Run to the Hills!
Ubiquitous Computing Meltdown

Pertti HUUSKONEN
Nokia Research Center, 955 Page Mill Road, Palo Alto, CA 94304, USA
pertti.huuskonen@nokia.com

Abstract. We have seen the future of ubiquitous computing, and it's gloomy. While the various technologies keep advancing at a breakneck pace, and half of human race are already carrying computing systems with them, the goal of transparently integrating all those devices and networks to usable ubiquitous systems seems to be receding further away every day. We are seeing around us major shortcomings in terms of usability, interoperability, and security, and expect that the situation in integrated systems will only get worse. The next decade will bring wonderful advances in individual devices, services and technologies, but the overall picture is not as rosy. In this chapter, we discuss the drivers of this undesirable development, while also observing some signs of more positive trends.

Keywords. Ubiquitous computing, calm computing, context awareness, usability, privacy, interoperability, systems design, overload

How Far We Have Come

Ubiquitous computing (or *ubicomp*) happened while we were not watching. Consider some of the visions set out by Mark Weiser and his colleagues at Xerox PARC in the late '80s [1, 2, 3]. In typical office settings, there would be large displays (*boards*) on the walls where people would project data for joint discussion. People would carry along *pads* that access networked documents over wireless links. People would wear *tabs* that allow for quick messaging and situated functions. Behind all this, there was assumed ubiquitous network connectivity for global information sharing.

Fast forward twenty years. Here we are, busily glancing through presentations projected on meeting room walls, reading email and browsing the net on our laptops, while waiting for phones to buzz in our pockets signaling incoming messages. The ubicomp vision has come true, albeit in a slightly different form than was originally conceived. Many of the essential elements are there – boards, pads, tabs, networks – but many of the functions are different.

Among other things, PARC researchers experimented with location aware systems. In their prototypes people would announce their location to colleagues [2], and systems would use that data for routing incoming information. Our present ubicomp world is only now grasping location awareness (discussed later in this chapter). Moreover, information routing has taken a secondary role with mobile devices that can access the data wherever. We no longer dial places; we dial people. The move from desk phones

to mobile phones has decreased the problem of routing, but at the same time, it has introduced new issues.

The rise of the mobile phone is arguably one of the most rapid technological developments in the history of humankind. In just about ten years, the mobile phone permeated the western world in such depth that it has changed many of the ways people live, work and play. Being always connected while on the move is now routine for masses, and the society is changing as a result. This is ubiquitous computing (or *ubicomm*, ubiquitous communication) to the extreme. The computation that works behind the scenes is invisible, as the users of those systems only see the end effect – being connected.

It's not only the Western world that is changing. Mobile phones are now bringing communications to many people who were so far beyond the reach of technology. Crowds in India, rural China, and remote villages of Africa are now grasping mobile phones by the millions every day. The drive for being connected seems so strong that many people are investing substantial fractions of their yearly income to afford mobile phones. While we write this, the number of cellular subscribers globally is about to surpass three billion. In just a few years, half of the planet's population will be carrying these communication and computing devices.

Another fundamental development is the World Wide Web. Just a nascent dream when the seeds of ubicomp were laid, the web today is a key enabler for much of our daily lives. Just about any activity can be made easier, or more interesting, through a couple of clicks. There's a new generation of computer users who have never lived in a world without the net, email, or instant messaging. Their life is to a great degree already happening in this electronic domain. Despite some of the problems that plague all of the Internet, we can arguably say that the WWW has make computing ubiquitous.

But the web is still a comparatively simple system. The scheme of servers, clients, HTTP, HTML, AJAX and related technologies is relatively easy to comprehend. It is a system that is fundamentally designed for human creation and human consumption. Granted, there are thousands of back-end databases that transform queries into dynamically generated listings, web service APIs and scripts that create UIs on the fly. Still, the web is most useful for human users, but less so for machines.

One of the key shortcomings of the web is that it is not easily machine-readable. Our browsers do not have any real understanding of the contents of the pages they render on our screens. Consequently, the burden of decoding the wealth of information in the web is left to humans (although greatly facilitated by search engines). As the amount of web content continues to grow, information overload will only get worse.[1]

There are various approaches to adding semantics to web content. *The Semantic Web* [4] adds descriptive metadata into web pages to make the contents machine-readable. However, this largely calls for human encoding of the semantics into metadata, which is a task that few people master today. A complementary approach is to let people add descriptive tags into pieces of web content (such as images or videos) creating *folksonomies*. This approach is far easier for average users, but suffers from noise, ambiguity, spam, and other worries.

Oblivious to the lack of rigorous semantics, millions of machines have silently been connecting to the Internet. Today, refrigerators display real-time stock data on their front panels. Traffic sensors count cars on highways and warn us of impending

[1] At the same time, the opposite problem – information starvation – can keep people from getting the information they need but do not know how to find.

congestions. Tiny web servers allow us to check the weather in remote sensing stations. There have been net-enabled bicycles, coffee makers, and even toasters. While many of these trials have been of limited practical value, the trend is clear. Networking is becoming so cheap and pervasive that it will be possible to reach literally almost any device through the Internet. Sensor nodes may be literally everywhere [5]. A major trend in the future of ubiquitous computing will then be the rise of the machines.

In research, ubiquitous computing always seems to be an unattainable goal, much like AI (artificial intelligence). We tend to take the present technologies for granted and hang the "ubicomp" label to technologies much further away. The various flavors of ubicomp – *pervasive computing, ambient intelligence, situated computing, sentient computing*, to name a few – emphasize different aspects of the same dream: an omnipresent, all-encompassing computational environment that can sense, adapt, automate, inform, and stay out of sight. Given the present state of developments, this seems an unreachable goal. Why? Read on.

1. The Ubicomp Overload

We believe that a ubicomp overload is inevitable. As embedded computing and communication infiltrates our society in an ever-increasing speed, we are bound to witness countless problems with that machinery. TVs no longer connect, fridge door passwords get lost, living room lights complain of "invalid command". People will encounter numerous situations where computer-based systems simply do not work as intended. This will annoy users to no end, and give rise to billions of hours wasted in phone support queues. By and large, users will still tolerate this, since computing is here to stay, despite its annoyances. They just have to face the pain to be able to function in the society. Over time, there will be consensus among manufacturers on the right ways to build and integrate systems – but by then, new technologies have introduced new complications.

Why would this happen? Because the whole point about an ubicomp world is an ecosystem of countless subsystems that are supposed to work together for realizing applications. So far, we have rarely been able to build systems that would not suffer from surprising interdependencies. This is no different today and in the future. The more moving parts we add, the more likely something is to break.[2]

There are examples of ubicomp systems that do comprise thousands of subsystems and, thanks to careful design and maintenance, do feature satisfactory performance and reliability. The aviation industry is an example of how myriad interconnected systems (aircraft, traffic control, ticketing) together form a reasonably successful ubiquitous computing environment. However, this success comes with a price in terms of maintaining costly safety requirements, extensive standards, maintenance, and other complications. Moreover, the need to comply with legacy systems makes new developments ever more difficult.

Computing is now being integrated by industries that so far had little experience with embedded systems, not to speak of networked, web-enabled systems. Consider such household items as refrigerators, ovens, air-conditioning or lighting. We have seen several trials where such systems have been integrated with various "smart"

[2] More robust ubicomp would call for self-organizing, self-diagnosing, self-repairing systems. Such technology is still largely a dream.

functions or web functionality. Such integration has historically been a fringe activity for appliance manufacturers. Suddenly, their R&D departments need to work with the complications of IP stacks, public key infrastructures, touch screens, WLANs, DVB streams and the like. It will take some time before the needed systems engineering will be everyday business for the average appliance maker.

Further issues, such as usability, reliability, and privacy will necessarily be of second priority for many companies on the market. It will be too costly, given the price margins of their products. As a consequence, there will be thousands of products that are simply not ready for the complications of human-machine interaction in the ubicomp world – unless there are strong incentives to make the systems more interoperable, for instance through legislation.

Maintenance of those systems will not solve the problem. Contemporary appliance repair involves identifying a failed subsystem (often, an electronics board) and then just replacing it with a new one. Such repair mostly addresses problems that are internal to the product, not system-wide issues. Moreover, system configuration is typically based on preconceived setups with some on-the-spot customization. Problems that arise from unexpected interdependencies between different systems are outside the expertise of appliance makers, and thus will be left to third parties. We envision a great rise of "ubihackers", after-market system repair houses that troubleshoot issues with ubicomp systems. [3]

Subcontracting those designs, or buying ready-made subsystems does not solve the problem completely either. Given the inevitable interdependencies between subsystems, going for really robust designs will be too costly. Spreading the issues out to multiple parties will make that problem worse. Standardization would help, but that route is slow, hard, and costly, and anyway carries little hope of success in the heterogeneous ubicomp world. Obviously some level of standards will always be needed, but in the case of ubicomp it is not clear who would have the means to enforce them.

2. The (Anti)social Ubicomp

One of the major movements in the Internet in the 21st century has been the rise of user-generated content. Such contemporary web sites as MySpace, Flickr, and YouTube (with countless followers) are based on social networking, sharing content, and ranking content and comments. The loosely defined "Web 2.0" label is attached to any site that to a great degree obtains its content from its users. What is the equivalent of this movement in the greater scope of ubiquitous computing?

The Internet has been connecting people since its beginning – email was one the very first application programs over it. Recently, there have been various attempts towards making it easier to find people, chat, discover common interests, flirt, and date. These systems then clearly serve the inherent human need to socialize and find friends and partners. As a by-product, they are creating valuable data that brings our social networks to the computing domain, which in turn can enhance ubicomp systems.

People often look for information through other people. Consider your email: if you are looking for a particular file, chances are that you search for it knowing the name of the person who sent it to you as email attachment. Or, you may not remember the name of that Vietnamese restaurant, but you remember who suggested it. As

[3] The trusty old plumber of the future will carry not a wrench but an Ethernet analyzer.

humans, we are used to indexing information more through people and places rather than directories and file names. Unfortunately, our current (non-Internet) ubicomp systems do not seem to make effective use of people as first-class data items. The systems are based on the artifacts of mainframe and desktop eras of computing: addresses, labels, files, directories. It is going to take radical redesigns before the systems start to better reflect and serve the human societies we are living in.

One major driver behind the Web 2.0 movement is the recent surge in the amount of digital content. Digital imaging has been showing the way. Digital cameras have by now become the norm for most consumers and many mobile phones now feature cameras. Myriads of images are filling the disks of personal computers. A substantial fraction of those images are being shared, either via email or via image sharing sites such as Flickr. After the surge in still imaging, the same phenomenon is now happening with video clips. Witness the thousands of crazy stunt videos in YouTube, filmed with cellphone cameras. All of this visual content from users, again, gives a socially meaningful way to reach people and their data.

Besides the visual content, images and videos carry other content in the form of metadata. For instance, JPEG images include metadata about the camera used (and some cases of the photographer), and trials are now underway to include metadata about the situation where the picture was taken [6]. This context information provides yet another way to access other data about the world. For instance, a picture can serve as a key into queries about the surrounding situation, such as: Where was this picture taken? Who are the people in the picture? How was the weather? What is the name of that restaurant? Do other people recommend that place? How can I book a table there?

In the fashion of Web 2.0, we could dub this philosophy as Ubicomp 2.0. Instead of building systems that contain complete pre-made databases, the role of system builders would be to provide frameworks where users then populate their data.[4] Preferably, the user data would be captured as a side effect of other activities. For instance, instead of asking people to name their favorite places, a ubicomp system would (anonymously) monitor the places where people frequent, and then see if people would recommend those places to other people. This approach treats the world and the people as a big sensor grid that gives ubicomp applications an edge.

However, the social networking sites and user-generated content sites are plagued with various kinds of problems. Spam messages litter newsgroups and blogs. Trojan horses, bots and other attacks masquerade as cool pieces of content, while cyber bullies and sexual predators hunt teens in MySpace. Given the human nature, it is not surprising that such problems would come up. It is to be expected that, once users start to contribute content into ubicomp databases, a great deal of that content will be harmful, or simply of poor quality. How can we find ways to prevent ubicomp systems of becoming as polluted as our email inboxes? Moreover, once you are in the sensor grid, how can you control the use of your sensor data? These are some of the questions that need to be answered in a satisfactory manner before ubicomp systems can go out in the society.

[4] This principle could be called "Build the database, and they will come".

3. Calm or Dazzling Computing?

Look at the future of ubiquitous computing. It's all there, in your browser. Any average commercial webpage gives you an idea of how it will look like. You are going to have the blinking banners, annoying animations, pesky pop-up windows, and adwords all over the place. Only, this time, it is not going to be limited to your web browser. It is going to be your fridge, your coffee maker, the office elevator, the car, or in fact any device with some kind of displays and some links to the net. All those devices will become dynamic, context-aware advertising platforms. And later, once nanotech really catches on, it will be in your t-shirts, lunch boxes, coffee cups. Not to speak of those bioware tattoos that blink with animated band logos.

One of the main principles put out in the original Xerox ubicomp vision was the notion of *calm computing*. Weiser and Brown [3] point out that the mission of ubicomp was not only to saturate our world with computing, but to design all that machinery in such a manner that it recedes to background. The ubicomp would be visible to us upon our wish, while otherwise the information would only get our peripheral attention. Their concern was that this aspect of the vision has been poorly understood. We agree, and predict that the future will be only worse. We believe that in our present information society the information overload will only increase. It's not going to be a walk in the woods; it will be a run through the casinos of Las Vegas.

Why would this happen? Because it can.

Business drivers call for the ubicomp overload, not for the calm. So far, many of the key information systems in our world have become platforms for advertising. Newspapers, magazines, TV, radio, films, phone catalogs, maps are some of the places where we daily encounter major amounts or advertising and product placement. The web is now a viable advertising platform, and shows promise of becoming the most important one. And, while we are writing this, advertising is quickly moving to the mobile domain. As customers, we need to put up with this largely unwanted information, since it is necessary to keep these platforms alive.

We believe that the same will happen with ubiquitous computing systems. This is becoming more practical than ever, as advertising has successfully moved to the electronic domain. Any device with sufficient computing, networking and/or interaction capabilities can be used for the purpose of grabbing our attention. As ubicomp moves on and more and more things become "smart" and networked, this possibility will inevitably come up. There will be all kinds of trials with placing commercial information in ubicomp systems. There will be some failures and some successes. Over time, we will have an understanding of how users will accept advertising in the omnipresent computing.

People might hate to hear clocks announcing time with "Ding-dong, ding-dong, it's burger time!" or washing machines going off "This housekeeping session was brought to you by Wish-Wash, the ultimate detergent". Or maybe they would not mind. We are already today getting our newspapers and TV for quite modest fees, largely thanks to advertising. If ads could pay for gadgets and appliances, some of us would be all the happier. We may think it's fine to get a new Internet-connected fridge for $20, as long as we are willing to watch those coupon offers on its front display. Or, more likely, cover the display with duct tape.

Many people will object to such developments. As usual with new tech, older generations will be slower to adapt. The teens of today might be happy to live inside a razzling and dazzling total music-tv-videogame-myspace-like experience, where all the

things around them are part of the great (ad-supported) ubicomp experience. Or then not. It could well be that the human physiology is fundamentally unsuited to constant information overloads. We are afraid that new kinds of mental effects will be observed, once such ubiquitous info bombardment becomes more common.

Rogers [7] proposes that the goals of calm computing are fundamentally wrong. People do not always want calmness; they want dazzle, sparkle, glitter. They want to be excited, stimulated, provoked, engaged. They want to be amazed by new surprising functions from their computing environment and feed their exciting new creations there. We take a more cautious stance: we think that this ultimately depends on the individuals, their lifestyle, their cultures, their goals and means of going about their life. Some will want calmness; some will not. Some are couch potatoes; some are active world healers. Let us try to design the ubicomp systems so that the choices are left to the people.

Chances are that ubicomp advertising will create a new kind of digital divide. In one end of the spectrum, there will be people who live in an ad-subsidized ubicomp world, receiving great parts of their computing and living support essentially for free. On the other end, there will be wealthy people who can afford to filter out any undesired information clutter from their world. They can afford the cars that do not roll the ads out upon stopping in the lights, and golf jackets that do not carry any dynamic e-ink logos. Once computing and communication becomes essentially free, the paradox may come up that it will become more and more costly for those who want to buy themselves their peace of mind. Those who can't afford the Zen will find new ways of hacking the advertising out – or just learn to ignore it.

Consider an air conditioner that will only turn on once you have reviewed a five-second commercial. Is that too crazy a scenario? Think that nobody would buy such products? Well, consider the obligatory copyright notices on a DVD that we today have to view before we get to the film. We can't even fast forward through the notices, as DVD controls are disabled for that program segment. In this case we have accepted a minor usability degradation to comply with the requirements of the rights holder. In the case of the air conditioner, you have accepted a major usability degradation to save money. We don't think these cases are too different. Moreover, crazier examples are on the way to the market. We just can't wait.

4. Context Awareness Considered Risky

There is a widely held belief in the field of HCI (Human-Computer Interaction) that context awareness is a key technology towards better interfaces and applications. To achieve more satisfactory interaction, ubicomp systems should have better understanding of the situations of the people they are dealing with. This seems quite logical, as people are very context-aware. We apply context information in a number of ways in our daily lives: in our conversations with other people, in our search of new interesting things, in our navigation through busy streets. It appears that to fully integrate with the human society, machines have to develop at least rudimentary context awareness.

Mobile computing has made this need more imminent. With desktop computing, the physical context could be more or less assumed. Mobile computers, in contrast, are moving with people into a variety of places and situations. Some ubicomp functions may be quite inappropriate in those situations. Consider the infamous example of

cellphones ringing in libraries, concerts, or churches. The function – alerting mobile users of incoming calls and messages – is useful for many cases, but without context awareness, the resulting blunders cause major disturbance. The phones should know when it is appropriate to ring. Yet, this function is extremely hard to implement successfully. As a result, people are adapting their lives instead. In the past decade, various social mechanisms have been devised to deal with this shortcoming in context awareness (such cellphone bans in some restaurants and announcements in shows to turn phones off).

4.1. Location Awareness

As another example, consider location awareness. Location has been the most popular form of context in the ubicomp literature, and numerous applications have been proposed that use location as a key source of information. Location-based services are appearing everywhere in the marketplace. Finding businesses through Google maps is today routine, and finding the nearest pizzeria via a text message is now possible through mobile networks. Personal content sites such as Flickr feature location information as metadata in user-contributed images. GPS navigators are becoming standard fare for drivers, and soon for pedestrians. The ability to track parcels, buses, flights, and other moving objects is making our life easier – or more up-to-date.

Location is the first form of context data that is really taking off. Why is it, then, that mobile operators have been silently dropping their early trials for locating people through their mobile devices? Why is it that the various prototype systems of finding people in offices through their active badges have invariably been fallen out of use, after the initial novelty has worn off? Apparently in our present society many people do not feel ready to publicly announce their position, particularly when such tracking happens through an obscure monitoring system. We may feel fine to tell our employers or spouses where we are during the day, and it may be acceptable to track individuals who are our dependents (such as children), but it appears that tracking people is largely unacceptable in a free society.

Widespread use of positioning will ultimately increase the acceptance, but we feel that the human need for privacy will remain a fundamental barrier to location awareness well into the future. Put bluntly, tracking people is wrong, while tracking things, services and information is fine. Put another way, users feel okay to pull location data but not push it. We do not expect this to change anytime soon, at least until the current generations of Internet users fade away.

4.2. Presence and Activity Recognition

What are the next kinds of context information to make it to the public use? At least presence information is already out there. Users of instant messaging and IP telephony are able to announce their availability through "busy", "unreachable", "online" presence attributes. This makes it easier for people to judge whether it is appropriate to approach the other party. Similar developments are available in mobile phones, though the applications have not yet caught on. Note that presence is usually information that people input explicitly. Automated sensing of presence data is still generally impractical.

Researchers around the planet are busy collecting sensor data related to humans and decoding it into user activities (for a recent survey, see [8]). At the moment, there

is much promise in the area of motion analysis. In labs we can now, with acceleration sensors and gyroscopes, detect such primitive motion states such as walking, standing, sitting, or climbing stairs [9]. Others are able to abstract ambient noise levels or video feeds into guesses of the surrounding places and situations [10].

Another promising research track is sensing presence via short-range networks, such as Bluetooth or Wi-Fi. If two phones are within the range of each other, it is also possible (but not certain) that their owners are also in each other's physical vicinity. Adding knowledge obtained from social networking analysis [11], we can today guess when someone is among friends or colleagues.

Presence can be a new source of information overflow. Unless there are sufficient filters, we could be flooded by situation updates from hundreds of people. More research and prototyping is needed before we can say what kinds of context data should be transmitted, to whom, and under what circumstances, and how such information should be made visible to the receiver.

4.3. What's the Right Domain?

No single source of context information – location, motion sensing, proximity, audio, video – gives 100% recognition of the human context. On the contrary, context awareness is likely to always remain approximate. Through sensor fusion, or combining information from various channels, we hope that the inherent redundancy will help us to reduce the amount of noise in our results, but still it is of little hope that foolproof generic context awareness methods would arise.

There is more hope with limited domains. As with AI (Artificial Intelligence) in general, limiting the scope of application invariably brings better performance. Choosing the right application area brings even better performance. So, we feel that while the goal of generic context awareness will be beyond reach, it is important to try out context information in all kinds of applications and, slowly, introduce the successful solutions to the generic ubicomp systems.

Some application areas are inherently unsuitable for context awareness. Automatic cellphone ring tone silencing, for instance, is a risky application. Working properly, it will be useful, but the failures can be socially catastrophic compared with the subtle benefits. We would hate to miss the emergency call in the middle of the night as the cellphone decided we should not be disturbed in our sleep, or lose our face as our cellphone mistakenly interpreted the opera hall to be our office and thus safe to ring.

Games, on the other hand, are a safer application area. Removed from the social responsibilities of our real lives, it is okay to fail and to lose face in a virtual gaming setting. In the context of a game, people are not real themselves, and the norms of society and rules of physics are relaxed, encouraging experimentation. While context aware features are not yet widely used in games, we expect that the new wave of augmented reality games [12] will make use of a multitude of context clues, besides location. Alternatively, contextual information can become a key game element, as in Manhattan Story Mashup [13].

Imaging is another application area that can benefit of context awareness. Digital image and video files can carry metadata about the context present at the time when the file was created, transferred, edited or displayed. The metadata can contain various features like optical parameters, location and orientation, the devices that were present (and hence, their users), and the messaging history for files that were sent. Such contextual metadata allows reconstructing the scene much after the fact, which can be

used for autobiographical purposes, as an automated field report or diary, or automated presentations. Importantly, the metadata allows more human-oriented searching: instead of tags or directories, we can search for people and places. New ways of sharing visual material are starting to come up, as online image galleries are starting to embrace location data (and later, other contextual metadata).

Besides imaging, context can also enhance many other kinds of personal content. In a recent book [14] we describe an architecture for metadata applied to personal content, such as music, imaging, and web pages, together with some less obvious content types such as online avatars, personalization settings, or fitness measurements.

Is context-enhanced personal content a "safe" application area? Yes and no. As long as the context data is gathered for personal uses and is properly protected, it is reasonably neutral. However, when the content objects (e.g. images) are shared, some of the metadata may be shared together with those objects, and that can introduce unwanted data leaks. For instance, if we email pictures containing names of people that were present when the pictures were taken, that metadata now leaks presence information that the people would consider private.

In general, context-enhanced personal content talks about lives of people in a rich and varied manner. Too rich, privacy advocates would complain. Once we start gathering and analyzing data about human lives (and context awareness does just that), we are entering an area with endless trade-offs between privacy and system functionality. We are expecting some major blunders in context-aware ubicomp systems to take place before there's sufficient experience on what's acceptable and what's not.

Ultimately, context aware systems would need to *understand human life* to offer meaningful help for humans. This goal is presently too far, and probably will be for quite some time. Machines lack direct access to our minds, and therefore have to resort into externally observable signals of our behavior. Even us humans, with a lifetime of training, have difficulty in making sense of other humans. In some limited domains it is already possible to guess what users of computer systems may be thinking (in help systems, for instance), and the number and scope of such systems will be increasing. On another front, computer models of the world are being devised [15, 16]. Still we are not expecting context aware systems with more than rudimentary models of the world and its people to appear in decades.

Why is this a problem? Well, a little context intelligence can be a dangerous thing. When the context understanding machinery works, it will simplify the users' lives. When it fails (which will always happen), those users suddenly have a yet another source of information they need to deal with. People will note the undesired function and either seek ways to understand what happened, repair it, or find ways of circumventing the problem. Given the ubiquitous sensor data and event logs, people would have to assume the role of process operators (much like those found in industrial plants and telecom centers) and maintenance technicians. This is hardly desirable to the general public. Implemented poorly, context awareness might just give new weight to the information overload.

5. Voices of Caution

In the above, we have discussed some developments that the field of ubiquitous computing is likely to go through. We argued that some of the key threats include:

- The current WWW has too little semantic level data
- Computing is spreading to places where it can't be managed
- Humans are going to be overloaded with too-visible ubicomp
- Commercial realities work against the goals of calm computing
- The problems with social networks will transfer to ubicomp
- Context awareness will create new social and usability problems

Each of these concerns needs to be taken seriously in the design of future ubicomp systems. Ubicomp seeks to encompass no less than the whole of human life; therefore, it is going to be at least as rich and complex as the current world we live in. Multidisciplinary talents will be needed in the iterative process of making ubicomp suit humans.

Imagine a group of professionals in computing and related fields, getting together for a ubicomp town hall meeting some time in the future, each voicing out their hopes and concerns from their own viewpoints. This is what you might hear:

THE USABILITY DESIGNER: "Looks like someone did not do their homework before letting all this systems out there. We now have adaptive this, adaptive that. You know, these menus that change per use, and the devices that try to guess what we really want. Didn't anyone look at the HCI research? We have known for a long time that people think adaptive systems are scary. Besides, switching those menus around destroys the all the spatial cues the poor users retain. Didn't you guys ever run any usability studies before letting it all out in the open?"

THE ENERGY CONSCIOUS: "Okay, so who was the bright one here who invented these multipart wearable computers? I mean, these jackets with 13 separate devices which makes a total of, um, 22 batteries? Did you ever calculate how many have to be replaced every week? When did you think those batteries would die – not on the critical moment when you really needed the info, no? It's a real pain to remember to charge you cellphones, so let' s not even get started with those multipart designs. I say, if you can't get a device go at least 2 years without charging, just fuggeddaboudit."

THE MEGAENGINEER: "Ubicomp will never scale. Okay, your systems may be fine in a lab or maybe with a couple hundred users, but have you looked at more realistic situations? Think bigger. Think like Shinjuku in Tokyo, which is the busiest subway station in the world. More than three million people pass through it on an average day, and maybe half of them during the morning rush hour. Are your ubicomp proximity networks prepared to face a million queries in just a few minutes? Or, take those RF-ID databases. Is your back-end server farm ready to identify those five trillion items out there?"

THE SOFTWARE DEVELOPER: "These ubicomp visions are all and well, but think of the poor developer who actually has to go in and write the software. Where are the standards? Where's the development support? Where are the cookbooks, API's, tracing tools, code profilers? If you look at stable platforms, such as Linux on PCs, all these necessities are in place. With ubicomp systems, there's nothing. Nobody's going to invest into developing software for such fragile platforms. I'll give it a few years and then look again."

THE VISUAL ARTIST: "Well, you may not realize it, but all this ubicomp stuff is really a blessing for people like me. I am a graphic designer, a web artist, banner creator, all that. This ubicomp boom has created thousands of new places where design work is needed. All those displays on the walls and windows, all the ads in those

gadgets, those animated t-shirts, all of that stuff has to be designed by someone. We are seeing the greatest demand ever for our designer skills. That's not too bad, methinks."

THE PRIVACY ADVOCATE: "Ubicomp will be end of the individual, the end of secrets, the end of nations as we know them. Nothing can be really kept away from those cunning data miners. Do you want your whole life be searchable in the Internet? Maybe you'd like it for yourself, but would you give that power to anybody? Would you use a keyless door entry system if you knew that Big Brother was watching it? If information were really free, how would you replace such societal necessities as banks and armies, which are largely based on secrets? How could we design ubicomp systems so that the privacy risks for the individuals could be minimized, while maximizing the functionality?"

THE FIELD TECHNICIAN: "There are so many systems out there, but, man, are they ever buggy. If you religiously stick to products and platforms from just two or three providers, then you do stand a chance, but otherwise you are doomed. Just like that house last year. We had this homeowner who insisted that we install this family tracker from 2Gether, the house messenger from YouGoez, and the gesture control from Stic-U-Late where he had got discount cameras or whatever. Well, hate to say, we never got it working. No matter what we did, those systems would simply refuse to connect. The customer sacked us, and later we heard that he had gone through five hack houses before he found someone who was willing to figure it out, with huge cost. They finally started it from scratch and got everything from Domoti-Con, pre-configured."

THE GOVERNOR: "Ubicomp has given us a time of unprecedented freedom. Our people are now more free than ever, free to move about, free to live, love, play, work, anything. Our society has come to a place where just about any activity can be carried out anywhere, connected by our information superhighways. What's better, we can now monitor the safety of our citizens much more thoroughly now that we have accurate location and activity patterns for everyone. Our machines are relentlessly monitoring the lives of millions of people, and prepared to take action as soon as anything abnormal occurs. Ubicomp has made the Homeland a true home."

THE BACK-TO-THE-NATURALIST: "I think we are relying too much on this ubiquitous technology. Just think of how dependent on the Internet people have become. Now they are also increasingly dependent on cellphones, navigators, pocket translators, RFID, speech recognition, and all that. People are losing even the basic skills of reading a map, or searching a lexicon, or even comparing price tags, as computers make all that so much easier. We are losing all those skills, and what happens when ubicomp suddenly fails? What if the networks just die and power runs out? What are you going to do? I think we should all take a step back and consider what are the so called essential functions we could in fact live without."

THE DIRECT MARKETER: "I don't see the same threats everybody is talking about here. It's like, 21st century, you know? There's no going back to those passive products of the past century. Our research tells us that customers do indeed want those smart packaging and networked products. Look: four families out of five have opted in to receive our breakfast service with the food items delivered and cartoons and news nicely bundled in the dining table screens. Kids love it. Parents love it too, as they get itemized spending reports. We are providing a service, and people like it. So, they are getting a few ads – is that too much to ask in return? I don't see the overload problem that you guys here are so obsessed with."

THE PESSIMIST: "It's no use to try and develop these smart systems. Nobody is going to use them anyway. Or if people will be foolish enough to really go for those solutions, soon the companies will collapse and those applications will just die. The technology moves so fast, it's naive to think that we could build anything stable. All that effort would be better used trying to make Windoze more bug-free. Or, rather, please stop wars, end poverty and cure cancer."

6. Design Options: Person-Centric or Environment-Centric?

A great deal of ubicomp research and development has focused on smart environments. Such technology follows humans, seeks to decode their whereabouts and tries to support their activities with relevant information. The machinery typically comprises wall-mounted cameras, machine vision, RFID, ambient microphones, public displays, embedded sensors and suchlike. The various flavors of this general concept (e.g. smart houses, ambient intelligence) differ greatly in terms of their architectures and functions, but the key principle is the same: the environment observes the users and adapts to them.

The contrasting approach is to place the functions with the people. This is the notion of wearable computing, where people carry computation and communication devices with them. Many of the functions, if not all, are mobile and follow the users anywhere. MP3 players, digicams, mobile phones, laptops, and navigators are typical cases where many key functions reside in the mobile devices. Obviously such mobile technology still needs major functionality from the environment to be useful: mobile networks, satellites, WLANs, web services, power outlets. With the surge in mobile technology in the past decade, it is no surprise that a great deal of ubiquitous computing research is now turning onto mobiles.

Whether computing is mobile or happening in the environment, does it make any difference to the end users? Well, yes. It matters less where the various functions are placed, but more where the resulting data is stored and accessed and who is in control of that data. We like to make a distinction between *person-centric* and *environment-centric* ubicomp. The former term emphasizes the role of users as the focal point of the ubicomp machinery, whereas the latter term puts the action in the surrounding infrastructure.

Arguably, mobile phones are person-centric ubicomp, at least judging by public perception. Users of that technology do not see the abstract networks behind the scenes – they just use a phone and magically it connects. The people may be aware that they are using some kind of networks while they talk and send or receive messages, but their immediate interaction happens with the mobile device. Probably a great many users are unaware that the cellular networks actively follow them and many of their actions are traceable in the operators' archives.

In cases where privacy risks are larger (e.g. in countries with hostile governments), person-centric ubicomp in general is safer for the users. For instance, consider the classic ubicomp example of networked tourist info displays. When you click a street display to receive personalized tourism info, should the display recognize you and then fetch your custom profile from the Internet, or should your mobile device recognize the display and then fetch the needed data to be shown on it? Both scenarios are technically feasible, depending on the circumstances, but in latter scenario the user's personal

information can be more easily protected. In general, the greater the privacy risks, the more attractive it becomes to place functions in local, personal computation devices.

Mobile phone users generally consider their devices very personal. Many people never share their phones with anyone. Some people claim that the phone is the first thing they would rescue out of a burning house. Others even give their phones affectionate names. The mobile phone is the first widely adopted connected mobile device that can serve as a base for personal, trusted data. This issue of trust becomes crucial when the devices contain large amounts of personally created content (such as images), socially valuable data (phonebooks), or context traces (location history). Where should this valuable private data live?

People like to feel being in control of computers, not the other way around (this view is taken, for instance, in several books by Donald Norman [17]). This also applies to their data. It is then natural that people would like their data live in places where they have the best chances to control its use: PC's rather than web sites, phones rather than operator's servers. Still, they would want their data to be retained with as automated backups as possible – a factor that speaks against local (mobile) storage. Yet again, networked storage is not an option when data links are expensive or very unreliable, or when trusted parties are not available.

Trusted parties for maintaining the data from our ubicomp systems have not yet really emerged. We turn over our search data to Google, our call logs to our operator, and our biometric data to Homeland Security. Yet we do not have full control over that data. In the course of history, mechanisms have been established to deal with trust in the financial sector. Banks and brokers are trusted parties for storing and managing our finances, with agreed conventions and legislation to support their operations. What are the equivalent parties for ubicomp? Granted, there exist agencies (such as Thawte) for proving digital identities, but that is only one part of the needed framework. Practical and widely accepted mechanisms for dealing with trust in ubicomp are still some way in the future.

In practice, the choice of where personal data should be stored in ubicomp systems is a complex trade-off in terms of reliability, traceability, privacy, access times and costs, power economy, and a myriad other factors. If there was a general rule that we could offer for considering tradeoffs between person-centric and environment-centric ubicomp, it would be this: Always err on the side of lesser risk; that is, person-centric ubicomp.

7. How We Will Cope

Humans are wonderfully adaptive animals. Our ancestors have been able to move from the sea to land, trees, and air; from gathering to hunting, herding and cultivating; from fields to factories and studios. As Kurzweil notes [18], after the industrial evolution each successive technological paradigm shift has happened with a quickening pace, and may continue to do so. We are certainly seeing exponential speedup with the technologies related to ubiquitous computing. In the Internet, masses now adopt applications within weeks. The question is, how fast can we keep adapting?

When changes in technology used to take years or decades, younger people more readily adopted the new ways and older generations slowly gave way. Now that changes happen far more rapidly, there is no time for natural replacement of the learned ways. Each new generation of users has to keep learning new things on an increasing

speed [19]. As the number of technological changes per unit time increases, and if the human ability to adapt stays constant, necessarily there will be more and more people who fail to embrace new technologies. This creates a natural slowdown for ubicomp developments.

While the reality may not be as simple, we are seeing at least anecdotal evidence of this phenomenon. For instance, younger generations of Internet users favor chat and instant messaging, but older users prefer their asynchronous email. Some teen users report it satisfying to have their TV, radio, web browser, messaging and homework happening simultaneously, while most middle-age users would probably find such multitasking most distracting. We have new generations of people entering professional settings who have spent substantial fractions of the their lives in virtual environments, such as MySpace, Second Life, and World of Warcraft. How will they transform workplaces to suit the kinds of computing they are used to?

Obviously there are not only generational differences but also perhaps greater differences between countries and cultures. Some people will easily deal with concepts that other people find quite unfathomable, or even appalling. For ubicomp, this means that once the technology is available, it will be difficult to predict when and in which parts of the globe individual applications of that technology will be adopted. Consequently, it will be harder to design for usability, as successful design relies on knowing the users.

The general public is increasingly encountering IT concepts and learning about them. Large masses now routinely use the Internet and mobile devices to seek information and connect to other people. More and more people are at least peripherally aware of the underlying basic concepts. Meanwhile, newer generations receive computer skills in schools (and, perhaps more importantly, from their peers). This will make it far easier for the public to adopt future ubicomp systems. Concepts that had little success in the past will be reinstated in the new setting.

As we said, humans are wonderfully adaptive animals. We will learn ways to cope with all the broken ubicomp that will come our way, learn to bypass the faulty bits and use the good bits, and later build better systems that work more the way we intended them to work. If needed, we will adapt our lives and societies to fit the technology. We have done it before, and we will do it again, with every new development that ubicomp brings us. Perhaps the future of ubicomp is not that bleak, after all.

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References

[1] M. Weiser: “The computer for the 21st century”, Scientific American, September 1991, pp. 94–104.

[2] R. Want, A. Hopper, V. Falcao, and J. Gibbons: “The active badge location system,” ACM Transactions on Information Systems, vol. 10 no. 1, January 1992, pp. 91-102.

[3] M. Weiser and J.S. Brown: “The coming age of calm technology” (1996) Available in: http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm (last checked April 20, 2007).

[4] T. Berners-Lee, J. Hendler and O. Lassila: “Semantic Web”, Scientific American, May 2001, pp. 35-43.
[5] G. Borriello, K.I. Farkas, F. Reynolds and F. Zhao: “Building a Sensor-rich World”, Pervasive Computing Vol. 6, No. 2, April-June 2007, pp. 16-18.
[6] S. Ahern, S. King, M. Naaman, R. Nair, and J. H. Yang: “ZoneTag: Rich, Community-supported Context-Aware Media Capture and Annotation”, in the Mobile Spatial Interaction workshop (MSI) at SIGCHI conference on Human Factors in computing systems (CHI 2007), San Jose, CA, USA, 2007.
[7] Y. Rogers: "Moving on From Weiser's Vision of Calm Computing: Engaging UbiComp Experiences", in P. Dourish and A. Friday (Eds.): Ubicomp 2006, LNCS 4206, pp. 404 – 421, Springer-Verlag, Berlin, Heidelberg 2006.
[8] M. Pantic, A. Pentland, A. Nijholt, and T. Huang: “Human computing and machine understanding of human behavior: a survey”, Proceedings of the 8th international Conference on Multimodal interfaces (ICMI’06), Banff, Alberta, Canada, November 2-4, 2006, pp. 239-248. ACM Press, New York, NY, 2006.
[9] T. Huynh and B. Schiele: “Analyzing features for activity recognition”. In Proceedings of the 2005 Joint Conference on Smart Objects and Ambient intelligence: innovative Context-Aware Services: Usages and Technologies (Grenoble, France, October 12 - 14, 2005) sOc-EUSAI '05, vol. 121. ACM Press, New York, NY, pp. 159-163.
[10] D. Smith, L. Ma, and N. Ryan: “Acoustic environment as an indicator of social and physical context”, Personal and Ubiquitous Computing, Vol. 10, No. 4 (March 2006), pp. 241-254.
[11] N. Eagle and A. Pentland: “Reality mining: sensing complex social systems”, Personal and Ubiquitous Computing, Vol. 10, No. 4 (Mar. 2006), pp. 255-268.
[12] W. Broll, J. Ohlenburg, I. Lindt, I. Herbst, and A. Braun: "Meeting technology challenges of pervasive augmented reality games”, in Proceedings of 5th ACM SIGCOMM Workshop on Network and System Support For Games (Singapore, October 30 - 31, 2006). NetGames '06. ACM Press, New York, NY.
[13] V. H. Tuulos, J. Scheible, and H. Nyholm: “Combining Web, Mobile Phones and Public Displays in Large-Scale: Manhattan Story Mashup”, in A. LaMarca et al. (Eds.): “Pervasive 2007”, LNCS 4480, Springer-Verlag, Berlin Heidelberg 2007, pp. 37-54.
[14] J. Lehikoinen, A. Aaltonen, P. Huuskonen, and I. Salminen: “Personal Content Experience: Managing Digital Life in the Mobile Age“, Wiley, London, June 2007, 382 p.
[15] Singh, P.: “Open Mind Common Sense: Teaching computers the stuff we all know”, http://openmind.media.mit.edu/, last checked August 17, 2007.
[16] anon: “OpenCYC: Formalized Common Knowledge”, http://www.opencyc.org/, last checked August 17, 2007.
[17] D.A. Norman: “Things that make us smart: Defending Human Attributes in the Age of the Machine”, Basic Books, 1993, 290 p.
[18] R. Kurzweil: “The Age of Spiritual Machines: When Computers Exceed Human Intelligence”, Penguin, 1999, 400 p.
[19] J. Gleick: “Faster: The Acceleration of Just About Everything”, Vintage, September 2000, 352 p.