Living in a Smart Environment – Implications for the Coming Ubiquitous Information Society*

Marc Langheinrich, Vlad Coroamă, Jürgen Bohn, Friedemann Mattern
Institute for Pervasive Computing
ETH Zurich
8092 Zurich, Switzerland
{langhein,coroama,bohn,mattern}@inf.ethz.ch

Abstract - *A good instrument for understanding the possible blessings and perils of new technology in general and ubiquitous computing in particular is the development and analysis of scenarios of the future. This paper presents some of the consequences implied by several such scenarios that have been developed in the interdisciplinary research project "Living in a Smart Environment – Implications of Ubiquitous Computing". To show how manifold and far-reaching such consequences might be, the paper emphasizes three particularly relevant implications. First, it discusses some of the deep economic paradigm shifts that could arise from a large-scale deployment of ubiquitous computing technologies. Second, it presents some thoughts on the impact smart environments might have on privacy. Last, it investigates issues of social compatibility and dependability of future ubiquitous computing applications, considering both impending pitfalls and emerging opportunities.*

Keywords: Ubiquitous computing, social implications, scenarios of the future, new economic paradigms, dependability, privacy.

1 Introduction

In the influential article "The Computer for the 21st Century" [29], Mark Weiser created a vision of omnipresent computers that would serve people in their everyday lives at home and work, functioning invisibly and unobtrusively in the background and freeing them from tedious routine tasks. While Weiser's basic principles – augmenting everyday artifacts with computation, sensing, and communication abilities; and using context to anticipate the user's goals and intentions – have been the subject of much research in the past years [14], the implications of comprehensively deploying such technology in society are much less understood. With its orientation towards the public as well as the private, the personal as well as the commercial, ubiquitous computing aspires to create technology that will accompany us throughout our whole lives, day in and day out. While developments in information technology never had the explicit goal of changing society, but rather did so as a side effect, the visions associated with ubiquitous computing expressly propose to transform the world and our society by fully computerizing it.

Yet as more and more research projects find their way out of the lab and get deployed in real-world settings (both in public prototype and in the consumer market, such as location systems or electronic handheld devices), the field of ubiquitous computing has, over the last few years, begun to enter the conscience of a large part of the general public. Recent discussions about consumer privacy with respect to the commercial use of RFID tags have shown that the public gradually realizes that this ongoing development may have a long-term impact on everyday life, with far-reaching consequences for society's ethical values.

This paper reports on some of the results of an interdisciplinary research project called "Living in a Smart Environment – Implications of Ubiquitous Computing" [15], which aimed at envisioning the social consequences of

* This contribution is based on earlier articles of the authors, see references [5] and [8].

ubiquitous computing through the development (and partial implementation) of a set of prototypical scenarios. These scenarios were used by participating researchers, such as computer scientists, engineers, sociologists, legal experts, economists, psychologists, and philosophers, to analyze and assess the social implications of a "u-society." By putting their various perspectives together, the project aimed at providing some of the answers expected by the scientific community and society in general: What are the areas that are likely to be affected by the large-scale deployment of ubiquitous computing technologies – in positive as well as negative ways? And what could be the long-term consequences? Out of this analysis, what conclusions for a socially sustainable technology can be drawn – so that positive developments are encouraged and those with large negative impacts are avoided? What could politics do to shape such a development?

In the remainder of this paper, we sketch the future scenarios developed in our project and briefly mention the consequences implied by these. To show how far-reaching such consequences might be, we present three particularly relevant implications – the deep economic paradigm shifts that could arise from a large-scale deployment of ubiquitous computing technologies, the potential privacy issues associated with it, and the general social compatibility and dependability of future applications based on these technologies.

2 Ubiquitous computing scenarios

Scenarios are a well-suited instrument to analyze future implications of technology for a number of reasons. First, several different technology trends may be extrapolated and combined into a single scenario to analyze the bundled effects that these technologies could induce. This is particularly interesting for the field of ubiquitous computing, which does not form a single technology, but a combination of many technologies. Second, in a scenario the different actors (e.g., producers, supermarket owners, and consumers in a shopping scenario) can be analyzed together with their specific interests, so that a picture of future conflicts of interests can be drawn. Another advantage of scenarios is that they allow an interdisciplinary analysis: Once the technically possible range is set, different approaches and various viewpoints can be applied. For example, by looking at all the steps where data is being collected, a privacy expert can analyze the privacy threats of the systems implied in the scenario and provide design guidelines for them. A sociologist may analyze the same scenario from an inter-human interaction point of view, etc.

The scenarios developed within our project have been published in a separate project report [9]. Several areas have been depicted in these scenarios, in an attempt to cover different typical life situations, but also to show some new applications enabled through the use of ubiquitous computing technology: The daily shopping in the supermarket, a meeting in an office including the journey of external meeting attendants, and the analysis of public as well as private transportation constitute daily life situations covered by the scenarios. The logistics of medical equipment in a hospital and a vastly enhanced everyday support for the blind are two new application areas of ubiquitous computing technologies that have been investigated.

The scenarios have been analyzed from the specific perspective of the participating experts, identifying potential societal consequences. After several intense discussions, 14 of the most relevant consequences have been collected and presented in [9]. They include socio-technical acceptance aspects (loss of control, dependency on systems, usability and manageability), economic issues (economical interests involved herein, new economic paradigms), social compatibility questions (fairness, digital divide, universal access to information, information reliability), privacy questions, as well as more general problems with the deployment of ubiquitous computing systems (ontologies, providing user feedback).

This collection of possible consequences was intended as a starting point for further investigations of the scenarios. Three of the main topics are presented in more detail in the following sections of this paper.

3 New economic paradigms

Many companies today already employ ubiquitous computing technology in the form of navigation and tracking systems that allow them to have up-to-date information about the condition of their assets and the deliveries from their suppliers, enabling them to immediately react to exceptional situations [27]. This trend towards a *ubiquitous information society* – the availability of information anywhere, anytime, and about anything – might not only make today's businesses more efficient, reliable, and customer-friendly, but could also stimulate the transformation of existing business processes and the emergence of entirely new business models. Two of such possible developments would be dynamic pricing and real-time insurance policies.

3.1 Dynamic pricing

The shopping scenario developed in [9] is a rather extreme example of new business models in the ubiquitous information society: In a future supermarket, all products are equipped with sensing, computing, and communication capabilities. These smart products are not only aware of their own state (e.g., fabrication date, temperature), they have also knowledge about other products in the vicinity and about relevant ambient conditions (e.g., the outside weather). In such a store, every product has its own price that changes according to a number of parameters. Products with an earlier expiration date, for example, will lower their price to encourage customers to buy them instead of other, more recently produced ones. When the outside temperature rises, soft drinks and ice cream could increase their prices according to an expected increase of demand. Regular customers may receive preferential prices when products "recognize" them.

Milk bottles that continuously vary their price may not be the most realistic example of *dynamic pricing*, neither from a feasibility aspect nor from the customer acceptance point of view. The scenario merely shows the degree of power that augmented products may achieve in a ubiquitous information environment. For other goods, however, highly dynamic prices may make much more sense. Such goods would exhibit three characteristics: First, they would be expensive enough so that the deployment of the necessary ubiquitous computing infrastructure would not increase their price significantly. Second, both sellers and buyers should benefit, i.e., at least a large enough fraction of the consumers representing a sizable market share should gain from such augmented products. Third, charging differently for the good should not be uncommon – the stronger and more noticeable a price discrimination is, the less it runs the risk of being perceived as a hidden surcharges levied upon unsuspecting consumers.

3.2 Real-time insurance premiums

Insurances are high-valued goods that seem to fulfill the above-mentioned criteria. Customers are already used to personalized and periodically changing insurance premiums – they often vary between each insured customer and typically change over time. Furthermore, as our discussion below will show, dynamic insurance policies based on ubiquitous computing technology have the potential to generate significant savings for the consumers, thus possibly prompting a large enough market share to convert from traditional, fixed-rate insurance policies.

Insurers nowadays have only limited information about their insured goods or customers. They typically split the insured assets into classes, based on only a few criteria collected before the risk coverage starts [21]. Car insurance premiums, for instance, usually depend only on the type of the insured car, the driver's experience, and maybe the type of location it is usually parked, even though the real risk of having a traffic accident depends on a large range of additional factors: such as the driven mileage, traffic and weather conditions, when and where the car has actually been driven or parked. Consequently, drivers with a lower damage risk (i.e., those who drive less, during better weather and traffic conditions, or maybe slower) pay more than they should for their actual risk, while higher-risk drivers pay less than their driving style would warrant. Such cross-financing from lower to higher risks takes place in numerous other insurance branches, where the insurer lacks information about the behavior of its insures, e.g., in transport insurances (how does the carrier handle and store the shipped goods?), or in health insurances (where nonsmokers usually pay the same rate as smokers).[1]

By providing the insurer with more diverse, exact, and up-to-date information about the insured assets, a much more accurate insurance rate could be calculated for each individual risk. This process of diversification would ultimately result in highly individualized insurance classes, each encompassing exactly one insured asset or customer. Given the substantial savings possible with such individual insurance premiums, many of today's overpaying low-risk customers might very well welcome a significantly reduced rate, even at the expense of their privacy and in spite of other threats implied by such omniscient insurers [10]. Insurers on the other hand would be able to gain market shares in the attractive segment of low-risk customers by being able to offer them much lower premiums. As low-risk customer change to the dynamic model, those sticking with the flat fee model would need to pay a higher premium, as the overall risk of the remaining class would consequently rise, prompting in turn even more drivers to change to the dynamic models.

Especially in the area of car insurance, a number of studies and pilot projects have recently begun exploring the options today's technology offers in terms of calculating such dynamic rates. Proposals suggest that car insurances should be distance-dependent [17], or account for various other aspects [10][21]. This would not only be more accurate, but would also give incentives towards less driving, which potentially could increase traffic safety and might have additional positive environmental consequences [17]. The same infrastructure would also allow governments to charge a "pay-per-use"-based road tax – a distance- and time-dependent congestion charge does seem a sensible alternative to today's jammed city centers.

3.3 Generalized pay-per-use

The concept of pay-per-use could potentially be taken much further, eventually reducing the number of long-term contracts in our life significantly (such as insurances, utilities, etc.) by allowing companies to individually offer and bill minute services. Similar to today's telephony market, where consumers are increasingly able to choose from a wide range of telecommunications providers for each individual call, a model that we call *day-by-day insurance* could allow customers to change their insurance on a regular, maybe even daily basis. For example, different risk estimation strategies could lead one car-insurer to offer the best rate on weekends, while another would have the best price per kilometer on highways, or when driving at night in rainy conditions. As with telephony least-cost-routers, the car could autonomously choose the most favorable insurer for that day – for example, after the driver entered the destination in the car's navigation system.

With ubiquitous information, pay-per-use could be generalized to virtually any transaction and to an almost arbitrary degree of refinement [13]. Accenture Technology Labs, for instance, presented a prototype of a chair that monitors its usage and creates a monthly billing statement [1]. While seemingly impractical for private homes, such a business model could very well appeal to restaurants or hotels that periodically refurbish and thus would prefer a leasing model to an ownership one.

Such ideas, however, raise various concerns. If consumers were to accept so far-reaching pay-per-use schemes and the monitoring of their personal habits implied by these, this would not only threaten their privacy. It would also give companies a permanent channel to their customers, enabling them to exercise control over the use of their products and services. Furthermore, it is not clear whether the trend towards more and more pay-per-use models does necessarily lead to more fairness throughout the society. Pay-per-use does indeed guarantee that costs are associated more precisely with their originators. Often, however, this is politically unintended or societally undesirable, and flat payments are rather perceived as being fair. An example can be found in public health

[1] This is known as the *information asymmetry* problem, a term that has been coined by George Akerlof in his article "The market for lemons" [2], for which he received the Nobel Prize in Economics in 2001.

insurances in Europe. In several countries (e.g., Germany), the health insurance premiums do not depend on the risk factors of the insured persons, but on their incomes. The health insurance premiums are thus also a way of social cross-financing with the goal of offering sufficient medical standards to the entire society. This model of societal fairness is widely accepted, even by many of those who pay more than they would if the premiums were risk-based. On an individual level, people also sometimes wish not to be charged continuously, but pay once and then use a service for a certain period of time. In many restaurants the morning buffet is not "pay-per-use", but "flat". Skiing resorts could easily charge skiers per-use, yet virtually all of them use a flat model. People seem to prefer the freedom that flat rates buy them over having to reflect every time they board a ski lift whether the descent is going to be worth the price.

Nevertheless, pay-per-use can be a feasible and for some domains desirable model. Since people tend to restrain their consumption when being continuously reminded of the price they pay, this model could also become a valuable political tool for steering developments (e.g., reducing the traffic through a mileage- and time-based tax). While such schemes could not be deployed on a large scale in the past because of lack of information, we are likely to witness the spreading of pay-per-use business and economic models in the upcoming ubiquitous information society.

4 Privacy implications of smart environments

By virtue of its very definitions, the vision of ubiquitous computing has the potential to create an invisible and comprehensive surveillance network, covering an unprecedented share of our public and private life: "The old sayings that 'the walls have ears' and 'if these walls could talk' have become the disturbing reality. The world is filled with all-knowing, all-reporting things" [18]. And with the economic possibilities described above, such a comprehensive coverage seems more likely to be put into place: Today's economic reality – shopping without participating in comprehensive profiling, buying instead of renting items in a pay-per-use scheme, as well as fixed insurance schemes that do not constantly transmit information to insurers – all of this might become an expensive luxury for well-off citizens, while the population at large would trade in their privacy for increased productivity and market transparency. This might very well be self-inflicted: given the immediate economic returns of consumer loyalty programs or low insurance rates, the rather vague threats of future privacy violations are easily enough ignored.

4.1 Facets of privacy

Even though critics continue to argue that "all this secrecy is making life harder, more expensive, dangerous, and less serendipitous" [6], privacy is still predominantly seen as a fundamental requirement of any modern democracy [26]. It is only when people are free to decide what to do with their lives, according to their interests and beliefs, and without fear of repression from their fellow citizens, that the necessary plurality of ideas and attitudes can develop that will prevent society being subjugated under a charismatic leader. Harvard law professor Lawrence Lessig [16] takes this requirement a step further and distinguishes between a number of motives for the protection of privacy in today's laws and standards:

- *Privacy as Empowerment*. Seeing privacy mainly as informational privacy, its aim is to give people the power to control the publication and distribution of information about themselves [30]. A recent legal discussion surrounding this motivation revolved around the question of whether personal information should be seen as private property (which would entail the right to sell all or part of it as the owner sees fit) or as intellectual property (which would entitle the owner to certain inalienable rights, preventing him for example from selling the rights to his own name to anybody else).

- *Privacy as Utility*. From the viewpoint of the person involved, privacy can be seen as a utility providing more or less effective protection against nuisances such as unsolicited phone calls or emails. This view probably best follows Brandeis' definition of privacy as "The right to be left alone," where the focus is on minimizing the amount of disturbance for the individual [28].

- *Privacy as Dignity*. Dignity not only entails being free from unsubstantiated suspicion (for example being the target of a wire tap, where the intrusion is usually not directly perceived as a disturbance), but also focuses on the equilibrium of information available between two people: as in a situation where you are having a conversation with a fully dressed person when you yourself are naked, any relationship where there is a significant information imbalance will make it much more difficult for those with less information about the other to keep their composure.

- *Privacy as a Regulating Agent*. Privacy laws and moral norms to that extent can also be seen as a tool for keeping checks and balances on the powers of a decision-making elite. By limiting information gathering of a certain type, crimes or moral norms pertaining to that type of information cannot be effectively controlled.

Depending on what kind of motives one assumes for preserving privacy, ubiquitous-computing technology can become the driving factor for changing the scope and impact of privacy protection as it exists today, and creating substantially different social landscapes in the future. This is because ubiquitous computing technology influences two important design parameters relating to privacy: the ability to monitor and the ability to search [16].

4.2 Ubiquitous computing and surveillance

The conscious observation of the actions and habits of our fellow men is as old as mankind itself. However, observations using automated systems differ from our nosy neighbors in one important aspect: while in the "good old days", anything out of the ordinary would attract the attention of our fellow citizens, it is now the ordinary, the everyday routine, that can be (and often is) the sole focus of tireless computerized monitoring. With ubiquitous-computing technologies, today's monitoring capabilities can obviously be extended far beyond credit-card records, call logs, and news postings. Not only will the spatial scope of such monitoring activities be significantly extended in ubiquitous-computing landscapes, but their temporal coverage will also greatly increase: starting from pre-natal diagnostics data stored on babies' hospital smart cards, to activity patterns in kindergarten and schools, to workplace monitoring and senior citizen's health monitoring.

Such comprehensive monitoring (or surveillance) techniques create new opportunities for what MIT professor emeritus Gary T. Marx calls border crossings: "Central to our acceptance or sense of outrage with respect to surveillance ... are the implications for crossing personal borders" [20]. He goes on to define four such border crossings that form the basis for perceived privacy violation:

- *Natural Borders*. Physical borders of observability, such as walls and doors, clothing, darkness, and also sealed letters and phone conversations. Even facial expressions can represent a natural border against the true feelings of a person.

- *Social Borders*. Expectations with regard to confidentiality in certain social groups, such as family members, doctors, and lawyers. This also includes the expectation that your colleagues do not read personal fax messages addressed to you, or material that you leave lying around the photocopier.

- *Spatial or Temporal Borders*. The expectation by people that parts of their lives can exist in isolation from other parts, both temporally and spatially. For example, a previous wild adolescent phase should not have a lasting influence on the current life of a father of four, nor should an evening with friends in a bar influence his coexistence with work colleagues.

- *Borders due to Ephemeral or Transitory Effects*. This describes what is best known as a “fleeting moment,” a spontaneous utterance or action that we hope will soon be forgotten or old pictures and letters that we put out in our trash. Seeing audio or video recordings of such events subsequently, or observing someone sifting through our trash, would violate our expectations of being able to have information simply pass away unnoticed or forgotten.

Putting ubiquitous-computing systems into place will most certainly allow far greater possibilities for such border crossings in our daily routines. Consider the popular vision of a wearable “memory amplifier” [24], allowing its wearer to constantly record the events of her daily life in a lifetime multimedia diary. While at first sight such technology promises assistance to those of us who frequently tend to forget small details, it also has substantial consequences for our privacy borders stemming from ephemeral and transitory effects: any statement I make during a private conversation could potentially be played back if my conversation partner gave others access to her multimedia diary. Even if this information were never disclosed to others, the very thought of dealing with people who have a perfect memory (and thus would never forget anything) would probably have a considerable effect on our interpersonal relationships.

The problem of spatial and temporal borders, on the other hand, is well known from the field of consumer profiles. Although such profiles are often the subject of public debate, the social and legal attitudes towards them have, until now, been relatively relaxed. Consumer acceptance is also much higher than the frequent negative news coverage might indicate, mostly because their negative consequences are often perceived as being rather minor (such as unsolicited spam) compared to their advantages (e.g., monetary incentives in the form of discounts or rewards). However, there are well-known risks associated with profiles, and their adoption as the basis for ubiquitous computing would only exacerbate such problems. Besides the obvious risk of accidental leaks of information [23], profiles also threaten universal equality, a concept central to many constitutions, basic laws, and human rights, where “all men are created equal”. Even though an extensively customized ubiquitous-computing future holds great promise, since it provides me only with the information that is relevant to my profile, it could at the same time constitute a severe violation of privacy, as large amounts of information might be deliberately withheld from me because I am not considered a valued recipient of such information.

Applying ubiquitous-computing technology in areas with primarily social borders – for example where a close social group interacts only among itself, such as families [22] or co-workers – might appear to alleviate some of the above concerns. Most participants would already share close relationships and tend to know a great deal about each other, without needing a system to compile a profile of their communication partner. Such systems, however, also raise the ante as to what type of information they handle. While a communication whiteboard for families may facilitate social bonding between physically and temporally separated members, it would also increase the risk of unwanted social border crossings by accidentally allowing Mum to read a message you left for your sister, or a visiting friend to be recorded in the house activity log even though you told grandma you would spend the weekend alone.

Natural borders, then, might be the easiest to respect when designing ubiquitous-computing systems. Here, the concept of surveillance is well known and usually fairly straightforward to spot, after all: if others are able to watch your actions behind closed doors, they are most certainly intruding on your privacy. Proponents of wearable computing systems often cite the fact that information could both be gathered and stored locally (i.e., on the user’s belt, or within her shirt) as a turnkey solution for privacy-conscious technologists [24]. Border crossings, however, are not only about who does something, but also what is happening. Even though a context-aware wearable system might keep its data to itself, its array of sensors nevertheless probe deep into our personal life, and the things they might find there could easily startle (and trouble) us, once such systems start anticipating our future actions and reactions. The feeling of having someone (or something) constantly looking over our shoulder and second-guessing us would certainly constitute a natural border crossing for most of us.

And the temptation of law enforcement subpoenaing such information not only to determine your physical data (were you at the crime scene?) but also to guess your intentions (by assessing the data feed from our body sensors) would certainly motivate legislation that would make the deletion of such information a crime, just as recent legislation against cybercrime [11] does for computer log files.

4.3 Searching and combining bits of information

All these examples serve to show that ubiquitous-computing environments, even when created for the greater good and with the best of intentions, will run a high risk of involuntarily threatening the personal borders that separate our private and public lives, simply because their monitoring capabilities will facilitate more of the border crossings described above. However, whether such crossings ultimately occur, given the opportunities created, will depend very much on the type of searching capabilities such ubiquitous-computing systems might offer.

Search technology is traditionally a topic in the fields of information retrieval or databases, rather than that of ubiquitous computing. However, the chances are high that such technology will be a basic building block of future ubiquitous-computing environments, as many of the envisioned applications in the field require precisely these capabilities. An automated diary collecting 24/7 audio and video data would not be much use unless it was combined with powerful search and retrieval technology that allowed us to comb large amounts of data for very specific information. And the ability to combine different information sources, especially large, innocuous ones such as walking patterns or eating habits, is the backbone of any “smart” system, which must make the best use of a large variety of different sensor input to take decisions that make it appear to understand what is happening around us.

Having thus both monitoring and search capabilities at the very core of their architecture, ubiquitous computing systems will very likely provide their developers, owners, and regulators with a significant tool for driving the future development of privacy concepts within society. Depending on the actual systems deployed, some of the motivating aspects of privacy as discussed above might become more or less prominent, thus influencing corresponding legal and social norms. However, as important as privacy is, it is merely the tip of the iceberg that constitutes the social implications of ubiquitous computing. In the following section we want to explore a bit more of the edges that lurk just below the waterline, where they seem to be of no immediate threat but where they could potentially become much more dangerous as the deployment of ubiquitous computing picks up speed.

5 Dependability and social compatibility

Life without computers is unimaginable for most of us today – embedded processors monitor the condition of high-risk patients around the clock, they control central heating in buildings, air conditioning in tunnels, and they safely guide airplanes between continents. The potential economic benefits of ubiquitous computing are certainly key factors for the further proliferation of information technology, such as novel indoor and outdoor positioning systems, ubiquitous communication platforms, and unobtrusive monitoring installations. However, with many of these early ubiquitous computing systems, we are still able to decide for ourselves whether we want to participate and live in such smart environments. But in a largely computerized future it might no longer be possible to escape from this sort of technologically induced dependence, which leads to a number of fundamental social challenges.

It is important to note that the augmentation of everyday objects with sensing, computing, and communication capabilities per se has a priori no negative implications. Augmented real world objects can contribute to the realization of novel services and applications which can be to the benefit of the individual and the society as a whole. An individual person, for instance, may consider the provisioning of context-dependent information while moving through smart environments (such as tour guides, navigation systems, or virtual collaborative work spaces) convenient and helpful. Furthermore, everyday environments augmented by ubiquitous computing technology can also provide means to alleviate the difficulties and disadvantages of marginal groups who find themselves at the fringe of society. A number of projects target elderly and physically disabled people, for example with electronic "memory aids," reading aids, and navigation systems [19], which enable such persons who are often neglected as marginal groups to participate more actively and autonomously in everyday life. A concrete example is the Chatty Environment [7] – a context-aware application which helps visually impaired people to orient themselves in new, unknown environments, thereby enabling them to lead a more independent life. Furthermore, the digital augmentation of real-world objects can help to compensate for deficiencies of cognitively challenged people. A smart jigsaw puzzle, for example, may not only help children or people with cognitive deficiencies to solve complex puzzles, letting them partake in the experience and feeling of achievement, but it also facilitates to match the capabilities of unbalanced players by providing aids to the "weaker" players [4].

More generally, intelligent interfaces and the concept of ubiquitous information access are often seen as key developments for bridging the digital divide, where different sections of the population have different abilities to participate in the information society. However, having more information opportunities does not necessarily mean more justice or freedom, simply because the potential dependencies and opportunities for manipulation would be so numerous they could overwhelm individuals, making it even more difficult to assess the trustworthiness of the information's source [5]. Information that is uncritical or sponsored by advertisers (and therefore one-sided) could become available free of charge, while independent, high-quality information would cost money, thus widening the digital divide even further. Since ubiquitous computing is not just about information itself, but is inherently linked to real-world objects, these new means of access and content control could easily lead to the digital divide becoming a real and perceivable rift in our everyday lives.

An augmentation of real-world artifacts with information processing and communication capabilities should thus not become an end in itself. Instead, the expected benefits must, from the beginning, be weighed against potential negative side-effects. It might even be advisable to deliberately stop the augmentation process at some point before the original fundamental qualities and characteristics of the augmented physical object are threatened to be lost. This not only preserves knowledge sustainability (it used to work this way and it still does), but also allows the user to deliberately opt-out and revert to the classical unaugmented utilization of the object. Another advantage of such a "soft" augmentation is that the usability of the augmented object is still sustained even in case of a technical failure of the augmented functionality. If, however, the inherent qualities and functionality of the original object are irrevocably changed, the usability of the augmented object depends on the availability and proper functioning of the technologies used in the augmentation process.

Either way, the application of ubiquitous computing technologies for the augmentation of physical objects and for the realization of ubiquitous information environments is very likely to induce new societal and technological dependencies. In particular, as the number of smart devices and interacting objects in our environment increases, the technical *dependability* of the thus provisioned services becomes an important issue. Traditionally, a user explicitly works with dedicated computer equipment which often consists of reliable quality components. With the expected coming of the ubiquitous information society, however, users find themselves suddenly acting right in the middle of a computerized smart environment. They have to cope with being caught in a crossfire of mass-produced smart artifacts and spontaneously interacting objects, each of which is prone to malfunctions due to technical defects or depleted batteries, for example.

This raises the question whether technical solutions to counter these difficulties exist, for example physical redundancy. However, as incorporating computing and communication technology into everyday artifacts requires small form factors and minimal energy consumption, it is often impracticable to employ hardware redundancy on the single devices to increase the fault-tolerance and robustness of smart object infrastructures, which further aggravates the situation.

An answer to these challenges may be found in alternative, more user-centered concepts and mechanisms in order to overcome service interruptions and device failures, such as an explicit diversification of system functions, for instance. Such a *diversification* can be achieved by providing fully independent ways of carrying out the same task, preferably based on separate sets of system resources wherever feasible. By having different types of devices, platforms, or communication means for achieving a certain goal, the available redundancy stemming from the heterogeneity of the surrounding smart object infrastructure can be exploited for achieving a *horizontal* diversification [25]. Further, as a cheap individual device may be prone to technical defects and malfunctions, a solution may lie in dramatically increasing the availability of a certain type of device, for example by providing it in large, abundant quantities. As a consequence, it is feasible to make the transition from requiring the availability and accessibility of one particular device to being in a position to use any device of a certain type at hand, which can be described as a *vertical* diversification [3]. This ensures that one can exactly use the kind of tool which is most suitable in a certain situation or for a certain task, instead of reverting to a different, potentially less suitable tool as it has to be done in the case of horizontal diversification.

6 Conclusions

Ubiquitous computing as an enabling technology for smart environments could have far-reaching consequences for society. While the smart laundry machine that queries our dirty clothes for washing instructions will not drastically alter the social fabric of our lives, other applications might very well do: What if parents will never lose track of their children because location sensors and communications modules are sewn into their clothes? How much control will producers of smart goods have over their customers subscribing to their pay-per-use business models? Will people feel constantly under surveillance by all the smart objects and wireless sensors that surround them, or will they forget about them and live their lives unchanged? Will this make the world a safer place, or will criminals find a way to use all this information to their advantage? And if artifacts become more and more autonomous and make human intervention and control unnecessary: who is responsible if something goes wrong?

Obviously, there are more questions than answers. But by speculating about the possible consequences of this technology and evaluating it within the framework of established concepts from fields such as sociology or economics, we might be able to see the warning signs just early enough to give society and policy makers enough information to steer the deployment of ubiquitous computing in ways compatible with society. The careful analysis of well-thought scenarios is a promising approach in that respect, helping us to steer the development of smart environments and the underlying ubiquitous computing systems in a direction that has more in common with Weiser's optimistic vision of the 21st century [29] than with the depressing mix of consumer terror and police state conjured up by some popular science fiction movies [12].

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