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A study on
Wearable Computing for Children
by Sreejith Unnikrishnan

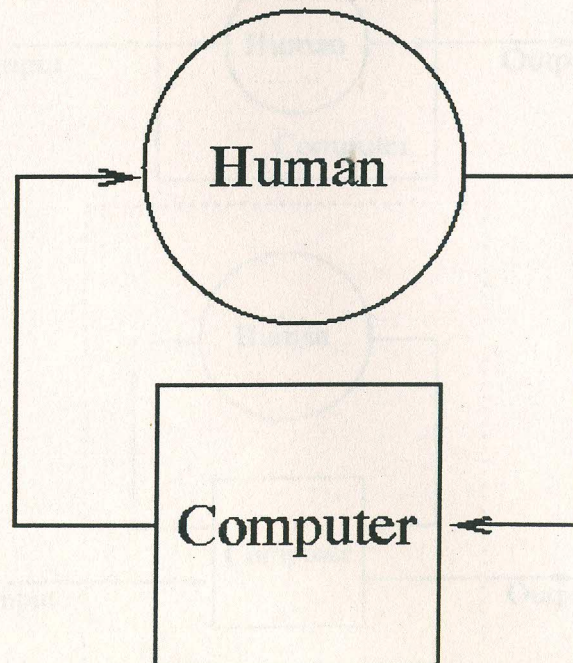
Guide: Prof. Ravi Poovaiah

Murad
(Ali Pamiak)

Wearable computing facilitates a new form of human—computer interaction comprising a small body—worn computer (e.g. user—programmable device) that is always on and always ready and accessible. In this regard, the new computational framework differs from that of hand held devices, laptop computers and personal digital assistants (PDAs). The “always ready” capability leads to a new form of synergy between human and computer, characterized by long-term adaptation through constancy of user—interface.

What is a wearable computer

A wearable computer is a computer that is subsumed into the personal space of the user, controlled by the user, and has both operational and interactional constancy, i.e. is always on and always accessible. Most notably, it is a device that is always with the user, and into which the user can always enter commands and execute a set of such entered commands, and in which the user can do so while walking around or doing other activities. The most salient aspect of computers, in general, (whether wearable or not) is their (reconfigurability) and their (generality), e.g. that their function can be made to vary widely, depending on the instructions provided for program execution. With the wearable computer, this is no exception, e.g. the wearable computer is more than just a wristwatch or regular eyeglasses: it has the full functionality of a computer system but in addition to being a fully featured computer, it is also inextricably intertwined with the wearer. This is what sets the wearable computer apart from other wearable devices such as wristwatches, regular eyeglasses, wearable radios, etc.. Unlike these other wearable devices that are not programmable (reconfigurable), the wearable computer is as reconfigurable as the familiar desktop or mainframe computer. Wearable computing will now be formally defined in terms of its three basic modes of operation and its six fundamental attributes.



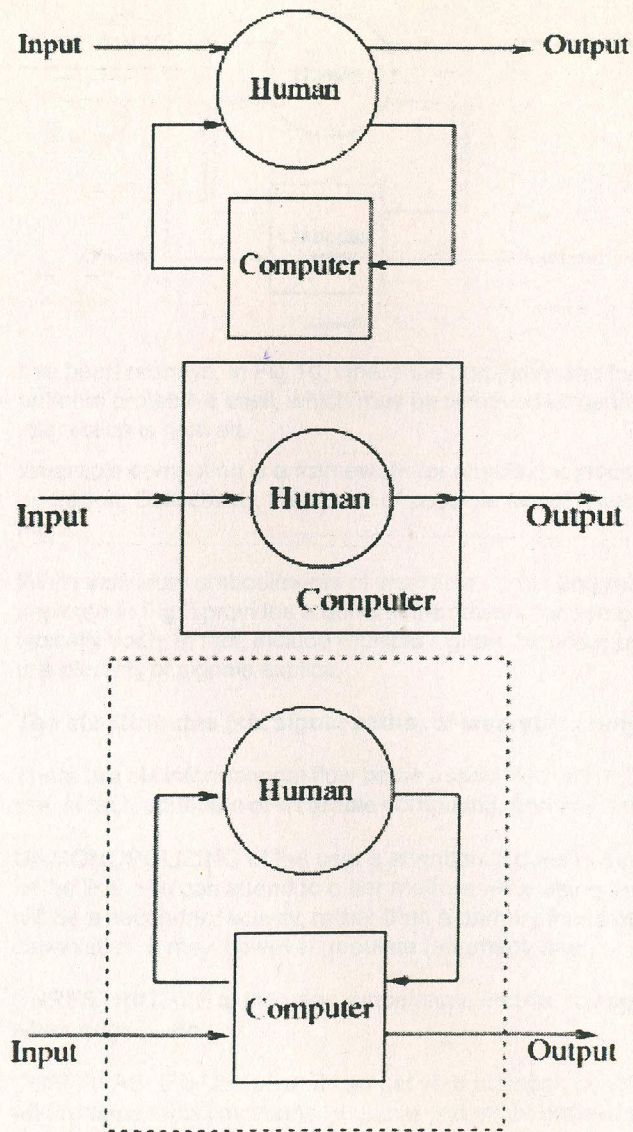
Operational modes of wearable computing

There are three operational modes in this new interaction between human and computer:

- **Constancy:** The computer runs continuously, and is "always ready" to interact with the user. Unlike a hand-held device, laptop computer, or PDA, it does not need to be opened up and turned on prior to use. The signal flow from human to computer, and computer to human, depicted in Fig 1a runs continuously to provide a constant user interface.

- **Augmentation:** Traditional computing paradigms are based on the notion that computing is the primary task. Wearable computing, however, is based on the notion that computing is NOT the primary task. The assumption of wearable computing is that the user will be doing something else at the same time as doing the computing. Thus the computer should serve to augment the intellect, or augment the senses. The signal flow between human and computer is depicted in Fig 1b.

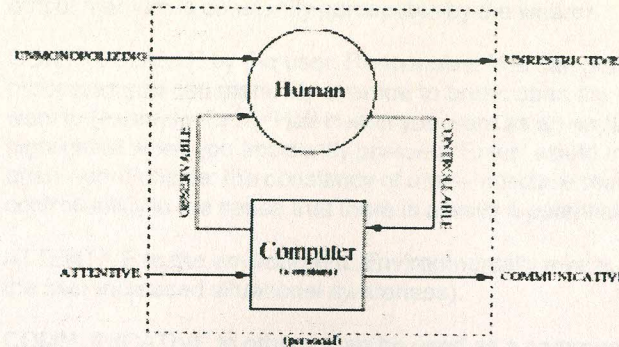
- **Mediation:** Unlike hand held devices, laptop computers, and PDAs, the wearable computer can encapsulate us (Fig 1c) It doesn't necessarily need to completely enclose us, but the concept allows for a



greater degree of encapsulation than traditional portable computers. There are two aspects to this encapsulation:

Solitude: It can function as an information filter, and allow us to block out material we might not wish to experience, whether it be offensive advertising, or simply a desire to replace existing media with different media. In less severe manifestations, it may simply allow us to alter our perception of reality in a very mild sort of way.

Privacy: Mediation allows us to block or modify information leaving our encapsulated space. In the same way that ordinary clothing prevents others from seeing our naked bodies, the wearable computer may, for example, serve as an intermediary for interacting with untrusted systems, such as third party digital anonymous cash "cyberwallets". In the same way that martial artists, especially stick fighters, wear a long black robe that comes right down to the ground, in order to hide the placement of their feet from their opponent, wearable computing can also be used to clothe our otherwise transparent movements in cyberspace. Although other technologies, like desktop computers, can help us protect our privacy with programs like Pretty Good Privacy (PGP), the achilles tendon of these systems is the space between us and them. It is generally far easier for an attacker to compromise the link between us and the computer (perhaps through a so-called trojan horse or other planted virus) than it is to compromise the link between our computer and other computers. Thus wearable computing can be used to create a new level of personal privacy because it can be made much more personal, e.g. so that it is always worn, except perhaps during showering, and therefore less likely to fall prey to covert attacks upon the hardware itself. Moreover, the close synergy between the human and computers makes it harder to attack directly, e.g. as one might peek over a person's shoulder while they are typing, or hide a video camera in the ceiling above their keyboard. Furthermore, the wearable computer can take the form of undergarments that are encapsulated in an outer



covering or outerwear of fine conductive fabric to protect from an attacker looking at radio frequency emissions. The actual communications between the wearer and other computers (and thus other people) can be done by way of outer garments, which contain conformal antennas, or the like, and convey an encrypted bitstream. Because of its ability to encapsulate us, e.g. in embodiments of wearable computing that are actually articles of clothing in direct contact with our flesh, it may also be able to make measurements of various physiological quantities. Thus the signal flow depicted in Fig 1a is also enhanced by the encapsulation as depicted in Fig 1c. To make this signal flow more explicit, Fig 1c

has been redrawn, in Fig 1d, where the computer and human are depicted as two separate entities within an optional protective shell, which may be removed or partially removed if a mixture of augmented and mediated interaction is desired.

Wearable computing is a framework for enabling various degrees of each of these three fundamental modes of operation. Collectively, the space of possible signal flows giving rise to this entire space of possibilities, is depicted in Fig 2.

While individual embodiments of wearable computing may use some mixture of these concepts, the signal path depicted in Fig 2 provides a general framework for comparison and study of these systems. The signal paths typically each, in fact, include multiple signals, hence multiple parallel signal paths are depicted in this figure to make this plurality of signals explicit.

The six attributes (six signal paths) of wearable computing

There are six informational flow paths associated with this new human—machine synergy. These signal flow paths are, in fact, attributes of wearable computing, and are described, in what follows, from the human's point of view:

UNMONOPOLIZING of the user's attention: it does not cut you off from the outside world like a virtual reality game or the like. You can attend to other matters while using the apparatus. It is built with the assumption that computing will be a secondary activity, rather than a primary focus of attention. In fact, ideally, it will provide enhanced sensory capabilities. It may, however, mediate (augment, alter, or deliberately diminish) the sensory capabilities.

UNRESTRICTIVE to the user: ambulatory, mobile, roving, "you can do other things while using it", e.g. you can type while jogging, etc.

OBSERVABLE by the user: It can get your attention continuously if you want it to. Almost—always—observable: within reasonable limitations (e.g. that you might not see the screen while you blink or look away momentarily) the

output medium is constantly perceptible by the wearer.

CONTROLLABLE by the user: Responsive. You can grab control of it at any time you wish. Even in automated processes you can manually override to break open the control loop and become part of the loop at any time you want to (example: "a big Halt button you want as an application mindlessly opens all 50 documents that were highlighted when you accidentally pressed "Enter" would make a computer more CONTROLLABLE. Infinitely—often—controllable: the constancy of user—interface results from almost—always observability and infinitely—often controllability in the sense that there is always a potential for manual override which need not be always exercised.

ATTENTIVE to the environment: Environmentally aware, multimodal, multisensory. (As a result this ultimately gives the user increased situational awareness).

COMMUNICATIVE to others: Can be used as a communications medium when you want it to. Expressive: allows the wearer to be expressive through the medium, whether as a direct communications medium to others, or as means of assisting the production of expressive media (artistic or otherwise).

Implied by the above six properties is that it must also be:

- **CONSTANT**: Always ready. May have "sleep modes" but never "dead". Unlike a laptop computer which must be opened up, switched on, and booted up before use, it is always on and always running.

- **PERSONAL**: Human and computer are inextricably intertwined.

- **PROSTHETIC**: You can adapt to it so that it acts as a true extension of mind and body; after time you forget that you are wearing it.

- **ASSERTIVE**: can have barrier to prohibition or to requests by others for removal during times when you wish such a barrier. This is in contrast to laptop computer in briefcase or bag that could be separated from you by a "please leave all bags and briefcases at the counter" policy of a department store, library, or similar establishment.

- **PRIVATE**: others can't observe or control it unless you let them. Others can't determine system status unless you want them to, e.g. clerk at refund counter in department store where photography is prohibited can't tell whether or not you are transmitting wireless video to a spouse for remote advice, in contrast to camcorder technology where it is obvious you are taking a picture when you hold it up to your eye.

Note that a computer mediation device with sufficient bandwidth can synthesize or even heighten the augmentational aspects. For example a sufficiently ATTENTIVE computer can sustain a sufficient illusion of being UNMONOPOLIZING that it could encapsulate the user and still provide the same experience as system running in the augmentational mode of operation. Similarly, a sufficiently COMMUNICATIVE machine, especially if "machine" is broadened to include mechanical mediation devices such as motorized exoskeletons, can synthesize the UNRESTRICTIVE attribute.

Fundamental issues of wearable computing

The most fundamental paradigm shift that wearable computing has to offer is that of personal empowerment. In order to fully appreciate the magnitude of this paradigm shift, some historical examples of tools of empowerment will

now be described to place wearable computing in this historical context.

Historical context

In early civilization, individuals were all roughly equal, militarily. Wealth was generally determined by how many head of cattle, or how many "mounts" (horses) a person owned. In hand-to-hand combat, fighting with swords, each individual was roughly an equal. Since it was impossible to stay on a horse while fighting, horses provided little in the way of military power, so that even those too poor to afford to keep a horse were not at a tremendous disadvantage to others from a fighting standpoint.

It was the invention of the stirrup, however, that radically changed this balance. With the stirrup, it became possible to stay on a horse while fighting. Horses and heavy armour could only be afforded by the wealthy, and even a large group of unruly peasants was no match for a much smaller group of mounted cavalry. However, toward the middle ages, more and more ordinary individuals mastered the art of fighting on horseback, and eventually the playing field leveled out.

Then, with the invention of gunpowder, the ordinary civilian was powerless against soldiers or bandits armed with guns. It was not until guns became cheap enough that everyone could own one — as in the "old west". The Colt 45, for example, was known as the "equalizer" because it made everyone roughly equal. Even if one person was much more skilled in its use, there would still be some risk involved in robbing other civilians or looting someone's home.

The shift from guns to cameras and computers

In today's world, the hand gun has a lesser role to play. Wars are fought with information, and we live in a world in which the appearance of thugs and bandits is not ubiquitous. While there is some crime, we spend most of our lives living in relative peace. However, surveillance and mass media have become the new instruments of social control. Department stores are protected with security cameras rather than by owners keeping a shotgun under the counter or hiring armed guards to provide a visible deterrent. While some department stores in rough neighbourhoods may have armed guards, there has been a paradigm shift where we see less guns and more surveillance cameras.

The shift from draconian punishment to micro management

There has also been a paradigm shift, throughout the ages, characterized by a move toward less severe punishments, inflicted with greater certainty. In the middle ages, the lack of sophisticated surveillance and communications networks meant that criminals often escaped detection or capture, but when they were captured, punishments were extremely severe. Gruesome corporeal punishments where criminals might be crucified, or whipped, branded, drawn and quartered, and then burned at the stake, were quite common in these times.

The evolution from punishment as a spectacle in which people were tortured to death in the village square, toward incarceration in which people were locked in a cell, and forced to attend church sermons, prison lectures, etc., marked the first step in a paradigm shift toward less severe punishments\cite{foucault}. Combined with improved

forensic technologies like fingerprinting, this reduction in the severity of punishment came together with a greater chance of getting caught.

More recently, with the advent of so-called "boot camp", where delinquent youths are sent off for mandatory military-style training, the trend continues by addressing social problems earlier before they become large problems. This requires greater surveillance and monitoring, but at the same time is characterized by less severe actions taken against those who are deemed to require these actions. Thus there is, again, still greater chance of being affected by smaller punishments.

If we extrapolate this trend, what we arrive at is a system of social control characterized by total surveillance and micro-punishments. At some point, the forces applied to the subjects of the social control are too weak to even justify the use of the word "punishment", and perhaps it might be better referred to as "micro management".

This "micro management" of society may be effected by subjecting the population to mass media, advertising, and calming music played in department stores, elevators, and subway stations.

Surveillance is also spreading into areas that were generally private in earlier times. The surveillance cameras that were placed in banks have moved to department stores. They first appeared above cash registers to deal with major crimes like holdups. But then they moved into the aisles and spread throughout the store to deal with petty theft. Again, more surveillance for dealing with lesser crimes.

In the U.K., cameras installed for controlling crime in rough areas of town spread to low crime areas as well, in order to deal with problems like youths stealing apples from street markets, or patrons of pubs urinating on the street. The cameras have even spread into restaurants and pubs — not just above the cash register, but throughout the pub, so that going out for pints, one may no longer have privacy.

Recently, electronic plumbing technology, originally developed for use in prisons, for example, to prevent all inmates from flushing the toilets simultaneously, has started to be used in public buildings. The arguments in favor of it go beyond human hygiene and water conservation, as proponents of the technology argue that it also reduces vandalism. Their definition of vandalism has been broadened to include deliberately flooding a plumbing fixture, and deliberately leaving faucets running. Thus, again, what we see is greater certainty of catching or preventing people from committing lesser transgressions of the social order.

One particularly subtle form of social control using this technology, is the new hands free electronic showers developed for use in prisons where inmates would otherwise break off knobs, levers, and pushbuttons. These showers are just beginning to appear in government buildings, stadiums, health clubs, and schools. The machine watches the user, from behind a tiled wall, through a small dark glass window. When the user steps toward the shower, the water comes on, but only for a certain time, and then it shuts off. Obviously the user can step away from the viewing window, and then return, to receive more water, and thus defeat the timeout feature of the system, but this need to step away and move back into view is enough of an irritant as to effect a slight behavioural modification of the user. Thus what we see is that surveillance has swept across all facets of society, but is being used to deal

with smaller and smaller problems. From dealing with mass murderers and bank robbers, to people who threaten the environment by taking long showers, the long arm of surveillance has reached into even the most private of places, where we might have once been alone. The peace and solitude of the shower, where our greatest inspirations might come to us, has been intruded upon with not a major punishment, but a very minor form of social control, too small in fact to even be called a punishment.

These surveillance and social control systems are linked together, often to central computer systems. Everything from surveillance cameras in the bank, to electronic plumbing networks is being equipped with fiber optic communications networks. Together with the vast array of medical records, credit card purchases, buying preferences, etc., we are affected in more ways, but with lesser influence. We are no longer held at bay by mounted cavalry. More often than being influenced by weapons, we are influenced in very slight, almost imperceptible ways, for example, through a deluge of junk mail, marketing, advertising, or a shower that shuts off after it sees that we've been standing under it for too long.

While there are some (the most notable being Jeremy Bentham\cite{foucault}) who may argue that a carefully managed society results in maximization of happiness, there are others who argue that the homogenization of society is unhealthy, and reduces humans to cogs in a larger piece of machinery, or at the very least, results in a certain loss of human dignity. Moreover, just as nature provides biodiversity, many believe that society should also be diverse, and people should try to resist ubiquitous centralized surveillance and control, particularly to the extent where it homogenizes society excessively. Some argue that micromanagement and utilitarianism, in which a person's value may often be measured in terms of usefulness to society, is what led to eugenics, and eventually to the fascism of Nazi Germany. Many people also agree that, even without any sort of social control mechanism, surveillance, in and of itself, still violates their privacy, and is fundamentally wrong.

As with other technologies, like the stirrup and gunpowder, the electronic surveillance playing field is also being leveled. The advent of the low-cost personal computer has allowed individuals to communicate freely and easily among themselves. No longer are the major media conglomerates the sole voice heard in our homes. The World Wide Web has ushered in a new era of underground news and alternative content. Thus centralized computing facilities, the very technology that many perceived as a threat to human individuality and freedom, has given way to low cost personal computers that many people can afford. This is not to say that home computers will be as big or powerful as the larger computers used by large corporations or governments, but simply that if a large number of people have a moderate degree of computational resources, there is a sense of balance in which people are roughly equal in the same sense that two people, face to face, one with a 0.22 calibre handgun and the other with a Colt 0.45 are roughly equal. A large bullet hole or a small one, both provide a tangible and real risk of death or injury.

It is perhaps modern cryptography that makes this balance even more pronounced, for it is so many orders of magnitude easier to encrypt a message than it is to decrypt it. Accordingly, many governments have defined cryptography as a munition and attempted, with only limited success, to restrict its use, and some have even defined it as a munition.

Fundamental issues of wearable computing

The most fundamental issue in wearable computing is no doubt that of personal empowerment, through its ability to equip the individual with a personalized, customizable information space, owned, operated, and controlled by the wearer. While home computers have gone a long way to empowering the individual, they only do so when the user is at home. As the home is perhaps the last bastion of space not yet touched by the long arm of surveillance — space that one can call one's own, the home computer, while it does provide an increase in personal empowerment, is not nearly so profound in its effect as the wearable computer which brings this personal space — space one can call one's own — out into the world.

Although wearable computing, in the most common form we know it today (miniature video screen over one or both eyes, body worn processor, and input devices such as a collection of pushbutton switches or joystick held in one hand and a microphone) was invented in the 1970s for personal imaging applications, it has more recently been adopted by the military in the context of large government—funded projects.

However, as with the stirrup, gunpowder, and other similar inventions, it is already making its way out into the mainstream consumer electronics arena.

An important observation to make, with regards to the continued innovation, early adopters (military, government, large multinational corporations), and finally ubiquity, is the time scale. While it took hundreds of years for the stirrup to be adopted by the masses, and tens of years for guns to be adopted by the masses, the spread of computer technology must be measured in computer years. As the technology moves faster, the military is losing its edge. We are entering an era in which consumer electronics is surpassing the technological sophistication of some military electronics. Personal audio systems like the SONY Walkman are just one example of how the ubiquity and sophistication of technology feed upon each other to the extent that the technology begins to rival, and in some ways, exceed, the technical sophistication of the limited—production military counterparts such as two—way radios used in the battlefield.

Consumer technology has already brought about a certain degree of personal empowerment, from the portable cassette player that lets us replace the music piped into department stores with whatever we would rather hear, to small hand held cameras that capture police brutality and human rights violations. However, wearable computing is just beginning to bring about a much greater paradigm shift, which may well be equivalent in its impact to the invention of the stirrup, or that of gunpowder. Moreover, this leveling of the playing field may, for the first time in history, happen almost instantaneously, should the major consumer electronics manufacturers beat the military to raising this invention to a level of perfection similar to that of the stirrup or modern handguns. If this were to happen, this decreasing of the time scale over which technology diffuses through society will have decreased to zero, resulting in a new kind of paradigm shift that society has not yet experienced.

Aspects of wearable computing and personal empowerment

There are several aspects and affordances of wearable computing. These are:

- Photographic memory: Perfect recall of previously collected information.
- Shared memory: In a collective sense, two or more individuals may share in their collective consciousness, so that one may have a recall of information that one need not have experienced personally.
- Connected collective humanistic intelligence: In a collective sense, two or more individuals may collaborate while one or more of them is doing another primary task.
- Personal safety: In contrast to a centralized surveillance network built into the architecture of the city, a personal safety system is built into the architecture (clothing) of the individual.
- Tetherless operation: Wearable computing affords and requires mobility, and the freedom from the need to be connected by wire to an electrical outlet, or communications line.
- Synergy: Rather than attempting to emulate human intelligence in the computer, as is a common goal of research in Artificial Intelligence (AI), the goal of wearable computing is to produce a synergistic combination of human and machine, in which the human performs tasks that it is better at, while the computer performs tasks that it is better at. Over an extended period of time, the wearable computer begins to function as a true extension of the mind and body, and no longer feels as if it is a separate entity. In fact, the user will often adapt to the apparatus to such a degree, that when taking it off, its absence will feel uncomfortable, in the same way that we adapt to shoes and clothing to such a degree that being without them most of us would feel extremely uncomfortable whether in a public setting, or in an environment in which we have come to be accustomed to the protection that shoes and clothing provide. This intimate and constant bonding is such that the combined capabilities of the resulting synergistic whole far exceeds the sum of either. Synergy, in which the human being and computer become elements of each other's feedback loop, is often called Humanistic Intelligence (HI).
- Quality of life: Wearable computing is capable of enhancing day-to-day experiences, not just in the workplace, but in all facets of daily life. It has the capability to enhance the quality of life for many people.

The terminology used to describe wearable computers and differentiate it from other types of computers and computing focuses on three aspects: how it is physically used, what is the environment of use, and what is the application?

Usage of the Wearable Computer

Two desirable characteristics of a wearable computer are use while in motion and use with one or both hands free. Neither of these characteristics characterize fully the wearable computers, but both convey the general spirit of what many desire in a wearable computer.

Mobility is a characteristic of several different types of computers; in particular "wearable computers" are as mobile as the individuals wearing them. Laptops are mobile. Nomadic computers, as pioneered by Steve Roberts, founder of Nomadic Research Labs (larger computers attached to bicycles or other transporting mechanisms) are mobile. So although everyone agrees that wearable computers are mobile, not all mobile computers are wearable, unless we extend the notion of "wearable" to include vehicles and the like.

"One or both hands free" is also a desirable characteristic. Wearable computers that leave both hands free include systems with speech-based input and other evolving hands-free input devices. Many current wearable computers use some form of single hand based input device such as a chording keyboard, a dial, or a pointing device.

Environment of Use

Wearable computers are used in a variety of different environments. Some are used without any environmental support. They are stand alone devices for data collection or delivery and are connected to an environment only for discharging their data or collecting new data for delivery in a process separate from their normal usage.

Wearable computers are also used to connect to an environment generally but not universally available. They can connect to the Internet, telephony infrastructure, GPS for location awareness, or a local area network, for example. Finally, wearable computers may connect to a specialized environment (for example, Boeing's "work cell") such as a room wired with special-purpose position monitoring sensors or special purpose cameras.

Wearable computers overlap with but are different from ubiquitous computers. Ubiquitous computers may or may not be worn. Active badges, for example, are worn. Smart desks, for another example, are not worn.

Application of the Computer

Some people advocate using the applications for which a computer is used as the defining characteristic. Wearable computers provide for private, information based applications. Thus, terms such as Personal Information Processing System and Personal Information Architecture were proposed as alternatives for the term wearable computers.

Terminology Conclusions

Part of the reason for this flexibility in definition is that there is considerable diversity in possible avenues of pursuit in this very broad field of research. That is, a wristwatch, with sufficient computational capability (e.g. heart rate monitor, wireless link to shoes, etc.) might fall under the general umbrella of "wearable computers" as well. Another example of such a system includes the portable maintenance aid designed to provide information to a technician at a maintenance site while some repair operation is underway. These "wearable information tools" generally provide the user with some sort of assistance.

Any definition will depend on agreement that does not yet exist on whether specific examples are wearable computer. Some of the issues associated with such a definition have been explored and have been characterized wearable computer with respect to other terms. It is declared that wearable computers are nomadic and mobile but not vice versa. It is also declared that there is an overlap between wearable computers and ubiquitous computers but no subsumption in either direction. The extent to which both the "wear" and the "computer" are important. This certainly provides a context for the four discussions that follow: market, technology, people, and application.

Market

One aspect that colors many of the disagreements in both approach and philosophy among the participants in the

workshop is the assumed market for their particular type of wearable computer. In this section the different types of markets are discussed and the assumptions made by various systems builders. The problem of acceptance of wearable computers has also been discussed. What are the inhibitors to general acceptance of wearable computers and how can these inhibitors be broken down? What are the market issues?

Type of Wearer

A fundamental source is the question of who is the target audience for the type of system under discussion. Four types of possible targets have been identified, each with their different characteristics.

Expert User (Analogous to Programmer/Hardware Hacker)

This system is owned, operated, and controlled by the wearer of the system. The wearer is assumed to be a computer sophisticate not only capable but desirous of configuring their own hardware and software. A typical system is constructed from components and the main goal of the wearer is either exploration of the technology or the ability to access customized, special purpose applications. An expert user system is considered a personal artifact and is not shared with others. This system communicates and exchanges data with other systems at the level of communication protocols.

Mass Horizontal Market User (Analogous to Home Computer User)

This system is owned, operated, and controlled by the wearer of the system. The wearer is not assumed to be a computer sophisticate capable or desirous of configuring their own hardware and software. This class of wearer demands ease of use and standard pre-programmed functionality. The wearer buys the unit off the shelf and the goal of the wearer is either perceived utility or enhanced social relationships. A system is considered a personal artifact and is generally not shared (or if shared, only with close personal friends or relatives). This system communicates and exchanges data with other systems at the level of data formats.

Dedicated Vertical Application User (Analogous to Typical Office Worker)

This system is owned and controlled by the employer of the wearer. The wearer may or may not be a computer sophisticate and is often discouraged or prevented from configuring either the hardware or the software of the system. This class of wearer accesses standard pre-programmed functionality although depending on the environment, they may be willing to take training in the use of the system. The employer buys or creates a custom system that is pre-configured for the applications of interest. The system sometimes is required to operate in an environment which is unfriendly to electronic systems; i.e. wet, cold, or noisy. The goal of the wearer of the system is increased productivity. This system may be shared in the same fashion as other tools in the workplace are shared. This system communicates and exchanges data with other systems at the level of data formats.

Physically Challenged User (Assistive Technology)

This system is tailored to the needs of a single individual with a unique set of disabilities. The wearer is not assumed to be a computer sophisticate capable or desirous of configuring their own hardware and software. This class of wearer also demands ease of use and standard pre-programmed functionality. The wearer buys a custom tailored system and the goal of the wearer is an enhanced ability to function in a predominantly non-disabled world. The system is desired to operate in many different environments and communicate with widely disparate external systems; i.e. automatic tellers machines, appliances, public transportation systems, etc. The system is typically not designed to be shared. This system communicates and exchanges data with other systems at the level of data

formats.

Market Niches

As can be seen from the proceeding discussion about the types of wearers, we are recreating a standard dichotomy between vertical (specialized) and horizontal (general purpose) markets. General purpose systems are designed to attract a very large market and are suitable for many different applications. Consequently, they are optimized for no particular application but because of competition and economies of scale, may eventually become available more cheaply and readily than specialized single task systems. Specialized features are typically designed for a particular type of wearer and, consequently, can be optimized for their use.

It is worth noting that, historically, there is a divide between general purpose and special purpose features that narrows over time but the products that end up in the divide struggle for acceptance for some time prior to general adoption (or rejection). The time period assumed is seven years. That is, there is a seven year period from the introduction of a technology that is aimed at extending the range of general purpose devices toward special purpose applications to the acceptance of this technology.

Inhibitors to General Acceptance of Wearable Computers

Four inhibitors to general use of wearable computers in vertical markets and one additional inhibitor in the horizontal market.

- **Ease of use of the user interface.** The user interface must be natural for the wearers. Since these devices in the vertical market are intended to be productivity enhancers, user interfaces that lead to incorrect operation will decrease productivity rather than increase it. In the horizontal market, unless there is great utility perceived from the devices, complicated user interfaces will face consumer resistance. A challenge in the user interface area is to have the user interface be learnable in 10 minutes by a new wearer.

- **Ergonomics and obtrusiveness of the device.** The wearable computer itself must be light weight, comfortable to the wearer in all conditions of use, and operate for a long time without battery change or charge. Any head-mounted display (HMD) must not call attention to the wearer. In an industrial or military environment, the HMD can be clearly noticeable but the total weight of the unit must be low. In an industrial environment, the HMD should be no more obtrusive than a pair of safety goggles or hard hat. In the consumer environment, the HMD should be no more obtrusive than a pair of glasses. The ultimate test of obtrusiveness might be whether or not a wearer is able to gamble in a Las Vegas casino without challenge.

- **Loss of dignity or self-determination.** In an extreme example, if there were a potential for surveillance of the wearer, the system might be unacceptable (assuming we rule out systems designed for tracking prisoners, etc.). In other subtle ways, there was a general fear that systems might be used to manipulate people through control and observation.

- **Necessity for new applications.** Conventional desktop computing metaphors are inappropriate for wearable computers; i.e. display size, hands-free interface, speech-enabled applications, etc. This requires new user interface designs for applications destined to run on a wearable computer.

- **Social acceptability.** In the consumer market, a certain amount of obtrusiveness is acceptable if the wearer either achieves a great deal of utility from the use of the wearable computer or if it is socially acceptable to wear a

computer. Social trends and fashion trends are difficult to predict but encouraging fashion leaders to wear computers will tend to break down barriers to general consumer acceptance of wearable computers.

Technology

The heart of a wearable computer is the technology used. It is the shrinkage of the components involved both in terms of weight and power requirements that makes wearing a computer a feasible activity. received little attention at the workshop. It is assumed that the actual computational portion of a wearable computer (the processor, memory, disks), are either sufficiently small so as not to represent significant issues or that they shortly will be that small. The focus is on a small part; i.e., Computer Human Interface. What receives attention are communication devices (treated broadly). Such communication devices included input and output devices as well as communication to elements of a system off the body and communication within elements of a wearable system.

Input Devices

Several innovative input devices that could be useful for wearable computers were either demonstrated or discussed at the workshop. Some of these devices were finger based.

A device that monitors finger joint movement consists of finger mounted micro-accelerometers that transmit impact pulses across the skin to a wrist mounted receivers that transmit the pulse and finger identification to a palm top computer. Additional information can be input from the fingers by using angle detection in Data Gloves, thin film resistors in Cyber Gloves and myoelectric signals in the Cyber Finger. The finger may also be used as a pointing device in a personal imaging system.

Other devices are based on using the mouth or face as an input device. One form of input was voiceless speech that converts lip motion to text via a lip-reading camera or myoelectric signals. Another is the use of facial muscles to trigger an input signal. Many of these devices are currently in the experimental stage.

Displays

Several different categories of displays include head mounted displays, occasional hand held display with a keypad and a constant use hand held display.

Communication to Other Elements of a Computing System

A no energy fiber communication system consists of a passive pico cell in a 15 ft. by 15 ft. room which receives information over optical fiber and converts the information to a RF signal. The light to the RF converter is also driven by the light energy arriving over the optical fiber.

This system potentially has a very high bandwidth and its actual bandwidth is limited by the capacity of the receiving system. Thus, installation costs of this communication system would only need to be borne once and upgrade to

higher speed communication systems would occur automatically as the wearable computers are equipped with higher speed receivers.

Communication among Elements of a Wearable Computer

Cables are one of the problematic areas of wearable computers. Cables are used to connect display devices with processors, for example. Every head mounted display currently in use requires a cable. Some input devices also require cables. Two approaches to eliminating cables from wearable systems. One of these is the use of the skin and the other is the use of clothing:

- Body based communication. The skin is capable of transmitting electric signals and can be used as a transmission medium. This is the basis of the finger input system demonstrated as well as demonstrations given elsewhere.

- Clothing based communication. Clothing can be made from optically based fibers and this can be used both as an internal communication infrastructure and a sensor for body stimuli. Body stimuli might include indicators of stress and mood as well as indicators of health.

People

The fundamental people issue is "what does it take to provide appropriate utility and ease of use to the targeted wearer community in the targeted environment". Within this capsule statement are four phrases that are discussed in more detail: targeted environment, targeted wearer community, ease of use and appropriate utility.

Targeted Environment

Wearable computers represent a total reversal from the days when the computers had to be air conditioned and humidity controlled and humans did not. A wearable computer must accompany its wearer if it is to be useful in its assigned tasks. A typical computer wearer operates out of doors as well as in a more controlled environment. This means that the wearable computer must be usable in conditions of bright sunlight as well as conditions of darkness. It means that it must be usable in conditions of heat and cold, of dryness and wetness, and in conditions of dirtiness and dustiness.

It isn't necessarily feasible for a single system to be able to operate satisfactorily in all of these different environmental conditions but it is incumbent on the designer of a wearable system to consider the conditions under which it will operate satisfactorily and make those constraints known to the consumer of the system.

Targeted Wearer Community

Four distinct wearer communities, each with its own needs are: the expert user, the mass horizontal market user, dedicated vertical application user, and the physically challenged user. Issues such as ease of use and utility will be different for each of these communities.

Ease of Use

Two, maybe conflicting, currents affect the ease of use of wearable computers. First is the user interface paradigm and second is the level of compatibility with existing desktop systems.

User interface paradigm. The desktop metaphor with its files and folders is suitable for a computer system that is used mostly for writing, calculating and other activities that occur at a desktop. It isn't necessarily optimal for a computer system that is worn by the user and operated without a modern pointing device in a variety of environments. The user interface should reflect the types of applications for which the system is to be used and the fact that the system is worn on the body. This reflection may be as simple as using pockets instead of folders as an organizing icon but is likely much deeper. Additionally, the metaphor of the point and click graphical user interface (GUI) quickly breaks down in speech enabled applications or other cases lacking a pointing device.

Compatibility with existing systems. Compatibility with existing systems both in the look and feel of a wearable system and in the ability to exchange data with existing applications is desirable. Use of existing look and feel has the virtue of enabling wearers to utilize their existing computer skills and to transfer these skills back and forth to the desktop. This ease of learning and transfer assumes that wearers are already computer users which is not necessarily true. Depending on the wearer community the users may or may not want to move between their wearable system and a desktop computer. In any case, ease of learning is only one aspect of ease of use and compatibility with existing look and feel must be traded off with total functionality. On the other hand, compatibility with data formats of existing desktop applications is essential to enable data to be easily moved between the wearable system and other systems with which the wearer will be interacting (even if indirectly). It is unlikely that wearable systems are going to be processing data that is different in kind from the type of data already being processed by desktop systems and so ensuring compatibility of data formats is a matter of appropriately engineering the wearable systems. Translators and virtual software layers are existing techniques that can be utilized to gain data format compatibility.

Appropriate Utility

Wearable systems should be fit for the tasks for which they are used. This is a main responsibility of the designer of such systems. Fitness for use implies paying attention to safety and ergonomics issues. It also means providing the ability, if the task requires it, to collaborate with others outside of the wearers immediate environment.

Safety and Ergonomics.

The safety issues associated with wearing a computer are two: (1) A wearer's attention is divided between the computer and other tasks being performed such as walking or driving. Clearly, paying attention to the computer at an inappropriate time could cause catastrophic results. Some forms of input and output are more attention dividing than others. Research is necessary to determine the amount of attention required to interact with a computer and to determine the amount that can be spared from everyday tasks such as walking and driving. (2) Cognitive dependence on the wearable computer from longer-term use. The hazard is that upon system failure, the user could be at risk (e.g. during a long bike trip when the user might have developed a reliance on a navigation system

comprising radar, GPS, etc.). Head mounted displays introduce their own safety issue since they occlude vision in some manner. Again, the amount of occlusion that presents a safety hazard in different environments must be determined through research. Head mounted display manufacturers and system builders must be aware of the safety issue. The results from long term usage of displays are also not well understood. Headaches, fatigue and other undesirable symptoms may result after extensive usage of the displays. Systems that are worn for a lengthy period of time will introduce various discomforts in the wearers. These results are going to vary depending on the age and physical characteristics of the wearer but, again, system designers and manufacturers of the various components must be aware of and take responsibility for the long term effect of using their systems.

Collaboration

For many tasks, it is important for the wearer to collaborate with other people. For example, a shopper may wish to send an image of a new sofa to a spouse for an opinion, a mechanic may wish to send a picture of a troublesome part to a remote expert for assistance in replacing that part, or an office user may want to share a screen display with a person seated nearby. Thus, a portion of the wearable system consists of image collectors, senders, and displays. How such functions should be integrated with other functions and with the user interface and how the wearer should interact with remote collaborators are all open questions.

Applications

At the workshop, six different types of applications were discussed: those for the disabled, personal use for day-to-day living, manufacturing, maintenance, emergency medical treatment and training. We now discuss these six application areas in more detail.

Disabled

The type of wearable system a disabled person will wear depends on the type of disability that they have. At the workshop, a system for the blind was demonstrated. This system was designed to help the blind with their global navigation problems. That is, where am I and how do I get to where I want to be. The system had a GPS connection, earphones to alert the wearer as to upcoming changes in direction or leaving the correct route and a planner that enables the wearer to inform the system as to a desired destination and route to that destination. There was much discussion about the appropriate type of system to accommodate for other handicaps but no one else had any specific system experience to discuss.

Personal

A wearable computer by virtue of always being with the wearer provides the opportunity to enhance individual capabilities. It also provides an opportunity to sense and act on aspects of the wearer not normally available to sensors.

The types of enhancement include those done at the direct behest of the wearer such as accessing a data base with information and those done by agents operating at the indirect behest of the wearer such as recognizing a face

and calling up identification information.

The types of actions based on sensing the wearer include: playing music of a particular type in response to mood sensing, health monitoring and reporting, and interrupting the wearer with e-mail and other messages when the wearer is not actively engaged in some other task.

Manufacturing

Data collection and quality control in food processing were discussed. These applications involved tasks which required the operators to use both hands while collecting the desired data. Additionally, the nature of the materials being handle precluded the use of hand based input devices; i.e. food products subject to contamination. Speech was used exclusively with visual and audio user feedback. Wireless RF networking was employed to log the data to a central database in real-time. High level industrial noise (>90db) offered many design challenges for speech input. Augmented reality manufacturing applications were also presented. That is, the computer system has some mechanism for sensing the wearer's field of view and then overlaying computer generated imagery over the real world being viewed. Thus, for example, assembling wire bundles for aircraft involved overlaying placement of the next wire in the wire bundle on an installation grid or assembling composite components involved overlaying templates over physical molds.

Maintenance

Maintenance applications discussed were not augmented reality but were concerned with delivering and receiving information to or from a maintenance technician. Generally, what was being delivered were repair procedures, schematics and trouble-shooting procedures, and what was being received from the technician was inspection information. One system for automobile repair was speech based, other systems used hand based input devices.

Emergency Medical Treatment

Emergency medical technicians (EMT) use wearable computers to take notes at the site of an accident, to monitor vital signs and transmit them to a hospital in advance of their arrival and to retrieve protocols of treatment. Speech has been used to navigate experimental systems but EMTs operate in very noisy environments and the system has to be able to recognize spoken commands in the presence of loud ambient sounds and stress.

Training

Wearable computers can be used in either classroom based training or on the job training. In the classroom, by having wearable computers that are aware of their location and that can communicate via wireless methods to larger systems, students can, for example, make personal annotations on materials presented in the class. On the job, for another example, manuals and procedures can be fed to students as they are trained to perform those kinds of tasks we have discussed above. The distinction between consulting with a remote expert and consulting with an instructor is very small for a person on the job.

Rigorous usability studies and experimental design evaluations are a much underused tool in computer science. Many of the tools used psychological research can be applied directly to computer science. Experimental design and statistics can be used to study the usability of a wearable computer system. Evaluations of the hardware and software can reveal information about the compatibility and effects on a wearable computer. Because much of the hardware and software used in a wearable system is newer technology it has not been around long enough to fully realize its capabilities and compatibility. It is critical to study and evaluate the systems and their effect on a wearable system. The constraints on user interfaces and size of hardware make usability studies critical to evaluating the system as a whole. I propose that these studies should be an incremental process over the lifetime of a wearable research project.

Experimental Design Evaluations

The University of Oregon recently did an experiment on the effect of a heads-up display (HUD) on pointing time. Because the HUD is a recent technology not much is known about the effects on performance using a HUD will have. The study found no significant difference between a HUD and a monitor which is important because many wearable computers will use a HUD of some form for a display device. The other hardware devices such as global positioning, wireless networks, alternative user input devices, and speech recognition systems are newer devices and the compatibility and performance can be evaluated in the same manner. The information gain by such studies could benefit the wearable computer environment by providing a base of knowledge and suggest which devices to move use. The older established technology is miniaturized and the impacts on the system can be evaluated in the same manner. Statistical methods can be used to compare the performance of different devices. By doing these studies in parallel with current research the results will aid in decisions about which devices and software packages to use.

Usability Studies

The constraints on the user interfaces and input devices make developing wearable computer challenging. The small screen size and low resolution of the screen make the design of a user interface difficult. The fonts much be larger and task switching become critical to making a wearable computer usable. The environment where the wearable computer is used will be constantly changing and the user interface will have to be adaptable to a number of constraints. The unsuitability of traditional pointing devices such as a mouse call for the need for alternative method of interacting with the user interface. A task oriented experiment can be used to evaluate the usability of a user interface and the interaction of user input. It is critical to test the system on non-computer science based users to reflect the actual user base of the wearable computer. Video taping users completing goal directed task can reveal flaw and successes in the user interface. As prototype wearable computers are developed usability studies will guide future development and research to make better devices.

Conclusion

By combining the results of usability studies and experimental design evaluations much can be learned about which directions to move towards in developing wearable computers. The HUD experiment recently completed at the

University of Oregon shows promise for using HUD in a wearable computer without impacting the performance of pointing related tasks. The wearable environment precludes most pointing devices due to lack of desktop space but the results provide a baseline metric for the general performance of the HUD. These tools are very underused in the general field of computer science and could add to the base of knowledge in computer science. The unique characteristics of the wearable computer field lend itself to studies of this form and can save time and money in many areas within the field. The small amount of reliable, valid studies that have been done on devices and user interfaces is worth studying to guide the future development of wearable computers.

A brief History of Wearable Computing

Foundations (F): Thinkers, innovations, and experiments that helped pave the way for wearable computers.

Complete Systems (C): Complete wearable computers (general or special purpose)

- 1268 (F): · Earliest recorded mention of eyeglasses
- 1665 (F): · Robert Hooke calls for augmented senses
- 1762 (F): · John Harrison invents the pocket watch
- 1907 (F): · Aviator Alberto Santos-Dumont commissions the creation of the first wristwatch
- 1945 (F): · Vannevar Bush proposes the idea of a "Memex" in his article "As We May Think" [MIT]
- 1960 (F): · Heilig patents a head-mounted stereophonic television display.
- 1960 (F): · Manfred Clynes coins the word "Cyborg"
- 1966 (C): · Ed Thorp and Claude Shannon reveal their invention of the first wearable computer, used to predict roulette wheels [MIT]
- 1966 (F): · Sutherland creates first computer-based head-mounted display [MIT]
- 1967 (F): · Bell Helicopter experiments with HMDs with input from servo-controlled cameras [Bell Helicopter]
- 1967 (C): · Hubert Upton invents analogue wearable computer with eyeglass-mounted display to aid lipreading [Bell Helicopter]
- 1968 (F): · Douglas Engelbart demonstrates chording keyboard in NLS (oN Line System) [SRI]
- 1972 (C): · Alan Lewis invents a digital camera-case computer to predict roulette wheels [Cal Tech]
- 1977 (C): · CC Collins develops wearable camera-to-tactile vest for the blind [Smith-Kettlewell]
- 1978 (C): · Eudaemonic Enterprises invents a digital wearable computer in a shoe to predict roulette wheels [Eudaemonic Enterprises]
- 1979 (F): · Sony introduces the Walkman [Sony]
- 1980 (F): · Upton and Goodman file for patent on LED raster display [Textron, Inc]
- 1981 (C): · Steve Mann designs backpack-mounted computer to control photographic equipment
- 1983 (C): · Taft commercializes toe-operated computers based on Z-80's for counting cards
- 1984 (F): · William Gibson writes Neuromancer
- 1986 (C): · Steve Roberts builds Winnebiko II, a recumbent bicycle with on-board computer and chording keyboard
- 1987 (F): · The movie Terminator is released

·	1989 (F): ·	Private Eye head-mounted display sold by Reflection Technology [Reflection Tech]
·	1990 (C): ·	Gerald Maguire and John Ioannidis demonstrate the Student Electronic Notebook, with Private Eye and mobile IP [Columbia]
·	1990 (F): ·	Olivetti develops an active badge system, using infrared signals to communicate a person's location [Olivetti]
·	1991 (C): ·	Doug Platt debuts his 286-based "Hip-PC" [Select Tech]
·	1991 (C): ·	CMU team develops VuMan 1 for viewing and browsing blueprint data [CMU]
·	1991 (F): ·	Mark Weiser proposes idea of Ubiquitous Computing in Scientific American [Xerox PARC]
·	1993 (C): ·	Thad Starner starts constantly wearing his computer, based on Doug Platt's design [MIT]
·	1993 (C): ·	BBN finishes the Pathfinder system, a wearable computer with GPS and radiation detection system [BBN]
·	1993 (F): ·	Thad Starner writes first version of the Remembrance Agent augmented memory software [MIT]
·	1993 (F): ·	Feiner, MacIntyre, and Seligmann develop the KARMA augmented reality system [Columbia]
·	1994 (C): ·	Lamming and Flynn develop "Forget-Me-Not" system, a continuous personal recording system [Xerox EuroPARC]
·	1994 (C): ·	Edgar Matias debuts a "wrist computer" with half-QWERTY keyboard
·	1994 (F): ·	DARPA starts Smart Modules Program
·	1994 (F): ·	Steve Mann starts transmitting images from a head-mounted camera to the Web [MIT]
·	1996 (F): ·	DARPA sponsors "Wearables in 2005" workshop
·	1996 (F): ·	Boeing hosts wearables conference in Seattle
·	1997 (F): ·	Creapôle Ecole de Création and Alex Pentland produce Smart Clothes Fashion Show
·	1997 (F): ·	CMU, MIT, and Georgia Tech co-host the first IEEE International Symposium on Wearables Computers

Details

1268 (F) **Earliest recorded mention of eyeglasses**

Roger Bacon made the first recorded comment on the use of lenses for optical purposes. However, by that time reading glasses made out of transparent quartz or beryl were already in use in both China and Europe.

1665 (F) **Robert Hooke calls for augmented senses**

Micrographia preface 1665: "The next care to be taken, in respect of the Senses, is a supplying of their infirmities with Instruments, and as it were, the adding of artificial Organs to the natural... and as Glasses have highly promoted our seeing, so 'tis not improbable, but that there may be found many mechanical inventions to improve our other senses of hearing, smelling, tasting, and touching."

1762 (F) **John Harrison invents the pocket-watch**

Harrison invented the first practical marine chronometer, a highly accurate and reliable clock needed to determine

the longitude of a ship.

1907 (F) Aviator Alberto Santos-Dumont commissions the creation of the first wristwatch

Alberto Santos-Dumont, one of the early experimenters in heavier-than-air flying machines, commissioned the famous jeweler Louis Cartier to manufacture a small timepiece with a wristband to his specifications. The wristwatch allowed him to keep his hands free for piloting.

1945 (F) Vannevar Bush proposes the idea of a "memex" in his article "As We May Think" [MIT]

While Bush thought the memex would be desk-sized rather than wearable, it is an early mention of the augmented memory. "Consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory."

1960 (F) Heilig patents a head-mounted stereophonic television display.

In 1960 Heilig patented a stereophonic television Head-Mounted Display (HMD). This was followed by his patent in 1962 for the "Sensorama Simulator" (US Patent #3,050,870), a virtual reality simulator with handlebars, binocular display, vibrating seat, stereophonic speakers, cold air blower, and a device close to the nose that would generate odors that fit the action in the film. See "Virtual Reality" by Howard Rheingold, 1991, pp. 49-67.

1960 (F) Manfred Clynes coins the word "Cyborg"

Manfred Clynes and co-author Nathan Kline first coined the phrase "Cyborg" in a story called "Cyborgs and Space" published in *Astronautics* (September 1960). The term was used to describe a human being augmented with technological "attachments". The story has since been reprinted in "The Cyborg Handbook" edited by Chris Hables Gray.

1966 (C) Ed Thorp and Claude Shannon reveal their invention of the first wearable computer, used to predict roulette wheels [MIT]

The system was a cigarette-pack sized analog computer with 4 push buttons. A data-taker would use the buttons to indicate the speed of the roulette wheel, and the computer would then send tones via radio to a bettor's hearing aid. Though the system was invented in 1961, it was first mentioned in E. Thorp, *Beat the Dealer*, revised ed. in 1966. The details of the system were later published in *Review of the International Statistical Institute*, V. 37:3, 1969. Thorp also disclosed a similar system for beating the Wheel of Fortune gambling game in *LIFE Magazine*, March 27, 1964, pp. 80-91.

1966 (F) Sutherland creates first computer-based head-mounted display [MIT]

Sutherland created a tethered HMD using two CRTs mounted beside each of a wearer's ears, with half-silvered mirrors reflecting the images to the user's eyes. Another system determined where the user was looking and projected a monoscopic wireframe image such that it looked like a cube was floating in mid-air. The bulk of the system was attached to the ceiling above the wearer's head, earning the system the nickname "Sword of Damocles." See <http://www.sun.com/960710/feature3/alice.html>

1967 (F) Bell Helicopter experiments with HMDs with input from servo-controlled cameras [Bell Helicopter]
Bell Helicopter Company performed several early camera-based augmented-reality systems. In one, the head-mounted display was coupled with an infrared camera that would give military helicopter pilots the ability to land at night in rough terrain. An infrared camera, which moved as the pilot's head moved, was mounted on the bottom of a helicopter. The pilot's field of view was that of the camera. See <http://www.sun.com/960710/feature3/alice.html> for more details.

1967 (C) Hubert Upton invents analogue wearable computer with eyeglass-mounted display to aid lipreading [Bell Helicopter]

Hubert Upton designed an analogue wearable computer as an aid for lip-reading. Using high and low-pass filters, the system would determine if a spoken phoneme was a fricative, stop, voiced-fricative, voiced stop, or simply voiced. An LED mounted on ordinary eyeglasses illuminated to indicate the phoneme type. The LEDs were positioned to enable a simple form of augmented reality; for example, when a phoneme was voiced the LED at the bottom of the glass illuminated, making it seem as if the speaker's throat was glowing. The work was presented at the Conference on Speech-Analyzing Aids for the Deaf, June 14-17, 1967, and was subsequently published in Upton, H, "Wearable Eyeglass Speechreading Aid," American Annals of the Deaf, V113, 2 March 1968, pp. 222-229.

1968 (F) Douglas Engelbart demonstrates one-handed chording keyboard in NLS (oN Line System) [SRI]

At the Fall Joint Computer Conference, Dec 8, 1968, Engelbart demonstrated the NLS system, one of the first personal computer that paved the way for both the interactive personal computer and groupware. The system included one-handed keyboard, word processing, outline processing, split windows, hypermedia, mouse, shared documents, e-mail filtering, desktop conferencing, annotation of shared documents, interactive sharing, quarter sized video sharing, turn taking, and network information.

1972 (C) Alan Lewis invents a digital camera-case computer to predict roulette wheels [Cal Tech]

Like Thorp and Shannon's system, Lewis used a radio link between data taker and bettor. The data-taker used the computer to predict the roulette wheel, then whispered the prediction via radio link to the bettor's hearing-aid radio-receiver.

1977 (C) CC Collins develops wearable camera-to-tactile vest for the blind [Smith-Kettlewell]

The result of ten years research, C.C. Collins of the Smith-Kettlewell Institute of Visual Sciences developed a five pound wearable with a head-mounted camera that converted images into a 1024-point, 10" square tactile grid on a vest. The system was tested as a visual prosthetic for the blind. See "Mobile Studies with a Tactile Imaging Device," C.C. Collins, L.A. Scadden, and A.B. Alden, Fourth Conference on Systems & Devices For The Disabled, June 1-3, 1977, Seattle WA.

1978 (C) Eudaemonic Enterprises invents a digital wearable computer in a shoe to predict roulette wheels [Eudaemonic Enterprises]

Using a CMOS 6502 microprocessor with 5K RAM, Eudaemonic Enterprises (Doyne Farmer, Norman Packard,

and others) created a shoe computer with toe-control and inductive radio communications with between a data taker and better. This is the only known roulette machine of the time to show a statistical profit on a gambling run, though they never made the "big score." See The Eudaemonic Pie, Thomas A. Bass, Houghton Mifflin Company, 1985.

1979 (F) Sony introduces the Walkman [Sony]

Sony introduces the Walkman, a commercial wearable cassette player. Later products would include Music CD-players.

1980 (F) Upton and Goodman file for patent on LED raster display [Textron, Inc]

Hubert Upton and James Goodman filed for a patent on a "vibratory scan optical display" where fiber-optical elements were driven by LEDs and scanned with an "electromechanical exciter." The patent was granted in 1982, patent number 311999.

1981 (C) Steve Mann designs backpack-mounted computer to control photographic equipment

While still in high-school Steve Mann wired a 6502 computer (as used in the Apple-II) into a steel-frame backpack to control flash-bulbs, cameras, and other photographic systems. The display was a camera viewfinder CRT attached to a helmet, giving 40 column text. Input was from seven microswitches built into the handle of a flash-lamp, and the entire system (including flash-lamps) was powered by lead-acid batteries.

1983 (C) Taft commercializes toe-operated computers based on Z-80's for counting cards

At least by 1983, Keith Taft was selling Z-80 based shoe-computers with special software for card-counting in blackjack. See The Eudaemonic Pie, Thomas A. Bass, Houghton Mifflin Company, 1985.

1984 (F) William Gibson writes Neuromancer

This book founded the genre of Cyberpunk, the dystopian future in which humans are augmented with computer implants.

1986 (C) Steve Roberts builds Winnebiko II, a recumbent bicycle with on-board computer and chording keyboard

Winnebiko II was the first of Steve Roberts' forays into nomadic computing that allowed him to type while riding. It included a packet data communication system for email via ham radio, an offline HP laptop, chording keyboard for typing while riding, and 20 watts of solar panels. The bike was later replaced by BEHEMOTH (Big Electronic Human-Energized Machine... Only Too Heavy), a more sophisticated system that included a heads up display. See <http://www.microship.com/>

1987 (F) The movie Terminator is released

Of special note are the scenes from the point-of-view of the Terminator cyborg, with text and graphical information overlaid on top of the real world.

1989 (F) Private Eye head-mounted display sold by Reflection Technology [Reflection Tech]

The display (designated the "P4") is a 720 x 280 pixel monochrome (red) monitor in a 3.5" X 1.5" X 1.25" package. Screen size is 1.25" on the diagonal, but the image appears to be a 15" display at 18" away. See <http://www.reflection.com/>

1990 (C) Gerald Maguire and John Ioannidis demonstrate the Student Electronic Notebook, with Private Eye and mobile IP [Columbia]

The IBM/Columbia Student Electronic Notebook Project used Toshiba diskless AIX notebook computers (prototypes) using direct sequence spread spectrum radio links to provide, the providing all the usual TCP/IP based services, NFS mounted file systems, X windows and a stylus based input systems + virtual keyboard, and running the Andrew environment. The work was first shown at the DARPA Workshop on Personal Computer Systems, Washington, D.C., 18 January 1990, and first published in J. Peter Bade, G.Q. Maguire Jr., and David F. Bantz, The IBM/Columbia Student Electronic Notebook Project, IBM, T. J. Watson Research Lab., Yorktown Heights, NY, 29 June 1990

1990 (F) Olivetti develops an active badge system, using infrared signals to communicate a person's location [Olivetti]

Olivetti developed a name badge that transmitted a unique id to IR receivers placed in rooms around a building. This allowed these "smart rooms" to track a person's location and log it in a central database. The badges measured 55x55x7mm, weighed 40g, and could be made extremely cheaply. See <ftp://ftp.orl.co.uk:/pub/docs/ORL/tr.90.2.ps.Z>

1991 (C) Doug Platt debuts his 286-based "Hip-PC" [Select Tech]

Doug Platt's system was a shoebox-sized computer based on the Ampro "Little Board" XT module. The screen was a Reflection Technology Private Eye display and the keyboard was an Agenda palmtop used as a chording keyboard attached to the belt. It included a 1.44 megabyte floppy drive. Later versions incorporated additional equipment from Park Engineering. The system debuted at "The Lap and Palmtop Expo" on April 16th, 1991.

1991 (C) CMU team develops VuMan 1 for viewing and browsing blueprint data [CMU]

Students in a Summer-term course at Carnegie Mellon's Engineering Design Research Center developed the VuMan 1, a wearable computer for viewing house blueprints. Input was through a three-button unit worn on the belt, and output was through Reflection Tech's Private Eye. The CPU was an 8 MHz 80188 processor with 0.5 MB ROM. See <http://www.cs.cmu.edu/afs/cs.cmu.edu/project/vuman/www/home.html>

1991 (F) Mark Weiser proposes idea of Ubiquitous Computing in Scientific American [Xerox PARC]

Ubiquitous Computing proposes a world in which most everyday objects have computational devices embedded in them. Weiser's Landmark article, The Computer for the 21st Century appeared the September 1991 issue of Scientific American, pp 66-75.

1993 (C) Thad Starner starts constantly wearing his computer, based on Doug Platt's design [MIT]

Starner had attempted previous wearables based on both a TRS-80 model 100 and a SPARC Workstation, but never got them working reliably. When he heard Doug Platt give a talk at the MIT Media Lab he shifted over to

Platt's system based on a 286 chip. In June '93, Platt and Starner custom made Starner's first working system with parts from a kit made by Park Enterprises, a Private Eye display, and the Twiddler chording keyboard made by Handykey. Many iterations later this system became the MIT "Tin Lizzy" wearable computer design. See <http://wearables.www.media.mit.edu/projects/wearables/lizzy/>

1993 (C) BBN finishes the Pathfinder system, a wearable computer with GPS and radiation detection system [BBN]

BBN's Pathfinder system was completed in Fall 1993, and included a wearable computer, Global Positioning System (GPS), and radiation detection system.

1993 (F) Thad Starner writes first version of the Remembrance Agent augmented memory software [MIT]

The Remembrance Agent (RA) was an automated associative memory that would recommend relevant files from a database, based on whatever notes were currently being written on a wearable computer. The systems was integrated into Emacs, and later was rewritten as part of continuing research by Bradley Rhodes. See <http://www.media.mit.edu/~rhodes/Papers/remembrance.html>

1993 (F) Feiner, MacIntyre, and Seligmann develop the KARMA augmented reality system [Columbia]

Steve Feiner, Blair MacIntyre, and Dorée Seligmann at Columbia University developed KARMA: Knowledge-based Augmented Reality for Maintenance Assistance. Users would wear a Private Eye display over one eye, giving an overlay effect when the real world was viewed with both eyes open. KARMA would overlay wireframe schematics and maintenance instructions on top of whatever was being repaired. For example, graphical wireframes on top of a laser printer would explain how to change the paper tray. The system used sensors attached to objects in the physical world to determine their locations, and the entire system ran tethered from a desktop computer. See <http://www.cs.columbia.edu/graphics/projects/karma/karma.html>

1994 (C) Mik Lamming and Mike Flynn develop "Forget-Me-Not," a continuous personal recording system [Xerox EuroPARC]

The Forget-Me-Not was a wearable device that would record interactions with people and devices and store this information in a database for later query. It interacted via wireless transmitters in rooms and with equipment in the area to remember who was there, who was being talked to on the telephone, and what objects were in the room, allowing queries like "Who came by my office while I was on the phone to Mark?"

1994 (C) Edgar Matias debuts a "wrist computer" with half-QWERTY keyboard [UofT]

Built by Edgar Matias and Mike Ruicci of the University of Toronto, this "wrist computer" presented an alternative approach to the emerging HUD + chord keyboard wearable. The system was built from a modified HP 95LX palmtop computer and a Half-QWERTY one-handed keyboard. With the keyboard and display modules strapped to the operator's forearms, text could be entered by bringing the the wrists together and typing. The system debuted at the CHI-94 conference in Boston, and is now slated for commercialization by LG Electronics (Goldstar). See <http://www.dgp.toronto.edu/people/ematias/papers/chi96> The same technology was used by IBM researchers

to create a "belt computer" — see: <http://www.almaden.ibm.com/cs/user/inddes/halfkb.html>

1994 (F) DARPA starts Smart Modules Program

DARPA starts Smart Modules Program to develop a modular, humionic approach to wearable and carryable computers. Develops a variety of products including computers, radios, navigation systems, human-computer interfaces, etc. that have both military and commercial use. See <http://web-ext2.darpa.mil/ETO/SmartMod/index.html>

1994 (F) Steve Mann starts transmitting images from a head-mounted camera to the Web [MIT]

In December 1994, Steve Mann developed the "Wearable Wireless Webcam." Webcam transmitted images point-to-point from a head-mounted analog camera to an SGI base station via amateur TV frequencies. The images were processed by the base station and displayed on a webpage in near real-time. (The system was later extended to transmit processed video back from the base station to a heads-up display and was used in augmented reality experiments performed with Thad Starner.)

1996 (F) DARPA sponsors "Wearables in 2005" workshops

This July, 1996 workshop brought together industrial, university and military visionaries to work on the common theme of delivering computing to the individual.

1996 (F) Boeing hosts wearables conference in Seattle

Boeing hosted a small conference on wearable computing August 19-21, 1996. In attendance were researchers and administrators from industry, academia, and independent laboratories. Several vendors of displays, speech recognition systems, and full wearable computers were also present. There were 204 people registered for the event.

1997 (F) Creapôle Ecole de Création and Alex Pentland produce Smart Clothes Fashion Show

The fashion show was a design collaboration between the students and faculty of Creapôle Ecole de Création (Paris) and Prof. Alex Pentland (M.I.T., Boston), with the goal of envisioning the impending marriage of fashion and wearable computers. Beginning in April 1996, designs were iterated and clothes produced, with the final runway fashion show was held at the Pompidou Center in Paris in February 1997.

1997 (F) CMU, MIT, and Georgia Tech co-host the first IEEE International Symposium on Wearables Computers

CMU, MIT, and Georgia Tech co-hosted the IEEE International Symposium on Wearables Computers in Cambridge, MA October 13-14, 1997. The symposium was a full academic conference with published proceedings and papers ranging from sensors and new hardware to new applications for wearable computers. There were 382 people registered for this event.

<http://iswc.gatech.edu/wearcon97/default.htm>

Summary

The fundamental wearable computer issues are those of innovation, invention, design and evaluation. The space of possible future applications is just beginning to become evident, and of the possible future directions, only a small fraction of those have yet been reduced to practice even at the prototype stage.

Neither the wearer community nor the tasks in which they are engaged are homogeneous and so single design solutions will not be optimal. The body as a platform for computation is fundamentally different than a desktop and so different styles of computation should emerge. On the other hand, the body has been used as a platform for computation at least since we began counting on our fingers and so the constraints imposed by making the computation body resident are not surprising.

Because of the newness of wearable computers, many inventions have yet to be made, and many of those made can only be evaluated by indirect means at this point. Thus, on one hand, what we have been discussing in this white paper is the traditional HCI litany of *know your user* and *evaluate your designs*. On the other hand, however, the types of wearers and the possibilities for designs are only now becoming apparent.

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