Ubiquitous Computing: Scenarios for an informatized world[1]

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Summary

Over the last 30 years, we have seen the power of microprocessors double about every 18 months. An equally rapid increase applies to some other technological parameters such as storage capacity and communications bandwidth. This continuing trend means that computers will become considerably smaller, cheaper, and more abundant – they are becoming ubiquitous, and are even finding their way into everyday objects. This is resulting in the creation of "smart" things that can access the Internet and its varied resources in order to optimize their intended purpose, and maybe even cooperate with each other.

Mobile phones are a forerunner in this technological field – they are now fully functioning computers equipped with a whole range of additional functionality such as localization technology, Internet connectivity, and voice recognition. They may well develop into control centers for a multitude of other personal auxiliary services, whilst at the same time splitting into individual functional components that can be worn as intercommunicating accessories.

In the medium to long term, ubiquitous computing will take on great economic significance. Industrial products (such as ready-to-serve meals, medication, articles of clothing, and toys) will become "smart" due to their integrated information processing capacity, or take on an electronic identity that can be remotely queried, or be equipped with sensors for detecting their environment (so that they would know, for example, where they were), enabling innovative products and totally new services to be developed.

However, an "informatized" world full of objects that can detect aspects of their environment and communicate with each other also has serious implications for privacy. Just as crucial is the question of who can or should decide to what information these electronically enhanced objects (which would, as a result, become electronic media) should have access. The social and political challenges of the ubiquitous computing era will be characterized by an increasing dependence on technology, control over the information to which everyday objects are linked, and the protection of privacy.

1. From Internet mobile phones to wearable computers

The effects of rapid progress in microelectronics, the convergence of communications and information technology, and the trend towards computerizing and networking everyday objects can best be demonstrated using the example of mobile phones. A few years ago, mobile phones were still so big, expensive, and limited in their functionality that they didn't sell very well and were often used more as a status symbol than a practical tool. This has changed very rapidly (Figure 1). In Europe, there are now more mobile phone users than car drivers. Many users have grown so accustomed to

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[1] This article is based on a study "From mobile phone to ubiquitous computer," which the author wrote by request of the Friedrich Ebert Foundation (used here by kind approval of the Friedrich Ebert Foundation). Some sections have previously been published in [12], and some passages of text in this article have been taken from earlier publications by the author [4 ,8, 9, 10, 11]. The author wishes to thank his colleague Elgar Fleisch for his comments on the commercial application of ubiquitous computing technology.

them and adapted their professional or even private lives to them that they can't imagine life without this technology.

Parallel to this development, within a short period of time the mobile phone has become a device that offers more than just the pure functionality of voice transmission. It has developed into a piece of equipment for which the German expression “Handy” is much more appropriate – not only has it become smaller, but it has also acquired new “handy” functions. The SMS short messaging system has become a completely unexpected success, especially with young people. Specifically for this target group, colored displays which permit the use of more attractive computer games as well as the viewing of forwarded photos and video clips, are now being integrated into the most up-to-date generation of mobile phones. The same applies to MP3 players, which offer high-quality music reproduction and could replace the classic “Walkman.”

Another additional function is connection to the Internet. In Europe this has been implemented using the WAP system, through which you can access Web sites from your mobile phone. However, this functionality has not been widely accepted in its current form, firstly because the transmission technology on which the system is based was not sufficiently well developed in 1999 / 2000 (for example, it wasn't “always on,” which meant long waits whilst connecting, making it awkward to use). Secondly, it is clear that the WAP system was not appropriately marketed. Expectations were too high, and consequently users were disappointed. The development of the i-mode system in Japan was a totally different experience – here, mobile commerce was not marketed as an application area as in Europe, but was intentionally targeted at twenty- to thirty-year-old women as a lifestyle feature. The term “Internet” does not appear in the advertising, the focus instead being on services for specific target groups (such as local events, horoscopes, weather forecasts, and even karaoke). Strict quality control, a clear pricing structure, and lots of free services as well as the ability to be “always on” without any explicit connection setup are further characteristics of the i-mode system, which is now beginning to gain ground in other countries, including Germany. Certainly in Japan it has been enormously successful – in the year 2001, it attracted more than ten thousand new customers a day.

Mobile phones are now fully functional computers with the capability to execute Java programs, even those they receive “wirelessly.” This opens up a whole new world of application possibilities. Even with the Japanese i-mode system, however, these mobile computers are not fully integrated into the Internet with all its services. They offer only highly limited functionality by accessing Web information via the conventional mobile telephony network. However, this may soon change, since prototypes of mobile “Internet appliances” already exist. Consequently, it will be possible to use a much broader range of services and options.

The functionality of mobile phones is currently expanding in different directions. One option, for example, is to add localization functionality – using radio direction finding and other positioning methods, mobile phones can already be localized to within a few hundred meters. By using satellite-supported GPS systems, localization can be as exact as about ten meters outside buildings. Providing mobile phones with an additional short-range radio interface (a range of about 10 meters can be covered with a thousandth of the usual transmission energy, as with the Bluetooth standard currently on the market) means that other personal devices belonging to the user can also profit from the communication and localization abilities of the mobile phone. The mobile phone implicitly becomes a personal base station and control center for a variety of other devices and “smart objects” nearby, which only have to be equipped with a simple, low-energy (and therefore very cheap and small) short-range communications module in order to be used for Internet services and other functions.

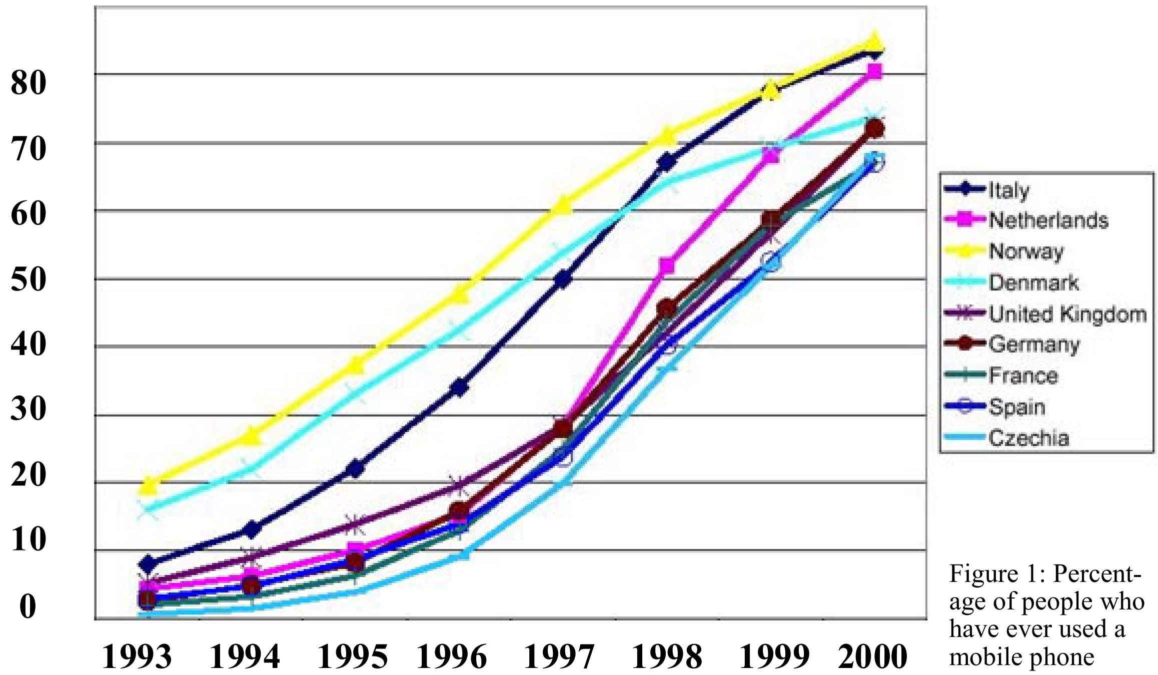

Figure 1: Percentage of people who have ever used a mobile phone

Another development is the so-called smart phone which, in addition to the usual mobile phone functionality, also takes on the role of a PDA ("Personal Digital Assistant"), with notepad and appointment scheduling functions, for example. Conversely, PDAs are taking on additional telephone functions. This can result in synergies – for example, the portable appointment scheduler can now be synchronized largely automatically with its counterpart in the office via mobile radio communications technology.

Integrating additional functions into mobile phones typically leads to an increase in size. This might be necessary because the display must be a minimum size, or because a means of input has to be provided. In contrast to this development is the trend towards the decomposition of the conventional mobile phone. You would only wear a light headset or "earpiece" (perhaps even as a piece of jewelry), with the microphone disappearing into a shirt button, both parts communicating wirelessly with the real mobile phone worn on a belt or in a wrist watch, which would also enable short messages and control functions to be displayed. Communications services, controls, displays, and additional functionality such as localization services, Internet access, and digital support can therefore be distributed across different personal "devices" (or rather, fashionable "accessories") that cooperate with each other. This might even go so far as having spectacles that look perfectly normal, but which display information over your normal view or even blend into it – which might some day enable the virtual red carpet, which the personal navigation system rolls out in front of your eyes to help you find your way in an unknown environment...

These aspects are often subsumed under the somewhat diffuse term "wearable computing." From a technical viewpoint, however, this is not about utopian cyborg visions where humans and computers merge into a single entity. The expectation is very simple – that the computer functionality and the devices that incorporate it should not only be "portable," but also, to a certain degree, become part of our clothing and be worn more or less directly on our bodies. An appropriate comparison might be between a "portable" pocket watch, which has to be taken out and opened up if needed, and a "wearable" wristwatch, which can be read at any time. Since its sensors are located close to the body, a wearable computer is also suitable for monitoring its user's health (and, if necessary, reporting values of vital functions via telemetry to a medical call center) or for reinforcing his sensory perception. In this respect, new qualities and functions are developing due to the proximity to the body which a normal mobile phone could never achieve.

The reason such ideas are only now partly being realized is quite simply because technology has not been sufficiently advanced until now. On the one hand, semiconductor technology has had to be developed so that complex functions could be integrated in a very small space, so that size, weight, and energy consumption were acceptable; on the other hand, it is only now that adequate communications technologies for use at very short range (for example "body area networks") are coming within reach. Last but not least, components such as miniature microphones and high-resolution small-format displays have not been available as low-cost mass-produced products until now. Since technical progress has slowly overcome these obstacles, we can soon expect to see such products.

Experiments are also being carried out on mobile phone voice recognition, which would simplify operation whilst driving, for example. In a broader sense, voice recognition always makes sense in situations where there is no room for controls – this would be the case with future devices that were "integrated" into clothing or worn as small fashion accessories. When it comes to highly restricted areas of conversation, voice recognition is already relatively good. In the future, higher processor speeds will also deliver sufficiently high recognition rates to enable other digital auxiliary functions (such as navigating in an unknown environment or querying timetables) to be used. We can also expect further increases in quality with the output of synthetic speech. It is a different story with functions that require the "comprehension" of spoken language within a context, such as language translation. Although research results are encouraging, this continues to be a tricky problem, where only slow progress can be expected.

Functions requiring a high computing capacity, large databases, or large storage volumes do not have to be implemented "locally" in the IT accessories themselves. For example, if a mobile phone or advanced digital auxiliary device is connected more or less permanently with sufficient speed to the Internet and its servers and services, the storage of data (photos or music, for example) or information processing (for example, automatic language translation) can also take place elsewhere "on the Net" where sufficient capacity, space, and energy are available. Only input and output data would have to be transferred wirelessly between mobile phones and background systems in order to give the user the illusion that his device was doing all this itself. Storing data on the Net also makes sense, so that if the small IT accessories were lost, the data would not be lost as well.

Which of these innovations will be first to arrive, and how successful it will be depends, of course, on a variety of circumstances and is not easy to predict. Technical factors (such as, for example, available bandwidth for wireless communications) and economic factors, but also primarily acceptability play an important role. From a technical viewpoint we can already estimate what at least appears to be feasible in the next few years by extrapolating Moore's Law (the doubling of processor power every 18 months and the associated reduction in size and decrease in costs for the same level of performance). What would appear to make sense from an economic viewpoint – for example, regarding the construction of an infrastructure or possible business models – is a far more complicated question to answer, as was recently demonstrated by some of the bizarre results of various UMTS frequency auctions. It is equally difficult to predict how personal information and communications technology will be accepted – satellite telephone systems turned out to be a failure (initially at least), whereas the short messaging system has been a totally unexpected success, given its scale. Whether innovations develop into something useful and acceptable for citizens can often only be decided with hindsight.

2. The trend towards computer technology that is both "invisible" and ubiquitous

Mobile phones with Internet connections, localization and voice recognition capabilities, or smart cards and PDAs that communicate with their environment via radio are the first indicators of the dawning of a "post-PC era," which is characterized by the virtually total networking of technical devices and everyday objects. This will be an era in which the computer no longer primarily appears in the form of a personal computer and which was once described by IBM Chairman Lou Gerstner as follows: "*A billion people interacting with a million e-businesses through a trillion interconnected intelligent devices.*"

What can we expect in this regard from this rapidly growing technical progress? It is becoming ever clearer that we are standing on the brink of a new era of computer applications that will radically influence our lives. In recent years PCs, the Internet, and the Web have already changed much, especially in business life. Today we are seeing indicators everywhere of a major convergence of entire industries in the fields of media, consumer electronics, telecommunications, and information technology. But the approaching wave of the technological revolution will affect us more directly, in all aspects of our lives – it is becoming apparent that our future will soon be full of tiny processors communicating spontaneously with each other, which will be integrated into the vast majority of everyday objects due to their small size and low price.

One reason for this is to be found in the long-term trend of microelectronics. Moore's Law [13], drawn up in the late 1960s by Gordon Moore, which states that the power of microprocessors doubles about every 18 months, has held true with astonishing accuracy and consistency. For the chip-producing industry, this has almost become a self-fulfilling prophecy, and they even produce their future-oriented "technology roadmaps" according to this law. A similarly high growth of efficiency can be observed for some other technology parameters such as energy requirements per computer instruction (Figure 2 shows the parameter MIPS/W for selected processors), storage density (Figure 3), and communications bandwidth. Conversely, prices for microelectronic functionality with the same amount of computing power are falling radically over time. Technology experts expect this trend to continue for many years to come, meaning that computer processors and storage components will become much more powerful, smaller, and cheaper.

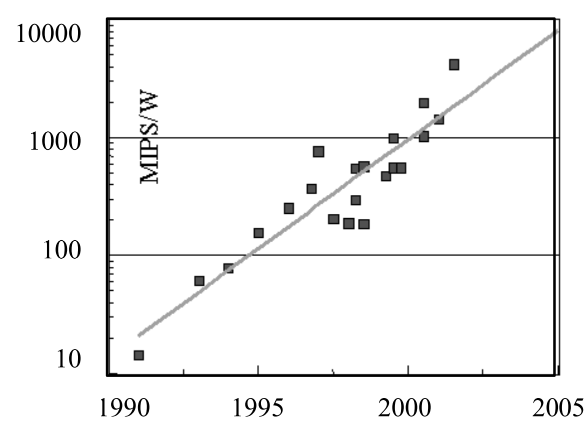

Figure 2

Recent developments in the field of materials science and solid-state physics could give computers of the future a completely different shape, or even mean that computers will no longer be recognizable as such because they will completely blend into their surroundings. One example in this context is light-emitting polymers ("illuminating plastic"), which enable displays consisting of highly flexible, thin and bendable plastic foils to be created – in the future, you might want to affix your Internet portal to the weather service as an adhesive film on your bedroom window instead of a thermometer or barometer. Laser projection from within spectacles directly onto the retina of the eye is another option currently being investigated as a replacement for traditional computer output media. Research is also taking place into "electronic ink" and "smart paper," which will enable pen and paper to become fully functional interactive and truly mobile input/output media, with a tried and tested user interface. Although there is still a lot of technical development work involved and a broad commercial application may be some years off, prototypes of electronic paper and ink already exist. If paper can be transformed into a computer or, conversely, computers into paper, the practical significance of such a development cannot be overestimated.

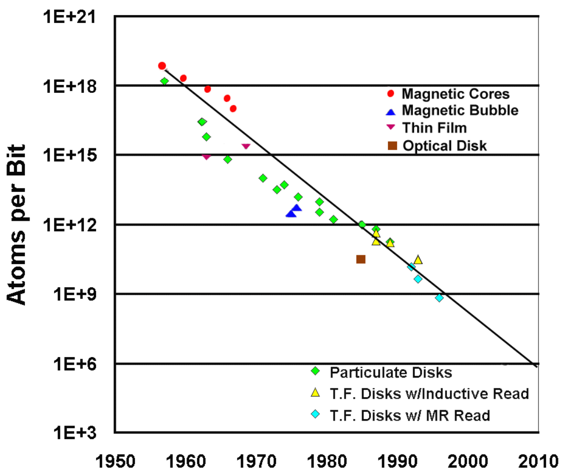

Figure 3

The results of microsystems technology and, increasingly, nanotechnology, are becoming more and more important. For example, they are producing tiny integral sensors that can record a wide variety of different environmental parameters. More recent sensors can not only react to light, acceleration, temperature etc., but also analyze gases and liquids or generally preprocess sensor input and therefore recognize certain patterns (for example fingerprints or facial forms). One interesting development in this regard is radio sensors that can report their measured data within a few meters distance without an explicit energy source – such sensors obtain the necessary energy from the environment (for example, by being irradiated with microwaves) or directly from the measuring process itself (e.g. temperature change or pressure).

Electronic labels also operate without a built-in source of power (so-called passive “smart labels” or RFIDs – “Radio Frequency Identification”). Depending on their construction, these are less than a square millimeter in area and thinner than a piece of paper [3]. In the form of flexible self-adhesive labels, they cost between €0.1 and €1 each, and therefore have the potential for replacing traditional barcodes for the identification of goods in certain areas. Their big advantages are that they do not have to be placed in the line of sight of the "reading device" (unlike the laser scanners currently used in supermarkets), that individual products rather than whole product groups can be differentiated, and that the electronic label can be used several times by recording different information on it. In certain ways this is a further development of the anti-theft technology involving security gates in department stores. However, this is not just about the binary information “paid/ stolen”; within milliseconds, several hundred bytes could be read and written “wirelessly” up to a distance of about two meters depending on the underlying technology.

What is interesting about such remote-inquiry electronic markers is that they enable objects to be clearly identified and recognized, and therefore linked in real time to an associated data record held on the Internet or in a remote database. This ultimately means that specific data and information processing methods can be related to any kind of object [15]. If everyday objects can be uniquely identified from a distance and furnished with information, this opens up application possibilities that go far beyond the original task of automated warehousing or supermarkets without cashiers, as outlined below.

Significant advances have also been made in the field of wireless communications. GSM mobile phone technology has established itself extensively and has become a so-called third generation system (UMTS) with higher bandwidth and better possibilities for data communications. Especially interesting are recent short-range communications technologies that need much less energy and make smaller and cheaper products possible. At the moment, such communications modules are the size of about half a matchbox, with further integration aiming to reduce their size even further. The price is only a few euros, and is expected to fall rapidly.

Another exciting development is the field of “Body Area Networks,” where the human body itself is used as a transmission medium for electrical signals of very low current. Simply by touching a device or an object, an individual identification code can be transmitted. (This could, for example, be supplied to the body by a wristwatch). This could be used for access controls, personalized device configuration, or the billing of services. Experiments are also taking place in the field of “wearable computing” with clothing containing conductive fibers. Fibers that can change their electrical resistance when they are stretched or bent will certainly make for interesting man-machine interfaces, allowing body movements to be captured, or triggering functions by gently pulling on an item of clothing.

Scientists are also working intensively on improved possibilities for determining the position of mobile objects (for example, via satellite-supported systems such as GPS or radio direction methods in mobile phones). As well as increased accuracy, the aim is also to make the receiver smaller and reduce its energy requirements. GPS receivers will soon be about the size of a credit card, including the antenna.

Many of these technological developments can be used together or even integrated. For example, in the field of “embedded systems,” fully-functioning computers including sensors and wireless networking functionality will be developed on a single chip that can be built into any device or everyday object for control purposes. High processor speed is not as important as producing chips that are small, cheap, and save energy. Such microchips – if necessary in conjunction with suitable external sensors, input and output interfaces, and communications functionality – are the primary components that can make everyday objects “smart.”

If you summarize these technology trends and developments – tiny, cheap processors with integrated sensors and wireless communications ability, attaching information to everyday objects, the remote identification of objects, the precise localization of objects, flexible displays and semiconductors based on polymers, electronic paper, and improved voice recognition – it becomes clear that the technological basis for a strange new world has been created: everyday objects that are in some respects “smart,” and with which we can communicate under certain circumstances on an almost natural level.

3. Everyday objects become "smart" and network themselves via the Internet

The “creeping revolution” induced by the sustained technological progress which is influencing not only the quantity but also the quality of information-processing capabilities is leading to a situation where there will be a plentiful supply of computing power. Smart cards that become worthless after being used in the form of telephone cards, or electronic labels that act as a substitute for bar codes – and which are on the verge of mass production – are the first indicators of a new wave of “single-use computers.”

This likely saturation of our world with information processing capacity heralds a paradigm shift in computer applications – tiny, cheap processors can be embedded into many everyday objects, can detect their surroundings via similarly integrated sensors, and can equip “their” object with both information processing and communications capabilities. This adds another completely new dimension to such objects – they could, for example, find out where they were, what other objects were in their vicinity, and what had happened to them in the past. They could also communicate and cooperate with other “smart” objects and, theoretically, access all sorts of Internet resources. Objects and devices could thus behave in a context-sensitive manner and appear to be “smart,” without actually being “intelligent.”

The phrase "ubiquitous computing", which is used in this context, was coined more than ten years ago by Mark Weiser, who was chief scientist at the XEROX Palo Alto Research Center until his early death in 1999 [16]. Weiser saw technology only as a means to an end, which should take a back seat in order to allow the user to fully concentrate on the task at hand. In this respect, the Personal Computer as a universal information technology tool would be the wrong approach, since its complexity takes up too much of the user's attention. According to Weiser, the computer as a dedicated device should disappear, while at the same time making its information processing capabilities available throughout our surroundings (ubiquitous computing in a truly literal sense). Intrusive technology should make way for "calm technology": "*As technology becomes more imbedded and invisible, it calms our lives by removing the annoyances… The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.*" It remains to be seen whether this apparent paradox does indeed take place, namely that despite the increasing quantity and ubiquitous nature of information, this information also becomes easier to use (perhaps due to more intuitive interfaces and more implicit information processing). While Weiser saw the term "ubiquitous computing" in a more academic and idealistic sense as an unobtrusive, human-centric technology vision that will not be realized for many years yet, industry has coined the term "pervasive computing" with a slightly different slant [2,6]. Though this also relates to pervasive and omnipresent information processing, its primary goal is to use this information processing in the near future in the fields of electronic commerce and Web-based business processes. In this pragmatic variation – where communications concepts, middleware concepts, and technologies for application-neutral data representation (e.g. XML) play a role alongside various mobile devices (such as smart phones and PDAs) – ubiquitous computing is already gaining a foothold in practice.

When talking about the paradigm of ubiquitous computing, it is interesting to note that, in claiming to bring computers into the world, it appears diametrically opposed to the maxim of virtual reality, that of bringing the world into computers. In fact, the vision of ubiquitous computing is not to isolate itself from the real world and construct an artificial world, but on the contrary, to enrich and make more comfortable the environment humans are used to, by means of discreet background technology. A synthesis for both these viewpoints exists in the form of "augmented reality" – this involves overlaying the real world with elements of a virtual, information-based world, for example by mirroring additional information for the user onto his spectacles, so that the real world is not excluded, but enriched.

As a consequence of objects being able to communicate with each other (for example, by telling other interested and authorized objects their location or sensor values), the Internet will also undergo an enormous change. It is a fact that the growth of the Internet is not only characterized by rapid, currently almost exponential growth with regard to the number of computers connected (if the current growth rate continues, more than one billion Internet-enabled computers are expected in the year 2005), but also by its qualitative growth. In the 1980s, it was primarily used for *person-to-person* communication – e-mail was the dominant application at that time – but the 1990s brought a completely new form of usage with the Web: now *people* were communicating via browsers on one side, with *machines*, namely Web servers, on the other side. The consequence of this was the multiplication of data traffic and, at the same time, this led to the rapid commercialization and popularity of the Internet. But now another qualitative leap forward has become apparent: the Internet of the future will be used principally for *machine-to-machine* communication – or rather, *object-to-object* communication. Since nowadays almost all computers in the world are connected to the Internet, an expansion of the Internet into everyday objects is the next step. Neil Gershenfeld from MIT's Media Lab expressed this as follows: "*In retrospect it looks like the rapid growth of the World Wide Web may have been just the trigger charge that is now setting off the real explosion, as things start to use the Net*" [5].

But what exactly does it mean if objects can communicate with each other? Envisioning concrete applications is not easy. However, the potential seems to be very high if objects can cooperate with each other, can theoretically access any information stored in databases or on the Internet, and can use any suitable Internet-based service available. So an automatic lawn sprinkler will profit not only from being networked with humidity sensors in the ground, but also from obtaining the current weather forecast free from the Internet. Another example is pens that digitize everything they write, and communicate this to an appropriate location. Many more applications are imaginable. The limits are less of a technological nature than an economic one (business models, standards, amortization of infrastructure, costs of information access etc.).

Localization technologies also have great application potential. In the future, it may be virtually impossible to lose things, or it may be possible to relocate lost objects, because the objects will know where they are, and can communicate this if necessary. Localization modules which, for example, use the GPS system are still too large, expensive, and imprecise, and consume too much energy for many applications. But continuing progress is being made on all four parameters, and for larger, more valuable objects, it is already worthwhile – for example, some hire cars are already secretly equipped with localization equipment. As technology progresses, simpler things will also profit from this possibility. Parents might appreciate it, for example, if their children's shoes and coats revealed their whereabouts, and even raised the alarm if the objects became too far separated outside the home.

In the same way, "tachographs" could be produced for a variety of objects. If an object knows where it is located, then it only needs to store this information regularly together with a time stamp or make a note on its own private (and secure) home page on the Internet. Later on, the "life trace" of this object could be very simply reconstructed. By comparing a variety of such life traces, it would be possible to determine the common context of different objects, or to obtain other information via this history (for example the hotel in which a location-sensitive travel bag has been).

Initially, it will be the higher priced appliances, tools and other objects that benefit from ubiquitous networking and "artifact intelligence" (and therefore contribute to the expansion of technologies and infrastructures). Sensor-supported information processing and communications capabilities will provide objects with substantial added value. But soon a lot of other, more trivial, objects (from calendar schedules to furniture, from toys to tin cans) will use the Internet with its many resources to carry out their tasks, even though their users may not be aware of this. Savvy business consultants have already coined an expression for business transactions that are carried out between machines or objects without human intervention: "silent commerce."

4. "Ubiquitous Computing" gains great economic significance

The new basic functions resulting from the progress of information and communications technology (such as the remote identification of objects, local "intelligence," networking of objects via the Internet, unconventional man-machine interaction principles etc.), and the possible resulting applications are set to gain great economic significance in the medium to long term. This can be illustrated using the example of remote identification.

A whole range of constantly improving techniques exists for identifying objects over a distance of a few meters. In addition to options that are not yet suitable for general use, such as biochemical marking and purely optical recognition (the automated identification of faces and vehicles is already yielding promising results), there are the electronic labels mentioned above [3]. In a more complex and therefore more expensive and larger form, these use batteries to regularly transmit a unique radio signal that can be recognized by the environment. In contrast to this, paper-thin, *passive* electronic labels measuring only a few square millimeters in area can be stuck onto objects or integrated into them during the manufacturing process, but require more complex "detectors." These transmit a radio signal to the labels and recognize their unique radio echoes; but the labels themselves are much cheaper and do not need batteries, and are therefore perfect for mass production.

Until now, such "smart labels" have been used as prototypes to increase the forgery-proofing of branded products (as a kind of electronic seal) or to optimize warehousing and production processes. For example, parts boxes on vehicle assembly lines can automatically control their own stock and transmit a signal to the warehouse and supplier as soon as they need replenishing. Using this method, suppliers receive precise information regarding the requirements and can deliver the necessary parts just in time. Another example is a pilot application of an English supermarket chain, where electronically labeled recyclable containers for perishable products are resulting in a clear reduction in the supply chain lead time and therefore increasing the time products spend on the supermarket shelf. This involves detectors automatically identifying every box and recognizing the expiry date of the contents in the interim warehouse and at the retail store.

Until now, most pilot applications for "smart labels" have been found in the automobile, logistics and transport industries. More recent application examples come from life sciences and the retail sector. Simple applications are limited to the basic functions of ubiquitous computing such as identification, localization, and tracing, where only the identifier is stored locally on the object. More complex applications are increasingly using sensors for the decentralized collection of data from the environment and working with what are known as notification services: in other words, smart objects report automatically if a specified condition occurs or if a preprogrammed rule (for example, regarding permitted temperature or duration of stay) is violated.

Generally speaking, a smart product can on the one hand automatically download (from a database or from its own homepage) the latest information such as a destination or updated user instructions; and on the other hand it can independently supply its informational counterpart, which resides somewhere on the Internet, with sensor data such as its location. In a certain sense, you could think of the object with its electronic label or radio sensors as the "body" of the object, with its informational counterpart being the "soul", storing object-specific data and even acting and communicating autonomously as an active information unit.

The new technologies of ubiquitous computing are therefore automating the process of linking the real world with everyday objects, products, and means of production with the virtual world of the Internet or e-commerce and supply chain management systems; in many ways, they are replacing man as the mediator between the real and the virtual world. As a consequence, this is facilitating new business processes that bring additional benefits to manufacturers, suppliers, and clients. These technologies are helping to reduce lead times, warehouse inventories, risks, and error rates. They can contribute to new solutions in the fields of maintenance and repair, security and liability, quality assurance, waste disposal and recycling, and ultimately create a variety of new services such as the consistent individualization or personalization of goods throughout the entire life cycle.

What Peter Harrop, IDTechEx expert, has to say about this is almost alarming: "*The next evolution involves fully automated communications on a vast scale. The fast-moving consumer goods industry will be transformed by trillions of one cent smart labels... Many new consumer benefits will be offered such as the food that tells the microwave how to cook it... Many markets for position services will be created such as low-cost gadgets that trace lost children, assets and animals and tags on one million vehicles permitting them to be located and their tax, license, etc. verified remotely.*" In the longer term, the process of remotely identifying objects along with wireless information access, mobile communications technology, and "wearable computing" pave the way for possibilities that go far beyond the optimization of business processes mentioned above and, to some extent, amount to an informatization of the world.

To give an example, imagine everyday objects such as furniture, packaged food, medication, and clothing being equipped with an electronic label that contains a specific Internet address as digital information (a "URL") which, to put it simply, points to the homepage of the object [7]. If you then read this Internet address with a device similar to a mobile phone just by pointing it at the object, the mobile phone can, independently and with no further assistance from the object in question, access and display the corresponding homepage via the mobile telephony network.

The user has the impression that the object itself has "transmitted" the information attached to it, although in fact it has been provided to the mobile phone via the URL from the Internet [1]. The information could for example be instructions for a tool, or cooking instructions for a ready-to-serve meal, or the information leaflet for medication. The details of what is displayed may depend on the "context" – for example, whether the user is a good customer and paid a lot of money for the product, whether he is over 18 years of age, what language he speaks, his current location, or to which world explanatory service from which encyclopedia company he has subscribed – but also maybe whether he has paid his taxes on time…

The appliance that we describe as a "mobile phone" may in the future take the form of a special pair of spectacles, or a piece of electronic paper for displaying information, in conjunction with a "pointer". Furthermore, it will not only be human users who are interested in the additional information on objects, but also other "smart" objects. A trash can, for example, may be very curious about the recycling characteristics of its contents, and a medicine cabinet may be concerned about its medication's possible side effects and best-before date. Theoretically, at least from a technical point of view, there is nothing to stop objects (or their informational counterparts on the Internet) exchanging information amongst themselves i.e. almost speaking with each other, as long as a common basis for communication in the form of a standardized formal language exists. Efforts are already being made to define product description languages.

Even if a detailed assessment cannot yet be made of these, it is clear that completely new applications will come into existence based on this multitude of smart objects. The digital added value of a manufacturer's own products can be very different from that of physically similar products marketed by the competition, and can tie clients more closely to his own added value services and compatible products. The maintenance and ongoing development of the global infrastructure necessary for such aspects – including the measures required to meet the increased need for security and data protection in such an environment – might even occupy a whole industry, similar to today's energy and telecommunications enterprises.

5. Social and political challenges

While a technical analysis may be able to predict what the future *could* bring, the question of what the future is *allowed* to bring can only be answered by means of a social process.

If information is attached to "electronically enhanced" objects, in other words physical objects effectively become media, who can or should determine their content? It is no secret that there are often arguments on the Internet over who owns address "xyz.com" and whether you can prohibit someone from adding a link to someone else's home page. There is also the question of which Web pages search engines should be allowed to deliver (instructions for making bombs? pages with pornographic content? racist views?) and who should take responsibility for them, and this is almost becoming a political issue. If, for example, ready-to-serve meals contained an electronic label, would a consumer protection institute be permitted to map this number using its own electronic directory onto information other than that which the producer intended (for example, to warn of allergies to the ingredients)? Or should this at least be permitted if the "viewer" specifically requests it?

To put this in more general terms: if objects are equipped with information or a means of identification that enables a personal digital assistant, maybe located in a pair of spectacles, to explain the world ("Computer, what's that?"), can real-world objects then be interpreted by the manufacturer of the smart spectacles in any way he likes? World views have often been the cause of disputes. Given a situation where cyberspace is approaching reality, partially overlaying or even merging into it, there are some things we must be prepared for – ultimately, some political questions of a fairly explosive nature must be asked.

Many other questions are generated by the informatization of the world, only a few of which are touched on here: if many objects can only function properly if they have access to the Internet or a similar infrastructure, this results in a far-reaching dependency on those systems and their underlying technology. If these fail, for whatever reason – design errors, material defects, sabotage, overloading, natural disasters etc. – then it could have catastrophic consequences on a global scale. If the correct functioning of the information technology infrastructure is vitally important to society and individuals, not only do we have to have appropriate security mechanisms, but the systems have to be designed from the outset with this in mind.

Another set of questions relates to the socially acceptable design of the technologies outlined and their applications. Using the most important functions should, of course, be simple and straightforward in order to prevent a "digital divide" in society reaching deep into our everyday lives. It is equally important to bear in mind that cartels, monopolies, or power concentrations could develop due to the expansion of the Internet into our everyday world, and how this could be moderated in a democratic society.

Last but not least, we should pay particular attention to the protection of privacy. The vision of ubiquitous computers expands the existing Internet problem of "online history" (in other words, the detailed recording of mouse clicks and Web pages visited) into a comprehensive "offline history" – whereas the Web surveillance of a person has previously been clearly limited to computer usage, there will often be no distinction between "online" and "offline" in a world full of smart everyday objects. As a result, this ubiquitous data will become more valuable. Whereas until now only a relatively limited view of a person could be obtained by rummaging around in data, a much more comprehensive picture can be painted of this person and his day-to-day behavior in the ubiquitous vision.

It seems clear that, without effective data protection measures, the technology of ubiquitous computing could be used to create a surveillance infrastructure that would render ineffective many existing laws and privacy protection mechanisms. Therefore basic legal considerations and new technical approaches, as well as much social and organizational effort, will be required in order to prevent this brave new world of smart, interconnected objects becoming an Orwellian nightmare. As Rossnagel would say [14]: Big Brother will be joined by lots of little brothers.

6. Perspectives

The technology trend is pointing quite clearly towards a continued informatization of the world – for example through embedding more and more processors into everyday objects and through the increasing connection of all kinds of devices to the Internet. From a technical and organizational viewpoint there are already many challenges to consider – the energy supply for objects, communications standards, and much more besides.

If technical progress means more and more everyday objects are becoming "smart" and therefore behaving unconventionally towards humans, then this will ultimately lead to a totally different world from that to which we are accustomed. The changes won't happen overnight; instead, this process will be more of a creeping revolution. Taken to its logical conclusion, a world which is literally permeated by information technology will sooner or later bring with it major social and economic consequences, adding a political dimension to ubiquitous computing and the associated future direction of the Internet.

The driving forces behind these underlying technological achievements are microelectronics and computer science, supported by basic research in the fields of physics and materials science. Dynamic development in these areas is continuing unabated, and its effects are increasingly influencing everyday life. It is therefore clear that the 21st century will be characterized less by major technological structures such as moon colonies, underwater cities, and atomic cars (as suggested by earlier popular futurologists), than by the application of tiny, practically invisible technology that is therefore easy to replicate and distribute. This involves biotechnology and nanotechnology as well as microelectronics. And looking further into the future, it is nanotechnology that should make a further decisive contribution to smart environments, creating tiny actors that actually make changes to the physical world.

But before the far-reaching expectations of nanotechnology can be fulfilled, we can look forward to seeing the effects of ubiquitous computing. It is already worth thinking about the economic and social prospects and the social and legal consequences this all could have, but most of all what role Europe should play in designing this "Internet of things"!

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