Omnia Fieri Possent

Everything may happen

Seneca, Ad Lucilium Epistulae Morales, Epistle 70

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Tom is in a good mood this morning. It's Friday and tonight he's going to the movies with Amy. After a shower, he briefly reviews the movies that are showing tonight. Info and clips are displayed by his new bathroom mirror. He requests a preview of "You've got mail," which is a rerun of some old movie about an e-mail romance. Personally, he would like to see some more action, but Amy will definitely love this one.

After breakfast he hops into a PeopleMover to go to the office. It's quiet this morning. He requests some music. The audio system of the PeopleMover starts playing one of his favorite songs, using his preferences from his SmartId. He decides to book "You've got mail." Payment goes through his SmartId, and tickets are downloaded onto it. He also makes dinner reservations. [...]

At ten past five, Tom hurries out of his office to a PeopleMover that will take him to the city center. Silly staff meetings. They always run late. When he arrives, Amy is not yet at the restaurant so he goes to the ReadingDesk to catch up on the latest news. Strange, the Desk doesn't show him his preferred news items. Damn! He forgot his SmartId at the office. And it's too late to pick it up. But that means he's Disconnected! No-one will be able to contact him. And he'll have to ask Amy to pay for dinner, and to buy new tickets for the movie! He'll refund her, of course, but it's definitely not the best way to start the evening. [...]

It's a bit past eleven when Tom arrives at home. Because he doesn't have his SmartId, he is glad he left open a window at his balcony this morning. He manages to enter his home through this window. Before he forgets, he quickly refunds Amy through the HomeSystem. He decides to go to the office to pick up his SmartId. He doesn't want to wait till Monday before getting it back. There are no PeopleMovers this late in the evening, so he takes his car. He (manually!) searches some music. He relaxes; he had a wonderful evening after all. Suddenly, a police car appears, flashing a stop sign ... .

The setting in the story of Tom and Amy is clearly not today's world. However, in the not so far future, the world may look a bit like the world of Tom and Amy. In fact, the story fits perfectly in the emerging Ambient-Intelligence (AmI) vision, as outlined in [1]. AmI is essentially a vision on tomorrow's world and the role of technology in that world. It builds on ubiquitous computing, as originally envisioned by Mark Weiser [2], but in comparison it is more human-centric. It integrates concepts from natural user interaction and autonomous and intelligent systems. The AmI vision is gaining traction both in industry and in academia, and it is often illustrated via scenarios as the one above. These scenarios typically sketch a world that is great to live in, suggesting that technology has a positive effect on quality of life. However, the story of Tom is not exactly typical in all respects. In typical scenarios, the main characters do not forget crucial items, and they don't enter houses through windows. And why is it that the police car appears at the end? Well, ... this is what actually happened.

It's 8:03am and HomeSecurity detects that Tom leaves the house. It switches to security level orange. [...]

At 11:23pm, HomeSecurity detects movement at the balcony. Someone enters the house. It doesn't appear to be Tom; HomeSecurity doesn't detect Tom's SmartId. The intruder immediately activates the HomeSystem. Since one minute has passed and HomeSecurity has not yet been switched to green, it goes to red. It immediately contacts Tom.

The intruder tries to transfer money from Tom's bank account, but HomeSecurity smoothly intercepts the transfer, of course without alerting the intruder. Since Tom doesn't respond within 60 seconds, HomeSecurity alarms the police. The intruder removes Tom's car keys from the SecurityBox, leaves the house, and starts the car. HomeSecurity reacts seamlessly by sending video images of the intruder, a picture of the car, and its license plate to the police. Of course, HomeSecurity tracks the car and keeps the police up-to-date. When it receives the expected SecurityCode from the police, it knows that everything is ok. It switches back to orange, waiting for the return of Tom.

The story of Tom and Amy illustrates the AmI vision and its potential, but it also shows the precarious balance between success and failure. With AmI, our daily lives may become very exciting and fun, or, without proper care, they may just as easily become a nightmare. In our opinion, the AmI vision has a lot of potential. It is up to us to realize it, and to make sure that nightmare scenarios are avoided. But as is often the case with predicting the future, in the end, only time can tell what AmI will bring us.

So what is this volume all about? AmI scenarios usually focus on the user and application perspective of technology. Users play a central role in the AmI vision. Nevertheless, in this volume, we turn our attention to the underlying technology, in particular, the underlying embedded hardware, software, and communication infrastructure. In other words, the volume explores some of the essential enabling and support technologies needed for a successful realization of the AmI vision. Before going into more details about the contents, we first provide some background information about this volume.

The basis for this volume was unknowingly already laid in 1999, when Jean Gelissen at Philips Research initiated a European project called Ozone. This project, which is ongoing at the moment of writing, aims at the development of platform and middleware technology for AmI. Ozone is thus an early initiative that explores the impact of AmI on embedded hardware and software. A second crucial step was the decision of the executive committee of the Design, Automation and Test in Europe (DATE) conference of 2003 to organize a special day on Ambient Intelligence. Diederik Verkest, the chair of DATE 2003, invited Twan Basten and Menno Lindwer from the Ozone project to organize this special day. A final step was the invitation by Mark de Jongh of Kluwer Academic Publishers to publish a book about the DATE special day on AmI. Menno unfortunately had to end his work as an editor in an early phase due to other obligations. Nevertheless, he certainly had an impact on the contents of this volume.

Our first decision was to not base the volume entirely on the DATE 2003 special day. The AmI vision is still too recent and the relation between AmI and embedded hard- and software still too fresh to draw sufficient relevant and high-quality material from a specialized conference like DATE. Therefore, we combined selective invitations for contributions to the volume with an open call for papers. To allow authors to explore the relation between AmI and embedded systems in the widest possible sense, we decided not to pose any restrictions but to simply give prospective authors a brief description of the AmI vision and its relation to embedded systems. To maintain some coherency, we asked all prospective authors to submit a two-page abstract first. Based on these abstracts, we made a selection and invited authors to write full papers. To guarantee the quality of the final contributions, all full papers were reviewed by two to four reviewers, and revised according to the reviews. The result is this volume with fifteen contributions. Together, they provide an interesting view on the impact of the AmI vision on embedded system design. Of course, this view cannot be expected to be complete in all aspects, nor will it be final in any sense. On the contrary, it's only a starting point, but a challenging and inspiring one.

After this brief history, it's time to have a closer look at the contributions. As mentioned, the fifteen papers in this volume have a common basis in the form of a brief description of the AmI vision and its impact on embedded systems:

Ambient intelligence (AmI) envisions the complete integration of technology into our environment so that people can freely and interactively utilize it. It is the combination of casually accessible networked digital devices performing all kinds of functions in entertainment, education, professional applications, etc. Technology shall be made invisible, embedded in our natural surrounding, present whenever we need it, enabled by simple and effortless interactions, and attuned to all our senses. The systems shall be intelligent in the sense that they are aware of and autonomously react to their contexts, in particular the users within those contexts.

Ambient Intelligence will have a major impact on embedded systems, software and silicon design. It introduces many new media applications and new user interface concepts. It requires the design of very powerful compute machinery for demanding media and user interface operations, as well as a powerful, omnipresent communication infrastructure. However, it will simultaneously require extremely low-cost and low-power designs for the compute and communication machinery that seamlessly and fully surrounds the users.

The volume is divided into two parts, Challenges and Developments. The first part, consisting of six papers, contains visionary papers and papers identifying challenges to be found in realizing the AmI vision. The second part, consisting of nine papers, contains concrete developments and first results towards the realization of the AmI vision.

The first paper in the Challenges part, *Embedded System Design Issues in Ambient Intelligence*, is based on the keynote speech of Emile Aarts at DATE 2003. Emile Aarts and Raf Roovers, both of Philips Research, explore the impact of the AmI vision on embedded systems in general. Their paper is a fitting start of this volume. They partition AmI devices into microWatt, milliWatt, and Watt devices, discuss the mapping of AmI functionality onto these devices, and emphasize the major design challenges.

In *Ambient Intelligence: A Computational Platform Perspective*, Luca Benini, University of Bologna, and Massimo Poncino, University of Verona, explore the architectural requirements for future generations of computational platforms. They start from a similar partitioning as Aarts and Roovers. Their conclusion in one word: Parallelism!

The third paper in the Challenges part investigates the embedded-system-software point of view. Anu Purhonen and Esa Tuulari argue in *Ambient Intelligence and the Development of Embedded System Software* that customizability, adaptability, and flexibility of embedded software will soon become the key issues.

Peter van der Stok of Philips Research continues in *Preparation of Heterogeneous Networks for Ambient Intelligence* with the networking and communication perspective. Despite (or should we say 'due to'?) the many standards that are available, means to cope with heterogeneity and interoperability turn out to be the real challenges.

The Challenges part concludes with two papers on security and privacy issues. This is not a coincidence. Security and privacy are hot topics and potentially the biggest challenge in the realization of AmI. If security and privacy are not guaranteed, AmI will fail without a doubt. The unfortunate story of Tom is just one example of what may go wrong when security systems are not carefully designed or when they are not functioning properly. In *The Butt of the Iceberg: Hidden Security Problems of Ubiquitous Systems*, Frank Stajano and Jon Crowcroft of the University of Cambridge argue that the mere quantity of devices in an AmI world is already sufficient to open up a whole new range of challenging problems in security and privacy. Srivaths Ravi and Anand Raghunathan from NEC, Jean-Jacques Quisquater from Université Catholique de Louvain, and Sunil Hattangadi from Texas Instruments focus in *Emerging Challenges in Designing Secure Mobile Appliances* on security of mobile devices. Mobile devices are obviously key components in realizing the AmI vision. They identify so many challenges that one is easily left with the impression that secure mobile devices are an oxymoron.

The Developments part continues with the remaining nine contributions. Fiora Pirri, Ivo Mentuccia, and Sandro Storri of “La Sapienza” University of Rome start this part with a description of an intelligent domestic robot positioned in an AmI home environment in their paper *The Domestic Robot - A Friendly Cognitive System Takes Care of your Home*. The paper is an interesting mixture of concrete achievements and results, and views on future developments in cognitive robotics.

The next two contributions discuss a topic that is a very good example of the impact of AmI on embedded system design, namely Quality of Service (QoS). To a user, the quality of a requested service, for example image quality of a requested video, is one of the most important concerns. An AmI environment should provide the best possible quality at all times. The highly dynamic environment with often limited and continuously changing processing and communication resources requires therefore adaptability and flexibility in the services. In particular, it must be possible to make quality-resource tradeoffs at any point in time. In *QoS-based Resource Management for Ambient Intelligence*, Clara M. Otero Pérez, Liesbeth Steffens, Peter van der Stok, Sjir van Loo, Alejandro Alonso, José F. Ruíz, Reinder J. Bril, and Marisol García Valls of Philips Research, Universidad Politécnica de Madrid, Eindhoven University of Technology, and Universidad Carlos III de Madrid present a unified approach to QoS in an AmI setting. In *Terminal QoS: Advanced Resource Management for Cost-Effective Multimedia Appliances in Dynamic Contexts*, Jan Bormans, Nam Pham Ngoc, Geert Deconinck, and Gauthier Lafruit of IMEC and Katholieke Universiteit Leuven focus on QoS-instigated resource management for multimedia services running in conjunction with 3D rendering applications. It is shown that software/hardware reconfigurability provides an important degree of freedom in the quality-adaptation process.

The fourth paper in the Developments part, *Scalability and Error Protection - Means for Error-Resilient, Adaptable Image Transmission in Heterogeneous Environments*, by Adrian Chirila-Rus, Gauthier Lafruit and Bart Masschelein of IMEC, also relates to quality. It presents a practical wavelet-based coding solution for the automatic, quality-based adaptability of image transmission over ubiquitous networks in the dynamic, heterogeneous AmI environment, with sometimes unreliable network connections.

Metaprogramming Techniques for Designing Embedded Components for Ambient Intelligence, by Vytautas Štuikys and Robertas Damaševičius of Kaunas University of Technology, is the fifth contribution in the Developments part. It describes how software-engineering techniques are adapted to the development of software and hardware components for AmI, taking into account the specific needs resulting from the AmI context. Three case studies demonstrate the validity of the presented approach. Zbigniew Chamski, Marc Duranton, Albert Cohen, Christine Eisenbeis, Paul Feautrier, and Daniela Genius of Philips Research, INRIA, Ecole Normale Supérieure de Lyon, and Université Paris 6 consider in *Application-Domain-Driven System Design for Pervasive Video Processing* also system-design techniques but they focus their attention on video processing, one of the core application domains in AmI. Video applications typically need many processing and communication resources, often leading to dedicated solutions. The paper describes a complete development chain for video applications, including methods and prototype tools.

The last three contributions in this volume bring us to the realm of high density networks, that is, networks with large numbers of often (very) small processing nodes. Such networks are essential in realizing an omnipresent AmI infrastructure that 'seamlessly and fully surrounds the users'. In *Collaborative Algorithms for Communication in Wireless Sensor Networks*, Tim Nieberg, Stefan Dulman, Paul Havinga, Lodewijk van Hoesel, and Jian Wu of the University of Twente present a new approach to communication in sensor networks. Since energy is the essential resource in such networks, the approach focuses on energy efficiency. Rex Min and Anantha Chandrakasan of MIT discuss energy-efficient wireless communication in more detail in *Energy-Efficient Communication for High Density Networks*. They emphasize the importance of accurate energy models, and they argue the need for performance-energy trade-offs and for application-specific solutions. They do so by presenting five myths of energy-efficient wireless communication. The final paper, *Application Re-mapping for Fault-Tolerance in Ambient Intelligent Systems*, by Phillip Stanley-Marbell, Nicholas H. Zamora, Diana Marculescu and Radu Marculescu of Carnegie Mellon University, investigates techniques to achieve fault-tolerance in high-density networks. Their techniques use the abundance of processing elements in such networks to cope with the run-time failures that will be unavoidable in networks of very many, very small, low-cost, low-energy elements.

What conclusions can be drawn from this volume? From the perspective of computational devices, the basic infrastructure enabling AmI can be partitioned into three classes of devices, based on energy consumption. The classes roughly correspond to mains-powered devices, wireless handheld devices, and wireless sensor-type devices. The characteristics of devices in these classes are fully determined by the available energy sources. Energy will become the most critical resource in an AmI environment. Wireless devices have an inherently limited power supply, and even the energy consumption of mains-powered devices is limited, mainly by the cooling capacity that can be built in.

The AmI infrastructure is characterized by the presence of large numbers of various kinds of devices, of all three classes, all connected and communicating with each other, and all fully integrated in our natural surrounding. Distribution, heterogeneity, and dynamism are key characteristics of the infrastructure. Distribution is obvious in the basic networked infrastructure, but future embedded systems will also contain many processor cores, memories, and other components on a single chip. Heterogeneity is present in the large variety of devices, in communication standards, media coding formats, processor cores, screen sizes, and so on. Typical sources of dynamism are the mobility of devices and users, applications that compete for shared processing and communication resources, and changing conditions of wireless networks.

Applications will run on top of the sketched infrastructure with all its characteristics. Traditionally, there is a tight coupling between applications and devices. It is clear that this one-to-one link will disappear. Application designers and system engineers will have to re-invent their design flows. To date, for example, designers often spend a lot of time optimizing applications for specific processors. But is that still meaningful if an application hops from one device to another from time to time?

The solutions presented in this volume to cope with particular AmI characteristics have one thing in common. They all focus on flexibility and adaptability. Prominent examples are QoS techniques, error-resilient and scalable image coding, and adaptive planning strategies used in intelligent robots. Also fault-tolerance and component-based design techniques fit the trend, and many other examples can be found throughout the book. At a first glance, the approach towards flexibility and adaptability may seem straightforward, but it turns out that a reliable and efficient realization is difficult. Another important observation in this volume is that security and privacy are crucial. Without secure infrastructure and privacy-respecting applications, AmI is deemed to fail. In conclusion, it is clear that many basic ingredients of the infrastructure needed to enable AmI are present today; the major challenge is to integrate all components into a smoothly operating whole.

Throughout history, technological advances have brought about many revolutionary changes in our daily lives. The last few decades, we have seen the rise of the personal computer, the breakthrough of Internet, and the introduction of mobile telephony. Other revolutions will follow, and the realization of the Ambient-Intelligence vision could certainly lead to one. Everything may happen. If sufficiently many people believe in it, we can make sure that Tom's evening will get a positive ending.

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