CREST project

Ambient intelligence : an annotated bibliography

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AMBIENT INTELLIGENCE

We survey the literature available on the topic of ambient intelligence (AmI) including its applications and some of the technologies it uses. We list a selection of key publications in the area, and provide a summary for each of the papers. Moreover, we discuss technologies used, we focus on ambient data management and artificial intelligence; for example planning, learning, event-condition-action rules, temporal reasoning, and agent-oriented technologies. The survey is not intended to be exhaustive, but to convey a broad range of applications, technologies, and technical challenges.

1. Introduction

The term Ambient Intelligence (AmI) was coined by the European Commission, when in 2001 one of its Programme Advisory Groups, the European Community's Information Society Technology (ISTAG), launched the AmI challenge [1], later updated in 2003 [2]. But although the term AmI originated in Europe, its usage and intended goals have been adopted worldwide, with many related projects and research programs in recent years. This very active area has been the subject of several collections of papers, and special issue publications (e.g. [3], [4], [5], [6], IEEE Intelligent Systems Magazine, Journal of Ambient Intelligence and Smart Environments (JAISE)) and several specialized workshops and conferences. Some examples are: the European Conference on Ambient Intelligence which its sixth edition will be held in Athens (Greece) on 11-13 November 2015, the International Conference on Ubiquitous Robots and Ambient Intelligence, running for the past 11 years and which its eleventh edition was held in Kuala Lumpur, Malaysia on 12-15 November 2014, the International Conference on intelligent environnements which its eleventh edition will be held in Prague, Czech Republic on 15-17 July 2015.

Ambient Intelligence is the vision of a future in which environments support the people inhabiting them. This envisaged environment is unobtrusive, interconnected, adaptable, dynamic, embedded, and intelligent. In this vision the traditional computer input and output media disappear. Instead processors and sensors are integrated in everyday objects. So for example, instead of using mice, screens, and keyboards, we may communicate directly with our clothes, household devices, and furniture, and these may communicate with each other and with other people's devices and furniture. The envisioned AmI environment is sensitive to the needs of its inhabitants, and capable of anticipating their needs and behavior. It is aware of their personal requirements and preferences, and interacts with people in a user-friendly way, even capable of expressing, recognizing and responding to emotion.

Most authors broadly share similar views of the features required for AmI applications. [7] identifies AmI as an intelligent, embedded, digital environment that is sensitive and responsive to the presence of people. The key features here are intelligence and embedding. By intelligence, he means the system is sensitive to context, is adaptive, learns from the behavior of users, and eventually, recognizes and expresses emotion. By embedding he means small, possibly minituarized devices that merge into the background of people's activities and environments. Similarly, [8] identifies five related key technology features: embedded, context aware, personalized, adaptive, and anticipatory.

The AmI environment is based on miniaturized and low-cost hardware, providing complex networks of heterogeneous information appliances or smart artifacts. These, individually or as an ensemble, can assist users in day-to-day or exceptional activities. They can demonstrate common sense and problem-solving ability, and assume responsibility for certain need, of the user, such as monitoring, alerting and helping users in their tasks. Advances in AmI are facilitated by the long-term increases in the power of microprocessors and nanotechnology, as well as the cost-efficiency of storage capacities and communication bandwidths.

Some of the more modest visions of AmI are near to realization, and others look more like science fiction for now. But the scope of potential applications is vast, and in this survey we look at many. AmI has the potential of freeing people from tedious regular routine tasks. It can provide assistance in many circumstances. For example parents may never loose track of their children in crowds, because of location sensors and miniature communication devices sewn into the fabric of clothes. Blind people may be guided in unfamiliar environments by intelligent signposts and public transport timetables that may communicate via wireless headsets [9]. Our washing machines may query our dirty clothes for the required washing programs. Traditional memory aids can remind the user about activities on their daily schedule, but more sophisticated memory aids, on the other hand, can be context- sensitive. They can observe the user in their activities, guess their desired tasks and on that basis issue reminders and guidance [10], [11]. AmI has potential applications in many areas of life, including in the home, office, transport, and industry; entertainment, tourism, recommender systems, safety systems, ehealth, and supported living of many different variations.

The potential of AmI at home has been the subject of research for at least a decade in some major industries. The Microsoft Corporation Domestic Home in Redmond, Washington, for example, showcases AmI-based smart appliance technologies for the home. There are no desktop or laptop computers, but the wallpaper is interactive, and can be controlled by tablet PCs. The mailbox outside tracks the mailman's location using GPS, and users can get a real-time estimate of when mail will arrive, on the mailbox display or by cell phone. RFID (radio frequency identification) tags embedded into envelopes even provide information about what mail is on the way. RFID tags are active barcodes, which attach digital information to objects. This technology is being increasingly used by industry for tracking inventory. These tags can be quite small and do not require a battery. In the Microsoft Home there are RFID tags on clothes as well. In a bedroom, by holding clothes up to a mirror which doubles as a screen one can get information about them, including whether matching items like a skirt or jacket are in the wardrobe or the laundry. The kitchen has an intelligent note board. If you pin a pizza coupon on it the restaurant's menu and phone number are displayed. You can call the restaurant with a tap on the board.

In the UK, British Telecom (BT) and Liverpool City Council have run trails on tele-care technology within a project devised by BT's Pervasive ICT Research Centre. The trial concerned a system that responded to crises in the home. Each home contained 12 wireless sensors, including passive infrared sensors, entry switch sensors, occupancy sensors, a toilet flush sensor, and a temperature sensor, all connected to a central gateway, and to a BT server, via a secure broadband IP channel. If a cause for concern is flagged, a voice call is made to the home's occupier. If he/she confirms that they are okay, voice recognition technology is used to cancel the concern, otherwise a voice alert is sent to selected personnel, who can then use a standard Web browser to access information about the inhabitant and the circumstances of the alert. Personalization and context-awareness have been some of the objectives of AmI technologies developed at Philips Research laboratories.1 In conjunction with sportswear manufacturer Nike. Philips has investigated biosensors that can be embedded in clothing to detect parameters such as heart rate, respiration rate, and blood oxygen levels. The aim is to provide personal fitness training and healthcare-monitoring within sports clothing. Another project is Philips Research's CAMP (Context Aware Messaging Platform), aimed at providing context awareness in mobile devices. Location is taken as an indicator of context, and a prototype system uses Bluetooth short-range wireless transmissions between stationary beacons and mobile devices. Beacons and mobile devices can transmit information, for example about their interests and offerings. Thus in a meeting with unfamiliar people, a beacon in the room could transmit their electronic business cards to your mobile device to help you identify them. Similarly, in a shopping center, a beacon could alert you via your mobile device about any friends that are nearby, and which shops they are in, as well as any special offers on products you are interested in.

Context awareness is also one of the key elements of the vision of ihospital proposed in [12]. The ihopspital, an interactive, smart hospital environment, provides context-aware communication, whereby for example, a message can be sent to the doctor responsible for a patient in the next shift, without the need to know who the doctor will be. Information about context, such as location, time, and the roles of the people present, and RFID-tagged artifacts, is also used for activity recognition; for example the activities of a ward nurse and doctor during the morning hours, handling reports and case files, may be interpreted as patient care or clinical case-assessment.

The use of AmI for leisure and tourism has been explored in [13], amongst others. It has been explored also in several EU-funded projects such as **AmbieSense** (2002-2005), and **FP6 e-Sense**(2006-2008, http://www.ist-e-sense.org/), and **FP7 Sensei** (2008-2011, http://www.sensei-project.eu/). Authors in [14], [15], within projects PEACH and TICCA, have explored the use of AmI for interactive museums. In their scenarios museum exhibits are equipped with several agent-controlled devices that are capable of producing a presentation about the exhibit but with different capabilities, e.g. pictures, video, text, audio. The devices sense approaching visitors and produce presentations, controlled by a multi-agent architecture and role-based real-time coordination mechanism.

Research into ambient recommender systems, for example, in [16], [17], [18], [19], authors attempt to extend the functionality of conventional recommender systems. This involves designing proactive systems that are intelligent and ubiquitous advisors in everyday contexts, which reduce the information overload for the user, and are sensitive, adaptive and responsive to user needs, habits and emotions. Recognizing human emotions and using this recognition to reduce user frustration, for example in games or tutoring systems, are also active areas of research within AmI (e.g. [20], and [21]). Recognizing and utilizing emotions have also been considered in other areas such as group decision making [22], [23].

Inevitably the social impact and the acceptance of such potentially powerful and intrusive technologies are topics of debate, and have been since their conception. The success and acceptance of AmI by the public will depend on how secure and reliable it is and to what extent it is perceived to allow the protection of the rights and privacy of individuals.

As well as setting out a technological vision of AmI, several characteristics are necessary for its social acceptance. For example it suggested that AmI systems should:

- facilitate human contact;
- be oriented towards community and cultural enhancement;
- inspire trust and confidence;
- be controllable by ordinary people—there should be an off-switch within reach.

The AmI vision may be thought of as the convergence of at least three areas of computing: ubiquitous computing, sensor network technology, and artificial intelligence. But AmI is now a very broad multidisciplinary endeavor, drawing on, and consequently enhancing, existing technologies, including ubiquitous computing, ubiquitous communication, intelligent user-friendly interfaces (e.g. multimodal, visual, sound, and speech), artificial intelligence and multi-agent systems. It is further supported by sensor network technologies, location, and motion trackers, medical devices, decision support systems, mobile communications, and wireless networks.

Progress in wireless technologies, sensor networks, display capabilities, processing speeds, and mobile services has paved the way to impressive developments in the AmI field. These developments help provide much useful raw information for AmI applications, and artificial intelligence and agent-based technologies have been explored to take full advantage of such information in order to provide the degree of intelligence, flexibility, and naturalness envisaged. Many AI techniques have been explored in this context, for example learning [24], case-based reasoning [25]), temporal reasoning [26], decision trees [27], and fuzzy logics (e.g. Hagras et al. [2004]). Some database techniques have also been used, such as event-condition-action rules [26]), and (extensions of) SQL-based data management techniques.

Agent technology is commonly used in AmI applications. This is not surprising, as the pervasive nature of AmI requires distributed information and problem solving, and agents are known to facilitate such architectures. Agents can be used as useful abstractions in AmI systems, for example for devices and functionalities, and as paradigms for implementation. They can be used at various levels: for example, to model individual devices present in the AmI environment, or they can be exploited at the middleware level to coordinate the activities of the lower level entities, or they can be used at a higher level to form the interface for humans.

[28],[29] for example, describe an architecture called SALSA, for health care, which uses agents as abstractions, to act on behalf of users, to represent services, and to provide wrapping of complex functionality to be hidden from the user. In [30], authors describe a mixed central and distributed approach to planning in an AmI environment where devices are represented by agents, and enter and leave the environment. [30] describes an architecture for an AmI-enhanced bookshop, where there is a one-to-one map from the elements of the bookshop (e.g. customers and audio-visual devices) onto agents in a parallel software world of agents.

Different architectures have been used for organizing agents in AmI systems. For example, in [30] describe a blackboard architecture whereby administrative agents look for messages and then contact appropriate service agents to deal with each message. Several other AmI proposals, in [26] they use a centralized agent architecture, where a single agent receives all the information and is responsible for all the decision-making. Robocare [32], for example, has an event-manager agent that processes all requests and then directs each request to an appropriate agent via agent-to-agent communication.

Other non-agent-based generic architectures have also been proposed. For example, [33] proposes architectures inspired by a model of human consciousness.

This Annotated Bibliography does not attempt to be exhaustive in capturing all possible disciplines and reported work within the AmI framework. It focuses primarily on applications and the intelligence aspects of AmI. It is biased towards the AI and agent technologies used in AmI, although where attempting to give a broader flavor of the field of work it touches on other prominent approaches and technologies.

This report is structured as follows. First, in Sections 2, explores several major applications of AmI. For each broad application a collection of papers are reviewed, and where necessary for understanding a technical contribution, a brief background material on the technology use dis provided. Then, in Section 3, we look in de tail at additional data management and AI technologies in development for use in AmI systems. Finally, in section 4 we conclude the report.

2 Ambient intelligence applications

2.1 Samrt home

A great deal of the vision of AmI is targeted at the home environment. AmI at home can provide context-awareness and pro-activeness to support everyday living. For example [34] the bathroom mirror can remind a person of the medication he/she has to take, and the car stereo can tune into the same station that was on during breakfast. Some ideas and functionalities are distant visions, such as self-monitoring and self-painting walls, and lighting and furniture recognizing emotions and moods; some have already produced prototypes, such as dormitories that learn simple preferences of their single occupiers regarding open or shut windows and level of lighting or heating. Some simple AmI-based devices are even routinely commercially available, such as temperature sensitive heating systems, movement-sensitive lighting, and light-sensitive blinds.

Various names have been used to describe homes equipped with pervasive technology to provide AmI services to the inhabitants. Smart Homes may be the most popular term, and others terms include aware houses, intelligent homes, integrated environments, alive, interactive, responsive homes/environments. Innovation in domestic technology has long been driven and marketed by the desire to reduce labor and improve the quality of time spent at home. This continues to be one of the motivations for development of AmI at home. Other factors include technological advances and expectations, and an increasing trend in a way of life that blurs the boundaries between home, work, and places of rest and entertainment.

A Smart Home environment is a home equipped with sensors and activators of various types to monitor activities and movement, and to monitor risk situations, such as fire and smoke alarms. In general, there are usually three main components associated with Smart Homes, a set of sensors, a set of activators for controlling the sensors and other equipment, such as cookers, windows, and so on, and computing facilities to which the sensors and activators are linked.

The sensors can, for example, detect if a Fancet is on or not, a weight is on a seat, or whether someone wearing an identifying tag has passed under a door joining two rooms. The sensor information may require some form of further processing to produce useful data, for example about location [28]. It can be used to trigger some form of intervention on the part of the Smart Home to avert disaster [26]. It can also be used to learn behavior patterns of the occupant [35].

The Smart Home concept is often used to support people with some cognitive impairment living on their own. Such homes are intended to provide better quality of life and greater levels of independence, and to reduce the need for institutionalization by extending the time that people can live in their own homes.

Alarm systems are standard conventional equipment provided currently in most homes. But the Smart Home concept goes much beyond these, to envisage systems that can monitor the resident's activities, compare them with his/her profile, take action if necessary, and provide help and guidance regarding safety, health, and medication, as well as entertainment and other matters. For example, currently there are alarm buttons in the home or around a person's neck or wrist to send alert in the event of emergency, fire, unconsciousness, or a fall. But the problem is that there may not be enough time for the user to trigger the alarm. To alleviate this problem there is a move towards alarms that can activate themselves, for example based on vital functions such as pulse rates and blood pressure. Similarly we have many standard automatic systems that switch the light on when they detect motion, but a Smart Home can turn the light on in anticipation of its resident's needs, or even turn the light on as a reminder or cue to where the resident should be moving.

AmI services envisaged in the home environment include the following.

- performing many everyday tasks automatically, thus reducing the burden of managing the house, for example, controlling household appliances and other objects to make household duties and maintenance tasks easier;
- improving economy of usage of utilities, such as electricity, by controlling the lights and window blinds, for example;
- improving safety and security, for example by preventing accidents, recognizing and rapid reporting of accidents, tracking people and providing entry access control with sophisticated interfaces. Safety/security can include the obvious, such as entry access control and alarm facilities, automatic safety protection for appliances such as irons and ovens, to safety in terms of health and biomedical monitoring, to buildings that monitor themselves and alert about, or even make, necessary reconstructions and repairs;

- improving quality of life, for example through entertainment and increasing comfort levels;
- supporting independent living for the elderly and the impaired. This is addressed in the next section, as it is an important application in its own right.

The technologies needed are diverse. Two main general components are a networked set of sensors and computing facilities, to integrate and interpret the sensor information, and learn or initiate action. The sensors can be specialized for sensing carbon monoxide, heat, motion, or for detecting whether a door or window is open or shut. Some specific applications of AmI at home may require multidisciplinary collaboration, in computer science, electrical engineering, and possibly aspects of medicine and general health care, social sciences, and occupational therapy.

Much of the work on Smart Homes concentrates on the hardware, sensors, and devices, but several authors [26] have argued that AI techniques can help the evolution of Smart Homes by bringing a degree of sophistication to the processing of information provided by the devices and sensors. This processing can be focused on learning user profiles [5], on diagnostic capabilities for determining whether a deviation from routine is a matter of concern, on advising whether or not a rescheduling of normal activities is possible after a deviation , and on combining elements of temporal and probabilistic reasoning to provide a more powerful setting for monitoring and intervening [26].

It has also been argued [26] that smart home applications and AmI, in general, can contribute to the advancement of AI technologies, by providing AI with nontrivial testbeds and scenarios, requiring integration and development of several techniques.

We start the survey of AmI at home with an overview scene-setting paper, and then move on to more technical papers. The papers describe three implemented home systems, GENIO, MavHome, and iDorm, illustrating advances in home ambient systems and the use of RFID tags, speech recognition, learning and fuzzy logics in this application.

FRIEDEWALD, M., DA COSTA, O., PUNIE, Y., ALAHUHTA, P., AND HEINONEN, S. PERSPECTIVES OF AMBIENT INTELLIGENCE IN THE HOME ENVIRONMENT. TELEMATICS INFORMATICS, 22, ELSEVIER, 221–238. 2005.

This article discusses the opportunities that ambient intelligence can provide in the home environment, and describes the risks, and the balance between the technology enhancing or overburdening life. In their view AmI solutions at home will cover four areas.

(a) Home automation

(b) Communication and socialization

(c) Rest, refreshing, and sport

(d) Household work and learning.

Home automation. This includes the control of electricity, heating, air-conditioning, ventilation, and fire and intruder alarms. Many such functions already exist, for example, motion detectors, sensitive air conditioners, automatic heating adjusters, and automatic sunlight-sensitive blinds. Several challenges have been identified for en- hancing such functionalities in intelligent homes. One is in providing more flexible interfaces for such functions, such as voice, hand gesture, and facial expression. Another is the adjustment of such functions according to the home's knowledge of the preferences of its residents. A third is in recognizing the user's likes or dislikes on the fly from their voices or facial expressions, and a fourth is in managing spaces shared by several occupiers, for example, friends and families. Maintaining security at home can go beyond ordinary access control to locks capable of identifying persons, hands-free unlocking, and affordable face/voice/iris recognition facilities. Such recognition techniques could also be used in other aspects of the home, for example to provide the preferred entertainment for the person occupying a room.

Communication and socialization. We already enjoy technological advances in fast access and communication via the Internet, with hand-held or hands-free devices, and with mobile photo and video facilities. AmI technological advances could provide access to digitalized documents, family photos, and films, regardless of location and equipment. They could also open up different ways of participating in the civil society, for example by e-participation and electronic voting in politics, referenda (e-governments), and unions. Furthermore, and possibly in the longer term, AmI may allow formation of ad hoc wireless social contacts and communities of people with shared interests and needs through spontaneous contacts of their virtual profiles, for example, people wanting to commute to a particular area.

Rest, refreshing, and sport. Resting can be supported by AmI through multifunctional, flexible furniture, with sensors embedded in the furniture measuring blood pressure and pulse for example, together with bio-identifiers recognizing the occupant of the furniture and recognizing their preferences, for example for a nap, massage, soft music, and so on. Databases can recognize and play a piece of music after the occupant hums a few bars of it. The home may contain AmI facilities dedicated to health and fitness, for example counting the amount of time spent using the stairs and estimating the calories used, as well as biomedical monitors to regularly check blood pressure and heart rates.

Household work and learning. Household appliances already reduce the amount of housework. AmI-embedded appliances can go further. For example washing machines can determine the program required for washing by checking the degree of soil of the clothes, vacuum cleaning robots can not only navigate around obstructions, but can also recognize small items and tell apart, for example, a small bottle top and an ear-ring on the floor. It could even be possible to discard cleaning appliances and embed cleaning properties within materials themselves. The refrigerator can become a kitchen computer displaying information about its contents, and listing missing items. The home AmI vision extends to entire buildings, where buildings have self-repairing elements: walls, floors, and ceilings monitoring the state of repair and warning when there is need for work, walls self-painting, gardens recognizing the need for mowing, and lawn mowing robots recognizing flowers that are to be preserved in their path.

Clearly realizing such visions presents major challenges, among them the context sensitive and personalized requirements of AmI (how to accurately recognize what the human inhabitant needs or wants). There are also social and cognitive challenges, for example how to provide the functionalities in such a way that they enhance life rather than overburden it, and how to ensure that they do not limit initiative and weaken the cognitive abilities of more vulnerable people, such as the elderly.

GARATE, A., HERRASTI, N., AND LOPEZ, A. GENIO: AN AMBIENT INTELLIGENCE APPLICATION IN HOME AUTOMATION AND ENTERTAINMENT ENVIRONMENT. IN PROCEEDINGS OF THE JOINT SOC-EUSAI CONFERENCE. 241–245. 2005

This paper describes the GENIO project, which is a collaborative effort between two companies in Spain, Fagor Electrodomesticos and Ikerlan, aimed at providing ambient intelligence at home. GENIO is Spanish for Genie, the one that grants your desires. In this work household appliances such as fridge, washing machine, oven, sensors, security, and heating devices are networked and managed by a central controller which can respond to, and hold, a dialogue with the user in natural language (Spanish). This central domotic controller is called Maior-Domo and has a visible avatar representation. A demonstrator has been built consisting of a kitchen and sitting room with various domestic and entertainment appliances controlled by Maior-Domo. Some of the appliances and devices and their capabilities are as follows.

- Oven. This has a database of recipes and once a recipe is chosen it can control the oven temperature, timing and, method of heating.
- Fridge. This has an RFID (Radio Frequency Identification) antenna and an RFID reader inside, allowing it to read the goods stored in it. The goods have to be equipped with RFID tags.
- A large panel containing the electronic circuit boards of a washing machine and a dishwasher. These circuit boards substitute for the actual appliances for the purposes of the demonstrator.
- A computer working as Maior-Domo. This can communicate with the oven, washing machine, and dishwasher electronically. It is also equipped with a speech recognition system (developed by means of Java, VXML, JSP, JavaBeans), a Text to Speech component, applications to command the appliances, and digital information such as photos, songs, and videos.
- A pocket microphone for the user, allowing wireless connection to Maior-Domo from anywhere in the environment.

Some example scenarios used in the demonstrator are the following.

- Reading emails. User: "Maior-Domo, how many emails do I have." Maior-Domo answers with a number and gives the sender of each one, from which the user can choose which one Maior-Domo should read for him.
- Activating washing machine. User asks Maior-Domo to wash his clothes by the time he gets back from work. Maior-Domo inquires when he will be back from work and which washing program is required, and on getting the answers sets the washing machine.
- Checking goods in the fridge and preparing a shopping list. User specifies a list of items he would always like to purchase, and can command Maior-Domo, by voice, to add further items to the list and download it.
- Preparing a recipe. User can ask Maior-Domo for a recipe, for roast chicken say, and specify the number of people it is required for. Maior-Domo adjusts the recipe to the

number required, and can on command, read the recipe line by line, pausing for a user command after each line.

- Entertainment. User can ask for some Mozart music, for example. Maior-Domo lists what is available and plays what the user selects, and stops on command.

The major contributions of this work are the real settings, the demonstrator allowing control of several appliances, and the voice processing. The proposed future work includes recognition of the person giving commands to Maior-Domo, for example to ensure that a child does not activate the security system or the oven.

This paper describes the MavHome (Managing An Intelligent Versatile Home) project at the University of Texas at Arlington. The objective of the project is to "create a home that acts as a rational agent," that has sensors and effectors, and that acquires and applies information about the inhabitants to provide comfort and efficiency. Comfort is in terms of the ambience of the environment, including temperature, ventilation, and lighting. Efficiency is in terms of the cost of utilities, such as gas and electricity. Thus the aims are twofold, to reduce the need for inhabitants to intervene to make changes for themselves in the environment, and to reduce energy consumption.

A Mavhome idealistic scenario is as follows. In Bob's house:

"At 6:45 am MavHome turns up the heat because it has learned that the home needs 15 minutes to warm to optimal temperature for waking. The alarm goes off at 7:00, which signals the bedroom light to go on as well as the coffee maker in the kitchen. Bob steps into the bathroom and turns on the light. Mavhome records this interaction, displays the morning news on the bathroom video screen, and turns on the shower. While Bob is shaving MavHome senses that Bob has gained two pounds over the last week. MavHome informs Bob that this has been a trend over the last two months and offers suggestions for changing his lifestyle. When Bob finishes grooming, the bathroom light turns off while the blinds in the kitchen and living room open (an energy saving alternative to Bob's normal approach of turning on the living room, kitchen and hallway lights). When Bob leaves for work, MavHome secures the home, lowers the temperature, starts the robot vaccum, and turns on the lawn sprinklers ...... MavHome tracks Bob's activities while he is away from home in order to inform him of problems at home and to have the house temperature and hot tub prepared for his return at 6:00."

The MavHome architecture is a hierarchy of rational cooperating agents, each agent consisting of 4 layers. These layers, from top to bottom, are: the Decision layer, which decides what action to execute based on information provided by other layers, the Information layer, which collects, stores, and generates knowledge for decision-making, the Communication layer, which is used for information-passing between agents, and between the house and external devices, and the Physical layer, which contains basic hardware, devices, and network within the house.

Information about the current state is passed on to the Decision layer via the Physical layer through the Communication and Information layers. Decisions about what actions have to be executed are passed on from the Decision layer to the Physical layer via the Information and Communication layers. In more detail, sensors collect data about the environment, and transmit the data to the agents through the communi- cation layer. The data is stored in a database and new data can be passed on to the decision layer, which may decide that an action should be executed. The decision is passed on to the information layer and stored in the database and passed on to the appropriate effectors in the Physical layer for action execution.

Communication is both point-to-point and publish-subscribe, and uses the CORBA (Common Object Request Broker Architecture) model, which is an industry standard specification developed by the Object Management Group (OMG) to aid the creation and usage of distributed objects. All agents register their presence using Zero Configuration (zeroconf) technologies. Zeroconf provides for automatic configuration and address allocation on wireless networks, allowing agents to join dynamically.

Mavhome combines several machine learning algorithms to learn the inhabitant's habits (it is assumed the home is inhabited by one person at a time), predict their next action and form action policies for manipulating the environment. To learn the inhabitant's habits, data mining is applied to data collected from observations of their activities and interactions with the environment, to extract patterns. The data mining is based on an approach that deals with time-ordered transactions [36]. To predict the inhabitant's actions, a compression algorithm called LZ78 [37] is used in conjunction with a history of the inhabitant's interactions with the devices in the environment. To learn action policies, reinforcement learning is applied with a model of the system as a Markov Decision Process (MDP), where states are associated with rewards and state transitions are probabilistic. Negative reinforcement is received when the inhabitant immediately reverses the automatic action of the system (e.g. turns the light back on).

All MavHome components are implemented and are being tested in two environments, a workplace environment and an on-campus apartment with a full time student occupant. In both environments the sensory information includes light, temperature, humidity, motion (via passive infrared sensors), seat (occupied or not), and door and window (open or closed) status. The apartment also has sensors for leaks, smoke detection, vent position, and CO detection. The aim of the experiments in both settings has been to minimise the inhabitant's manual interaction with devices. Variations in the learning algorithms are mapped against reductions in manual interactions. The results reported indicate a reduction of between 72% and 76% in both environments.

HAGRAS, H., CALLAGHAN, V., COLLEY, M., CLARKE, G., POUNDS-CORNISH, A., AND DUMAN, H. 2004. CREATING AN AMBIENT-INTELLIGENCE ENVIRONMENT USING EMBEDDED AGENTS. IEEE INTELL. SYST. 12–20.

This work reports the use of fuzzy logic-based techniques to learn user references in an ordinary living environment. They have devised an experimental intelligent inhabited environment, called the iDorm (intelligent dormitory) at the University of Essex, UK. The iDorm contains space for various activities such as sleeping, working, and entertaining, and contains various items of furniture such as bed, desk, wardrobe, and multimedia entertainment system. It is fitted with multiple sensors and effectors. The sensors can sense temperature, occupancy (for example user sitting at desk, user lying in bed), humidity, and light levels. The effectors can open and close doors, and adjust heaters and blinds.

The iDorm has embedded computational components including:

(1) *iDorm embedded agent.* This receives readings from the sensors about time of day, room light and temperature, outside light and temperature, state of window (closed, open), and user's activity, for example sitting at desk, sitting, lying in bed, using entertainment system, computer, and so on. It contains the user's learned behavior, and on the basis of this and the sensor data, it computes any appropriate actions, using a fuzzy logic technique. The actions include adjusting a fan heater/cooler, lights, or blinds.

(2) *A robot.* This is a physical robot under the control of the iDorm agent. The robot is equipped with some navigation capabilities, such as obstacle avoidance, and can move and carry items such as food, drink, and medicine. iDorm is aware of the robot's location and sends it instructions for moving to a destination and carrying objects.

iDorm deals with two types of rules, static (user-independent) rules such as how to react in an emergency, and to lower the lights and temperature when the room is unoccupied, and learned rules reflecting the user preferences. Each user is identified by a unique ID. When a new user enters the room there is a monitoring period to sense user activities. This provides examples for the learning phase. Learning is based on negative reinforcement, as it is assumed that users change something in their environment when they are dissatisfied with it. The learning uses a fuzzy logic-based technique called Incremental Synchronous Learning (ISL).

After monitoring and learning, the iDorm agent can take control of the environment. If the user behavior changes, the learning system may need to modify some of the rules, so it will go back to a learning phase in which there can be a repeated learning process. There is an Experience Bank, which stores the previous occupants' rules. After the initial monitoring phase the system tries to find a best match from the bank. So the learning starts from some initial rule base. The paper reports a limit of 450 on the number of stored rules.

2.2 Domestic care, assisted living

One application area of ambient intelligence that has attracted much attention is support for independent living for the elderly. Better health care and quality of life have caused an increase in longevity. Demographic changes provide challenges for healthcare and maintenance of quality of life. We have seen, and may continue to see, an increasing shift in resources from institutional care towards providing care at home and towards preventative care. It is hoped that AmI-supported home automation can provide much better quality of life for the elderly than institutions. It is also hoped that the preventative quality of such support can have further important advantages in terms of cost effectiveness, by reducing the need for providing dedicated carers and institutional services.

Thus the main aims of the AmI research in this area have been to support independent living for elderly people, primarily people who might be in the early stages of cognitive or physical impairment who may be able to live in their own homes and would prefer to do so, but may need monitoring for the sake of their safety and well- being. The following papers illustrate a broad range of activities in this application, from technology implemented systems, to more theoretical concepts, as well as studies of the attitudes of targeted user groups.

2.2.1 RoboCare Project

Robocare is an ongoing project3 with the long term goal of contributing to improving quality of life of elderly people living independently in their homes, through the use of AI technologies to realize cognitively enhanced embedded technology. "The RoboCare Domestic Envirionment (RDE) is an experimental setup which recreates a three-room flat. It is intended as a testbed environment in which to test the ability of the do- motic technology built by the various research units, such as non-intrusive monitoring, domestic robots and environmental supervision."

The papers describe two contributions in this direction.

- A tracking system for people and robots, exploiting stereo vision; and
- A task execution-monitoring and supervision component.

The two components provide a prototype system deployed in the testbed domestic environment. The entire system is based on an e-service-oriented architecture, and is composed of several hardware and software agents, each providing a set of services. The two components are integrated via an e-service-oriented middleware, where all agents provide their functionalities as services. The activities of all agents are organized by an event manager, which processes all requests for services and directs them to the appropriate agents. The tracking and monitoring components together with the event manager provide the Active Supervision Framework (ASF).

The tracking system. The tracking system is the primary component to help recog- nize interesting situations and report them to the decision-making agents within the monitoring part. It uses stereo vision technology to determine the 3D position of people and to track them as they move. Also by extracting a set of features, such as height and size, from the images, it makes it possible to identify certain poses, for example if the tracked person is lying on the ground, or sitting in a chair.

This system, thought of as an agent, provides services including whereis, whichpose, howlong-in-a-pose, howlong-here, howmany-persons, howmany-robots, robot-close-to-a- person, what-activity. Robots are distinguished from people by equipping them with special tags. Moreover, to simplify the task, the authors exclude crowded environments, allowing no more than 2–3 persons, and monitor only a portion of the domestic envi- ronment. The stereo vision system (a pair of Firewire webcams) is placed in a fixed position and can thus make use of information about the background to distinguish people. The software agent, which processes the images, distinguishes between the foreground (people/robots) and the background, computes the 3D position of the fore- ground, and associates each 3D cluster of the points with a particular robot from its tag or a nonspecific person. A special algorithm is used to attempt to distinguish inanimate objects from still animate ones. So that for example, when a person sits at a table and puts a bottle on it, after a while the bottle, but not the person, becomes part of the background, because the edges of the images of the bottle show low activity.

The execution monitoring and supervision system. The monitoring agent has knowledge of the assisted person's usual schedule. This is a set of predefined activities with resource constraints and predefined durations and other temporal constraints, such as, one activity cannot start before another starts, or cannot start before the end of another, and so on. The example given includes 6 activities.

A1: breakfast, A2: lunch, A3:dinner, A4, A5, A6: taking medication, with temporal constraints specifying the earliest start times and latest end times for A1, A2, A3; minimum required lapsed time between the end of A1 and start of A2; and between the end of A2 and start of A3. Furthermore, A4 should be done within a predefined time lapse after A1, A5 should be done immediately before A2, and A6 should be done immediately after A3.

The execution monitoring and supervision system has two tasks: one is to recognize if the actual situation, as informed by the sensors and the tracking system, has diverged from the schedule, and if so, fire an appropriate rule for repairing this. Another task is to ensure that all scheduled activities are actually executed, and issue warnings or alarms if they are not.

The actual situation is compared with the expected schedule in terms of temporal and resource constraints, and delays, variations in durations, and resource breakdowns, are identified and dealt with. A delay is represented by inserting a new temporal relation- ship. A variation in an activity's duration is represented by replacing the activity with a new one with the new duration but with all other characteristics remaining the same. A resource breakdown is represented by inserting a new ghost activity, which eats up all the resources that are no longer available. The schedule thus augmented is then fed into the ISES procedure (Iterative Sampling Earliest Solution), which is a constraint-based method originally designed to solve Resource constraint project scheduling problems with time windows [38]. If the temporal constraints are deemed to have become unsatisfiable, a warning is issued. If not, the resource constraints are checked, and if they have become conflicting a schedule revision is attempted.

In the example of, the A1–A6 activities, whether a person is eating is assumed to be determined by the tracking system recognizing the position of the person as seated at a table in a particular room. A delay in any of the activities A1–A3 will have an impact on the schedule of the other activities, and a substantial delay in any of the activities A1–A3 may mean that one or more of A4–A6 cannot be executed in times compatible with their temporal constraints.

The system also attempts to detect unexpected events happening and recognizing whether or not they have caused inconsistencies with the normal schedule. An exogenous event may inflict a temporal or resource inconsistency with the schedule, the former happens, for example, when the extra event forces some scheduled activity beyond its deadline; the latter happens when an activity is forced within a time frame when resources are not available for it.

2.2.2 Georgia Institute of Technology - Aware Home Research initiative (AHRI)

The initiative has a three-floor, 5040-square-foot home as a residential laboratory for interdisciplinary research and evaluation. There are several objectives including designing interactive environments for the elderly and exploring the social implications of such technologies. Some examples of the work reported are as follows.

I.L.S.A. (The Independent LifeStyle Assistant) [39] passively monitors the behavior of inhabitants and alerts caregivers in cases of emergency, for example a fall. It is a multi-agent system in a Jade environment. Each agent in the system is responsible for one aspect, for example monitoring use of medications, issuing reminders, monitoring mobility, coordinating responses, and learning patterns of behavior. There are also a phone agent and a database agent. The agents need to interact with one another to achieve their goals. For example, the medication agent generates a reminder for taking a medicine, this is processed by the response coordinator agent, which then sends it to the phone agent. Finally the phone agent delivers the reminder.

The agents have sensors and actuators, and may have plan libraries that they use for recognizing the intention of users from their activities and for choosing the system's response. A focus of the project has been on high level reasoning capabilities in three main respects, machine learning, goal recognition, and response generation. Machine learning is used to learn schedules of regular activities of the inhabitants, to build models of which sensor firings correspond to which activities, and to raise alerts when an activity occurs that is probabilistically unlikely. Goal recognition is used to deduce the goal of the inhabitant from their observed actions. This is based on a system called PHATT (Probabilistic Hostile Agent Task Tracker) [40]. PHATT uses a plan library of simple hierarchical task network plans. One very simple one is shown in Figure 1 indicating that doing action a, then action b, and then action c, achieves goal S. The observations of the action executions provide an execution trace. This is used to form probabilistic hypotheses about the actor's goal, and these, in turn, generate sets of pending (expected) actions.

The response generation is done in three stages, first the individual domain agents generate context-free responses, that is responses based only on their own domain in- formation. These are sent to the central response coordinating agent, which prioritizes

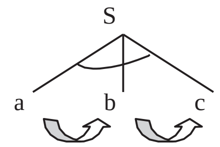

Figure 1: A simple hierarchical task network.

them, thus injecting some degree of context-awareness, and also groups them. Finally, according to the decision of this agent, the response is directed to a device, for example the phone.

For field studies the I.L.S.A system was installed in several homes, including homes of system engineers and elderly clients. An evaluation of the system and the lessons learned, particularly in the use of agents and AI techniques, are given in [41] and [42]. The evaluation found that the use of agents did not provide the expected benefits. In particular, the need for coordination of the agents and centralized control outweighed the benefits of the distribution and independence of components provided by the agent architecture. The machine learning, on the other hand, was found to provide enhancements. In another paper [43] complications that arise with goal recognition in the I.L.S.A. setting are discussed. These include recognizing multiple goals with interleaved execution of actions in their plans, and recognizing when goals are abandoned. Another complication is partial observability of actions. The latter two are particularly relevant in the elder care setting where plans may be abandoned due to forgetfulness and reminders need to be issued, and where the clients may not be in favor of having their every move observed.

- *Memory Mirror.* This is deployed as a memory aid in the home and is intended to help with memory confusions that arise between the repeated episodes of frequent tasks, for example “Did I take my vitamin today or was that yesterday?”, “Has anyone fed the fish?”, “Did I take pain medication an hour ago, or did I decide to wait a bit longer?”.

  The memory mirror provides a visual log of the movement and usage of specified objects during a period of time (e.g. 24 hours of a day). As a person uses an item, the usage is posted to the mirror and is recorded in a history log. The memory mirror also warns of possibly lost items as it tracks their removal and return from specific locations, normally their usual storage locations, such as medications on a nightstand. The memory mirror system uses RFID technology.
- *Gesture Pendant.* This is a small pendant that the user can wear, which is equipped with a wireless camera. The system can monitor the user’s hand movements and can look for loss of motor skills and tremors, thus noticing onset of illness or problems with medication. It also provides hand movement interface to some devices, such as lighting and entertainment devices, reducing the need for dexterity and understanding of using switches and remote controls.
- *The Technology Coach.* Elderly people often have to use home medical devices and the correct usage of such devices is crucial to their health. But these devices are often not designed with the cognitive issues that come with aging in mind, and the instructions are often created by marketing departments, rather than by designers. So older adults, typically, need initial training, and often follow-up daily assistance, to use these devices. The Technology Coach’s objective is to provide assistance in this, by providing ongoing feedback in using home medical devices. The system watches the use of the device via different tracking technologies and provides appropriate guidance. It combines two complimentary research efforts. One is aimed at understanding what kind of training and feedback should be used for older adults, by evaluating the use of conceptual and procedural feedback for both short-term and long-term use of the device [44]. The other is to track and assess the use of the device by developing new techniques for modelling complex chronological tasks and new methods for recognizing actions from sensor data.

NIEMELA, M., FUENTETAJA, R. G., KAASINEN, E., AND GALLARDO, J. L. SUPPORTING INDEPENDENT LIVING OF THE ELDERLY WITH MOBILE CENTRIC AMBIENT INTELLIGENCE: USER EVALUATION OF THREE SCENARIOS, B. SCHIELE ET AL. EDS., LECTURE NOTES IN COMPUTER SCIENCE, VOL. 4794, SPRINGER-VERLAG BERLIN, 91–107. 2007.

This paper reports a qualitative study of three ambient intelligence scenarios using focus groups of elderly people in two countries, Finland and Spain. The work is part of a project called MINAmI.5 The project has the overall aims of developing and validating AmI applications that use mobile phones and adress the associated ethical and privacy issues. The applications concern health and safety monitoring at home, particularly for the elderly.

The three scenarios developed for the focus group study deal with monitoring the taking of medication, monitoring sleep, and home security. In these scenarios the mobile phone was used as the user's device for reading tags and sensors and for interacting with the AmI systems, the argument being that mobile phones are the best known and most commonly used mobile devices. The scenarios were animated as cartoons, each 1– 3 minutes long. Two focus groups of elderly volunteers were used in Finland (one with 4 members and one with 10), and one in Spain (with 5 members). In addition, one focus group of medical experts was used in Finland and one in Spain. The elderly groups were mixed in sex and in their background experience with computers and mobile phones. The method of study was to allow a cartoon to be watched and then follow it by an open debate, where the participants were invited to take part in informal discussions of the presented material and any other related matters. Each scenario took 1–2 hours.

The first scenario involves a medication event monitoring system. In the cartoon Tom is given a smart pillbox by his doctor. The cap of the pillbox has a counter for opening and closing events and a clock. The pillbox communicates with a mobile phone by a wireless connection such as Bluetooth and can display on the mobile phone, the timed record of the cap openings and closings (assumed to represent the taking of medication). The data is also sent to an Internet database. If Tom forgets to take his pills for several days, the pillbox sends the information to a care center, which notifies the doctor.

The second scenario involves sleep monitoring, in particular sleep apnoea, a condi- tion that causes interruptions in breathing during sleep. The monitoring is done via a sensor device that is worn on the forehead. The device detects EEG (electroencephalo- graphic) brainwaves and movements of the head. The data can then be read, by taking a mobile phone near it, and sending the data to a healthcare center to be analyzed for abnormalities.

The third scenario deals with security at home. In the cartoon an elderly lady, Mrs S., lives in a big house equipped with sensors. When she moves to the stairs the lights come on automatically, and when the sensor system is set to security mode it can monitor movements in the house. For example when her dog goes to the basement a notification is sent to her mobile phone, and when a burglar attempts to enter the house through the basement an alarm is sounded in the house.

In the evaluation, the first scenario was judged the least favorable one. There were three reasons for it on the part of the elderly focus groups. They felt that it was too intrusive on their privacy, and that the data should not be reported to their doctor. They felt that relying on such devices would weaken people's cognitive abilities, and they felt that the system would not be suitable for the majority of the elderly who take not just one medication but a variety. The expert focus groups were also concerned about privacy and data confidentiality, for example employers getting hold of the data and not funding private medical care for those employees who are deemed unreliable in taking their medication.

The second scenario was evaluated more positively by all groups, the elderly prefer- ring the use of home equipment to having to wait in hospitals and sleeping in unfamiliar surroundings. The experts felt that the system could not replace hospital testing, but had some value in monitoring, and possibly cutting down on further hospital visits and use of resources, if it proved to be reliable. The third scenario was also viewed posi- tively, where all involved felt it would lead to feeling safe, but all expressed concerns about the initial and maintenance costs. Overall, mobile phones were deemed suitable and feasible devices for user interfaces with AmI systems. It is interesting to note that another elder assisted living project, Roberta [45], had based the user interface on tablet PCs, and in the evaluation found that few of the elders liked them or managed to learn to use them despite training.

In this paper, authors study also looked at possible cultural differences in attitudes towards AmI. The Finnish groups were more concerned than the Spanish about privacy and security of the data collected via such systems. The Spanish, on the other hand, were more concerned than the Finnish about whether the home care and security centers could be trusted to access homes in alarm situations.

2.2.3 Event-Condition-Action (ECA) Rules for Smart Homes for elderly care

Several works make use of ECA rules and various extensions of them for applications in Smart Homes and supported living for the elderly.

ECA rules have the form:

On <event expression> If <condition>

Do <action>.

The intuitive reading of such rules is that on detecting certain events, if certain conditions are true then certain actions should be executed. The event part (first line) is the trigger of the ECA rule. The rule is triggered if an event occurs that matches the event part of the rule. Then if the condition (second line) of a triggered rule is true the rule fires, requiring execution of the action (third line).

In [46], the authors advocate the use of AI techniques to augment sensors and hardware-oriented technologies for Smart Home applications. They suggest that Smart Home applications can be enriched by AI techniques, and moreover that Smart Homes can provide a good range of applications and test beds for AI, which is typically less complex and less computationally prohibitive than many more conventional AI problems.

Here and in all the papers mentioned in the following, on the group's work, their proposed setting is a house or an apartment in a typical residential care institution, which provides independent but supported living. The support is provided by sensors and alarms connected to a central monitoring facility that performs all the reasoning. It is assumed that the person resident in the apartment wears a tag and that appliances have sensors and remote activators. There are sensors, for example, for heating, doorbell, phone, and so on; and medical facilities that can feed information into the central monitoring system about various statistics such as blood pressure and glucose level. The sensors are assumed to record, in effect, information about the movements of the resident, possibly with time stamps, and duration of stops at each location. The papers do not deal with sensor technology and data interpretation, but assume that the sensors provide information that can be fed into the ECA rules.

In [47] the authors, advocate augmenting ECA rules with temporal features to facilitate the following two functionalities.

- Monitoring patients and reacting to observations; and
- longer term observations to help towards lifestyle profiling to be used by carers.

For the first functionality, the ECA rules are aimed at recognizing when a situation is hazardous, potentially so, or nonhazardous.

2.2.4 Abductive Logic Programming for Smart Homes for Elderly Care

Proposals have been made in [48] and [49] for the use of abductive logic programming within an agent model for AmI applications for the elderly.

In [48], preliminary suggestions have been made to use temporal abductive logic programming theories for specifying rules for assisting elderly people in their homes. Specifically mentioned are diary reminder and medication assistance systems. In the former, an ALP theory specifies when and what to remind the user about, for example to remind of a forthcoming appointment with the optician and that all spectacles have to be taken to the appointment. The reminders are issued according to the preferences of the user who can specify how frequently and how close to the event they wish to be reminded. In the medicine assistance system, it is assumed that pill bottles have sensors that can monitor the time when a dosage is taken out of the bottle. On this basis abductive logic programming is used to issue reminders of when the next dosage is to be taken, according to the time the last was taken and the required frequency. Also, in reaction to a medicine being taken, reminders are issued about any dietary restrictions that have to be followed, for example no tea or coffee to be taken for the next two hours.

2.3 EHealth care applications

In the following a review of several papers that have explored agent technologies, learning, and case-based reasoning techniques in applications of ambient intelligence in healthcare, and in particular in hospitals and residential care institutions.

MUNOZ, M. A., RODROGUEZ, M., FAVELA, J., MARTINEZ-GARCIA, A. I., AND GONZALEZ, V. M. CONTEXT AWARE MOBILE COMMUNICATION IN HOSPITALS. IEEE COMPUT. 36, 38–46. 2003.

FAVELA, J., RODRIGUEZ, M., PRECIADO, A., AND GONZALEZ, V. M. 2004. INTEGRATING CONTEXT-AWARE PUBLIC DISPLAYS INTO A MOBILE HOSPITAL INFORMATION SYSTEM. IEEE TRANS. INF. TECHNOL. BIOMED. 8, 3, 279–286.

RODRIGUEZ, M., FAVELA, J., PRECIADO, A., ANDVIZCAINO, A. 2005. AGENT-BASED AMBIENT INTELLIGENCE FOR HEALTHCARE. AI COMM. 18, 3, 201–216. 2005

These papers report studies conducted in a hospital, which in collaboration with the hospital workers, led to the development of three scenarios for information management and interaction in that environment. The scenarios were then used for the specification of autonomous agents for the design of ambient intelligence environments for hospitals, and also for the design and implementation of an agent-based middleware, called SALSA.

The broad features of hospitals relevant to their study and reflecting their use of agents are the distributed nature of information, the need for collaboration, mobility of the personnel and devices, and the need to access accurate medical information in a timely fashion for decision-making.

One scenario involves a doctor (Garcia) who is examining a patient in a ward and receives a message on her PDA with a floor map indicating that the X-ray results of a patient in a nearby bed (patient P in bed 225) are available. She moves to a nearby hospital information system (HIS) display, which detects and identifies her and changes the display to one personalized to her, including her messages, personalized calendar, and information about the patients she is in charge of. The doctor selects the information about patient P and views the recent X-rays. The HIS, which is aware of the context, that is the patient, the newly arrived X-rays, and a possible need for a diagnosis, opens a window with access to various items of information, including the hospital medical guide relating to P's current diagnosis, and references to previous similar cases. Garcia selects to view a previous patient's records. The system infers that Garcia is interested in finding information about alternative treatments for P and recommends Web sources of digital libraries considered reliable by the hospital practitioners.

Another scenario involves a hospital map display alerting a cardiologist to the presence of a traumatologist on the next floor. Opportunistically the cardiologist sends a message to the traumatologist requesting a discussion session regarding a patient. The traumatologist accepts via

PDA, approaches a HIS display unit by means of which the two specialists have a collaborative session about a patient's case while accessing information about him online.

The third scenario involves a patient, Ana, in a waiting room, who requires her PDA to recommend a cardiologist. The PDA makes a recommendation and in addition informs Ana that one of the recommended cardiologist's patients is in that waiting room, in case Ana wishes to approach her for a conversation.

In the SALSA architecture, agents are used as abstractions, to act on behalf of users, to represent services, or to provide wrapping of complex functionality to be hidden from the user. The system is required to be context-sensitive, where context is identified by user and device identification and location, role of users, time of events and interactions, and users' personal information stored in their PDAs. The agents have a standard life cycle of learning, through observations and messages (all through XML messages), thinking, and executing actions, including communications.

A hospital prototype system has been implemented. This includes a context-aware client, and a hospital information system (HIS). For the purpose of the former, doctors and nurses carry handheld computers that estimate their location, and depending on their roles, the client can inform them of other users, nearby, in the form of a displayed list. The HIS records patients' data, and the HIS agent monitors the changes in such data, and uses rules (much like ECA rules) to decide what information should be communicated to which users. For example when the HIS agent becomes aware that a doctor is in the vicinity of a patient and the patient's test results have been entered, the agent informs the doctor.

Authors in [50] describe in greater detail, the approach taken in location tracking in the hospital application and report related experiments. The approach is based on the use of radio frequency signal strength between mobile devices and access points of a WLAN (wireless local area network) infrastructure. A signal propagation model can be used to estimate the distance between the mobile device and the access point on the WLAN. But greater sophistication is needed to deal with complications such as walls, furniture, and other people in the way. To address this, they use neural networks, and a back-propagation learning algorithm. The neural network is trained by a variety of signal strengths at several locations in a building, for the four directions, north, south, east, and west. The location estimation component is integrated within the SALSA architecture by wrapping the trained neural network as one of the agents in the architecture. In the hospital application, given the decay of the signal strength from floor to floor one location estimation agent was trained for each floor.

2.4 Shops, Shopping, Recommender Systems, Business applications

This section includes papers on a variety of topics related to shops and business. We look at shops as responsive environments, with devices controlled by software agents that react to the presence of customers according to the customers' identities and profiles. Then we look at a proposal for ubiquitous commerce, which brings e-commerce and AmI together, with a framework for context-dependent interaction between shops and shoppers. We look at work on recommender systems in open connected environments, with emphasis on adapting known user profiles in one domain for use in another domain. The section continues with a proposal for AmI-based product aftercare and maintenance, and concludes with some example demonstrations of AmI-based products, including fabrics with embedded electric units.

DA SILVA, F. S. C. AND VASCONCELOS, W. W. MANAGING RESPONSIVE ENVIRONMENTS WITH SOFTWARE AGENTS. J.APPL. ARTIF. INTELL. 21, 4, 469–488. 2007

DA SILVA, F. S. C. AND VASCONCELOS, W. W. AGENT-BASED MANAGEMENT OF RESPONSIVE ENVIRONMENTS. IN PROCEEDINGS OF ADVANCES IN ARTIFICIAL INTELLIGENCE, 9TH CONGRESS OF THE ITALIAN ASSOCIATION FOR ARTIFICIAL INTELLIGENCE, 224–236. 2005.

These papers describe how software agents can be used to model and implement responsive environments. A responsive environment is described as one which senses events occurring in it and reacts to these events. This reactive behavior is provided by software agents, and the responsive environment is a combination of a physical world and agents.

KEEGAN, S., O'HARE, G. M. P., AND O'GRADY, M. J. EASISHOP: AMBIENT INTELLIGENCE ASSISTS EVERYDAY SHOPPING. J. INFORM. SCI. 178, 3, 588–611. 2008

This paper also focuses on applications of AmI in shopping, with the aim of providing a synergy between AmI and e-commerce to bring about what they call U-commerce, namely ubiquitous commerce. Their work is within the context of the Single European Electronic Market (SEEM) vision, which has the objective of developing an electronic framework in which different participants in the economy can collaborate. The authors describe the architecture and implementation of a system called Easishop, which aims at providing context-dependent exchanges of information and negotiation between shops and shoppers. The architecture is based on a multi-agent structure with the agents equipped with BDI (belief, desire, intention) concepts. Each shopper has his own agent, as does each shop.

GONZALEZ, G., LOPEZ, B., AND DE LA ROSA, J. L. L. MANAGING EMOTIONS IN SMART USER MODELS FOR RECOMMENDER SYSTEMS. IN PROCEEDINGS OF 6TH INTERNATIONAL CONFERENCE ON ENTERPRISE INFORMATION SYSTEMS(ICEIS). 5, 187–194. 2004

GONZALEZ, G., LOPEZ, B., AND DE LA ROSA, J. L. L.. SMART USER MODELS FOR TOURISM: A HOLISTIC APPROACH FOR PERSONALISED TOURISM SERVICES. INFORM. TECHNOL. TOURISM J.: APPLICAT. METHODOL. TECHNIQUES, 6, 4, COGNIZANT COMMUNICATION CORPORATION. 2004

GONZALEZ, G., DE LA ROSA, J. L. L.,DUGDALE, J., PAVARD, B., EL JED, M., PALLAMIN, N., ANGULO, C., AND KLANN, M.2006. TOWARDS AMBIENT RECOMMENDER SYSTEMS: RESULTS OF NEW CROSS-DISCIPLINARY TRENDS. IN PROCEEDINGS OF ECAI WORKSHOP ON RECOMMENDER SYSTEMS.

These papers discuss ambient recommender systems, where the focus is to provide personalized information without increasing the need for direct feedback and input from users. They focus on capturing user data for recommender systems. The primary aim of their proposed system, called Smart User Model (SUM), is to lower the burden on users for initialization procedures involved in providing data, while still aiming to provide users with personalized information. SUM aims to capture user information in a generic way in order to make it feasible to transfer user data from one domain in which the user has been profiled to another in which he has not. The assumption is that the next generation of recommender systems will have a portable user model to interact with multiple open, distributed, heterogeneous services, and will use ontologies to transfer user preferences across the services.

KOPACSI, S., KOVACS, G., ANUFRIEV, A., AND MICHELINI, R. AMBIENT INTELLIGENCE AS ENABLING TECHNOLOGY FOR MODERN BUSINESS PARADIGMS. ROBOTICS COMPUT.-INTEGRAT. MANUFACTUR. 23, 247–256. 2007.

This discuss the possible role of AmI in manufacturing. The authors argue that economy and environmental requirements are imposing new trends on manufacturing, whereby not just products but long term product aftercare and services will be in demand, and subject to competition. Thus, authors argue, there will be increasing demands for product life-cycle management (PLM), and in particular, conditional and predictive maintenance, and it is in these that the contribution of AmI may be important. More conventional forms of maintenance are often either based on breakdowns, where repairs are done when something breaks down, or are based on periodic and systematic checks and repairs. But if sensors can provide continuous or regular information about products and this information can be integrated with background information, for example the history of the product or similar products, then intervention can take place before a problem arises, and only when needed.

The paper describes work on a European project called FOKsai, which is concerned with providing knowledge management tools and AmI support for SMEs (small to medium enterprises) to support extended product management and aftercare. The project has the participation of four European SMEs and the goal is to provide knowledge bases and diagnostic tools to make the aftercare provided by the companies more efficient and more effective.

2.5 Musems, Tourism, Groups ans institutions, Others

In recent years the tourism industry has realized the advantages of providing personalized tailor made information to users. This section starts by describing work in that direction, first in the context of museums and heritage sites and then in the context of visiting a city. We then look at contributions of

AmI in group decision making support and in institutions, and end with an AmI application in monitoring driving.

BUSETTA, P., MERZI, M., ROSSI, S., AND ZANACANARO, M. 2003. GROUP COMMUNICATION FOR REAL-TIME ROLE COORDINATION AND AMBIENT INTELLIGENCE. IN PROCEEDINGS OF THE WORKSHOP ON ARTIFICIAL INTELLIGENCE IN MOBILE SYSTEMS (IN CONJUNCTION WITH UBICOMP'03).

BUSETTA, P., KUFLIK, T., MERZI, M., AND ROSSI, S. 2004. SERVICE DELIVERY IN SMART ENVIRONMENTS BY IMPLICIT ORGANISATIONS. IN PROCEEDINGS OF THE 1ST INTERNATIONAL CONFERENCE ON MOBILE AND UBIQUITOUS SYSTEMS (MOBIQUITOUS). IEEE COMP. SOCIETY.

The work described in these papers concerns responsive/active environments, and in particular interactive museums. A typical scenario considered is one in which a visitor to the museum requests, possibly via his PDA, a presentation about one of the exhibits. Several facilities, modelled as agents, are able to produce the presentation with different capabilities, for example pictures, audio, video, or a combination of audio and video. The visitor is near some facilities for the presentation, for example screens or speakers, and his PDA may also have the capability of displaying the presentation in a limited way. The visitor may be part of a group, for example a family, or in the vicinity of other people, and the museum may have information about the visitor's interests, for example from previous visits.

The architecture chosen is a multi-agent system capable of forming implicit organizations. The organization is implicit in that it is not preprogrammed and there is no explicit formation phase. This is facilitated by role-based communications and over-hearing. The experimental communication infrastructure, called LoudVoice, involves streams of messages (called multicast channels) that can be heard by many agents. The FIPA-compliant messages have headers such as REQUEST, QUERY, INFORM, DONE, and the senders and receivers can be role identifiers, rather than individual agent identifiers.

COSTANTINI, S., MOSTARDA, L., TOCCHIO, A., AND TSINTZA, P. DALICA: AGENT-BASED AMBIENT INTELLIGENCE FOR CULTURAL-HERITAGE SCENARIOS. IEEE INTELL. SYST. (SPECIAL ISSUE ON AMBIENT INTELLIGENCE), 23, 2, 34–41. 2008.

This paper describes the use of multi-agent technologies in combination with sensor and satellite tracking and PDA technologies for two heritage applications. One application is in providing personalized information for visitors to Villa Adrianna, which is an extensive ancient Roman villa. The other application is in tracking heritage artifacts during transportation, to prevent theft and to maintain an ambient atmosphere in terms of temperature and humidity. The multi-agent system used, called DALICA, relies primarily on logic programming for its specification and implementation.

PETERSEN, S. A. AND KOFOD-PETERSEN, A. THE NON-ACCIDENTAL TOURIST: USING AMBIENT INTELLIGENCE FOR ENHANCING TOURIST EXPERIENCES. IN NETWORK-CENTRIC COLLABORATION AND SUPPORTING FRAMEWORKS, L.CAMARINHA-MATOS, H. AFSARMANESH, AND M. OLLUS, EDS., INTERNATIONAL FEDERATION FOR INFORMATION PROCESSING (IFIP). VOL. 224, 619–626. 2006.

This paper describes a scenario about guiding tourists through the city of Trondheim. The scenario is intended to incorporate the use of AmI for the tourist and the use of virtual enterprises for the businesses in Trondheim that wish to enhance the tourist experience and at the same time enhance the reputation of the city as an attractive place to visit and increase their own trade. The project, Wireless Trondheim, is a collaborative effort between the local council and the university in Trondheim.

In this scenario the tourist arrives in Trondheim on a ship and on leaving the ship signs for the Trondheim experience (TE), which provides her with a PDA. The goal of the tourist is to see and enjoy the city in one day, and she can express this goal by selecting some key points to indicate her interests, for example medieval Trondheim, local food, and shopping. The tourist's goal can be planned for by the TE to produce a sequence of activities. In this, information is used from virtual enterprises (VEs) formed by city businesses and service providers. For example, there may be one such VE consisting of a museum, a concert organizer, a restaurant, and a taxi company, collectively offering a single package, of a guided tour of the museum, a visit to the shopping centre, lunch at the restaurant, a concert at the cathedral and transport back to the ship. The VEs may have access to the tourist's profile collected by the TE and offer their package only if it is compatible with the profile. The TE may choose a number of such VE packages to present to the tourist, according to what it knows about the tourist's desires and goals. Once the tourist chooses one package, the TE guides the tourist through the activities. It can also use the location trackers to provide information about the architecture or history of the buildings, shops, and bargains that may be on offer as the tourist passes them in the city. TE may also have access to other TEs guiding other tourists from the ship and may give information to the tourist about who else from her group may be having lunch at the restaurant and attending the concert.

3 Other data management and AI techniques

In the previous reviews, we have seen several uses of AI, databases and agent technologies, including ECA-rules, temporal, abductive, case-based reasoning, learning and fuzzy logics. In this section we look at other AI and database technologies that have been explored and advocated for use in AmI applications. Among these we look at papers that identify the need for, and make proposals towards, context-aware data access, distributed planning, self-organization, and embodied systems.

3.1 Context-Aware Data Management

In [51] and [52], authors argue that in the past decades, work on databases has concentrated on content-based access, but AmI applications require context-aware access and data management strategies and solutions. Content-based data management focused on efficiency, whereas context-aware data management focuses on usefulness. A context-aware data management system should be able to deal with queries such as: "Get the report I prepared last night before dinner for this afternoon's meeting," or "Find restaurants nearby which I have not visited for half a year." Such queries will require different answers for different users and different answers at different times for the same user.

The authors consider context to be the situation in which the user tries to access the database. They identify two forms of context: user-centric, and environment-centric. Each can be divided into various subcategories.

A user-centric context may be:

- Background (e.g. interest, habit), from a user profile;
- dynamic behavior (e.g. task, activity), from a user agenda;
- physiological state (e.g. body temperature, heart rate), from body sensors; or
- emotional state (e.g. happiness, anger, fear), from multimodal sensors and analysis of user features.

An environment-centric context may be:

- Physical environment (e.g. time, location, temperature), from sensors;
- social environment (e.g. traffic jam, surrounding people), from service providers; or
- computational environment (e.g. surrounding devices), inferred from user location and activity.

The issues the authors identify include:

- How to acquire, categorize and model contextual information;
- how to exploit contexts to answer a user's data request;
- context-aware query language for users;
- how to effectively communicate answers to the users on small hand-held devices;
- what context-aware strategies are needed, both for finding useful answers to queries and for presenting the answers to the users.

3.2 Planning

Planning concerns the problem of how to achieve a goal state starting from a known initial state. A plan is a sequence or partially ordered collection of actions that if executed starting from the initial state, is expected to achieve the goal state. There are several ways that plans and planning can be used in AmI scenarios, for example in Smart Homes. Planning can be used to coordinate the capabilities of the available resources to provide a solution or perform a task. Planning for AmI may have to deal with multiple agency ; plans can be used, for example, to

- provide task guidance and reminders to inhabitants;
- allow AmI systems to share task execution with inhabitants;
- identify emergencies when the inhabitant is not doing what they are supposed to be doing or is not doing it correctly.

A discussion and survey of this is provided in [53].

3.3 Self Organization

In [54], authors are concerned with the dynamic nature of AmI environments where devices enter or leave. They argue that in the future, for AmI systems to be useful, they need to have the flexibility and adaptability afforded by self-organization. A system that is carefully predesigned for anticipated scenarios cannot deal with unforeseen changes of devices or appliances in the environment. They argue that what is required is a system that is capable of self-organization into ensembles constructed from the available resources, to be responsive to user needs and desires.

Some static predesigned AmI systems are already available or at least easily feasible. For example, in a smart conference room the projector may switch to the next speaker's presentation as he approaches the front, dim the lights when the presentation starts and turn them up again when the presentation is finished. In such a scenario the devices work together according to an ensemble anticipated by the designer. This means that a change in the requirements or devices will probably have to be dealt with manually and possibly rather clumsily by the programmers. Self-organization may be a solution for overcoming such shortcomings.

To enable self-organization, the authors propose goal-based interactions, as opposed to the more customary function-based (or action-based) interactions such as "turn on," "turn off," "play," and so on. With goal-based interactions, the user should be able simply to specify his goal, rather than to specify a sequence of actions that if executed would achieve his goal. A motivating example is for the user to specify the goal "I want to watch (the film) Chinatown now" and have the ensemble of devices work out which devices and what sequence of functionalities (actions) are needed. For example, turn on TV, turn on VCR, select video, position video at start, adjust air conditioning to a comfortable temperature, adjust sound level, adjust room lights, set TV channel for video viewing, and so on. In this way, goal-based interaction abstracts away from devices and functionalities, and allows the interaction with the system to be based on the user's view/goals rather than on the system's view of the world.

Goal-based interaction requires intention analysis, that is translating the user de- sires into concrete goals (possibly also taking context information into account), and strategy planning, mapping the goals to sequences of actions by devices. This latter can be realized through an explicit modelling of devices by precondition/effect rules, which turns the strategy planning problem into a familiar, classic planning problem.

Based on these concepts, the authors have produced an experimental system called SODAPOP (Self-Organizing Data-flow Architectures supporting Ontology-based problem decomposition). The work has been done within a German-based project called DYNAMITE (Dynamic Adaptive Multimodal IT-Ensembles). SODAPOP is a middle- ware for self-organizing AmI systems. It consists of channels and transducers. Briefly, the channels are message busses and the transducers are the devices. The transducers subscribe to channels by declaring what messages they are able to process and whether they can allow other transducers to process the same message concurrently. When a channel receives a message it decomposes it via its strategy planning to simpler messages that the subscribing transducers can handle and sends these to them. The channels are capable of receiving and decomposing goal-based messages and the pub- lish/subscribe approach of the transducers allows on-the-fly formation of ensembles. A system example is given containing a TV, a stereo, a speech input device, a display unit, and an avatar. With this setup, for example, the audio of a film may be rendered through the stereo if its audio quality is judged superior to the TV. Also all outputs may be rendered through the avatar.

3.4 Embodied Systems – PEIS

In [55] authors report work in combining robotics, ubiquitous computing and AI technologies, to provide not just a connected environment of interacting devices, but with emphasis on performance of physical tasks by robots. The intention is to provide Physically Embedded Intelligent Systems (PEIS), in what they call a PEIS ecology, namely a cooperative physical environment facilitated by communication.

A motivating scenario is given in the following. Johanna is 76 years old and lives in a small house. Just before she wakes up, her fridge realizes that there is little milk left. It sends a request for a bottle of milk to the local store and Johanna’s autonomous trolley goes to the store to collect it together with the usual daily newspaper. When Johanna gets out of bed her motion is detected and the coffee machine starts to make coffee. A team of robots brings her breakfast items to the table. As Johanna leaves the bathroom the cleaning robot starts cleaning it.

To study the viability of such scenarios and concepts, the authors have constructed a PEIS-Home, which is a mini-apartment with a living are, kitchen, and bathroom. The ceilings have been lowered in order to provide space above them for cables and computing equipment, and to provide observation spaces. The Home is equipped with two Magellan Pro robots, a tracking component and a monitoring component. The tracking component is a localization system using Web cameras mounted on the ceiling to track colored objects; the robots have colored tops. The monitoring system is for the use of the human experimenters to observe the activities inside the Home, and it consists of a visualization tool and a record/playback tool. Both robots, Pippi and Emil, have communication and fuzzy logic-based negotiation functionalities. Emil, in addition, has a conditional planning functionality.

In one reported experiment, Emil receives a request to wake Johanna up. It delegates the task to the other robot, and generates a plan for the waking up consisting of three steps, go to bed, talk to Johanna, go to sofa. It tells Pippi of the first step. Pippi executes the action, keeping track of its whereabouts by the tracking device, and notifies Emil when it is at the bed. Emil communicates the next action of the plan to Pippi, and so on, until the task is accomplished. The communication between the devices assumes a shared (tuple and event based) ontology.

3.5 Decision Trees

Authors in [56] discuss the use of decision trees in smart home applications. The main uses identified are in recognition of usual and unusual events in smart homes and prediction of next events.

Decision trees provide a graphic representation of possible combinations of attribute values. They may be user friendly because of the visual nature of the representation. Furthermore, it is straightforward to translate them into rules for automated reasoning. A decision tree is a collection of tests. The nodes represent tests of given attributes and the branching at each node represents the possible values of the attributes. The leaves provide classifications of the instances.

In smart homes, sensor data can be collected regarding the whereabouts of the person, his interaction with appliances (turned light/cooker on/off) and the duration of events (light on for 4 hours, cooker off for 3 hours). This data can then provide a training set for creating decision trees, a process called induction of decision trees. The resulting decision tree can then be subjected to postpruning either simply visually or using a standard decision tree pruning algorithm.

The assumption here is that the decision tree and the set of values used for its induction represent normal activity. Decision trees are appropriate for domains that can be represented by attribute-value pairs, with finite value sets and a predetermined set of attributes. Also they work best if the set of possible values is small; many algorithms support only binary splits. Furthermore, incorporation of an explicit notion of time remains a research issue. The paper does not report any concrete application, implementation, evaluation, or experimentation.

4 CONCLUSION

In this selective survey we looked at several application areas of ambient intelligence, including the smart home, care of the elderly, healthcare, business and commerce, and leisure and tourism. In these, we looked broadly at trends, requirements, and challenges, as well as at technical developments and implemented demonstrators. We also looked at studies of the attitudes of human target groups towards these applications and technologies.

Furthermore, in the context of AmI we looked at several data management and artificial intelligence technologies, including event-condition-action rules, production rules, learning, fuzzy logics, planning, plan recognition, temporal reasoning, and case- based reasoning. We looked at how current technologies are being used and what extensions are thought to be necessary. We also looked at several approaches to using agents, for example as abstraction tools, for modelling devices and their interactions, and as middleware.

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