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Ambient Intelligence: Beyond the Inspiring Vision

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Abstract: Ambient Intelligence (AmI) has emerged in the past 10 years as a multidisciplinary field within ubiquitous computing, attracting considerable research, funding and public attention and leading to many research groups, and conferences specifically focused on Ambient Intelligence topics. From its conception, AmI has always been a field strongly driven by a particular vision of how ICT technologies would shape our future. This has given the AmI vision, essentially as proposed by ISTAG, an excessively central role in shaping the field and setting its research agenda. We argue that this inspiring vision should no longer be the main driver for AmI research and that we should now re-interpret its role in the background of 10 years of research.

In this paper, we reflect on what it means for AmI to move behind its foundational vision and we identify a number of emerging trends around some of its core concepts, more specifically the notion of intelligence, the system view and the requirements process. The main motivation is to search for alternative research directions that may be more effective in delivering today the essence of the AmI vision, even if they mean abandoning some of the currently prevailing approaches and assumptions. Overall, these trends provide a more holistic view of AmI and may represent important contributions for bringing this field closer to realisation, delivery and real social impact.

Key Words: Ambient Intelligence, design, innovation, scenarios, situated intelligence, open innovation, global computing, ubiquitous computing
Category: D.2.1, D.2.10, H.1.2, I.2.0, K.4.2

1 The Ambient Intelligence vision

Ambient Intelligence (AmI) is a compelling vision of smart environments that are reactive to people and able to make our actions safer, more efficient, more informed, more comfortable or simply more enticing. It proclaims that our environments will be embedded with visual, audio or many other types of sensing systems, pervasive devices, and networks that can perceive and react to people, sense ongoing human activities and proactively respond to them. The AmI vision began its influential role at the turn of the century, when the Information

Society and Technology Advisory Group (ISTAG) of the European Commission published an influential set of reports on the topic and gave AmI a prominent role in the FP6 IST programme. The subsequent association of AmI with the European policies towards the knowledge society, as agreed at the Lisbon Council of 2000, and the continued financial backing in the following research programmes contributed to make AmI a very active research topic. Academic researchers and companies were mobilised to contribute towards the realisation of the AmI vision. In the past 10 years this vision has emerged as a multidisciplinary field within ubiquitous computing, attracting considerable research, funding and public attention and leading to many research groups and conferences specifically focused on Ambient Intelligence topics.

1.1 Defining characteristics of AmI

There are many defining characteristics of AmI that can be traced back to the origins of ubiquitous computing. Both fields share many similar assumptions and challenges, such as spontaneous interoperation, seamless integration between physical and virtual environments and natural interaction. Ambient Intelligence, however, places a particularly strong focus on intelligent interfaces that are sensitive to their users. To a large extent, these distinctive characteristics have been largely set by the ISTAG reports on Ambient Intelligence, in which AmI is described as follows: "*[...] humans will be surrounded by intelligent interfaces supported by computing and networking technology which is everywhere [...]. AmI [...] is aware of the specific characteristics of human presence and personalities, takes care of needs and is capable of responding intelligently to spoken or gestured indications of desire, and even can engage in intelligent dialogue. Ambient Intelligence should also be unobtrusive, often invisible: everywhere and yet in our consciousness - nowhere unless we need it. Interaction should be relaxing and enjoyable for the citizen, and not involve a steep learning curve.*" [ISTAG(2003)].

This description points out some of the most fundamental ideas in what was to become the prevailing AmI vision: the idea of a radical and technology-driven change to existing environments and people's lives; the view of networked devices strongly embedded into the environment; the idea of transparent systems that do not need to be noticed by people; the anticipatory and proactive nature of the system that frees people from manual control of the environment; and intelligent interfaces that will be able to understand and adapt, not only to the presence of people, but also to situations of everyday life, including peoples' moods, activities or expectations. Even though these properties are not written in any mandatory document they are largely implicit in the papers, conference calls or mission statements in this area and have clearly become key elements in the AmI research agenda.

1.2 Objectives

Recently, an increasing number of researchers in the field have started to question the traditional assumptions behind the dominant visions of Ubiquitous Computing and AmI, and particularly the strong technologically deterministic view underlying many of the envisioned scenarios. The key reason why this is happening is essentially because Information and Communication Technologies (ICT) are already becoming an integral part of our everyday life and therefore are increasingly facing the social realities that will necessarily shape its future evolution. This calls for a move from visionary perspectives of the future to a new focus on the challenge of actually being able to deliver real value today. In this paper, we aim to reflect on what this means for the AmI vision, and its foundational role for AmI at large. We suggest that it is time for the AmI field to move beyond its founding vision and embrace important emerging trends that may bring this field closer to realisation, delivery and real social impact.

In section 2, we discuss the reasons why we believe this reflection to be important. In section 3, we discuss what this might mean in terms of new research directions, and specifically explore three topics: intelligence, system support and scenarios. The paper ends, in section 4, with the enumeration of the main implications and conclusions of this reflection for AmI research.

2 Moving beyond the AmI vision

After almost 10 years of considerable research effort, it is now possible and timely to look back at the visionary scenarios, the research results, and reflect on the overall accomplishments of this area. Overall, we should recognize that we now have a much more thorough understanding of the problem domain and also appropriate solutions to some of the specific issues involved. However, we must also acknowledge the existence of a persistent gap between the promises of the area and its real achievements. In particular, some of the central features of AmI, such as its anticipatory nature or strong personalisation, are not only far from being achieved, are also being increasingly questioned. Moreover, the field has not matured yet to the point of enabling incremental research, a cornerstone for any research area. We would expect to be witnessing the emergence of enduring principles and of a growing body of research findings and solved challenges. Instead, much of the research effort still seems to be devoted to the creation, very often from scratch, of technologies and systems for enabling the scenarios described in the AmI vision.

From its early days, AmI has always been a field strongly driven by a particular vision of how ICT technologies would shape our future. These visions of the future are important because they have the power to catch peoples' imagination and also because they can challenge us to think outside common mindsets and look for new possibilities. In the case of the AmI vision, it has inspired a whole generation of researchers into a quest for the immense possibilities created by the incorporation of machine intelligence into our everyday lives. However, from a research perspective, there are important risks in such a strong focus on an inspiring vision of the future.

The most obvious one is that the vision may turn out to be wrong. However, a vision of the future of technology it is not meant to be seen as a prediction. It is only meant to promote debate, reflection and communicate possible scenarios, and so, as long as everyone fully understands the implications of this, failing to make the right predictions should never be a problem.

Less obvious, albeit potentially more relevant, is the risk of techno-utopia. The term expresses visions of society with ideal living standards thanks to advanced science and technology, in which for every possible problem people might have, there will be some technological solution to solve it. Techno-utopian discourses have been very common with the introduction of technological breakthroughs, such as the telegraph, the telephone, the TV and many others. They promise revolutionary social changes on the basis of the breakthroughs enabled by technology and they can be incredibly seductive and motivating when new and strongly disruptive technologies are emerging into society. However, they have often failed to live up to expectations mainly because of their technologically deterministic nature. They place a strong focus on the new features enabled by a technology, without paying enough attention to the social dynamics around those features and their potential adoption. This is typical of a stage in which technology is emerging, but not yet generally available. As a consequence, they normally reflect unrealistic assumptions about the evolution of human practices and even about the complexity or scalability of the proposed scenarios. To make things worst they often mimic existing functions, while failing to envision the really disruptive nature of many innovations.

Working towards a vision of the future also raises the risk of neglecting the challenges of the present. This is what Bell and Dourish call the proximate future, a future just around the corner but always postponed [Bell and Dourish(2007)]. Working for the proximate future, allows everyone to take their favourite challenges and assume that all the limitations of the present will soon be solved by someone else. The consequence is that real issues remain unsolved. Moreover, this may often be used as the justification for the lack of delivery when it comes to bringing value to the real problems of today.

Finally, there is also the risk that too much convergence on a single vision of the future may end up excluding alternative visions. A common vision may promote the convergence of multiple efforts towards a common goal, thus contributing to make it more reachable. However, a continuous questioning of the current assumptions and the generation of new hypotheses should also be an integral part of a sound research process.

These risks have been particularly striking for the AmI vision. Unlike other fields, AmI is not mainly driven by well-know technological problems or by some immediate and widely accepted user needs. It is an area where a wide range of fields and technological areas come together around a common vision of the future and the immense possibilities such future will bring. This has given the AmI vision, essentially as proposed by the ISTAG, an excessively central and foundational role in which it may have been oversold. Interestingly, these risks seem to have been considered by the ISTAG itself which refers to the AmI vision as a starting point and refers that "*future scenario building and iterations of the vision should treat AmI as an 'imagined concept' and not as a set of specified requirements*" [ISTAG(2003)]. However, rather than promoting reflection as expected, the inspiring vision put forward by ISTAG has become a unifying element for the field, assuming an almost normative role and clearly exacerbating the previous risks.

Ubicomp in general also faced a similar challenge with Mark Weiser's foundational vision. For many years, it was also the almost inevitable citation in many ubicomp papers, and was often presented as the motivation for the work itself. After some debate [Bell and Dourish(2007), Rogers(2006)], the ubicomp community is now learning how to re-interpret the meaning of that vision, seeking alternative foundations and in fact overcoming many of the previously mentioned risks. We argue that, similarly, the AmI vision, in its currently prevailing form, may no longer be the most effective driver for AmI research. We should now seek to re-interpret its role in the background of 10 years of research since its original inception. The AmI vision has played an important role in establishing this field, but it is now time for AmI to move beyond that foundational vision.

3 New directions for AmI research

The main reason for questioning the AmI vision is to seek alternative research directions that may be more effective in taking this field closer to the idea that the integration of information systems into our everyday environments may have a profound and positive impact in society. This is the essence of the AmI vision, but realising it may turn out to be very different from what we envisioned a decade ago. In this section, we revisit three core concepts of AmI research: intelligence, systems, and scenarios. For each of them, we discuss new ways to look at the realisation of the AmI vision and consider some of the respective implications for AmI research.

3.1 From intelligent environments to situated intelligence

Perhaps the most prevailing idea in Ambient Intelligence is the notion of the caring environment that senses and intelligently reacts to people, anticipating desires and intentions. This part of the AmI vision has given context-awareness a prominent role. Moreover, it generated the assumption that Artificial Intelligence should be able to detect, model, and understand situations of life in a way that would allow the system to pro-actively take the most appropriate actions. This particular notion of intelligence is an integral part of some of the most enticing AmI scenarios and has inspired a broad body of research into new techniques for improving the sensing, inference and reasoning processes. However, it has also become one of its most challenged assumptions, generating a growing level of criticism that essentially questions its feasibility and added value.

The feasibility issues are essentially linked with the inherent complexity associated with modelling situations of life. We can acknowledge the huge potential of machine learning techniques, but the fact remains that most of the reasoning processes suggested for AmI scenarios involve extremely complex inferences based on relatively limited and imperfect data. Many of the challenges involved can be compared with the challenges of achieving a human-level understanding of the world, which in the past eluded what would become known as classical or strong AI. Leahu et. al. claim this is the reason why AmI is failing to scale from prototypes to realistic systems [Leahu et al.(2008)]. Without questioning the role of AI in ubicomp, they call for a redirection of the AI effort into what they designate as Interactionist AI, in which the generation of intelligent behaviour tries to capitalise on the fact that AmI is directed towards Humans and, therefore, can leverage on their own behaviour to generate alternative notions of situated intelligence. A similar argument is presented by Rogers [Rogers(2006)] who argues that the specifics of context in real life are too subtle, subjective, fluid and hard to identify to be modelled. This would hinder the system to make sensible predictions about what someone is feeling, wanting or needing at a given moment. Rogers also questions the merits of the vision itself when she asks if we would really want to live in a world in which computers would take on our day-to-day decision-making and planning activities. As an alternative research agenda she proposes a significant shift from proactive computing to proactive people in which technologies are designed not to do things for people, but to engage them more actively by extending their practices. Greenfield, who boldly claims that "*We're just not very good at doing smart*" [Greenfield(2006)], also questions the merits of this vision. Trying to remake the very relations that define our lives based on a technical paradigm can be easily associated with new levels of frustration and inconvenience into even the most basic operations of our everyday lives than with any worthwhile outcomes. Similarly, Punie points out that an intelligent environment that takes decisions on our behalf while maintaining itself as transparent as possible, may very well harm rather than facilitate AmI acceptance [Punie(2005)].

Many of these critical perspectives can be framed within a wider debate that can be traced back to the influential work by Suchman on the role of plans in situated action [Suchman(1987)]. The philosophy behind situated action argues that plans are mostly resources that will have to be combined with many other situational variables to actually generate behaviour. Plans and predictability are far from having the prominent role they are normally attributed with in setting our actions. Interfaces should thus focus on the ability to react to unanticipated actions actually taken and minimise the need to model and anticipate user actions. It is sensible to appreciate this argument when we consider how road navigation systems only become accepted after they were able to become totally adaptive to the drivers deviance from planned routes, quickly estimating a new route rather than telling the driver that he or she was taking the wrong way. In his theory of Embodied Interaction [Dourish(2001)], Dourish also builds on these ideas to reinforce the importance of situated practice in generating meaning and intelligence. This would point at the importance of leveraging on patterns and existing practices of the living world rather than overcome them. Similarly, within the context of the smart home [Taylor et al.(2007)], Taylor et. al. argue that the vision of the smart home, as an environment that senses and intelligently reacts to people's actions, is too complex and fails to bring any real benefits. Instead, they suggest that intelligence in the house is the result of people's daily practices and their innate ability of making a building into a home. Therefore, this sort of technology should not be concerned with offering intelligence, but rather with offering people at Home further resources to act and think.

These contributions to the discussion around the meaning of Ambient Intelligence are more than mere critics. They point out several alternative strategies for re-thinking the meaning of intelligent behaviour. Those strategies essentially revolve around two main complementary directions: situated forms of intelligence and a strengthened collaboration with Humans.

3.1.1 Situated Intelligence

The concept of situated is common across a vast range of disciplines, including cognitive sciences, artificial intelligence and robotics. The behaviour and cognitive processes of a situated agent should be, first and foremost, the outcome of a close coupling between agent and environment [Lindblom and Ziemke(2002), Pfeifer and Scheier(1999)]. This definition makes no assumptions about the ability of the agent to reason about the meaning of what is happening around it. In fact, in his work on behavioural decomposition, Brooks claims that modelling should be avoided as much as possible [Brooks(1991)]. As an alternative he proposes that the emergence of machine intelligence should result from basic responsive elements that are able to create the appropriate dynamics when interacting with their environment.

Traditionally, AmI research has taken the opposite direction, focusing very strongly on the creation of models for all sorts of relevant situations and environments. Seeking for situated forms of intelligence may provide a refreshing alternative for AI research in AmI. They should enable AmI systems to achieve a close coupling with their social and cultural environment without modelling those environments. Instead, intelligence would emerge from the way in which people empowered with AmI technologies will be able to act more effectively in their environment. The intelligence of the system would not be measured by the ability to understand what is happening, but by the ability to achieve a rich coupling with users who interpret, respond to, and trigger new behaviour in the system. This view must also accommodate the idea that intelligence already exists in the way people organise their practices and their environments. This means that physical settings, e.g. houses, cities or workplaces, already represent and reflect evolving knowledge, social values and Human intelligence at play. Instead of trying to model the complex and subtle forms of intelligence embedded into those realities, we can seek to empower people into the process of improvised situated action that characterises everyday life [Dourish(2001)].

3.1.2 Exposing ambiguity and empowering people

Revisiting the notion of intelligence in AmI may also involve reconsidering the role of Humans, particularly by exposing them to some of the ambiguities raised by the imperfect sensing and imperfect inferences. Letting people handle some of the semantic connections of the system and the ambiguities that may arise, would overcome many of the complex issues associated with the need to perfectly sense and interpret the state of the world that many AmI scenarios seem to announce. In a sense, however, this is the opposite of the view that AmI systems need to be transparent and invisible, and it may also seem like a move backwards in a field that has so often proclaimed the ability to anticipate user needs and react accordingly. However, we should recognise that many of the complex inference problems suggested for AmI are in fact trivial when handled by people. Moreover, even when inferences are simple, systems are not uniform and there will always be some type of technical discontinuity that may affect sensing and thus the ability to always get it right. As suggested by Edwards and Grinter, if we admit that inference in the presence of ambiguity is inherently prone to errors, then we should accept that ambiguity should not be hidden from the parts of the system that may need it or from the users who may need to understand the pragmatics of sensors, interpretation and machine action [Edwards and Grinter(2001)]. Therefore, instead of trying to hide those inevitable discontinuities behind an utopian view of seamless systems, new research is needed to allow people to handle that ambiguity in ways that become empowering without being disturbing. Previous work has highlighted how the ambiguity generated by imperfect infrastructures, when exposed, can quickly be appropriated by people as an interaction resource [Benford et al.(2006)] from which they create their own meaning. Seamful design [Chalmers and Maccoll(2003), Rudstrom et al.(2005)] has been emerging as a design approach that specifically seeks to accommodate these discontinuities, or seams, as design resources, acknowledging that once exposed they can become part of the practices associated with technology. As suggested by Sengers and Gaver, ambiguity and the different interpretations it can generate may even play an important role in allowing different perspectives and motivations to be applied to the same technologies [Sengers and Gaver(2006)].

Empowering people is also about enabling them to generate their own meaning for the interaction with AmI systems. This should provide a real path towards user-driven AmI scenarios that provide meaningful functionality that is effectively valued by potential users. Rather than removing the "burden" of choosing, AmI should make decisions easier to judge and support new practices that allow people to more intelligently undertake their lives. Maybe the smart coffee machine is not necessarily the one that is able to guess when we want a coffee and starts preparing it, but, instead, one that empowers us to understand why the coffee today is not as good as usual, and maybe take some informed action about it. Instead of having the system deciding for us, we can leverage on the system for making our choices more informed and promoting serependity. Moreover, giving people more control may be an essential step in unleashing the creativity and the everyday life connection that has so often been missing from AmI research, extending it into more playful and creative practices.

3.2 From AmI platforms to a service eco-system

The AmI literature includes a vast range of AmI architectures and frameworks that basically aim to provide the appropriate infrastructure for AmI systems [Bravo et al.(2006)]. The need for a service control platform has been pointed out in [ISTAG(2003)] as one of the main research implications towards AmI. The ultimate goal of these platforms is to transparently manage the relevant resources in the physical and virtual spaces, orchestrating the various computational components into a rich, adaptable, flexible, and open system that assists people in their everyday live activities. Typically, these platforms include a number of sensing devices, some intelligent components where modelling and reasoning occur, and some actuators through which the system acts in the physical world. This view embraces two important assumptions regarding system design: the first is the existence of a local infrastructure that will be installed and configured to support the AmI environment, enabling all the networked devices in the environment to coordinate their actions; the second is the existence of generic sensors that will provide the context information that multiple adaptation processes will then use to serve the needs of people in that environment.

Both these assumptions embrace a very strong view on the role of instrumentation, in which a rich and complex set of devices and services is installed to transform a common environment into an intelligent environment. However, we can now realise that this type of system support faces several important challenges regarding its ability to scale and serve an open ended set of functions. The main problem is the huge amount of embedded knowledge that must be brought together to bootstrap the system and make it work. There is too much hidden behaviour and too many assumptions about the environment and the way the system is deployed. As pointed out by Friday, configuration has been one overlooked aspect of middleware platforms: " *This knowledge is typically 'just there', i.e. is established a priori by system developers or 'power users', or is even so implicit to the scenario that the authors do not realize that they are making these assumptions in the first place!*" [Friday et al.(2005)]. The main consequence is that these systems become extremely hard to repurpose or to deploy in new settings. Creating even the most basic AmI application ends-up requiring intensive development, adaptation, deployment and management work, typically by experts in the infrastructure. This is normally an overwhelming effort when compared with the anticipated benefits of the prospective applications, and ultimately means that they will be too complex to use in real-life deployments.

Another consequence of this view is the implicit assumption of a strong coupling between infrastructure and the scenario envisioned for the space, leading to specific concepts of AmI environments, such as the smart meeting room, the smart class, the smart conference assistant or the smart home. The assumption is that, given a particular space and some notion about the intended audience and their local practices, we will be able to create an AmI environment, both hardware and software, that will enable useful, engaging, stimulating or entertaining services to people. However, when we consider that AmI should be everywhere and that, wherever they go, people expect to find valuable AmI functionality, the previous association becomes a lot less obvious. Human activity is very dynamic and subtle, and most public places are also highly dynamic and support a vast range of social practices that do not map directly into any immediate service needs. In those cases, identifying what is valuable to people is very hard and obviously leads to great uncertainty regarding the type of support needed and the type of resources needed to create such support. This uncertainty ultimately leads to a conflict between the perception of the system creator about what might be useful functionality and the services that users will actually value. Considering the variety of tasks that people may want to perform in any public space, it becomes obvious that creating a complex hardware and software infrastructure dedicated only to a particular view of what might be interesting services is a very limited approach.

Revisiting AmI assumptions regarding system support may take at least two complementary paths: focusing on a global eco-system of services and evolving towards a "commons" model of creation. Both these paths are strongly framed by the emergence of Global Computing and the Web 2.0 paradigm.

3.2.1 A global service eco-system

The trend towards Global Computing provides an entirely new framework for re-considering system support for AmI and represents a major opportunity for uncovering disruptive solutions and innovative models. In particular, a balanced combination between global services and situated devices may provide the key to widespread deployment of AmI: Global services provide functionality that can be relevant anywhere, thus obviating the need to create dedicated services on a case-by-case basis. Situated devices, such as sensors, displays, networks, and personal devices provide context and enable meaningful links to be created between multiple global services and the physical environment.

Let us consider the common example of the Home environment, which is becoming increasingly rich in digital devices. In addition to the already ubiquitous personal devices, such as mobile phones, PDAs and MP3 players, several others digital and networked artefacts are now also becoming common presence at Home, such as energy meters, video cameras, digital photo frames or Nabaztags. Rather than having to coordinate their presence in the Home environment through some type of AmI platform, these devices are increasingly already associated with their own services. Consider for example the case of an energy meter. It is certainly useful to plug it to some device and directly observe the indicated energy consumption values. It is even better to be able to share information with other devices in the home, giving us the opportunity to maintain a record of our energy consumption and possibly aggregate data from multiple meters. However, the real value may emerge when our energy meter becomes associated with some external service dedicated to energy optimisation to which we can delegate the analysis of our energy consumption. This would not only make the process much easier for people, who no longer need to maintain any local infrastructure, as it also opens up the possibility for several value-added services, such as rich visualisations, personalised power saving advices, and gregarious data comparisons that are in themselves a form of ambient intelligence.

This trend has been steadily reducing the role of the personal computer as the central information hub for the house and is opening the path for AmI systems that overcome the need for local generic system platforms. It also seems to indicate how important it will be for the AmI vision to have a larger market of networked, web-based IT commodities, that may integrate AmI system as basic building blocks. For AmI research, this does not mean waiting for those commodities to emerge, but rather to start researching how some of the current pieces may be commoditised or how to make simpler systems with the simpler commodities we already have today. For example, photo frames may quickly become commoditised displays not only for family photos, but also for an arbitrary range of service associated with their environment, as already being proposed by systems such as FrameIt or FrameChannel. This represents a shift from creating intelligent systems to the creation of elements that deliver intelligent behaviour and are able to incorporate their behaviour into a larger eco-system of services and resources.

3.2.2 A World of Prosumers

A particularly challenging limitation to the creation of appropriate system support is the existence of a "*chicken and egg*" problem with applications. Without a clear set of killer applications it is very hard to identify requirements and make informed design decisions. How can anyone create an infrastructure to support a thing that cannot yet be understood and defined? On the other hand, without a rich infrastructure it is very hard to create an integrated environment where applications may leverage on each other to support, as a whole, the notion of an intelligent environment. Furthermore, different application domains, e.g. home, car, work, or streets, they all have different constraints and so hamper common approaches to system support for AmI.

Despite its fundamental nature, this issue does not need to be an eternal dilemma. The alternative might be to blur the distinction altogether, by focusing on re-usable elements that are applications in the sense that they provide some useful service directly to users, but at the same time have the ability to become building blocks to the creation of multiple systems. The success of Web 2.0 has shown us plenty of examples of systems based on this principle. The concepts of mashability, crowdsourcing, and "commons", in the sense of a set of shared and accessible community resources, have been opening the path for new development models in which Prosumers (both producers and consumers) make the contributions that deliver the vast majority of end-user value [Kazman and Chen(2009)]. Each contribution aims to support some specific functionality, but their data and services can easily be recombined and appropriated in many ways, leading to an incremental model that evolves naturally without actually being planned. Thackara argues that an increasingly blurred distinction between users and producers will replace the traditional point-to-mass paradigm of the manufacturing era, enabling the emergence of a new kind of immersive innovation in which the creation of a service or situation is achieved through mass participation [Thackara(2005)]. The importance of open contribution is also referred by Rogers who proposes the existence of small-scale toolkits and sandboxes that would offer the means to facilitate creative authoring [Rogers(2006)].

Rather than designing the core platforms and the applications on top of them, AmI also needs to find its own path towards enabling the emergence of prosumers, which are able to identify new needs, create the appropriate support, and share it with others with similar needs.

3.3 From scenario-driven requirements to social innovation

User scenarios are a valuable and much utilized method in Human-Computer Interaction (HCI) and Software Engineering. A scenario is a story that may contribute to the design process by helping a design team and the potential beneficiaries of the system to reason about situations of use, even before those situations are actually created. They can serve multiple design, collaboration and communication purposes [Carroll(1999)], and different scenarios can be created to exemplify the use of certain functionality or design decisions. Thus, scenarios can be tightly coupled with design solutions, concrete conceptual assumptions or theories regarding the elements and agents at work in a certain setting doing a certain activity.

Scenarios have also become an important element in AmI because of their capacity to materialise an otherwise abstract vision into concrete situations of life. The AmI literature is thus rich in scenarios that demonstrate how AmI technologies would add value to those situations. The problem with most of those AmI scenarios is that they are often too shallow when compared with the reality they try to model. Any scenario, in addition to what it explicitly describes, also includes a setting that implicitly defines many other assumptions about the usage situation. This is fine when we are considering the constrained setting of a desktop application or addressing a well-know and formal situation of use. However, in AmI, the setting is the complex frame of everyday life, which is much more varied, unconstrained, and difficult to anticipate than what most scenarios seem to suggest. Moreover, scenarios are often conceived by a technology creator to illustrate the potential of that technology, and therefore their characteristics are not determined by the findings from in-depth studies of the respective usage situation, but essentially by the need to raise the specific problem that the technology can help solve. Friedewald et. al. in their analysis of the AmI scenarios and roadmaps in various application domains [Friedewald et al.(2007)], identify a number of ways in which the full implications of those scenarios seem to be overlooked, such as the characteristics of the envisioned population, the level of personal control over technology and the assumptions regarding information flow.

This tendency for the oversimplification of the situations represented in the scenarios can easily lead to what Barton and Pierce have called "magic" to describe unreasonable assumptions about technical, economical or societal characteristics that so often pervade this type of scenario [Barton and Pierce(2006)]. This "magic" may involve amazing leaps over barriers to adoption or unreasonable expectations on how people, society, or technology will change. Too much "magic" corresponds to an oversimplification of the challenges, of all sorts, involved in making that scenario for real, and a design process based on unrealistic scenarios will ultimately lead to an unrealistic system that no one will actually adopt. Therefore, even if they look futuristic and technically exciting, scenarios should be considered with moderation. On the one hand, they need to be futuristic to match the ambitious AmI vision they intend to instantiate. On the other hand, they are often too constrained and too distant from reality to represent realistic usage situations.

There is yet another problem with the way scenarios have been used in AmI. While scenarios tend to emphasise a technologically deterministic and utilitarian view of technology development and its societal dissemination, information technology is increasingly being used to fulfill many other kinds of interests, desires or ambitions, rather than just solving problems in the way it used to [Harper et al.(2008)]. AmI technologies are strongly disruptive and targeted at the mundane life, a complex social environment, made of myriad circumstances that cannot easily be anticipated and served. Rather than just enhancing or mimicking existing practices, technological progress may completely redefine the underlying problems and offer entirely new innovation opportunities that cannot be foreseen until the technology reaches society. Therefore, a naive scenario may be strongly misleading and completely miss the true potential of a disruptive technology such as AmI.

The way in which scenarios have been utilised by the AmI community may not be the most effective way of uncovering the potential of AmI, but this means that we need to find alternative ways to design for new situations of use. This may be achieved by bringing the concept of technology domestication to the core of AmI, by increasingly promoting the incorporation of Human values into the design of AmI systems and by taking a broader perspective on the scope of application domains and social problems addressed by AmI systems.

3.3.1 Domestication

Scenarios in AmI have been mostly designed by technology creators to highlight the merits of the technology. This is typically associated with a "diffusionist" view of innovation [Alahuhta and Heinonen(2003)], whereby technology is perceived to develop independently of society, having a subsequent impact on societal change. However, recent history of ICT has shown us how social innovation is an increasingly important element in innovation and how multiple forms of participative design are gaining a central role as innovation tools. These views challenge the traditional passive role of the user as a mere adopter of technology and call upon a more participatory role in which technology and society are shaped at the same time as part of the innovation process [Alahuhta and Heinonen(2003)].

The concept of domestication is central to this process and is seen as a negotiation through which technology may be accepted into everyday life and adapted to the specificities and power relations of the micro-social contexts in which it is going to be integrated. Domestication means going far beyond the obvious, and actively search for the emergence of new practices around technology. As Dourish points out "*Practices develop around technologies, and technologies are adapted and incorporated into practices*" [Dourish(2001)]. This notion of practice is seen as being not only what the technology enables but also how that action fits into a wider scheme that makes it meaningful. In a domestication process technology and society mutually affect each other and they both evolve in that process. Domestication is therefore not just about technology that is easy to use. It is mostly about involving users in a sociological sense where they are able to accept and find a meaningful presence for the technology in the myriad situations of their everyday lives [Hallns and Redstrm(2002)].

To a certain extent, domestication processes have always been part of ICT innovation, but the pervasive and continuous presence of AmI significantly raises the need to actively promote domestication and to do so much sooner in the innovation process. Given the huge potential of the technologies involved, trying to identify initial requirements is nearly hopeless. It is very hard to create a match between the many potential applications of the technologies involved and the myriad circumstances that may give value to the use of those technologies in a particular mundane situation. Instead, the focus should be on finding possible connections between worthwhile outcomes and the features enabled by technology. In a domestication process, technology gets slightly changed to facilitate those connections, and new practices may emerge to potentiate the value brought by the use of the technology.

Most often, these emerging practices can only be realised once the technology becomes available on a continuous basis in the daily life of target users. The only effective way to evaluate and support their evolution is by observing how they are used in the type of environment for which they are being designed. This requires an eco-system of services, communities and places that is not easy to create on a lab or small scale demonstrator. Simulations and lab experiments may be useful for early evaluations, but they sacrifice the richness, unpredictability and diversity of the social environment of a real setting. Therefore, the effective development of these technologies must be strongly anchored on the realisation of long-term deployments in real settings, where the richness and subtlety of social situatedness can fully emerge and lead to innovative appropriation of the technology. Multiple open innovation methodologies have been emerging to actively stimulate the participation of users in the evolution of the technologies. In particular, Living Labs have become very popular in Europe [ENOLL(2010)] as a user-driven open innovation eco-system that involves all the relevant players in the value chain of a new technology and seeks to promote open innovation through a continuous dialog between technology creators and the potential users of that technology. A Living Lab may create a long-term open environment for experimentation and co-creation, bringing together the necessary critical mass of commodity and enabling services for unleashing the creative potential of the new technologies and actively seek for the paths towards its domestication.

3.3.2 Human Values

The AmI vision has always proclaimed the need to place a strong focus on people and their experience with technology. This awareness of the importance of the user experience and of the ability to incorporate it in early stages of the design life cycle has also been widely acknowledge in Human-Computer Interaction in general. At a more basic level, the user experience may consider usability issues such as quantitative measures on task-completion, but increasingly user experience is concerned with a much broader set of issues such as pleasure, fun, aesthetics, boredom, annoyance and so on. Still, even this broader view on the user experience does not really take into account the high-level values that may be involved in the adoption of AmI technologies. AmI scenarios tend to offer a neutral or even excessively positive perspective of technology, implicitly favouring values that are traditionally associated with the use of ICT, such as efficiency and connectedness. However, the nature of AmI technology can make a very strong impact on key values, such as privacy, security, connectedness, togetherness, creativity, ownership, and many others. Therefore, the consideration for human values, capacity, and culture must increasingly become explicit in the fundamental design choices that will shape AmI technology. This represents a shift from trying to understand individuals, their individual experience with technology, and how they are going to take advantage of this technology to a greater emphasis on what is desirable from a social and cultural perspective, and why people would want to give technology a place in their lives.

Bringing Human values to the forefront of the innovation process means, first of all, to acknowledge that a technology that is so socially disruptive as AmI is far from being neutral and will strongly impact on multiple and potentially conflicting values. It also means that alignment with particular values will increasingly become the critical factor in the adoption, rejection or appropriation of AmI technology. As we have an increasingly broad range of technical possibilities that can also offer adequate user experiences, the key criteria for technology adoption will naturally move away from technical or user experience issues into the way that particular technology is aligned with our values. A broad range of new interaction design methodologies have been emerging that focus on making human values an integral part of systems design, such as Value Sensitive Design [Friedman and Kahn(2003), Friedman(1996)] or Worth-Centred Design (WCD) [Cockton et al.(2009), Cockton(2005)]. These methodologies are not recipes for successful design, but they can promote consideration for alternative designs in which technical features are effectively aligned with explicitly selected values.

3.3.3 New Problem Domains

AmI scenarios cover multiple application domains from Healthcare to Tourism or Smart Homes. However, it is undeniable the disproportionate weight of a relatively small number of well-known scenarios in setting the research agenda. Typical examples may include the detection of emergency situations associated with elderly people living alone, the refrigerator that automatically makes the food inventory and orders needed items or the smart home that adapts the lighting according to the mood of the inhabitants. The reasons behind this concentration on a small number of scenarios are rooted on the same reasons that gave scenarios a primary role in AmI, as discussed at the beginning of this section. What is worth stressing is that the AmI community should make an effort to broaden the scope of problems being addressed and specifically to revise the respective priorities. Some obvious problems may be very interesting as research challenges, but maybe the type of solutions we can achieve today are too far from perfect to make any real impact. On the contrary, there are many other problems in the world, perhaps less obvious for most of us, but for which AmI could already have a major impact today. These may include global problems such as poverty, safety, social connectedness, the digital divide, isolation in big cities, energy optimisation, road safety or environmental sustainability. It is obvious the huge role that technology may have in helping to overcome some of these problems. For example, since they were published, the Millennium Development Goals [UN(2009)], set by the United Nations, have been the theme of some high profile technology competitions. This trend represents a clear path for setting bigger challenges and seeking real impact in the world today that may be particularly pertinent for AmI as well.

Overall, this is a call for looking outside the research laboratory and seek for a more relevant research agenda that addresses important but often neglected issues associated with the messiness of everyday practice [Bell and Dourish(2007)]. Rather than designing for specific and unusual needs we have the opportunity or even the obligation to consider how to augment existing practices in ways that deliver real value to people. This represents a shift from perceived motivations embedded in common scenarios to a realistic tackle of the world's most serious problems. This also means assuming that studying and understanding problems must become increasingly central to the innovation problem, rather than having pre-formatted solutions seeking for problems. The real research will often be in actually discovering the specifications of the problem through repeated fieldwork and deployment [Dias and Brewer(2009)].

4 Conclusions

In the 50's, when plastics were one the major innovations (not because they had just been invented, but because a whole generation of plastic-made products was hitting the market), some popular visions of the house of the future, predicted that the houses would be entirely made of plastics, both the structure and the decoration, to the extent that one would be able to wash the interior with a hose. These predictions have clearly failed when we look at specific visions like this. However, the essential vision that plastics would become ubiquitous to the extent they would strongly shape our society was probably modest when we consider the ways in which they are currently present in our lives. Similarly, the idea that computers will be in the most diverse scenarios of our everyday lives, enabling new forms of intelligence and radical societal change is also beginning to happen today. However, we must also acknowledge that, in the end, the nature of the systems and services that will constitute AmI, may turn out to be very different from what we are currently envisioning, and therefore AmI should not get stuck to particular visions of its future.

AmI as a field is still strongly anchored on the visions that lead to its emergence, and therefore questioning that vision may easily seem like questioning AmI itself. However, revisiting the AmI vision and questioning some of its assumptions should not be seen as an exercise of disappointment, recognition of failure, or even criticism to AmI as a field. Instead, we believe it should be seen as an integral part of the research progress in which a vision of the future should always be seen as a starting point from which we depart towards realisation and not an objective in itself. Therefore moving beyond the vision should be seen as sign of progress, a sign that vision has already fulfilled its role and that the field is now ready for something bigger. Also, moving beyond the vision, does not necessarily means searching for a new one, but fully understanding the meaning and implications of what it represents. At least at the level of discourse, the AmI vision, as proposed by ISTAG, already distanced itself from technological determinism. It clearly highlighted the importance of an holistic view that considers people and many other non-technical challenges as crucial to the realisation of AmI, more specifically it states: "*to be acceptable, AmI needs to be driven by humanistic concerns, not technologically determined ones and should be controllable by ordinary people*" [ISTAG(2001)]. Technology has gained a clear predominance in AmI, but the field is now at a tipping point, where promises must be delivered and expectations must be confronted with reality. The available technology is already enough to do much more than what we have done so far, and therefore AmI can no longer be about a vision of a new world for the future, and driven by distant and overblown research agendas focused mainly on technological features. AmI has the obligation to start delivering valuable services, not for the future or the constrained environments of the labs, but today and for the messiness and imperfections of the real-world, even if this means moving beyond an inspiring vision that may already fulfilled its goal.

References

[Alahuhta and Heinonen(2003)] Alahuhta, P. and S. Heinonen, 2003: A social and technological view of ambient intelligence in everyday life: What bends the trend? Tech. Rep. Research report RTE 2223/03, VTT.

[Barton and Pierce(2006)] Barton, J. and J. Pierce, 2006: Quantifying magic in ubicomp systems scenarios. in *UbiSys 2006 Workshop at Ubicomp2006*, Orange County, California, USA.

[Bell and Dourish(2007)] Bell, G. and P. Dourish, 2007: Yesterday's tomorrows: notes on ubiquitous computing's dominant vision. *Personal and Ubiquitous Computing*, **11**(2), 133 – 143.

[Benford et al.(2006)] Benford, S., A. Crabtree, M. Flintham, A. Drozd, R. Anastasi, M. Paxton, N. Tandavanitj, M. Adams and J. Row-Farr, 2006: Can you see me now? *ACM Trans. Comput.-Hum. Interact.*, **13**(1), 100–133.

[Bravo et al.(2006)] Bravo, J., X. Alaman and T. Riesgo, 2006: Ubiquitous computing and ambient intelligence: New challenges for computing. *Journal of Universal Computer Science*, **12**(3), 233—235.

[Brooks(1991)] Brooks, R. A., 1991: Intelligence without representation. *Artif. Intell.*, **47**(1-3), 139–159.

[Carroll(1999)] Carroll, J. M., 1999: Five reasons for Scenario-Based design. in *Proceedings of the Thirty-Second Annual Hawaii International Conference on System Sciences-Volume 3*, p. 3051. IEEE Computer Society.

[Chalmers and Maccoll(2003)] Chalmers, M. and I. Maccoll, 2003: Seamful and seamless design in ubiquitous computing. *In Proceedings of Workshop "At the Crossroads: The Interaction of HCI and Systems Issues in UbiComp. 2003"*.

[Cockton(2005)] Cockton, G., 2005: A development framework for value-centred design. in *CHI '05 Extended Abstracts on Human factors in computing systems*, pp. 1292–1295, Portland, OR, USA. ACM.

[Cockton et al.(2009)] Cockton, G., D. Kirk, A. Abigail Sellen and R. Banks, 2009: Evolving and augmenting worth mapping for family archives. in A. Blackwell, editor, *Proceedings of HCI 2009 - People and Computers XXIII - Celebrating people and technology.*

[Dias and Brewer(2009)] Dias, M. B. and E. Brewer, 2009: How computer science serves the developing world. *Commun. ACM*, **52**(6), 74–80.

[Dourish(2001)] Dourish, P., 2001: *Where the Action Is.* MIT Press.

[Edwards and Grinter(2001)] Edwards, W. K. and R. E. Grinter, 2001: At home with ubiquitous computing: seven challenges. in *Proceedings of the 3rd international conference on Ubiquitous computing*, Atlanta, GA.

[ENOLL(2010)] ENOLL, 2010: Open living labs: The european network of living labs. http://www.openlivinglabs.eu/.

[Friday et al.(2005)] Friday, A., M. Roman, C. Becker and J. Al-Muhtadi, 2005: Guidelines and open issues in systems support for ubicomp: reflections on UbiSys 2003 and 2004. *Personal and Ubiquitous Computing*, **10**(1), 1–3.

[Friedewald et al.(2007)] Friedewald, M., E. Vildjiounaite, Y. Punie and D. Wright, 2007: Privacy, identity and security in ambient intelligence: a scenario analysis. *Telemat. Inf.*, **24**(1), 15–29.

[Friedman(1996)] Friedman, B., 1996: Value-sensitive design. *Interactions*, **3**(6), 16–23.

[Friedman and Kahn(2003)] Friedman, B. and J. P. H. Kahn, 2003: Human values, ethics, and design. in J. A. Jacko and A. Sears, editors, *The human-computer interaction handbook: fundamentals, evolving technologies and emerging applications*, pp. 1177–1201. L. Erlbaum Associates Inc.

[Greenfield(2006)] Greenfield, A., 2006: *Everyware: The Dawning Age of Ubiquitous Computing*. New Riders Publishing, 1st edition.

[Hallns and Redstrm(2002)] Hallns, L. and J. Redstrm, 2002: From use to presence: on the expressions and aesthetics of everyday computational things. *ACM Trans. Comput.-Hum. Interact.*, **9**(2), 106–124.

[Harper et al.(2008)] Harper, R., T. Rodden, Y. Rogers and A. Sellen, 2008: *Being Human: Human Computer Interaction in 2020*. Microsoft Research Ltd.

[ISTAG(2001)] ISTAG, 2001: Scenarios for ambient intelligence in 2010. Tech. rep., EC.

[ISTAG(2003)] ISTAG, 2003: Ambient intelligence: from vision to reality.

[Kazman and Chen(2009)] Kazman, R. and H. Chen, 2009: The metropolis model a new logic for development of crowdsourced systems. *Commun. ACM*, **52**(7), 76–84.

[Leahu et al.(2008)] Leahu, L., P. Sengers and M. Mateas, 2008: Interactionist AI and the promise of ubicomp, or, how to put your box in the world without putting the world in your box. in *Proceedings of the 10th international conference on Ubiquitous computing*, pp. 134–143, Seoul, Korea. ACM.

[Lindblom and Ziemke(2002)] Lindblom, J. and T. Ziemke, 2002: Social situatedness: Vygotsky and beyond. in *2nd Int. Workshop on Epigenetic Robotics: Modeling Cognitive Development in Robotic Systems*, p. 7178, Edinburgh, Scotland.

[Pfeifer and Scheier(1999)] Pfeifer, R. and C. Scheier, 1999: *Understanding Intelligence*. MIT Press.

[Punie(2005)] Punie, Y., 2005: The future of ambient intelligence in europe : The need for more everyday life. in *Media, Technology and Everyday Life in Europe: From Information to Communication*, pp. 141–165. Ashgate, roger silverstone edition.

[Rogers(2006)] Rogers, Y., 2006: Moving on from weiser's vision of of calm computing: engaging UbiComp experiences. in *Ubicomp 2006*, Vol. LNCS 4206, pp. 404–421, Orange County, California, USA. Springer-Verlag.

[Rudstrom et al.(2005)] Rudstrom, A., K. Hook and M. Svensson, 2005: Social positioning: Designing the seams between social, physical and digital space. in *Proceedings of 1st International Conference on Online Communities and Social Computing, at HCII 2005*. Lawrence Erlbaum, Las Vegas, NV.

[Sengers and Gaver(2006)] Sengers, P. and B. Gaver, 2006: Staying open to interpretation: engaging multiple meanings in design and evaluation. in *Proceedings of the 6th conference on Designing Interactive systems*, pp. 99–108, University Park, PA, USA. ACM.

[Suchman(1987)] Suchman, L. A., 1987: *Plans and situated actions: the problem of human-machine communication*. Cambridge University Press.

[Taylor et al.(2007)] Taylor, A. S., R. Harper, S. Laurel, I. Shahram, S. Abigail and M. Perry, 2007: Homes that make us smart. *Personal and Ubiquitous Computing*, **11**(5), 383–393.

[Thackara(2005)] Thackara, J., 2005: *In the Bubble: Designing in a Complex World*. The MIT Press.

[UN(2009)] UN, 2009: Millennium development goals. http://www.undp.org/mdg/.