Ethics and Information Technology **5:** 17–26, 2003.

Simulation and augmentation: Issues of wearable computers

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Abstract. As the physical and digital worlds interact, some fields of technoscience have started to shift from an approach emphasizing simulation – in which the physical is replicated in the digital – to one focusing on augmentation, in which the digital is utilized to enhance the physical. A good place to study the implications this shift has on the individual is the field of personal wearable technologies. Here, the body is not simply extended by information and communication technologies (ICTs), but also becomes their intimate host. This represents a new step in the conceptualization of the synergy between individual (body) and technology (environment), and also affects the ways in which the role and character of each actor are defined. This paper explores some of the theoretical re-orientations underpinning the development of wearable computers and how these shape the relationship between body and environment.

Key words: augmentation, body, digital, embedded computing, personal technology, physical, simulation, ubiquitous computing, wearable computer

Introduction

In this paper I argue that the relationship between the physical and digital worlds is changing, mainly due to the sharp increase in the amount of research and development (R&D) projects that use *augmentation* (connectivity and responsiveness), rather than *simulation* (replication and separation) as a guiding principle. The growing importance of augmentation is reflected in the increasing number of personal technologies that are used in synergy with the body, rather than as stand-alone artefacts, of which wearable computers are the best example. Although the simulation and augmentation approaches are not mutually exclusive, the shift is not only pervasive enough to be discussed in its own right, it also introduces new ethical and conceptual issues in the relationship between humans and technology.

In what follows I will describe what the shift from simulation to augmentation entails and how it has affected fields such as artificial intelligence (AI) and virtual reality (VR). I will then describe how it is closely related to the creation of the new field of wearable computers. Taking wearable computers as the case in point, new issues concerning the relationship between individuals and technology in an era of augmentation will then be presented. Finally, different ways of interpreting personal augmentation through wearable computers, from the most recurrent themes in the literature – empowerment and control – to aspects that have been largely neglected in the literature, such as the shaping of experience and the losses that accompany every augmentation, will be analysed.

Background: The interactions of physical and digital worlds

The digital world is the world created inside the computer, it is the world of computer generated information, the world of bits. The physical world, on the other hand, is the world outside the computer, the world of atoms, of people and artefacts. Bits and atoms have always been related. Ever since the invention and commercialization of the modern computer these two worlds have interacted to create a variety of meanings and concepts, such as electronic documents, electronic icons, desktop/virtual workspaces, intelligent systems, smart suits, cyberspace and universal location systems. However, their relationship is not static, it is constantly being re-designed and re-conceived.

While characterizing the city of the future, in his book *City of Bits*, William Mitchell (1999) analyzes the relationship between the digital and physical worlds through a design lens and describes two distinct phases: Initially, the physical was pushed into the digital, giving rise to digital artefacts that looked like their physical counterparts (e.g., desktop icons). Now, we are moving towards a phase of "functionality without virtuality" (ibid., p. 43) where the digital is pushed into the physical, creating artefacts whose 'digitality' is hidden. A number of artefacts are exemplars of this: wearable computers, conductive fabrics that work as touch screens (Kahney 2000), newspaper headline scanners that connect directly to the internet (Guernsey 2000), air conditioners with communication capabilities (O'Connell 2001), and artefacts that track patients' weight loss (Knapp 2000).

In this second phase it is no longer necessary or desirable to make visible the digital component, but rather to make it pervasive. In a sense, Mitchell is describing a combination of embedded computing – in which artefacts are made 'smart' by means of enhancement through networking and computing abilities – and ubiquitous computing, where invisible computing devices are located everywhere and nowhere.

Mitchell's analysis helpfully hints at the tension that exists between these two worlds. However, by focusing solely on the process of design, Mitchell falls short of addressing how this shift alters the nature and demands placed on each sphere, and how, in turn, this affects the relationship between people and technologies.

Taking Mitchell's observation as a starting point, I argue that in the fluid relationship between physical and digital worlds two broad approaches can be identified: one uses the digital elements to imitate the physical environment, keeping both spheres relatively independent; to this approach I give the name of simulation. The other focuses on using the digital world to enhance the physical world; this approach I call augmentation.

These two approaches have long co-existed, however their relevance within the academic/research millieux has not always been the same.[1] Recently numerous leading academic institutions, technology development firms and military institutions are investing significant amounts of money in the development of products – e.g., wearable computers, implants, augmented reality apps, etc. – that fall under the category of augmentation.

As stated above, in the simulation approach digital objects are endowed with characteristics of the physical world, but both spheres are kept relatively independent. Hence, computers had (and still have) icons such as trash bins and folders and, were (and still are) run by actions, such as copy, cut and paste that imitate their physical counterparts (Mitchell 1999). The example of the introduction, in 1984, of the Macintoshþ computer to the market is illustrative. It's graphic, user-friendly interface, was considered intuitive and transparent exactly because it replicated a well-known physical environment thus making it easier for anyone to interact with the digital. Until then the digital world was presented in a form familiar only to programmers.

Simulation is characterized by an assumption of separation between digital and physical that gives rise, for example, to concepts of individuals that "leave their bodies behind" in order to enter a digital world that replaces the physical world[2] (cf. Turkle 1995; Rheingold 1991); and to ideas of disembodied minds continuously (re)configuring themselves in the world of virtuality (cf. Turkle 1996; Stone 1992).[3] Simulation is also predominant in the period of self-contained, "good-old-fashioned artificial intelligence (GOFAI)" (Floridi 1999) projects that have as a main objective the emulation of the human mind. With mind being understood as a logical reasoning machine that works through the processing of symbols.

Nowadays, with the rise of information and communication technologies (ICTs) and pervasive digital networks, notions of augmentation are becoming ever more popular. Augmentation goes a step beyond simulation, the digital is incorporated in the physical without necessarily showing its presence: Physical actors maintain their traditional shapes and bodies, but these are augmented with digital functionality, i.e., with added computational and communicational capabilities. Here, the human is no longer *the measure of all things*, the entity that machines are designed to imitate. The human body is viewed as being deficient, in need of improvement, of being enhanced with computing capabilities.

Augmentation, then, relies on the coupling of a human or nonhuman actor with a computational device that participates in the processing of information. Rather than building self-contained machines, machines and humans are coupled together into a new hybrid actor. Rather than leaving the body behind, real world information and computer generated information are brought together, allowing the individual to simultaneously affect and be affected by both realities.[4]

The main difference between simulation and augmentation is that the latter is rooted in notions of connectivity and responsiveness between the digital and the physical, rather than replication and separation. In the augmentation framework the physical actor

[1] For instance, in the 50s and 60s, one could both identify simulation-research, e.g., the field of artificial intelligence that came to be in this period, and augmentation-research, space suits constituting the first example of wearable computing.

[2] Films like *Lawnmower Man* and *Star Trek*, among others, contributed to popularizing this notion.

[3] It is important to note that for the authors cited here the separation between physical and digital does not diminish the importance of the experience of the digital.

[4] See discussion on augmented reality below for more on this issue.

hosts the digital computational device, creating new synergies that are beyond each individual actor. The human body becomes an integral component of the global sociotechnical information systems. The *Land Warrior* program,[5] an ambitious project funded by the US military sets the pace here. Its long-term goal is to create a superhuman, augmented soldier that can "fight in combat with satellite imagery of the battlefield, ballistic accuracy calculations and instant communications a click away on the computers embedded in [his] uniform .... With a global positioning system, thermal weapon sights and other gadgets, [the] soldier can immediately identify friends and enemies and see where his shots will hit" (Hopper 2001). Armed with this technology the soldier becomes "a totally, 100 percent integrated system .... Th[e] computer ... basically control[s] and manag[es] all the subsystems he's wearing" (ibid.), his body is transformed into a personal-area-network, and becomes a node within the larger network.

Besides signifying a major change in designing, understanding and using technology, it is also possible to discern how the use of augmentation as a guiding principle reflects (and is reflected on) changes in the conceptualization of humans. However, as much as there seems to be a consensus that this emphasis on augmentation is already visible, there is no general agreement on where it will lead and what its implications will be.

From artificial intelligence (AI) to augmented intelligence

Several different definitions of AI, emphasizing either the importance of intelligence or that of the computing devices, have been proposed. Their differences notwithstanding, they share a core idea: AI is the science that tries, through the use of computing devices, to duplicate (and perhaps eventually replace), the workings of the human brain when engaged in a task requiring intelligence. AI takes human intelligence – as applied to one (or more) specific task(s) – as the measure to be applied to the machines it builds.

The history of AI dates back to the mid/late 1950s, and in recent years two streams within the discipline have been identified: strong and weak artificial intelligence. The difference between these two streams lies in distinct assumptions regarding the (future) abilities of the thinking machines. Strong AI advocates consider that machines will one day think like human beings (e.g., Kurzweil 1990, 1999; Moravec 1988, 1999; Warwick 1997). Weak AI advocates, on the other hand, believe machines can only emulate certain traits of human intelligence.

The emphasis on strong AI projects that characterized the first decades of artificial intelligence research (until the mid-80s) has been largely replaced by growing efforts in the development of weak AI projects, which are usually less ambitious in scale, cheaper and easier to implement. Nowadays, most commercial applications of AI fall under this category (Wallace 2001), e.g., games, language translation, natural-language understanding, fault diagnosis, robotics, and supply of expert advice.

The shift in understanding the nature and limitations of human cognition and computation – its nature and limitations – has been accompanied by a more indicative one: the increase of augmented intelligence research and projects.

Artificial intelligence, strong or weak, is based on a model of emulation, separation and replacement (cf. Mann and Niedzviecki 2001). Even recent approaches, such as connectionism, that rely on parallel distributed computing, separate between human and computing actors.

Augmented intelligence, on the other hand, utilizes a distributed model of information processing: the cognitive task is split between the various networked actors. The recurrent dream of the perfect memory – assisted by a computing device that records and helps recall every aspect of one's daily life – is a good exemplar of this networked model.

With these new connections, new synergies among the actors are produced, the effects of which are still largely unknown. For instance, if before we spoke of intelligent machines when they could successfully imitate human behavior, will we soon speak of efficient humans as they imitate the machine? If so, what values are being lost as we acquire more efficient characteristics? And what kind of efficiency is being promoted here?

From virtual reality (VR) to augmented reality

A similar shift can be observed in the area of virtual reality (VR) development. Virtual reality, a dream of the late 80s and early 90s, employs computer generated information to create digital worlds of similar experiential richness to the physical world. Interaction in VR environments allows (or forces, depending on the view) the individual to leave his/her body behind and be immersed in a new exclusive reality. VR, once thought of as part of everyone's future life, now belongs to the domain of very specialized and contrived environments, where all actions are defined

[5] <http://www.fas.org/man/dod-101/sys/land/land-warrior.htm>.

a priori, for instance, games, physics, astronomy and medical applications.

At the same time, augmented reality applications are on the rise. Augmented reality relies on the fusion between computer-generated information and 'real world' information. Barfield and Caudell (2001, p. 6) argue that augmented reality "can be thought of as an advanced human-computer interface technology that attempts to blend or fuse computer-generated information with our sensations of the natural world." Augmented reality aims to enhance human capabilities by providing new ways to interact with the 'real world' that are facilitated and mediated by digital devices.

While VR is totally immersive, thus forcing the user into a 'new' world, augmented reality combines both types of information, physical and digital, allowing the user to simultaneously see him/herself in the virtually enhanced space and manipulate real life objects. This type of application is frequently discussed in terms of its navigation value. It fulfills the dream of always being at home, safe in any environment. Think, for instance, of the tourist arriving in a strange country and immediately seeing all the outdoor signs translated into his/her own language, indicating how to arrive at his/her desired destination.

Again here the implications of augmented reality are not fully drawn out. It is possible to conceive that for the system to work efficiently both wearer and environment must become more contrived, more artificial, run by explicit rules. The wearer must move within limited spaces, and perform the most common actions. The environment must accommodate the impositions of the technological system, and be shaped accordingly.

Wearable computers

Not only has the shift from simulation to augmentation affected the evolution of existing disciplines, it has also stimulated the creation of new ones: personal wearable computing emerges as an epitome of augmentation – both at the level of intelligence and reality – as it relates to the human body.[6]

A wearable computer is defined as a "fully functional, self-powered, self-contained computer that is worn on the body ... [and] provides access to information, and interaction with information, anywhere and at anytime" (Barfield and Caudell 2001, p. 6).

The philosophy of wearable computers is, on the surface, one of personal empowerment: wearable computers as the path for the augmentation of human sensory and cognitive abilities (c.f. Barfield and Caudell 2001; Mann 1998). As stated above, several projects/groups are trying to develop wearable computer applications that will help wearers navigate through unknown space. In Japan, an initiative by the National Institute of Advanced Industrial Science and Technology plans to do this by using an augmented reality application, by overlapping digital and physical information on the wearer's head mounted display (Knight 2001); In Belgium, Starlab, a blue-sky research laboratory, reckons with the idea of creating an e-clothing line, I-wear,[7] that among other things does the thinking for its wearers! For instance, e-clothes may guide their wearer using sensory input released directly onto the body: When the wearer is moving in the right direction the clothing piece becomes warm, when moving in the wrong direction it cools down (Brébant 2000).

While the actual development and implementation of wearable computers has been slow – happening mainly in closed environments, such as the workplace or military – the dreams behind them fly fast and high. If initially, wearable computers were considered *tools* designed to give wearers instantaneous and constant access to information. Nowadays the ultimate goal is to make them proactive, that is, responsive, networked and 'aware.' This shift implies much more than technical solutions, it implies a shift in the perception of the computer's identity: wearable computers, no longer tools, become 'technological companions,' "extensions of the self' or a 'second skin.'

Awareness, in the field of wearable computers, translates into the creation of computing devices that can recognize, adapt and (re)act to their 'owner,' their 'location,' and the 'activity' being performed. Awareness is built through the development and incorporation of sensors, such as infrared, accelerometers, temperature sensors, biological indexes, among others (see Table 1). These sensors take an analog stimulus from the environment (or body) and convert it into electrical signals that can be interpreted by a digital device with a microprocessor (Barfield and Caudell 2001).

The information provided by the sensors can be processed locally, to perform context aware tasks such as navigation and communication, or remotely, when the information is processed by a third party, for instance, when monitoring cardiovascular activity. In this second case the wearer does not even need to be conscious that the information is being transmitted.

Wearable computer research focuses mainly on four general areas:

[6] Implants, such as those developed by Kevin Warwick and his team, are also good examples of human augmentation.

[7] <http://www.starlab.org/bits/intell_clothing/index.html>.

Table 1. Sensor typology (from Barfield and Caudell 2001, p. 15)

Sensor type	Stimulus	Use in smart spaces
Mechanical	Position, acceleration, force, shape, mass, displacement	Detecting people's/object's position, weight, movements
Acoustic	Volume, pitch, frequency, phase, changes	Detecting sounds, interpreting speech
Biological	Heart rate, body temperature, neural activity, respiration rate	Measuring people's mood, mental state, physical state
Optical	Refraction, light wave frequency, brightness, luminance	Computer vision detection, IR motion/presence detection
Environmental	Temperature, humidity	Monitoring the conditions of the environment that people are in

- Medical/health, to monitor the body
- Work, to augment efficiency and productivity, and accommodate the walking office phenomenon
- Security, to augment or diminish physical abilities, and
- Leisure, for life-style applications.

Medical applications aim at increasing the possibilities for monitoring the body, and on capturing body-related information that would otherwise be concealed or go undetected. An area in great expansion, it is still mainly composed of ambitious projects in the prototype stage. The most critical stumbling blocks are: reliability (the computer must never breakdown), security (the confidential nature of the data means the connections between different nodes must be secure), and safety (it must be proven that it is not harmful to wear a computer 24 hrs/day).

A variety of projects are currently under development in this area. For instance, Swiss researchers at the University of Lausanne are working on an application that tracks the amount of energy output and activity patterns of overweight men and women. This application will combine a GPS satellite logger and an accelerometer, to track both indoor and outdoor activities. The GPS logger will measure the position, speed and displacement of the wearer when outdoors; the accelerometer has sensors to record frontal and vertical acceleration and movement. The idea behind it is that by knowing how much energy they spend on their daily activities, wearers will be encouraged to continue exercising (Knapp 2000). Besides the many obvious problems that have been identified by the research team – the device does not monitor calorie intake and needs to be worn 7 days/week in order to establish activity patterns – this project, still in a pilot phase, poses significant privacy threats for the wearer.

Another example is Sensatex's[8] *Smartshirt System*, a project originally funded by Defense Advanced Research Projects Agency (DARPA). This project, still in the prototype phase, tries to develop a smart shirt – described on Sensatex's website as "the shirt that thinks" – that measures or monitors biometrical data for a range of purposes such as maintaining a healthy lifestyle, health care, and occupational and public safety (i.e., security). The (marketing) information contained on the website announces that the *Smartshirt* will combine wireless communication capabilities and multiple localized and configurable sensors to monitor vital signs and critical data – such as heart rate, body temperature, neural activity and respiration rate – from the human body. Sensatex adds that spontaneous information exchange will be supported on two levels, between the different sensory applications within the garment, and wirelessly to receivers off the body. In the works for a couple of years, Sensatex has not yet announced its first commercial version.

The field of *work* is probably the fastest growing area and also the one in which we find the first examples of real life implementation. This is because the applications being proposed here rely on technologies that are already in place. Xybernaut's[9] *Mobile Assistant V (MA V)* is representative of wearable computers in this category. The MA V targets workers who need to be able to perform hand-free computing and exchange information with third party databases. It features a belt or vest-worn CPU, a small wrist-worn keyboard, a microphone and hear phone, and small screen display (head mounted or not according to preference). The different parts of this system are connected and exchanging information and can be

[8] <http://www.sensatex.com>.
[9] <http://xybernaut.com>.

supplemented with other pieces, such as a wireless modem.

Within the field of *security* – military and law enforcement – prospective wearable computer projects will augment or diminish physical abilities. After the recent events of Sept. 11 investment in this area has increased exponentially, with some experts now arguing that this is the future of wearable computers. On this note, the independent business conference on wearable technology, *Tech-U-Wear 2001*,[10] changed the program and tone of its second day to focus on security and surveillance procedures and applications. An example of a project in this area, is DARPA's ambitious *Exoskeleton*[11] which aims at creating a frame that fits over the human body and is designed to be strong and pro-active. The exoskeleton is intended to help a soldier know the precise location and movements of his/her colleagues (through the use of mechanical sensors), help him/her detect sounds and interpret sounds (acoustic sensors), communicate wirelessly to others, and monitor his/her mood, mental and physical conditions through the use of biological sensors (see Table 1 for a sensor typology).

Finally several applications are being developed for *leisure*, life-style choices. Life-style applications are believed to be the 'killer app' that will turn wearable computers into everyday apparel (Barfield et al. 2001; Barfield and Caudell 2001). Paradoxically, there is also a general consensus that until these applications look and behave like actual clothing they will not be accepted by the general public and become mainstream items (ibid., Post and Orth 1997). Given this paradox, products envisioned for this area are the most ambitious, and products developed the most banal. The electronic clothing line, ICD+,[12] developed by *Levi's*™ and *Philips*™ is a good example. Despite being described as the "1st brick in the China Wall" (Philips 2000) its first commercial product, released on the market in 2000, was a hooded jacket, whose only functionality was incorporating an MP3 player and a mobile phone, allowing the wearer to effortlessly switch from one to the other.

The boundaries and objectives of these areas are neither sharply drawn nor mutually exclusive. In fact, they constantly overlap, and they use one another's development in their own research. The military asserts that its development of technologies meant to increase soldier security can, and are likely to be, used for the civil society in the monitoring of health indicators at a later stage. On the civil side, Japanese researchers have produced a bionic power suit, targeted for nurses, that increases their physical abilities helping them lift patients and lowering the risk of back injuries (Hadfield and Marks 2001).

Implications of augmentation through wearable technologies

In all the products described above, implicit assumptions about the needs and desires of the wearers are being made by the technology's developers and proponents. Their views of the world are 'inscribed' in the technology, shaping its form and functionality (Akrich 1992). For instance, the *Exoskeleton* project assumes that something as complex as a soldier's mental condition and mood can be measured through the use of biological sensors – but does not reveal the criteria upon which it will be modeled. Projects within the medical field take for granted that constant knowledge and monitoring of one's physiological state is not only desirable but imperative.

These assumptions are even more persistent in the long term vision for wearable computers. In the future, proponents predict, "[wearable] computers will monitor our physiological state, perform the duties of a secretary and butler in managing our everyday life, and protect us from physical harm" (Barfield and Caudell 2001, p. 24). There is no place for doubts regarding the demand and urgency of this personal augmentation.

Also missing from this picture is the recognition that the augmentation of the physical through the digital does not result in physical plus digital, but in a new entity with its own specificities (cf. De Kerckhove 1995). An augmented human being has a distinct reality, and this raises new issues regarding the place of the human body and self in its relation to technological artefacts.

In the available, often popular, literature the implications of augmentation are usually discussed as issues of empowerment (who and what should be augmented?) and control (will augmentation give humans more or less control over their environment?). There are those who believe that augmentation should be extended to all actors (human or not) and that this will provide humans with increased control over their surroundings, and consequently over themselves. Others believe that augmentation should be applied only to human actors, otherwise there is a risk of being controlled by the environment. What is at stake here are the implications of extending the communicative and pro-active capabilities of different types of actors.

[10] <www.tech-u-wear.com>.

[11] <http://www.darpa.mil/DSO/thrust/md/Exoskeletons/index.html>.

[12] <http://www.terra.com/technology/articulo/html/tec1483.htm>.

A typical futuristic vision of those who defend the need for pervasive augmentation looks like this: The house of the future will be equipped with augmented technological artefacts, appliances and inhabitants. For instance, the phone is networked with several other artefacts, and is able to detect when the shower is being used, or when dinner is being served. By sensing other appliances' activities (and inhabitants' behavior), it automatically shifts messages to the voice-mail in moments when it assumes the masters don't want to be disturbed. The rooms can, among other things, sense the occupants' health condition and determine if anyone in the room needs special care. For instance, if person A has a heart condition, the room will constantly monitor signals from his/her wearable biological sensors and send off an alarm if the measurements become critical. On top of that, everyone, using his/her own wearable computer connect to the internet, chat with family members and undergo a health check-up, all this while sitting on the living room couch.

Hence, for those who argue for pervasive augmentation, the creation of a 'smart' environment – i.e., responsive, networked, and to a great extent, docile – is synonymous with human empowerment. Although this argument is most vocally made by those who produce and sell technology, it is also an opinion held within academia. For instance, William Mitchell (1999) and Neil Gershenfeld (1999), professors at the Massachusetts Institute of Technology, argue that the problem with today's technological artefacts is that they still cannot communicate with their surroundings and, by lacking communication abilities, they lack awareness (and submissiveness) towards the needs of their human owners. When the environment is constituted by augmented actors that can communicate with one another and adapt their behavior to the needs of their human owners/users, then human life will be easy and convenient. Underlying this argument are two powerful assumptions: (1) that individuals have a need and desire to augment their innate capabilities, and (2) that their actions, desires, dreams – in sum, the individuals themselves – can be predicted and modeled into the surrounding artefacts.

The arguments are varied amongst those who criticize pervasive augmentation. For instance, technology critic Natalie Jeremijenko (n.d., quoted in Mann and Niedzviecki 2001), argues that when we started calling things 'smart,' we also started referring to ourselves as dummies (e.g., *computers for dummies*, *pregnancy for dummies*, among others). Implying that this is an inverse correlation, she warns of the dangers of pervasive augmentation.

A related, if somewhat distinct, position is voiced by Steve Mann, considered by many the father of wearable computing. Mann also defends the idea that when creating 'smart' artefacts we are effectively reducing human ability to interact and respond to the decisions taken by the technology (Mann and Niedzviecki 2001). However, Mann asserts that the way to address this issue is by creating wearable computing devices that enhance the individual. To this notion he gives the name of 'humanistic intelligence' (HI), a type of intelligence that relies on the creation of new synergies between wearable computer and body. This synergy results in an "intimate and constant bonding [and] is such that the combined capabilities of the resulting synergistic whole far exceeds the sum of either" (Mann 1998).

Like Jeremijenko, Mann believes pervasive environmental augmentation is diminishing for human beings. However he treats this issue like a competition: 'Smart' artefacts are unavoidable, and the human is no longer enough to keep up with them. The solution, then, is for humans to be perfected and enhanced through technology. In order to maintain (or regain) personal autonomy it is necessary to augment (through technology) human capacities.

Another related, and recurrent issue, is that of 'control': Do wearable technologies give individuals more or less control over the environment? Some think wearable technologies give their wearers more control over the environment (cf. Gershenfeld 1999; Barfield et al. 2001; Mann 1996, 1998). For instance, a wearable computing device can be used to protect its wearer's privacy by controlling the data flow: when, where, how, to whom and what kind of data is transmitted.

The same privacy argument is used by those who warn of the dangers of 'control' *by* the environment. If an individual is equipped with a wearable computer that can transmit and receive data to, and from, a third party, can't that third party establish a *de facto* control over the wearer by recording each and every move he/she makes? If, for instance, that wearable is used in the workplace isn't it possible that it may be used for employee monitoring purposes?

The issue of control is all the more important given that it does not have to be enforced by anyone, it can be built directly into the technology's architecture. Behavior can be effectively regulated and shaped by building constraints within the wearable computer's code (cf. Lessig 1999). For instance, a 'work' wearable computer can be programmed to, after five minutes of perceived inactivity – inactivity being defined by the wearable's owner, not its user – send a message directly to the wearer's retina saying 'go back to work.' This issue is more critical in instances in which the wearable is not owned by the individual, and runs on proprietary software, since the possibilities of reverse engineering these 'biases' are very limited.

This points to a dimension that is deeper than the issues of power and control, it highlights the ways in which interaction with the technology shapes behavior, and the not always acknowledged fact that all technologies have biases built into them, thus favoring some situations and behaviors over others (see for instance, Winner 1980; Latour 1991). Wearable computers shape the way in which the world is experienced because, in one way or another, they mediate the wearers' engagement with the world, arguably more intimately than ever before. Thus, the question is not so much whether we are empowered or controlled by the technology, but whether the technology is able to faithfully process and facilitate all types of human behavior. In what ways does this mediation shape the wearer's engagement with the world? What are the biases of wearable computing?

Marshall McLuhan discusses some of the implications of augmenting ourselves through technology. For McLuhan (1962, 1964, 1988) the human psyche and social complex is affected every time a new technology is introduced. Every augmentation introduces a change in the ratio of senses, and is always accompanied by a reduction. For instance, McLuhan (1962) argued that in the shift from oral and tactile cultures to a literate culture, the individual gained a sense of perspective and individualism, but lost a sense of identification with the world and with his/her community. Mumford (1972) made a similar argument when saying that as a result of over-dependence on the car man had begun losing his legs.

The same question can be asked about wearable computers. While augmenting ourselves through this new digital prosthesis, what is being lost? With wearable computers this question is even more pertinent, since the body is not only being extended, its 'nature' is also being transformed. The body is becoming part of the information loop, becoming part of the global information network system.

The process of mediation is a good example. For a wearable to learn to adapt to its user to the point of predicting his/her next move, it relies on continuous, constant usage. This learning can be made more efficient and effective, optimizing further usage, if the wearer sticks to regular patterns of behavior. Variables that are unknown or new will not be effectively processed and may cause delay in the response, or be ignored altogether. There is a danger, then, that wearable computers will favour the known – the routine, or that which is pre-programmed – while filtering out the unknown, the new.

The unknown can also be that which cannot be quantified, that which cannot be computationally assessed. Certain human faculties, like spontaneity and instinct, are not easily measured and predicted. Will these be devalued in favour of those that are more compatible with computational logic? If, for instance, doctors rely on computers to help them diagnose illnesses, is it possible that when the computer cannot complete a diagnosis the doctor will be too afraid to go with his/her experience?[13]

Wearable computers can also be used, deliberately or not, to influence social interaction and behavior. If wearable computer makers decide, as most European cell phone carriers did, to charge higher rates for communicating with someone who utilizes a different network, how will this affect interpersonal relationships? If it becomes easier and more convenient to communicate with individuals that are equipped with wearable computers, are all those who can't afford it, or don't know how to use it, going to be excluded? If the wearable does not work in the subway, will more people take the car to work? If, on the other hand, the connection speed is better in places sponsored by its brand (say, a given shopping center) will more people start shopping there? By enhancing connectivity with some actors in the environment, wearable computers create selective spaces of increased visibility while relegating others to invisibility.

Conclusion

Wearable computers are one of the best examples of the turn to a culture of augmentation. In an augmented culture, the human body is no longer simply extended through technology it becomes its host, creating new synergies between both. In this process the character and social role of body and technology change, and the effects this will have on personal and social behavior are still largely unknown. Some can be formulated in terms of empowerment and control, others are related to the ways in which the medium shapes the message, in this case human experience.

The shift from simulation to augmentation says much about the relationship between humans and machines, between bits and atoms. In a culture of simulation the digital imitates the physical and the human is taken as the model for the machine, while in a culture of augmentation this movement is reversed. Now, the physical is no longer imitated, it is rather enhanced by the digital. The human ceases to be the measure of all things, becoming insufficient and in need of improvement by joining the machine. For a long time man was the measure of all things. Is

[13] See Lightman's (2000) *The Diagnosis* for a fictional account of an episode of this sort.

it now time to “make humans in the image of the machine”?

Acknowledgements

The author wishes to thank Lucy Suchman, Michel Ferrari, and Keith Oatley for their insightful comments and suggestions on an earlier version of this paper.

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