in the property specification language of UPPAAL but "E A <> [] P" will not. Condition complexity is proportional to verification complexity (aspects such as how many clocks and channels the system has and how sophisticated the conditions imposed over them are).

We provide a graphical depiction of how these symbols are combined in Figure 13 and refer the reader to [41] for a formal semantics and deeper coverage of the subject which is not in the spirit of this article.

We now provide some examples on how the TCTL notation can be used to specify conditions to be explored as part of the basic behaviour of a Smart Home system.

They represent classical patterns in the specification of behavioural properties for formal verification (see [41] and [46] for more details on systematic studies of property specification) E<>P (P is reachable), E [ ] P (potentially always P), A <> P (inevitable P), A [ ] P (invariantly P) and P → Q (consequence). Notice that here the symbol "→" in sentence "P → Q" is Boolean implication and does not have a path-based or temporal-based semantics.

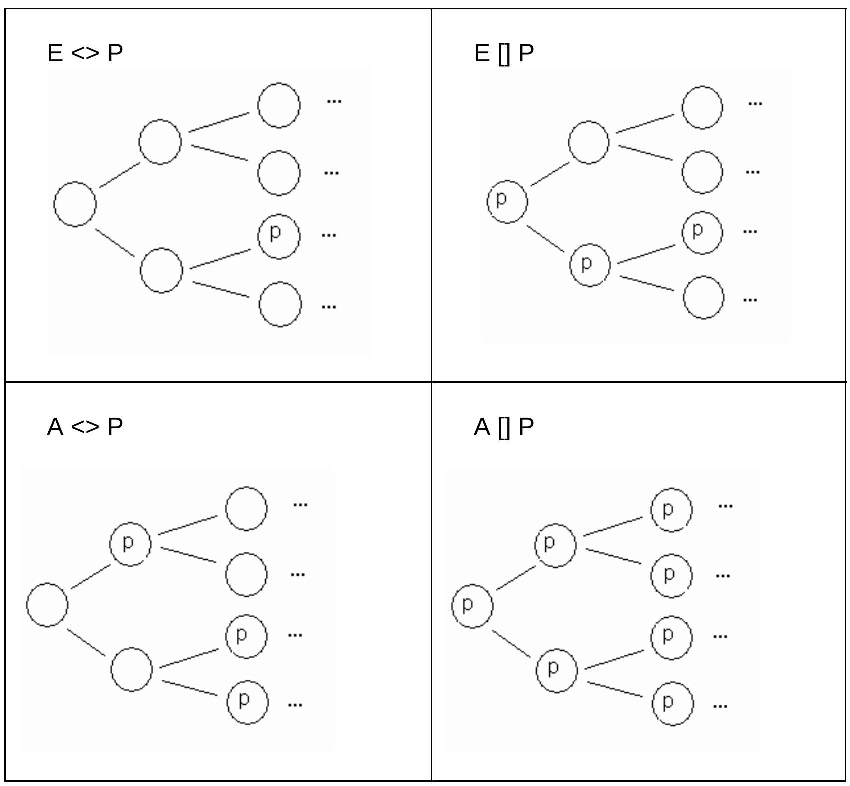

Fig. 13: Graphical interpretations of some basic property specification schemas

a) General Schema Formula: E<>P

Informal Description: Does a path exist where P eventually holds?

Sample of Property Instances:

E<> (EnvironmentController.on and AtHome==false)

Intuitive Meaning: Is it possible for the system to reach a state where the patient is not at home but the heating/air conditioning system is on?

b) General Schema Formula: E [ ] P
Informal Description: Does a path exist where P always holds?
Sample of Property Instances:
E[ ] burglarAlarm.active imply burglarAlarm.idle
Intuitive Meaning: Does a path exist where an activated burglar alarm will be deactivated?

c) General Schema Formula: A <> P
Informal Description: Will P eventually hold for all paths?
Sample of Property Instances:
A<>Thermostat.idle
Intuitive Meaning: Will the thermostat eventually return to the idle state?

d) General Schema Formula: A [ ] P
Informal Description: Does P always hold for all paths?
Sample of Property Instances:
A [ ] ! (vitalSignsMonitor.bloodSugar>0 && AtHome==false)
Intuitive Meaning: It is not possible for the system to reach a state where blood sugar is monitored when the patient is not at home.

e) General Schema Formula: P → Q
Informal Description: Whenever p holds will q also hold?
Sample of Property Instances:
kitchenSmokeAlarm.active --> AlarmManager.contactFireBrigade
Intuitive Meaning: Whenever the kitchen smoke alarm is active, the alarm manager will contact the fire brigade.

Tools like UPPAAL allow an exploration of a system being designed at several levels of rigorousness. The first step that can be taken is to simulate the behaviour of the system. This is usually a random simulation, although some systems will allow different levels of guided simulation, either by the user or by a trail left out of a counterexample created by the system (after a failed attempt to prove that a behavioural property is true). The next level of exploration is more rigorous and is about using a formal language similar to the one briefly presented above to state a behavioural property and using the verification algorithm to verify that the stated property is true of the modelled system.

These verification tools are an excellent means for examining traditional computing systems and provide a way ahead to design AmI systems more rigorously. However these tools are usually tailored to either verify software or hardware specifications and we believe the new blend of hardware and software linked through a network that forms the AmI technological layer and in particular their interaction with humans (the beneficiaries of the real system, e.g., the occupant of the Smart Home) through a variety of interfaces make AmI systems novel and demands new and more holistic approaches.

9. 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 a number of areas of possible application. We expanded upon what currently is the driving force of AmI: Smart Homes.

The area has attracted significant attention, sometimes under different names like *intelligent ubiquitous systems* or *intelligent environments*. An indication of this is the rapidly increasing number of scientific conferences, journal papers, books published, commercial exhibitions and governmental projects.

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 expend 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 major successes (PC, Internet, World-Wide-Web, mobile computing) interspersed with unfulfilled expectations. 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 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.

References

1. R. Want. “Rfid – a key to automating everything”. *Scientific American*, 290:46–55, January 2004.
2. C. D. Nugent and J. C. Augusto, editors. *Proceedings of 4th International Conference On Smart homes and health Telematic (ICOST2006)*, Assistive Technology Research Series. IOS Press, 2006. Belfast, UK.

3. J.C. Augusto and D. Shapiro, editors. Proceedings of the 2nd Workshop on Artificial Intelligence Techniques for Ambient Intelligence (AITAmI'2007). Co-located event of IJCAI'07. Hyderabad, India, Jan. 2007 .
4. hilips. 2007. www.research.philips.com/technologies/misc/homelab/ .
5. Moore's Law at 40 - Happy birthday". *The Economist* (2005-03-23).
6. ay Kurzweil (2001-03-07). "The Law of Accelerating Returns". KurzweilAI.net.
7. A. Black, MF. McTear, ND. Black, R. Harper. "Voice based access to a medical database". *Personalised Health Management Systems, Stud Health Technol Inform* 2005; 117: 232-6, ISBN: 978-1-58603-565-5
8. uropean Commision, eEurope 2005; "eHealth: Commission calls for better use of technologies that empower patients, improve healthcare and save lives".
9. Philips, 2006. www.research.philips.com/technologies/syst_softw/ami/ .
10. iemens, 2006. http://networks.siemens.de/smarthome/en/index.htm .
11. okia, 2006. research.nokia.com/research/projects/sensorplanet/ .
12. TT, 2006. www.vtt.fi/uutta/2006/20060602.jsp .
13. ST Advisory Group. *The european union report, scenarios for ambient intelligence in 2010*, 2001. ftp.cordis.lu/pub/ist/docs/istagscenarios2010.pdf .
14. .C. Augusto and D. Cook. *Ambient Intelligence: applications in society and opportunities for AI*. Lecture Notes, tutorial given during 20th International Joint Conference on Artificial Intelligence – IJCAI'07, Hyderabad, India, January 2007.
15. . Weiser. "The computer for the twenty-first century". *Scientific American*, 165:94–104, 1991.
16. N. Streitz and P. Nixon. "Special issue on 'the disappearing computer' ". In *Communications of the ACM, V 48, N 3*, pages 32–35. ACM Press, March 2005.
17. M. Weiser. "Hot topics: Ubiquitous computing". *IEEE Computer*, 26(10):71–72, 1993.
18. D. Saha and A. Mukherjee. "Pervasive computing: A paradigm for the 21st century". *IEEE Computer*, 36(3):25–31, March 2003.
19. A. Greenfield. Everyware: The Dawning Age of Ubiquitous Computing. Peachpit Press, 2006.
20. S. J. Russell and P. Norvig. Artificial Intelligence: A Modern Approach (Second Edition). Prentice Hall, 2003.
21. H. Raffler. "Other perspectives on ambient intelligence", 2006. www.research.philips.com/password/archive/23/pw23_ambintel_other.html .
22. K. Brooks. "The context quintet: narrative elements applied to context awareness". In *Proceedings of the International Conference on Human Computer Interaction (HCI 2003)*. Erlbaum Associates, Inc., 2003.
23. A. Dix, J. Finlay, G. D. Abowd, and R. Beale. *Human–Computer Interaction, 3rd edition*. Prentice Hall, 2003.
24. D. J. Cook and S. Das, editors. *Smart Environments: Technologies, Protocols and Applications*. JohnWiley and Sons, 2004.
25. JC. Augusto and CD. Nugent. Designing Smart Homes: the role of Artificial Intelligence. Springer, 2006.
26. Tunstall, www.tunstall.co.uk/4_6telecare.htm (accessed March 2007).
27. H. Pigot, A. Mayers, S. Giroux, B. Lefebvre, and N. Noury V. Rialle. "Smart house for frail and cognitive impaired elders". *UbiCog '02: First International Workshop on Ubiquitous Computing for Cognitive Aids*, Göteborg, Sweden, Sept. 2002.
28. G. A. Abowd, I. Bobick, E. Essa, and W. Mynatt. "The aware home: Developing technologies for successful aging". *Proceedings of AAAI Workshop and Automation as a Care Giver*. July 2002.
29. D. Cook. "Health monitoring and assistance to support aging in place". *JUCS*, 12(1):15–29, 2006.

30. A. Helal, W. Mann, H. Elzabadani, J. King, Y. Kaddourah, and E. Jansen. “Gator tech smart house: A programmable pervasive space”. *IEEE Computer magazine*, pages 64–74, March 2005.
31. JC. Augusto, P. McCullagh, V. McClelland, and J-A. Walkden. “Enhanced Healthcare Provision Through Assisted Decision-Making in a Smart Home Environment”, *Proceedings of the 2nd Workshop on Artificial Intelligence Techniques for Ambient Intelligence (AITAmI’07)*, pages 27–32. IJCAI, 2007.
32. JC. Augusto and CD. Nugent. “A new architecture for smart homes based on ADB and temporal reasoning”. In D. Zhang and M. Mokhtari, editors, *Proceedings of 2nd International Conference On Smart homes and health Telematic*, pages 106–113. Assistive Technology Research Series, Volume 14. IOS Press, 2004.
33. JC. Augusto. “Ambient intelligence: The confluence of pervasive computing and artificial intelligence”. In *Computing Everywhere*. A. Schuster, editor. Springer Verlag, 2007.
34. ACM-Pnueli, 1996. URL: www.acm.org/announcements/turing.html .
35. CM-SPIN, 2001. URL: www.acm.org/announcements/ss_2001.html 36. The explosion of Ariane www.ima.umn.edu/~arnold/disasters/ariane.html
36. Leveson and C. Turner, “An Investigation of the Therac-25 Accidents,” *Computer*, July 1993, pp. 18-41.
37. ondon transport plan, 2005-2010, (last accessed in March 2007) www.london.gov.uk/mayor/transport/tfl-investmentprog2005.jsp
38. L.T. Kohn, J.M. Corrigan, and M.S. Donaldson, eds., “To Err Is Human: Building a Safer Health System”, National Academies Press, 2000, p. 80; http://darwin.nap.edu/books/ 0309068371/html .
39. R. A. Schrenker. “Software Engineering for Future Healthcare and Clinical Systems”, *Computer,* April 2006 (Vol. 39, No. 4) pp. 26-32.
40. “The Way Forward for NHS Health Informatics; Where should NHS Connecting for Health (NHS CFH) Go from Here?” *A report on behalf of the British Computer Society (BCS)* by the BCS Health Informatics Forum Strategic Panel is available to read and download at www.bcs.org/hi/forward .
41. B. Berard, M. Bidoit, A. Finkel, F. Laroussinie, A. Petit, L. Petrucci, Ph. Schnoebelen, P. McKenzie. “Systems and Software Verification (Model-Checking Techniques and Tools)”. Springer Verlag.
42. “Concurrent Development of Model and Implementation”. A. Gravell, Y. Howard, J. C. Augusto, C. Ferreira, and S. Gruner. Proceedings of 16th International Conference on “Software and Systems Engineering and their Applications”. Paris, France. December 2-4, 2003.
43. Corbett, J.C.; Dwyer, M.B.; Hatcliff, J.; Laubach, S.; Pasareanu, C.S.; Robby; Hongjun Zheng. “Bandera: extracting finite-state models from Java source code.” *Proceedings of the Int. Conf. on Software Engineering.* Page(s):439 - 448. 2000.
44. Kim G. Larsen, Paul Pettersson, and Wang Yi. “UPPAAL in a Nutshell”. International Journal on Software Tools for Technology Transfer. Number 1-2, pages 134-152. 1997.
45. Arthur McFall. “Checking Behavioural Properties Of Smart Homes.”. *MSC in Informatics*. University of Ulster. 2005.
46. "Patterns in property specifications for finite-state verification". M. Dwyer, G. Avrunin, and J. Corbett. In *Proceedings of 21st International Conference on Software Engineering, ICSE99*, Los Angeles, May 1999.

Juan Carlos Augusto's research experience since 1998 has been focused on AI-related problems and mostly related to temporal reasoning. His latest research activities have explored the application of spatio-temporal reasoning to Ambient Intelligence in general and Smart Homes in particular. During his academic work he produced nore than 60 publications, most of them related to the area of Ambient Intelligence. He has given invited tutorials/seminars for international conferences and companies and co-chaired many international events, including AITAmI´06, AITAmI´07, and ICOST'2006. He is also serving as Editorial Board member for four international Journals.