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UBIQUITOUS COMPUTING AND NATURAL INTERFACES FOR ENVIRONMENTAL INFORMATION

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Abstract

The next computing revolution's objective is to embed every street, building, room and object with computational power. Ubiquitous computing (ubicomp) will allow every object to receive and transmit information, sense its surroundings and act accordingly, be located from anywhere in the world, connect every person. Everyone will have the possibility to access information, despite their age, computer knowledge, literacy or physical impairment. It will impact the world in a profound way, empowering mankind, improving the environment, but will also create new challenges that our society, economy, health and global environment will have to overcome. Negative impacts have to be identified and dealt with in advance. Despite these concerns, environmental studies have been mostly absent from discussions on the new paradigm.

This thesis seeks to examine ubiquitous computing, its technological emergence, raise awareness towards future impacts and explore the design of new interfaces and rich interaction modes. Environmental information is approached as an area which may greatly benefit from ubicomp as a way to gather, treat and disseminate it, simultaneously complying with the Aarhus convention. In an educational context, new media are poised to revolutionize the way we perceive, learn and interact with environmental information. cUbiq is presented as a natural interface to access that information.

Sumário

O objectivo da próxima revolução em computação é dotar todas as ruas, edifícios e objectos com poder computacional. A computação ubíqua (ubicomp) irá permitir a todos os objectos receber e transmitir informação, sentir o seu redor e agir em concordância, ser localizado de qualquer ponto do mundo, ligar todas as pessoas. Todos terão possibilidade de aceder a informação, independentemente da sua idade, conhecimentos informáticos, literacia ou impedimento físico. Irá ter impactes globais profundos, dar poder à Humanidade, melhorar o Ambiente, mas também criará novos desafios que a nossa sociedade, economia saúde e ambiente global irão ter que ultrapassar. Têm que se identificar e lidar com os impactes negativos com antecedência. Apesar destas preocupações, os estudos ambientais têm sido maioritariamente ausentes nas discussões sobre o novo paradigma.

Esta tese procura examinar a computação ubíqua, a sua emergência tecnológica, chamar atenção para futuros impactes e explorar o design de novos interfaces e modos de interacção ricos. A informação ambiental é abordada como uma área que pode beneficiar grandemente da ubicomp como meio da sua recolha, tratamento e disseminação, cumprindo simultaneamente com a convenção de Aarhus. Num contexto de educação, os novos media revolucionarão o modo como percepcionamos, aprendemos e interagimos com informação ambiental. cUbiq apresenta-se como um interface natural para aceder a essa informação.

Glossary

3GPP - 3rd Generation Partnership Project

ABS - Acrylonitrile Butadiene Styrene

AGPS - Assisted GPS

AmI - Ambient Intelligence

AMOLED - Active-matrix Organic Light-Emitting Diode

ANSI - American National Standards Institute

APR - Acoustic Pulse Recognition

AR – Augmented Reality

ARG – Augmented Reality Game

ARGs - Augmented Reality Games

ATP – Adenosine Triphosphate

B2B – Business to Business

BAU - Business as Usual

BCI – Brain-computer interface

BPL - Broadband over Power Lines

BSI (Bundesamt für Sicherheit in der Informationstechnik) – German Federal Office for Information Security

CAD - Computer-aided Design

CCTV - Closed Circuit Television

CGI - Computer-generated Imagery

ChLCDs - Cholesteric Liquid Crystal Displays

CNRI - Corporation for National Research Initiatives

CNTs - Carbon Nanotubes

CPU – Central Processing Unit

CRT – Cathode Ray Tube

CSCL Computer Supported Collaborative Learning

CSCW Computer Supported Collaborative Work

DoD – Department of Defense

DOF - Degrees of Freedom

DRAM – Dynamic Random Access Memory

DST - Dispersive Signal

EAN – European Article Number

EEG - Electroencephalography

EPA – Environmental Protection Agency

EPD - Electrophoretic Display

EULER - Environment of Ubiquitous Learning with Educational Resources

fMRI - Functional Magnetic Resonance Imaging

fNIR - Functional Near-Infrared Spectroscopy

FOV – Field of View

FP6 - 6^{th} Framework Programme

FTIR – Frustrated Total Internal Reflection

GDP - Gross Domestic Product

GHG – Greenhouse Gas

GOMS - Goals, Methods, Operators, Selection

GPS- Global Positioning System

GUI - Graphical User Interface

HCI – Human-Computer Interaction

HMD - Head Mounted Display

IC - Integrated Circuit

ICT – Information and Communication Technology

IEEE - Institute of Electrical and Electronics Engineers

IMOD - Interferometric Modulator

IP- Internet Protocol

IPCC - Intergovernmental Panel on Climate Change

IR - Infrared

ISO – International Organization for Standardization

ISR - Intelligence, Surveillance, and Reconnaissance

IST - Information Society Technology

ISTAG - Information Society Technologies Advisory Group

ITO – Indium Tin oxide

ITRS – International Technology Roadmap for Semiconductors

KLM - Keystroke Level Model

LBG – Location-based Game

LBS - Location-based Service

LCD – liquid crystal display

LED – Light Emitting Diode

LPM - Location Pattern Matching

MAN - Metropolitan Area Networks

MAN - Metropolitan Area Networks

MEMS - Micro-Electro-Mechanical Systems

MLC - a memory element capable of storing more than a single bit of information

MMOG - Massively Multiplayer Online Game

MPU – Microprocessor Unit

NIR – Near-infrared light

NIR - Non-ionizing radiation

NUI – Natural user interface

OECD - Organization for Economic Co-operation and Development

OLED – Organic Light Emitting Diode

OLPC – One Laptop Per Child. Project to build low-cost, low-power laptops for children in poor countries.

OS (Operating System) – program that manages other programs

PAN - Personal Area Network

PARC - Palo Alto Research Center

PDLCs - Polymer Dispersed Liquid Crystals

PEDOT- Poly (3,4-ethylenedioxythiophene)

PervC /PvC – Pervasive Computing

PHOLEDs - Phosphorescent Organic Light Emitting Diode

PMOLEDs- Passive-Matrix Organic Light Emitting Diode

POI- Point of Interest

PSS - Poly(styrenesulfonate)

RF- Radio-Frequency

RFID - Radio-Frequency Identification

RoHS – Restriction of Hazardous Substances

SAW – Surface Acoustic Wave

SETI – Search for Extraterrestrial Intelligence

SLC - memory element which stores one bit in each cell

SME – Small and Medium Enterprises

SPDs - Suspended Particle Devices

SWCNTs - Singlewalled Carbon Nanotubes

TDOA - Time Delay of Arrival

TFT - Thin Film Transistor

TOLED – Transparent OLED

TUI – Tamgible User Interface

Ubicomp - Ubiquitous computing

UPC – Universal Product Code

UV- Ultraviolet

UX - User Experience

VOIP – Voice over IP

VRD - Virtual Retinal Display

W3C - World Wide Web Consortium

W-CDMA (Wideband Code Division Multiple Access) – a type of 3G cellular network

WEEE - Waste Electrical and Electronic Equipment

WHO – World Health Organization

WiMAX - Worldwide Interoperability for Microwave Access,

WIMP – Windows, Icons, Menus, Pointer

WPAN - Wireless Personal Area Networks

WSN - Wireless Sensor Network

WTP – Willingness to Pay

WWAN - Wireless Wide Area Networks

WWRF - Wireless World Research Forum

Table of Contents

List of Figures

List of Tables

1. Introduction

We live in an information society. Information has become an immaterial good with economical, political and social value. In a globalized world information is so powerful that, depending on its use, it may foster growth and prosperity or be the downfall of whole economies and societies.

As information grows, so does technology, part of which in turn is directed at better gathering and diffusing information, feeding a cycle of information $\rightleftharpoons$ technology growth.
Information and communication technologies (ICT) keep our world connected, and since the invention of the telegraph and telephone, precursors of modern ICTs, information and communication opened the possibility of an almost instantaneous information exchange, through a widely distributed network. This explosion, whose epitome lies on the Internet, is directly connected to our exponential development as a global civilization.
As information explodes and becomes available to a significant part of the world's population, the necessity to have access to it is gradually created by its existence. Instantaneous distance communication is now commonplace, even necessary, to the point that in modernized world, a person without access to TV, telephone or internet, is considered socially isolated and lacking, when compared to his/her peers. Therefore it is imperative that everyone who wishes to access information is able to do so.

Access to information near us is also growing in demand. The amount of information now available, together with the community's ability to be an active source, has to be put in use, or else lost in the internet's maelstrom. People have the need to learn, express and contribute at a variety of levels. A topic that has been increasing information-wise is the environment. It is usually represented by a local situation with global repercussions – this fact turns local and global citizens into stakeholders and increases their need to be informed and involved. In addition, the Aarhus Convention grants the public rights regarding access to information, public participation in decision-making and access to justice in environmental matters.

Ubiquitous computing proposes to unite long range and short range access to information, interconnect smart objects and increase user-friendliness. Future computing will be as ubiquitous as electricity and happen without our conscious awareness. Interacting with objects

will be so intuitive that we will only focus on the task, rather than on the tool, as we do with current ITs. People will interact as they would with another human, through gestures, speech, or even less, by moving their eyes, or simply thinking. Everyday materials will be augmented with electronics. The paper we write on, the table, window, wall, or any other object will recognize and allow us to interact. Even our clothes will be enhanced, with safety features or simply informative ones: location, our public profile, their life-cycle, price and where to buy. Objects will be self-aware and will be able to communicate between themselves without human intervention, saving our ever more precious time. New forms of visualization and auralization will be possible and indeed useful to access the breath of data available. Information both "man-made" and gathered by the countless sensors, wirelessly connected and distributed throughout the world, in our houses, woods, air, rivers, bloodstream.
In a wider scope, not only individual buildings, but existing cities will be augmented with features and services presently unheard of. Some will even be built from scratch to properly accommodate ubiquitous computing. With ubiquitous computing our lives will be filled with new and immersive experiences.

As any other human advancement it will carry impacts, which must be properly assessed before fully committing to this vision. Its nature surpasses that of normal ICTs, it breadth will encompass every humanized land and object, maybe more, and will influence our society, health, economy, lifestyle, politics and the environment.

This dissertation is divided in six major chapters:
The first and second concern ubiquitous computing as a vision and computing paradigm: understanding its origins, overviewing the present and assessing trends. Furthermore, state-of-the-art technologies are presented, which enable the existence of ubicomp.

Next a focus is made on interaction. Models are presented and natural human-computer interfaces are described: computer vision, RFID, remote sensing, paper augmented and brain-computer interfaces, eye-tracking, speech recognition, touchscreen and acoustic detection, augmented reality, haptics, new forms of audio emission, autostereoscopic 3D visualization, e-paper, OLEDs and chromogenic materials. Their advantages and disadvantages and examples of present and future implementations are also given.

Interactive media design is summarily explained and considerations about present interaction methods and systems are made.

The fourth part concerns probable impacts associated with a “ubicomp world”. In it, positive and negative impacts are described for several aspects. They represent world activities and dynamics, both human and non-human aspects which are expected to experience a greater impact. Topics concern society, economy, health and the environment.

The fifth section highlights the importance ubiquitous computing could have in the gathering and dissemination of environmental information. Several topics are approached: the importance of environmental information in a geopolitical sense; types and contexts of information; technology roles; advantages of ubicomp on the learning process, current problems and projects concerning environmental information; and how ubicomp, interfaces may be used to solve those problems, aid in specific environmental aspects, to enhance the collection and access to environmental information.

In the sixth chapter, a tangible interface is presented. cUbiq explores a way to connect the physical world with virtual environmental information.

1.1. Defining Ubiquitous Computing

"This is great, because I hate computers, and there are no computers here!" a museum benefactor proclaimed, not realizing that the furniture contained 17 Internet-connected embedded computers communicating with hundreds of sensor microcomputers.

Defining ubiquitous computing is not as simple as to define a new kind of computer with different capabilities than its predecessors. It's as intricate as defining a new way of interacting and access information, communicate, play, a whole new way of living.

Mark Weiser, Chief Technology Officer at Xerox Palo Alto Research Center (PARC), coined the term "ubiquitous computing" as a computing paradigm in which technologies "weave themselves into the fabric of everyday life until they are indistinguishable from it" (Weiser 1991). He and Seely Brown considered three major computing eras, according to a computer/human ratio (Table 1.1):

Table 1.1. Major Computer Paradigms (adapted from Weiser, et al., 1996)

Major Trends in Computing	
Mainframe	Many people share a computer
Personal Computer	One computer, one person
Ubiquitous Computing	Many computers share each of us

This vision is attainable not by computers, but computing with the processing power that once powered them, now with much smaller microprocessors and embedded in the environment, distributed in everyday objects. Like electricity in the present day, ubiquitous computing ("ubicomp") will be hidden from our senses, unless needed, and everywhere around us. There will be sensing and processing of information in our clothes, in our floor, the paint on the wall, cars, entire buildings, and everything will be connected constantly sending and receiving information from one another.

Sometimes misinterpreted, Weiser even tried to stop using ubiquitous computing (Ishii 2004), he was even cited as saying to John Seeley Brown "They've completely missed the nontechnical part of what ubiquitous computing is all about" (Galloway 2004). His concept of ubicomp wasn’t filling the world with computers, but making our interaction with them much more intuitive and unobtrusive through “transparent” interfaces (Ishii 2004).

1.1.1. The Blind Men and an Elephant

The idea behind a ubicomp world is probably as old as science-fiction. Man was always enthralled by the possibilities technology provided, seemingly magical, sci-fi writers and futurists transformed this wishful thinking in literary pieces and visions even before the technology necessary to make such worlds even existed.

Especially since Weiser’s seminal article: "The Computer for the 21st Century," was published in Scientific American, as the idea of ubiquitous computing spread throughout the world, many people and organizations defined their concept of what the future would and should be. Many different names appeared, some of them with slight deviations, but every one inspired on the same vision (Table 1.2).

Table 1.2 Comparison of ubiquitous computing definitions (adapted from Jeon and Leem, 2007). Sources: (Tripathi 2005), (Greenfield 2006), (Weiser, 1996), (Tripathi 2005), (Institute for the Future 2006), (Phillips) (Ballmer 2008)

Scholar / Institute	Definition
Mark Weiser	Ubiquitous computing has as its goal the enhancing computer use by making many computers available throughout the physical environment, but making them effectively invisible to the user.
Alan Kay	Third paradigm computing
Ken Sakamura	Ubiquitous computing is being able to use computers anywhere at any time.
Friedermann Mattern	Everyday objects will become smart and they will all be interconnected.
IBM	Pervasive computing delivers mobile access to business information without limits from any device, over any network, using any style of interaction. It gives people control over the time and the place, on demand.
Donald Norman	Invisible computing.
Adam Greenfield	Everyware.

Phillips and ISTAG	Ambient intelligence.
Neil Gershenfeld	The World. Information technologies are finally growing up, so we can interact with them in our world instead of theirs.
Steve Ballmer	Fifth computing revolution

Some concepts are differentiated primarily by their focus and orientation, but in the end, humans will experience a world of ubiquitous computing:

Table 1.3. Conceptual differences (ISTAG 2003)

Designation	Focus	Orientation
Ambient Intelligence	Users in their environment	User-pull
Pervasive Computing	Next generation computing technology	Technology-push

Because pervasive technology, despite its orientation being "technology-push", will be designed always considering its users and their environment; similarly, ambient intelligence will be designed always depending and considering the advancements in technology. Two different paths, the same goal.

1.2. Present state of ICTs

In the last few decades computing has experienced many revolutions which empowered humankind, giving us for the first time an overload of information we couldn't process, or didn't have the time to.

In addition to having a computer per person as an affordable mainstream product, the rise of the Graphical User Interface (GUI) enabled the average person to take advantage of this tool. The emergence of internet was a breakthrough in information access, now users could search for virtually anything, previously unreachable, in the comfort of their homes, but still mainly from institutions or tech-savy people. With the Web 2.0 advent they now could actively participate in the making of information. Users now had a chance to make that universal knowledge database a two-way street. Through weblogs, wiki-pages, videos, this collective intelligence, now use their spare time to share information as a global community. The internet can even be used as a medium for democracy and public participation: pressuring for

government transparency, transforming pyramidal hierarchies into a net structure, blurring the existing gap between the government and citizens (Chapman 2008).
At the same time mobile phones appeared, and became much smaller, powerful, ubiquitous, and truly portable. Many gained new functions and are now cameras and mobile internet access points with GPS functionalities. I don’t consider this a paradigm change, but a very important step towards a future of ubiquitous computing, maybe in a way Mark Weiser did not envision would happen.

There are still many technologies that need to mature before ambient intelligence (AmI) is fully realized, and many nations are contributing to make it faster, from the USA to South Korea and Japan. Europe is also trying to be in the forefront of those technologies’ development through its Framework Programmes, now in their 7th version (Table 1.4.).

Table 1.4. Differences in Information Society Technology between the present and the AmI vision (ESTO 2003)

IST today	**The IST in FP6 vision (AmI)**
PC based	“Our surrounding” is the interface
“writing and reading”	Use all senses, intuitive
“text” based information search	Context-based knowledge handling
Low bandwidth, separate network	Infinite bandwidth, convergence
Mobile telephony (voice)	Mobile/Wireless full multimedia
Micro scale	Nano-scale
Silicon based	New materials
e-Services just emerging	Wide adoption
< 10% of world population on-line	Word-wide adoption

We clearly don’t live in a “present tense” ubicomp world. The dominant tense on this subject can be called “proximate future”, not a distant future, but one “just around the corner”. In fact of the 108 papers comprising the Ubicomp conference proceedings between 2001 and 2004, 47% of the papers are oriented towards a proximate (and inevitable) technological future (Dourish 2006).

Some of the most forefront nations are Singapore and Korea, which are taking big steps to build an information infrastructure.

One of the most wirelessly connected countries, Singapore is a 434 square miles island, and its wireless hotspots cover more than 1/4 of that area (ITU 2005) with 43,6% of the population using internet regularly (NIDA 2008).
Six months after Weiser's article in Scientific American, the National Computer Board launched IT2000 Masterplan, which attempted to connect nearly every school, home and workplace, creating an "intelligent island". In December 2004, 92,2% of the population owned a mobile phone, 73,3% of the island's homes had a computer (Dourish 2006). Its train system also has smart card ticketing and advanced closed circuit television (CCTV) to provide a seamless and safe transportation, and is considered a laboratory for radio-frequency identification (RFID) pilot research projects and innovative RFID products developer (ITU 2005).

Korea is also a country where the internet is widely used: in December 2007, 76,3% of the population used internet regularly (NIDA 2008). According to a 2008 report, the population segment between the age of 10 and 40 have a staggering usage rate of more than 99,6% (NIDA 2008).
In 2004 The Minister of Information and Communication launched IT389, a technology plan that proposed to transform Korea into a ubiquitous society by 2010. It takes its name from three infrastructures (Broadcast Convergence Network, Ubiquitous Sensor Network, Next Generation Internet Protocol) eight services (Wireless Broadband, Digital Multi-media Broadcasting, Home Network, Telematics, RFID, W-CDMA, Terrestrial Digital TV, VOIP), and nine equipment fields (Next-Generation Mobile Communications, Digital TV, Home Network, System-on-Chip technology, Wearable PC, Embedded Software, Digital Contents, Telematics, Intelligent Service Robot).
Korea is also building New Songdo City, the first in the world designed and planned as an international business district. Digitally connected and environmentally sustainable, this "u-city" will be built with the latest technology – RFID systems, sensor networks, smart card applications, intelligent building and transport systems among others, and all information systems - residential, medical, business - will share data.

Portugal in 2007 had 40% households with internet access, but the number of mobile phones even exceeds its population, having 116% mobile subscriptions in 2006 (Eurostat 2008). Portugal is considered a good test-bed for new technologies, despite not being a world-relevant developer.

1.3. Dimensions and Trends

Pervasive computing compares to a traditional PC like batteries to a power plant: not as powerful, but available everywhere, in different shapes, for many different applications.
- Jochen Schiller, Freie Universität Berlin

Through universities, private companies and military research, technology will continue to evolve in unexpected ways. It will appear in various forms and contexts. Ubiquitous computing applications can be classified according to the characteristics they manifest:

Table 1.5. Ubiquitous computing dimensions (adapted from Jeon and Leem 2007)

Dimension	Characteristic	Description
Subject	Generality	Most of society uses ubiquitous computing through a computing environment that have simple interface and autonomy
	Specialty	Specific individual or group uses ubiquitous computing to achieve a specific purpose
Time	Always	Anytime network connectivity is guaranteed
	Temporary	Ubiquitous computing environment can be used at specific time
Space	Person	Ubiquitous computing exists at a personal scale
	Room	Ubiquitous computing exists at the scale of the room
	Field	Ubiquitous computing exists at the scale of the public space
Place	Mobility	Anywhere connectivity of network is guaranteed
	Fixation	Ubiquitous computing environment can be used at specific place

In those dimensions, ubicomp can be an asset to everyday life. It can be used in different contexts, providing a service to its users (if activated willingly) or “subjects” (if unintentionally triggered). Some opportunities are described in the “Impacts” chapter

Services can furthermore be classified according to their “subject”, “time” and “place” dimensions (all of them are transversal in scale, depending on the space they were designed for).

Table 1.6. Classification of ubiquitous computing services (Jeon and Leem 2007)

Subject	**Time**	**Place**	**Case**
Generality	Always	Mobility	Asset management/ automatic toll and fee collection/ billing and payment/ context aware marketing/ crime prevention/ facility management/ offering learning/ pet tracking/ vehicle information programs/ vehicle tracking
		Fixation	Emergency care/ environment care/ health care/ security/ support for learning and qualifications training
	Temporary	Mobility	Augmented reality game/ benchmark marketing/ object shopping/ vehicle navigation
		Fixation	No result
Speciality	Always	Mobility	Barrier free navigation/ market survey/ part tracking/ pollution monitoring/ spatial and temporal information
		Fixation	No result
	Temporary	Mobility	No result
		Fixation	No result

This classification, albeit a good one, only allocates one service to one combination of dimensions. There are situations where this might not be the case. As an example: Automatic toll – if the vehicle is used as reference, it falls under “mobility”, but if the toll is the reference, it should be classified under “fixation”. The service is only performed at that place.

Recent developments point that computing in general and especially ubiquitous computing applications are developing towards a region of Mobility, Always and Generality dimensions (Figure 1.1.) and from a kind of interaction in which the human had to be present so that "things worked", to proactive computing in which humans themselves and their behavior are subject to computer analysis and at the same time supervisors of that information. In this automatic computing, objects "talk" to each other without human intervention.

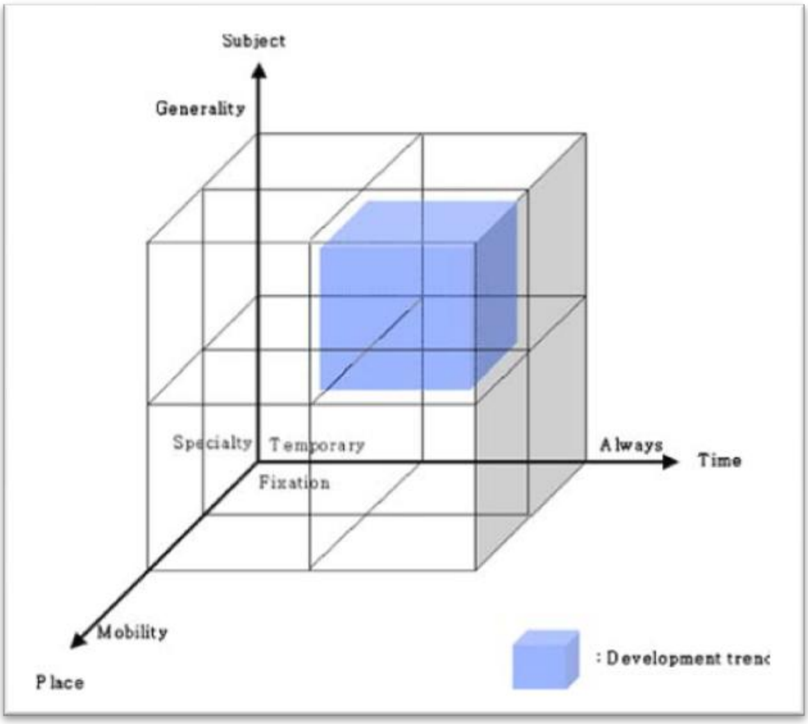

Figure 1.1. Ubiquitous computing trend in Time, Mobility and Subject (Jeon and Leem 2007)

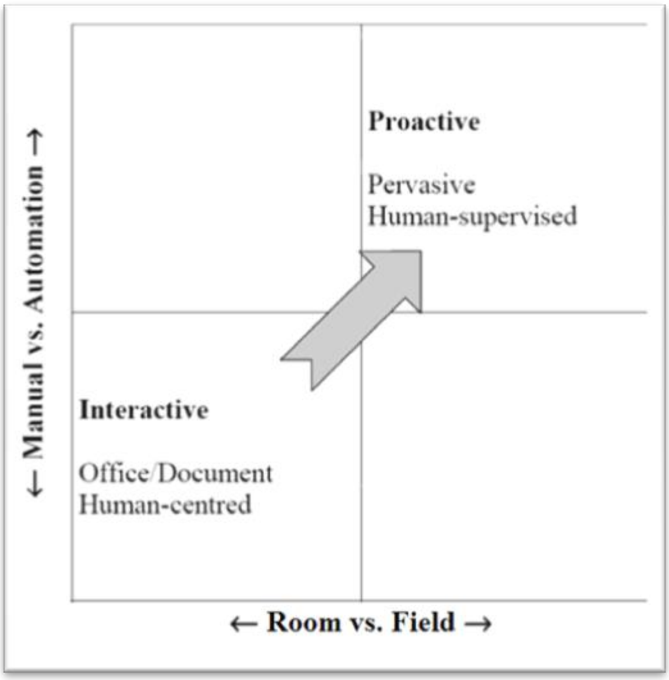

Figure 1.2. Ubiquitous computing trend in Automation and Space (ESTO 2003)

According to a survey done by the German Federal Office for Information Security (BSI-Bundesamt für Sicherheit in der Informationstechnik) to several experts, most areas of application will emerge or be augmented by ubicomp within the next 7 years (Figure 1.3)

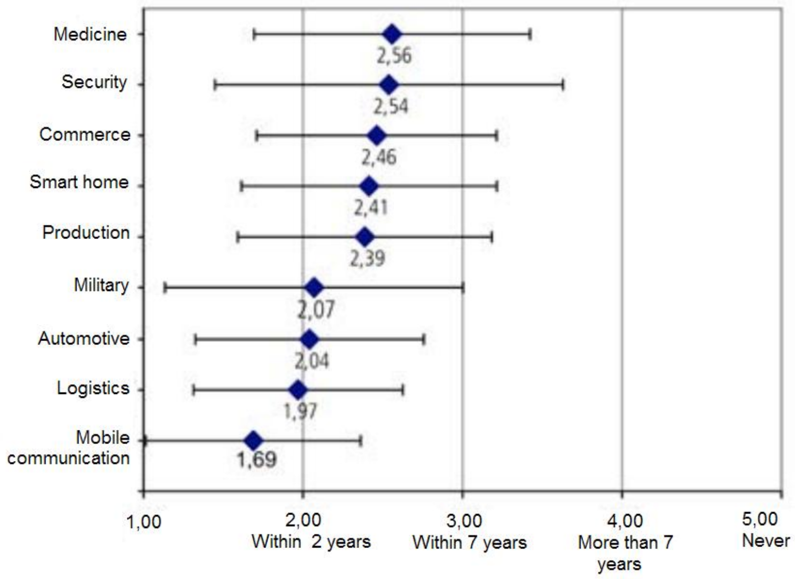

Figure 1.3. The expected breakthrough of ubiquitous computing in selected application areas (average and deviation) (BSI 2006).

Considering the expert's opinion in, and if we look at the average, there are two significant pieces of information.

One is the fact that no area widely uses ubicomp applications until now. The other is the implication of the averages being very close to each other in time (less than 5 years apart), which may seem odd, taking into account that technologies tend to appear gradually, and so does their applications.

An explanation may be that most R&D laboratories were born after Weiser's paper and therefore only in the recent years products started to get out of the labs and into the industry. In addition since this technology is not independent like a personal computer, it needs other areas and spaces to connect to, which may not be prepared. As an example, Nokia builds RFID-enabled phones, but doesn't sell them yet to ordinary clients because the infrastructure needed to make them useful (supermarkets, transportation systems, etc) is inexistent.

The reason why averages are so close is that technologies were developed in parallel, they just need each other to connect. Naturally gradual development/implementation can still occur - estimate's deviation span can be as wide as ten years.

ICTs are only now starting to mature in quality and quantity, enough to start fulfilling the vision's requirements.

2. Technologies

Although some technologies can provide a ubiquitous computing environment, there is still much to be done before they are truly pervasive in our lives.

According to BSI, surveyed experts make a distinction between two forms of ubiquitous computing:

PvC1: when pervasive computing starts to increase in number and quality, performing information processing in the background without explicit human commands, profiling users much like the internet today.

PvC2: using real artificial intelligence, not only contextual information, but access to it in a case-by-case need, even in unfamiliar contexts.

The following image illustrates the enabling technologies, and the determining factors behind them. They influence what characteristics PvC will have, which in turn will include positive or negative impacts, further described in the "Impacts" chapter.

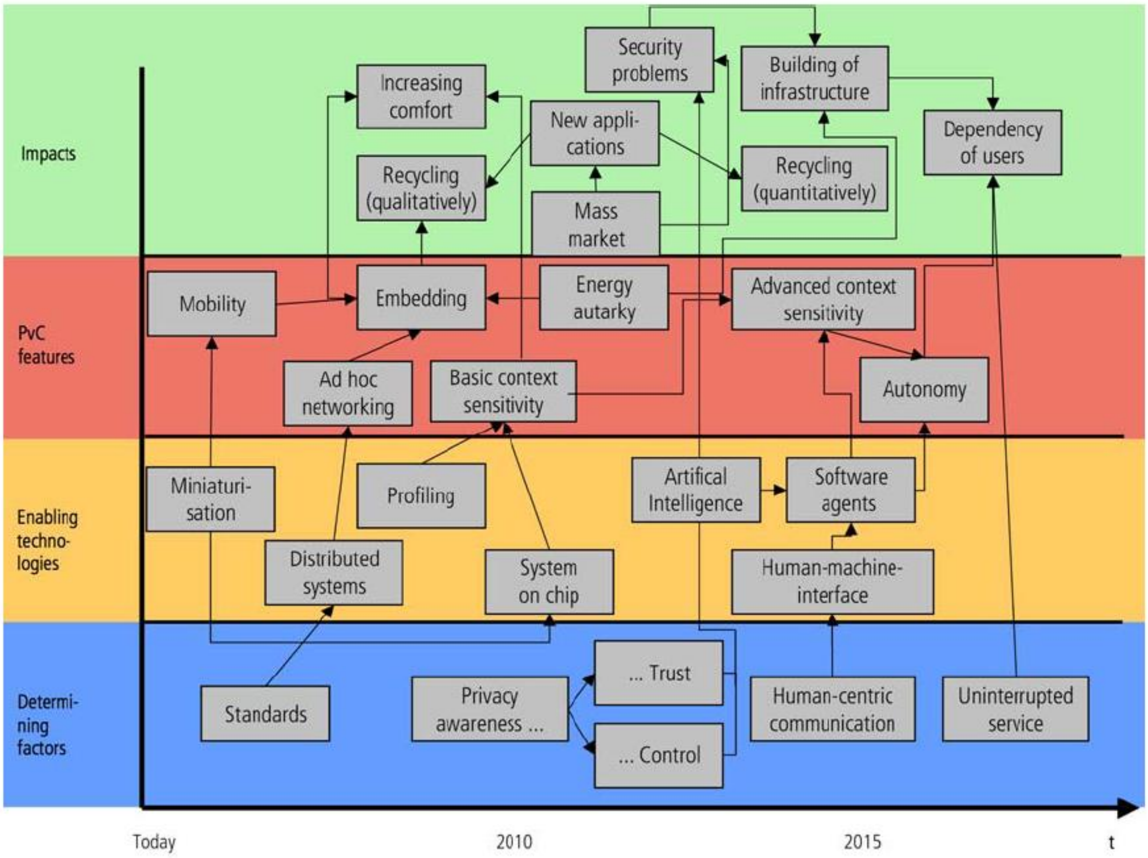

Figure 2.1. Key dependencies, trends and developments in ubiquitous computing (BSI 2006)

Arrows within the same category represent evolutionary processes in time, whereas arrows across categories represent influences. Timescale may be inaccurate, because it's based on predictions.

In this visualization grid, the intricacy of ubiquitous computing is evident, even more considering only key aspects are represented. According to the experts, during PvC1 mobility, ad hoc networking and embeddedness will start to appear in individual devices. The mobile phone, being so widespread is the most probable option for an even bigger offer of communications, control and other applications than we have today. But these devices will still be confined to manufacturer-defined applications. Only PvC2 will bring a truly open networking structure, as well as widespread energy autarky, automation and much more developed context awareness.

Some technology fields are crucial for ubicomp. They are represented in Figure 2.2 according to their relevance.

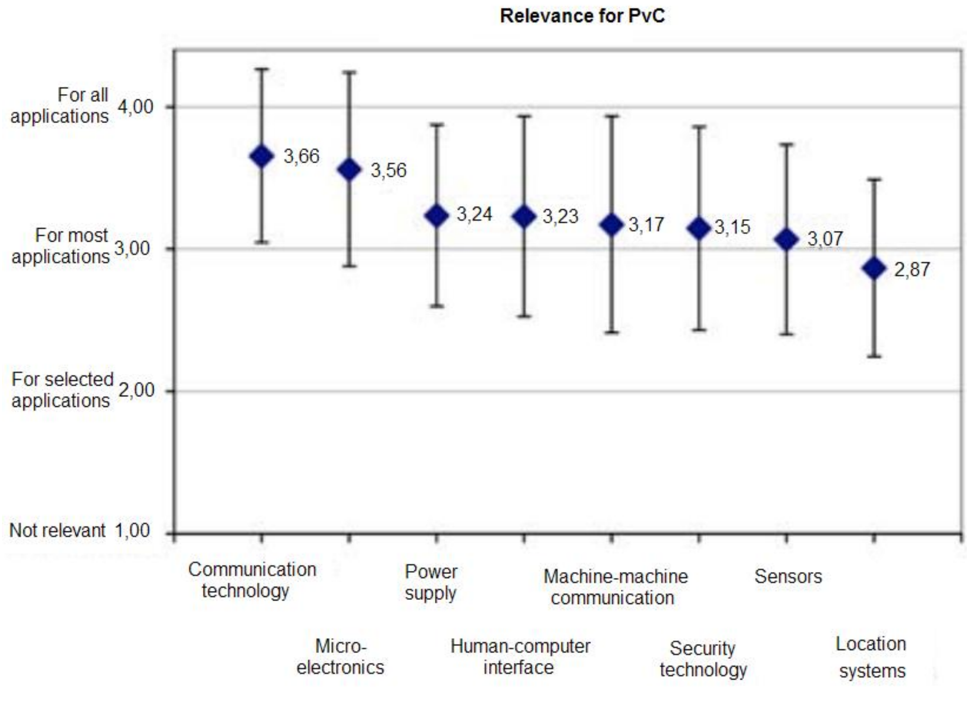

Figure 2.2. The comparative relevance of the eight technology fields for ubiquitous computing (adapted from BSI 2006).

These technologies are expected to mature within the next 5 years. Some are needed in order to guarantee certain ubiquitous computing characteristics (Table 2.1). The selected characteristics are relevant to nearly all application areas, to a varying degree.

Table 2.1. Technology fields necessary to implement ubiquitous computing characteristics (adapted from BSI 2006).

	Mobility	Embededdness	Ad-hoc-networks	Context awareness	Energy autarky	Autonomy
Microelectronics	x	x				
Power supply	x		x		x	x
Sensor technology			x	x		x
Communication technology	x		x	x		x
Location technology	x			x		x
Security technology		x	x	x		x
Machine-machine communication		x	x	x		x
Human-computer interface		x		x		x

ISTAG also indicates required technologies, stressing the ones needing significant research. Most fields are the same as the ones indicated in Table 2.1., but Ambient Intelligence, although similar to PerC, gives a special importance on the “intelligence” component of technology.

In the following table, they are divided as contributing towards Ambience or the Intelligence sector.

Table 2.2 - AmI components that require significant research (ISTAG 2003)

Components for ambiance	Components for intelligence
Smart materials	Media management and handling
MEMS and sensor technology	Natural interaction
Embedded systems development technology	Computational intelligence
Ubiquitous communication	Contextual awareness
I/O device technology	Emotional computing
Adaptive software	

2.1. Enabling Technologies

2.1.1. Microelectronics

Microelectronics plays an important part in ubiquitous computing, because many devices will be required to be small and/or invisible. It deals with the miniaturization, manufacture and application of integrated circuits (IC). Today microelectronics is widely used in medical and automotive industry and has been decreasing in size considerably, now being as small as 65nm (Fujitsu 2008).

Present-day ICs are based in silicon as a semiconductor. They're still too expensive for some applications such as RFID (BSI 2006), which must be extremely low cost to be used effectively. In contrast, plastic ICs, which uses carbon compounds as semiconductors, although inferior in performance, can be made by simple and cheap printing processes.

Micro-Electro-Mechanical Systems (MEMS) is the integration of mechanical, sensor, actuator and electronic components into one substrate. They are fabricated using the same methods as ICs and are usually in the micrometer scale. They are also called system-on-a-chip, because it can sense, process, and act, controlling the environment (CNRI 2008).

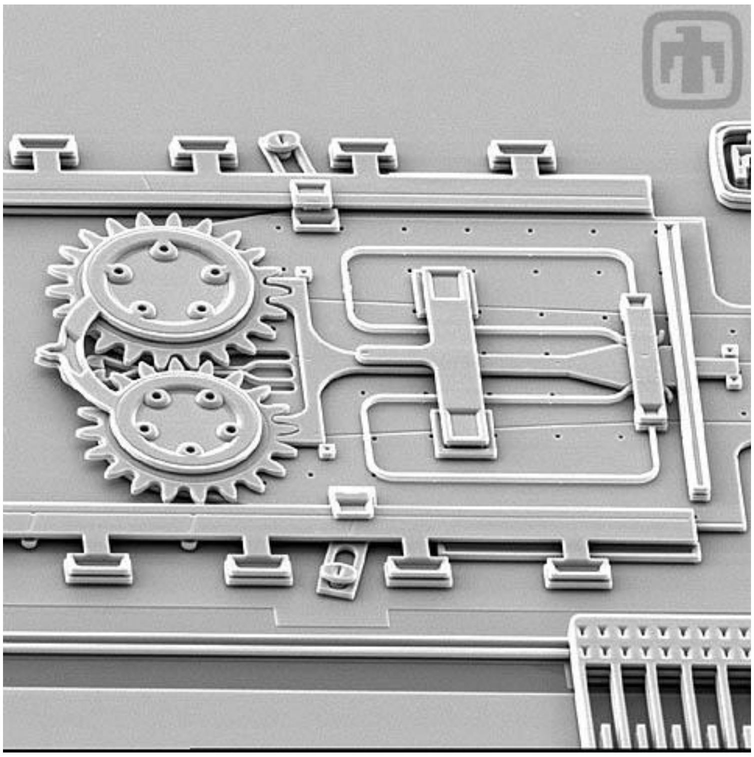

Figure 2.2 – MEMS clutch mechanism. Gears are 50micrometers across. (McWhorter 2008)

The trend in microelectronics continues to be towards greater density, smaller size and cost, in accordance to Moore's law (Figure 2.3). Gordon Moore's law states that transistor density in a chip of a given size will double approximately every 2 years.

Because processors will be so small and inexpensive and consequently disposable, they'll appear at previously inconsiderable places: clothes, paper books, on the floor, scattered everywhere. This is also true for GPS receivers which can be as small as 2.8 x 2.9mm, enabling most objects to be location-aware (Takeshi 2009).

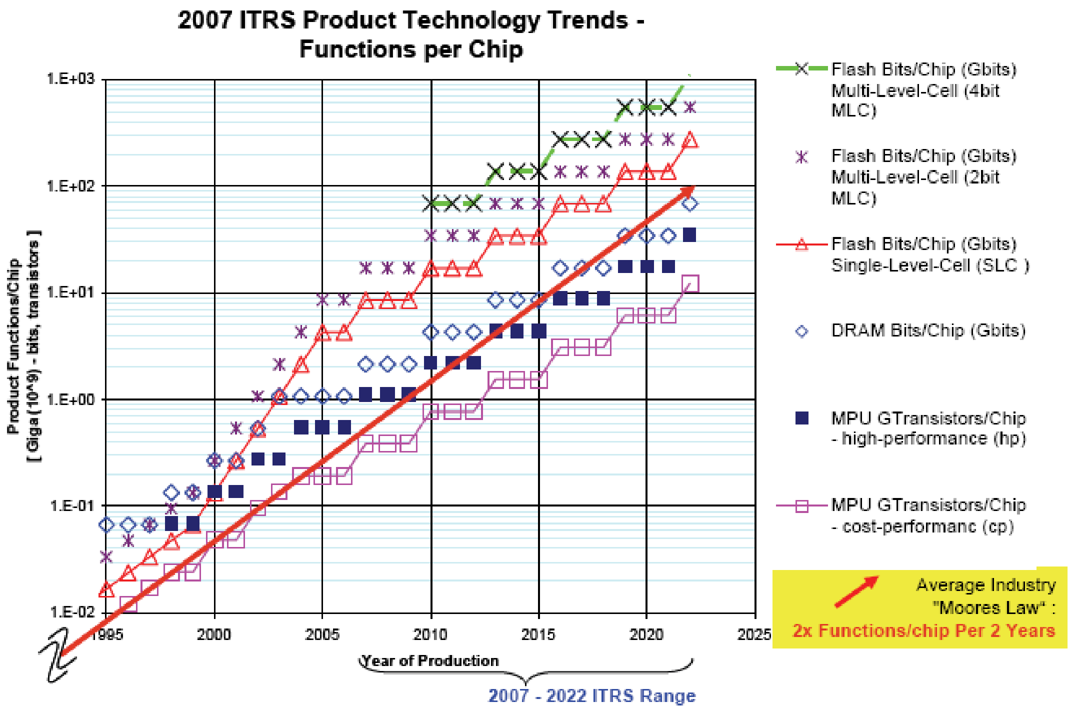

Figure 2.3 – ITRS Product Technology Trends' relation to Moore's law (ITRS 2007)

2.1.2. Sensors

A major element in the ubicomp vision is the possibility of having automated processes according to specific changes or events in the real world.

The definition of sensor is not unanimous. The terms "sensor" and "transducer" have often been used as synonyms. The American National Standards Institute (ANSI) standard MC6.1 defines a transducer as "a device which provides a usable output in response to a specific measurand" (Instrument Society of America, 1975 cited by National Materials Advisory Board, 1995). This definition encompasses devices such as the thermometer, which converts temperature into a change in mercury volume.

In the context of ubiquitous computing, sensors are used to capture analog environment information (quantitatively or qualitatively) and convert it to an electric signal. Then it can be processed by a CPU and further displayed or used to control actuators, for instance. Sensors are used in emerging input technologies, which are described in the next chapter.

Sensors can be classified based on the energy form in which the signal is received (Table 2.3).

Table 2.3 – Sensors by energy form (adapted from National Materials Advisory Board 1995). Examples retrieved from Vernier, 2008.

Energy Form	Example of measurands	Examples
Radiant	Intensity, reflectance, refractive index, wavelength	Light sensor, Geiger counter, IR sensor
Mechanical	Pressure, torque, acoustic wavelength, linear and angular velocity/acceleration	Accelerometer, dynamometer, microphone
Thermal	Temperature, state of matter, entropy,	Thermometer, calorimeter
Electrical	Voltage, current, resistance, capacitance	Charge sensor, ohmmeter
Magnetic	Field intensity, flux density	Magnetic field sensor, magnetic compass
Chemical	Concentration, pH, oxidation/reduction potential, reaction rate,	Dissolved oxygen sensor, conductivity sensor, biosensor

They can be produced as an integrated component on a chip (system-on-a-chip), and at a MEMS scale (BSI 2006). Usually sensors only send electric information to be processed by a controller, but some, called "smart sensors", can process it by themselves and send the actual value (e.g., in degrees Celsius) (Smart Sensor Systems 2006).

Wired networks are expensive to install and maintain, and limited in size. An emerging class of sensor technology is called wireless sensor network (WSN). WSNs are networks of distributed sensors nodes, wirelessly interconnected (Figure 2.4). Each node can have GPS technology incorporated in them, to determine their absolute, and consequently relative position.

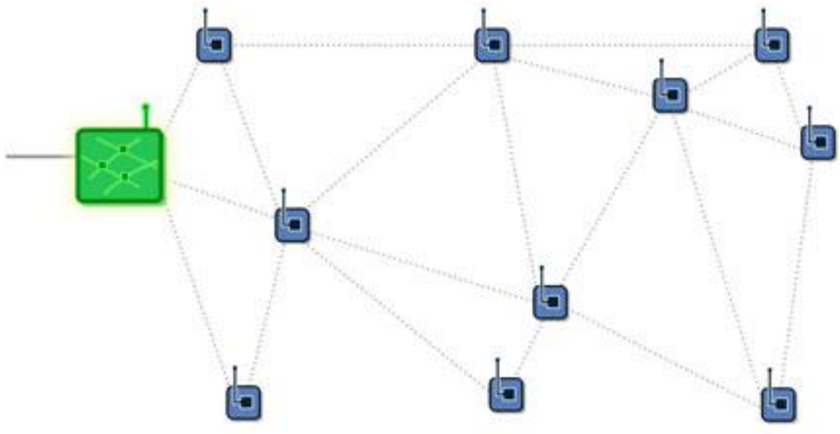

Figure 2.4. Wireless sensor network (source: Dust Networks)

Sensor node's cost and size can greatly vary, but mostly they are used in low-power, low bandwidth applications. In some cases nodes can be placed in known locations, in other applications nodes are placed in a non-deterministic pattern.

Due to sensor's size and fragility, they can stop transmitting due to destruction or obstacles blocking RF signal. WSN nodes are autonomous, so when this happens, the dynamic network can adapt and self-organize in an *ad-hoc* fashion, to minimize loss of information (Martinez 2003)

Smart Dust is a Berkeley University WSN project based on "motes" – inexpensive, small, ultra-low power sensors. Motes can be painted on the wall and be powered by vibrations, solar light or changes in barometric pressure (energy-scavaging) (Pister 2001).

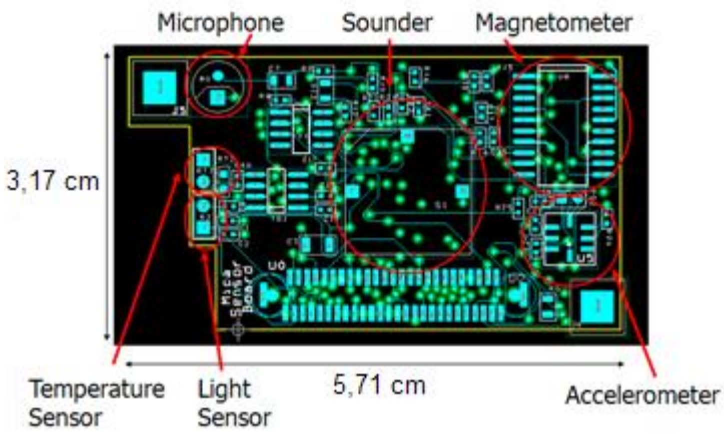

Figure 2.5. Mica Mote (adapted from Woo, 2002).

Sensors can be used in a multitude of ways. In a ubiquitous computing environment, they could be used as means of identification, through biometric analysis of eyes, fingers, weight and steps; presence detection for surveillance and automating processes like turning on lights, opening doors or displaying impersonalized information; home healthcare, by analyzing blood components, heartbeat, urine, sending results automatically, without needing constant nurse care; environment monitoring (e.g., dissolved oxygen levels at different river segments).

Information is almost always obtained by direct measuring of a variable. But there are also means of indirect measurement. One example is the biosensor class. Biosensors are defined as sensors that use biomolecules and/or structures to measure something with biological significance or bioactivity (Stetter, Penrose and Yao 2003). Biological recognition is accomplished using three basic mechanisms. These include biocatalytic, bioaffinity, and microbe-based systems. These biological recognition systems have been linked to electrochemical, optical-electronic, optical, and acoustic transducers (Rogers and Mascini 2006).

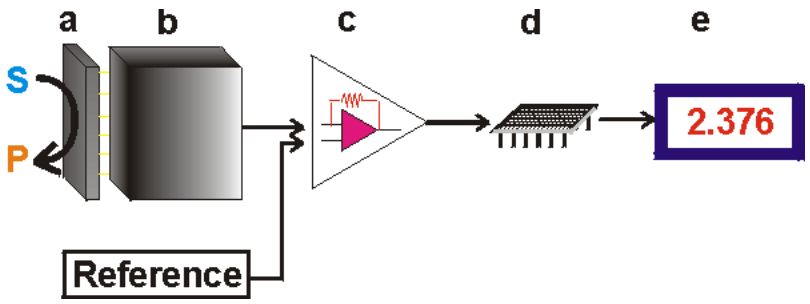

Figure 2.6. Biosensor, an analytical device which converts a biological response into an electrical signal The biocatalyst (a) converts the substrate (S) to product (P). This reaction is determined by the transducer (b) which converts it to an electrical signal. The output from the transducer is amplified (c), processed (d) and displayed (e) (Chaplin and Bucke 2004).

Inexpensive and portable biosensors are being developed (Intel 2008). Some can carry up to 10 different sensors (Intel 2007) (Figure 2.7).

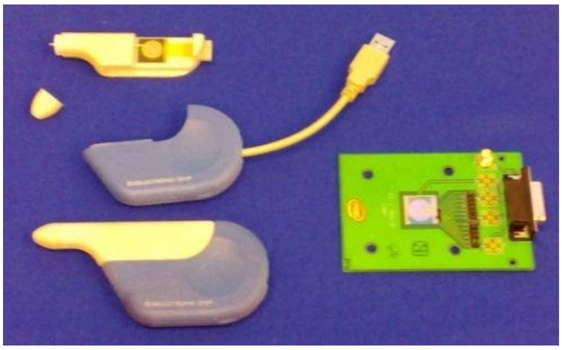

Figure 2.7. – Intel's electronic biosensor. Retrieved from Demerjian, 2007.

Sensors and targets can be mobile or fixed. (Markowsky 2002). Sensors can also be remote or in-situ. These possibilities are exemplified in Table 2.4.

Table 2.4. Sensor-target relation and examples (adapted from Markowsky, 2002).

	Fixed sensor node		**Mobile sensor node**	
	Remote	**In-situ**	**Remote**	**In-situ**
Fixed Target	Changes in land use detected by geo-stationary satellites	Humidity sensing	Satellite, monitoring sea temperature	Land-mines robotic sensor
Mobile Target	Car speed detected by police radar	Monitoring Airborne particulate matter	Aerial photograph, bird migration	Monitoring pollutants in rivers with distributed sensors

2.1.3. Power Supply

Supplying power is no problem for devices plugged into the power grid with cables. However, mobile and wireless systems with energy self-sufficiency have become important in recent years.

The most usual form of providing energy to unplugged systems is through (rechargeable) batteries. But it must be taken into consideration that for mobile systems the energy/size and sometimes energy/weight ratios are very important. Nickel alkaline batteries (NiCd and NiMH) have been widely used in the last 20 years, NiMH reaching a density of $1J/mm^3$. Lithium batteries can have up to $3J/m^3$ but aren't rechargeable. Lithium-ion batteries are and have a ratio of 1J/mm3. Among its advantages is having almost no self-discharge, and the absence of a "memory effect" - when batteries are partially discharged and don't recharge to its maximum capacity (Electricity Storage Association).

Fuel Cells have 10 to 40 times the energy density of batteries but only 20-50% of it can be transformed in electricity. They are not an economical viable solution for ubiquitous computing because its fuel production is still very expensive, but will probably decrease as the car industry uses them as an alternative power source. Other sources include MEMS, specifically micro heat engines and storing energy in rotating micro machinery (ESTO 2003).

An ideal technology would enable self-sustainable and wireless provision of energy, preferably harvested from environmental sources (Table 2.5):

Table 2.5. Energy-converting technologies (adapted from BSI 2006).

Technology	Energy Production
Photovoltaic cells	Convert solar energy into electricity
Piezoelectric generators	Convert mechanical to electrical energy by means of piezo crystals
Thermoelectric generators	Create electrical voltage with temperature differentials between two different metals
Electromagnetic generators	Electromagnetic energy conversion occurs according to the familiar dynamo principle
Capacitive and electrostatic generators	Use capacitive or electrostatic charges in an electric field to produce energy.
Thermomechanical generators	Create mechanical energy, which must then be transformed into electrical energy
Electrokinetic microchannel batteries	Electricity is generated as ion-charged fluid (salt water) passes through microchannels or porous filters, thus separating the fluid's electric potentials.

Ubiquitous computing devices are not only mobile but wireless, therefore means of supplying energy wirelessly are being developed. The biggest problem is the way to do it without dissipating energy and without harming anything in its path (when using concentrated beams such as LASERs)

Inductive coupling is a method which consists in placing the chargeable device on or near a charging surface. Both the surface and the device possesses coils, which create a magnetic field. The surface automatically seeks resonance and adapts to the device, powering it (with the advantage of being able to transfer data as well).

An MIT Professor, Marin Soljačić powered a light bulb 2 meters apart using magnetic resonance, even with an obstacle between both coils (Figure 2.8). Magnetic fields travel freely through air and have little effect on the environment or, at the appropriate frequencies, on living beings.

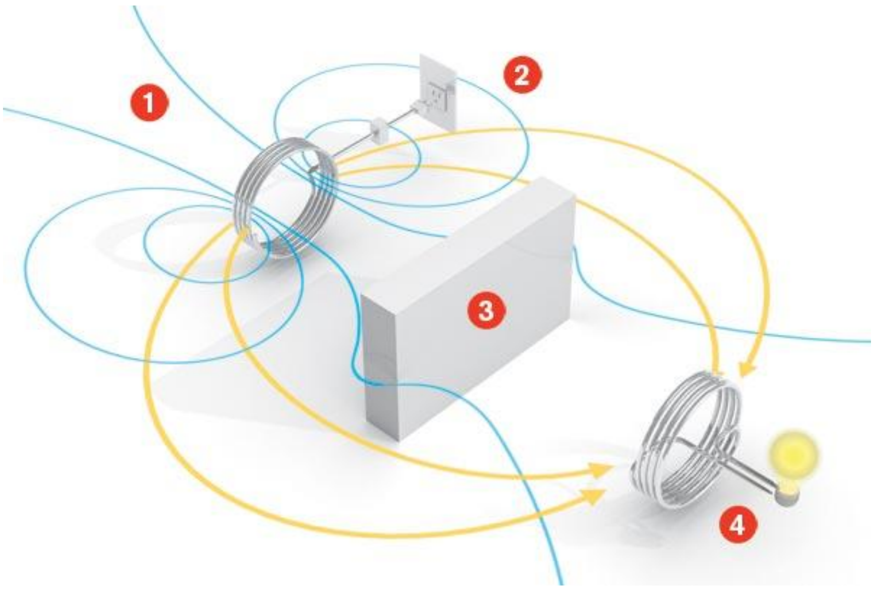

Figure 2.8. Magnetic Resonance. 1- Resonant copper coil attached to frequency converter and plugged into outlet; 2- Wall outlet; 3- Obstacle; 4- Resonant copper coil attached to light bulb. (Chu 2008)

This method is safe and easy to use. Some products already provide this technology: Fulton Innovation's e-coupled is a charging surface supporting many devices; passive RFID tags are also powered this way, when near a reader's antenna.

There are two ways to mitigate the energy supply problem: one is to develop technologies on the supplying end, the other is decreasing consumption on the demanding end. More recently, the reduction in size of chips and their increasing efficiency along with software-based energy saving are reducing power demands.
Researchers at the University of Michigan have made a $1mm^2$ processor, that when coupled to a thin-film battery of the same size would power it for 10 years, and measure $1mm^3$. The processor uses only 30 pW of power when idle, and when active, 2.8 pJ of energy per computing cycle (about as tenth of the energy used by the most energy-efficient processors available) (Greene 2008).

In MEMS case the use of biomolecular motors such as enzymes offer an alternative to silicon-based systems. The integration of biomolecular motors with nanoscale engineered systems enables the development of hybrid organic-inorganic devices capable of using ATP as an energy source (Figure 2.9) (Soong et al. 2000). This approach may enable the creation of a new class of sensors, mechanical force transducers, and actuators, providing energy exactly where it is needed.

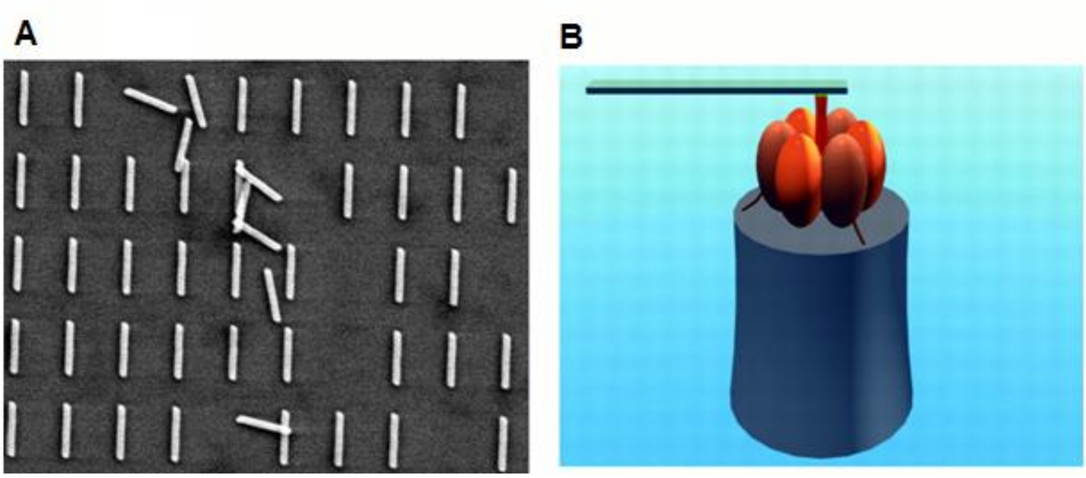

Figure 2.9. ATP as energy source (A) Nanopropeller (length 750 to 1400 nm, diameter 150 nm). (B) The device consisted of a Ni post (height 200 nm, diameter 80 nm), an F1-ATPase biomolecular motor, and a nanopropeller (length 750 to 1400 nm, diameter 150 nm). Adapted from Soong, Bachand, et al., 2000.

2.1.4. Networks and Communication

Networks are one of the most essential aspects of ubicomp, particularly wireless communication. Without it, devices wouldn't be allowed to send information between each other or to remote users. Computing wouldn't be autonomous and truly ubiquitous.

For a better understanding, the Wireless World Research Forum (WWRF) developed a conceptual model of communication between humans and surrounding technologies. The MultiSphere reference model is constituted by 6 levels (WWRF 2001):

Figure 2.10 The 6 levels of the MultiSphere model (WWRF 2001)

Table 2.6. Multisphere model

Level	Description
Level 1: Personal Area Network (PAN)	The PAN defines communications happening at our body. Elements are "wearables" or even part of our body, that can find and link to each other.
Level 2: The Immediate Environment	This level of communication encompasses all the interactions between us and near objects, which will be aware of us and our preferences. Refrigerators will know what we like and ask us if we want to order automatically, TVs will warn us when our favorite program is starting, and toasters will toast bread with the right level of toasting.
Level 3: Instant partners	We interact with other people or more complex systems or might just want to relay information through them. In the future, wireless possibilities should enable an easier and richer interaction with close people. Community websites are a glimpse of the need we have to communicate with people that are close to us.
Level 4: Radio Accesses	Ubiquitous coverage of wide areas is a requisite, as it was for the success of mobile communications. The user must be able to publicly access information whether from their PAN or through instant partners.
Level 5: Interconnectivity	The value of communications technologies is said to grow proportionally to the square of the number of the connected devices. Therefore is of utmost importance that interconnectivity is assured, through communication standards.
Level 6: Cyberworld	In the outer sphere, outside our real world, lies cyberworld communication. This level encompasses communications between people through virtual agents, between virtual agents and people (augmented reality), or even between virtual agents, in a virtual world. This trend is already visible in MMOGs.

Wireless communication occurs almost exclusively by modulations of electromagnetic radio waves. Infrared plays a small role as an alternative.
Modulation methods convert data into a form that can be transmitted via antennas through the air. In general, modulation refers to alterations in a carrier signal in response to a message signal. The amplitude, frequency and phase of the carrier signal can all be altered (modulated).

Several different network technologies exist, with different characteristics such as quality of service, frequency, but most importantly: range and bandwidth/speed. They can also be referred to by their IEEE (Institute of Electrical and Electronics Engineers) or 3GPP (3rd Generation Partnership Project) standards.

Bluetooth (IEEE 802.15.1) is primarily used to connect computing to its peripherals, or between mobile phones. Usually used for small size data only, due to its low transfer rate. Bluetooth is used in Wireless Personal Area Networks (WPAN) range.

Ultra-Wide Band (UWB), or IEEE 802.15.3, is substantially different from conventional narrowband frequency and spread spectrum technologies such as Bluetooth and Wi-Fi. UWB uses an extremely wide band of radio-frequency spectrum, while not emitting enough energy to be noticed by narrower band (Wi-Fi) devices (Figure 2.11). This spectrum usage allows devices to transmit more data in a given time period than the more traditional technologies, but they must be kept in close proximity, WPAN range (Intel 2005).

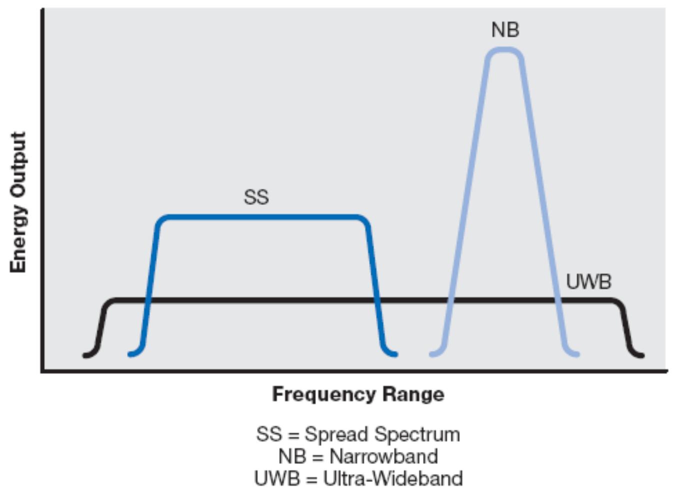

Figure 2.11. Ultrawideband frequency and energy output (Intel 2005)

Wi-Fi (IEEE 802.11a/b/g) is a widely supported wireless internet technology used in Wireless Local Area Networks (WLAN), with a range up to 140m around a “hotspot” - using omnidirectional antennas. That range can be extended to 10km using mesh networks, in which “nodes” deployed, laptops or fixed access points that act as a router, and transmit data from one node to the next (M9 Systems 2005). This increase in range places Wi-Fi into two usage segments: Wireless LAN and MAN (Metropolitan Area Networks). Mesh networks are limited by the need of a large subscriber base to cover large areas. Another disadvantage is the sharing of bandwidth (Intel 2004).

The WiMAX (IEEE 802,16) addresses two usage models: fixed and mobile. The former requires an antenna, similar to a satellite dish, on the subscriber’s site. A mobile version is being considered by mobile phone companies as an alternative to current services, especially with data-intensive accesses. This standard bases its communications on a grant-request protocol that, unlike 802.11, prevents data collision and therefore uses bandwidth in an efficient way. It was originally design to provide WMAN service, as a result the loss of bandwidth by sharing costumers is not as significant as in Wi-Fi. WMAN’s range is up to 50km (Intel 2004).

Another type of wireless access is through Cellular Networks such as 2,5 Generation networks (GPRS) and 3G networks (UMTS). Cellular networks are predominantly used in mobile phones and its standards are not regulated by the IEEE, but by the 3GPP. Although their range is up to 30km, shorter than WiMAX, they are considered Wireless Wide Area Networks (WWAN). This is due to the fact that it has a much larger install base, antennas cover almost entire countries. Speed varies from 1.8, 3.6, 7.2 to 14.4 Mbps (GSM Association 2008).

The following figure summarizes and compares the bandwidth and range of the most relevant networks:

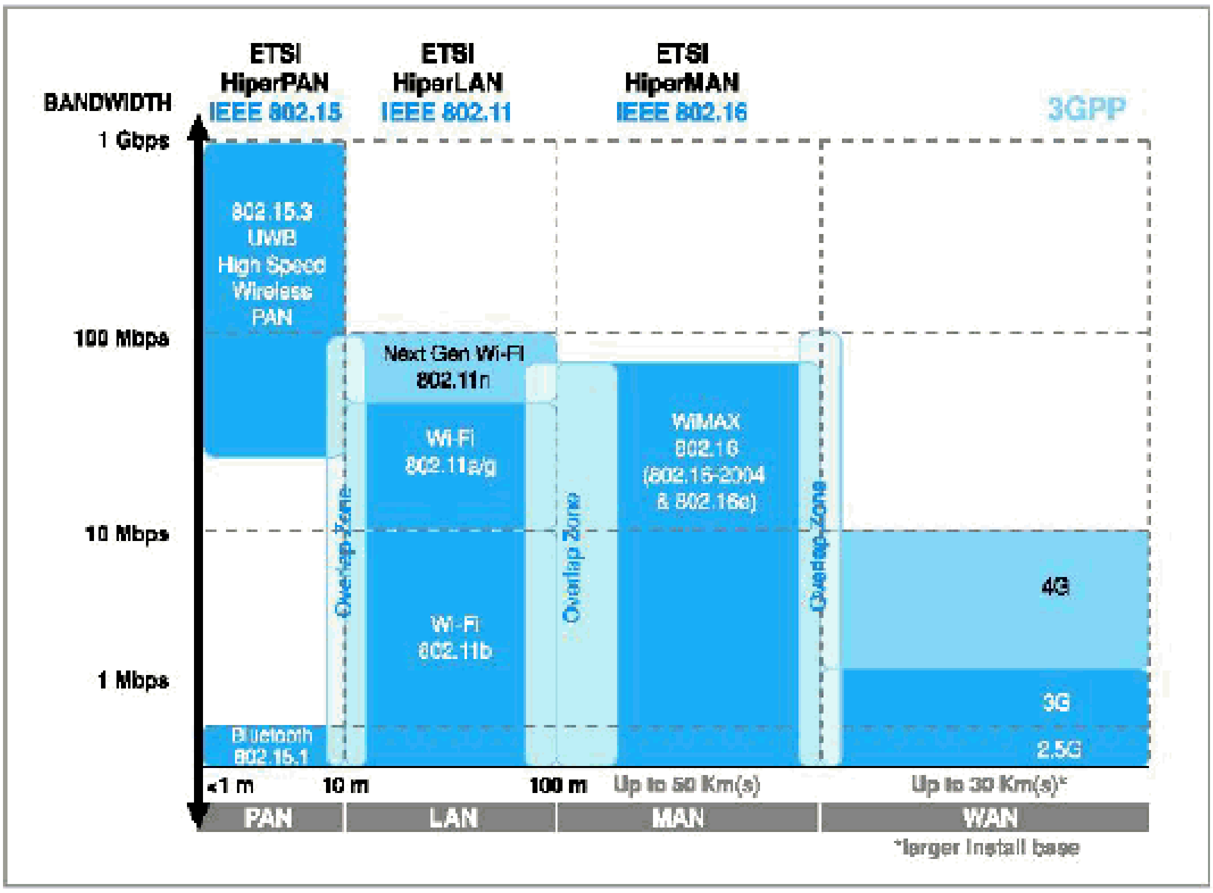

Figure 2.12. Wireless Networks bandwidth and range(Intel 2004)

Another form of ubiquitous internet access, although not wireless, is BPL (Broadband over Power Lines). BPL uses the high frequency portions of power lines which aren't used by electricity. Speed can be up to 3Mbps, enough for most types of usage (De Argaez 2008). This technology is very attractive because it's cheap and every house has a plug in it, so even isolate, rural areas could have internet access.

This could be an interesting adoption by non-mobile, ubiquitous computing devices such as updatable advertising billboards or an interactive window.

Enabling everyday objects to communicate with each other will bring innumerous benefits. Current standards compete with each other and are not compatible between them, creating a digital barrier. The solution to this problem, according to Neil Gershenfeld, is Internet 0. Internet-0 uses Internet Protocol to transmit bits, and because "light bulbs do not need to watch movies at broadband speeds", data can be transmitted slowly.

This has big implications concerning interdevice internetworking.

A bit has a physical size, they are radio, electrical or light pulses. Its speed (approximately the speed of light) multiplied by the time it takes to send the pulse equals the bit's size.
The problem with high speed networks is that their bits are much smaller than the network (30cm for a data rate of 1Gbps) so they send many bits before detecting a collision.
If information was sent at a data rate of 1Mbps, a bit would be 300m long - enough to encompass a building network. Whereas small pulses reverberate off interfaces such as metal cabinets (in the case of radio signals) or wire junctions (for electrical signals), large pulses literally fill every inch of the air or wiring within a house.
If the network is bigger than the signal, "problems arise at the interfaces between pieces of the network. Slight mismatches in the transmission properties at the interfaces generate spurious signals. Moreover, two computers that start transmitting simultaneously may not discover the collision until after they have sent many bits. That is why high-speed networks require special cables, active hubs." Therefore, for slow data transmission, devices no longer require special interface equipment. (Gershenfeld *et al* 2004)

In order to connect that many objects, identifying them becomes essential. Current IP (version 4) was developed in the 1970s. Their addresses may be 32 bits long, which means 2^{32} different addresses, around $4{,}3 \times 10^9$. Due to an exponential growth of connected devices, IPv4 is running out of space (Greenfield 2006), expected to be exhausted by 2010-2011 (Huston 2008). It is obviously insufficient to fulfill the aim of connecting billions of objects.
Its successor, IPv6, will be extended to 128 bits long, translating into 3.4×10^{38} discrete addresses. On a world scale, that would be roughly $6{,}5 \times 10^{23}$ for every square meter on Earth's surface (Greenfield 2006), more than enough to connect every grain of sand.

The objective of connecting objects also implies thinking about the modifications it would undergo, particularly on its size, form, weight or price.
A conventional antenna is typically between a quarter and half a wavelength long - a car radio antenna is around 75cm long, a quarter of a wavelength of a 100MHz FM station (Langley, 2008). A stamp with a long antenna wouldn't be very usable.
Professor Langley at Sheffield University is conducting a research on small antennas that could be incorporated in our clothes, to be used in telemedicine, military applications or any

other ubiquitous computing scenario. Already measuring 133 x 24 x 9.5 mm (Langley 2006), they aim to reduce that size to a 50th of a wavelength until 2011.

2.1.5. Location Systems

Geo-localization plays a big role in ubiquitous computing. Much of the information sent or received by the user is context- and place-sensitive. In a world of connected things, their place may also be of some importance, for example, to find a book in a big library. Bruce Sterling coined the term “Spime” for these “internet of things” objects. A traceable, “auto-googling” object, which contains meta-data about itself. So we could, for instance, see a person wearing a t-shirt we liked, and automatically access information about it’s brand, price, and buy it on the spot. Or find something, if lost or stolen.

There are many location systems and technologies. The most widely used is GPS (Global Positioning System), but other systems are available, for example AGPS (Assisted GPS), signal processing or RFID. Jeffrey Hightower and Gaetano Borriello developed a taxonomy of those systems:

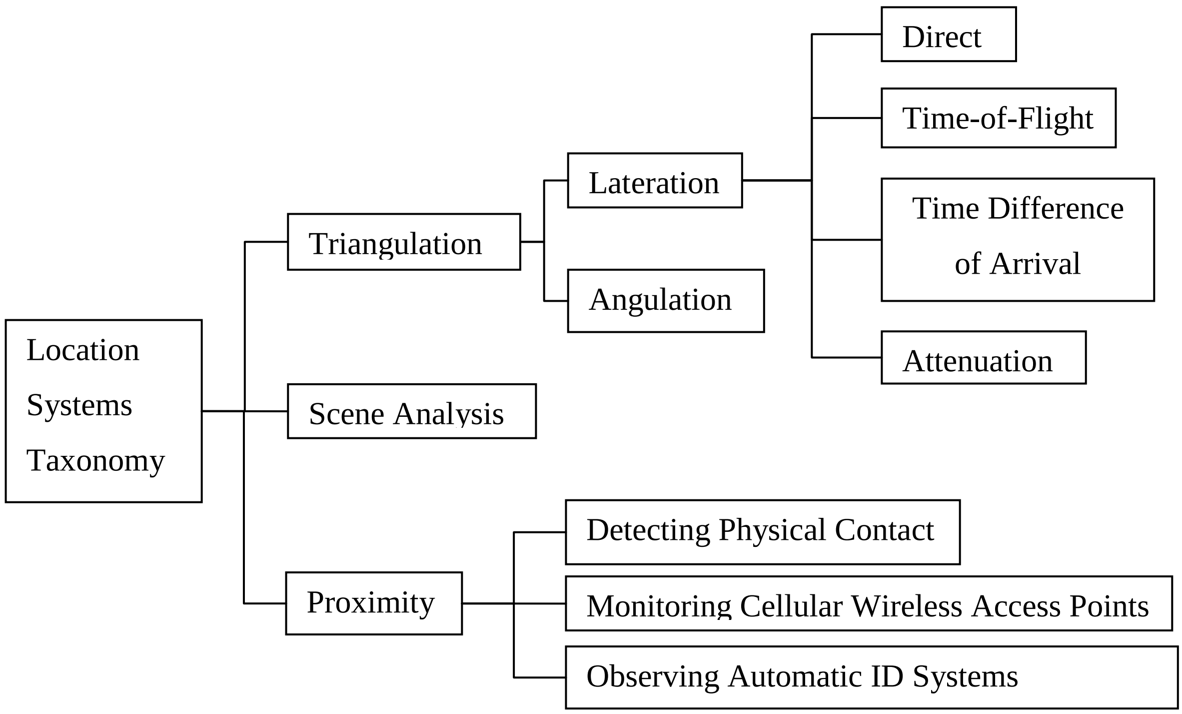

Figure 2.13. Taxonomy of location systems (adapted from (Hightower and Borriello 2001)

The principal techniques for automatic location are Triangulation, Scene Analysis and Proximity.

1. Triangulation relies on the geometric properties of triangles to determine position
It can be divided in 2 different subcategories: lateration and angulation

1.1 Lateration
This method consists in calculating an object's position by distance measurements. In a 2D space, 3 non-collinear points are required (Figure 2.14.), in 3D space, 4 non-coplanar points.

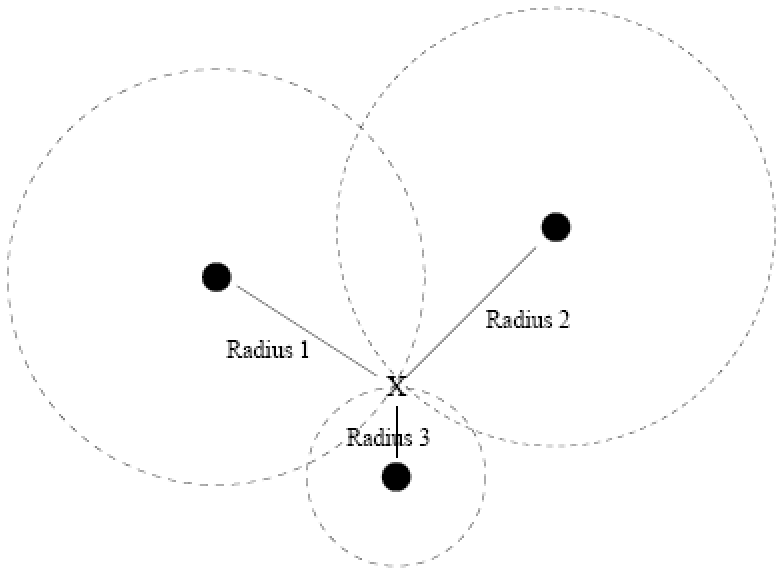

Figure 2.14. Lateration

Distances can be calculated through three different methods:

1.1.1 Direct – Direct measurement with a scaled object (measuring tape, ruler, or other object with a known size)

1.1.2 Time-of-Flight – Distance is calculated by measuring the time it takes a signal/object to travel between 2 points (source and sensor), at a known velocity.

1.1.3 Time Difference of Arrival - Time delay estimation of the source signals is first performed on pairs of sensors. This information is then used for constructing hyperbolic curves with each couple of sensors at the foci of the curves. The difference between the distances from the focuses to a point on a hyperbola corresponds to the estimated delay. Source location is also identified by intersecting the curves (Tai-Chi Consortium 2007).

1.1.4 Attenuation – By comparing the strength of the signal when emitted to its strength when received.

1.2 Angulation

Angulation requires a known distance between two reference points and two angles as seen in Figure 2.15.

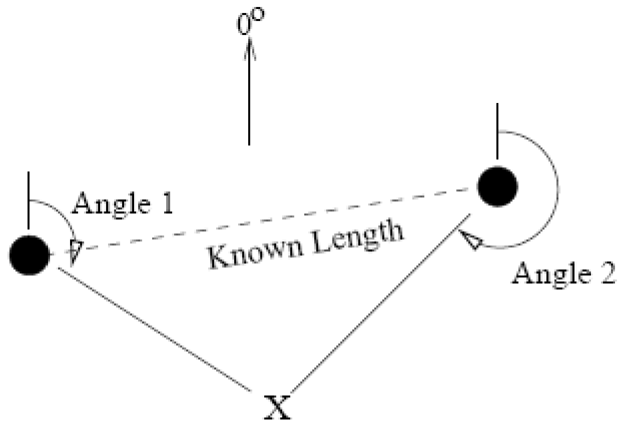

Figure 2.15 Angulation

2 Scene analysis

Scene analysis consists of calculating position by observing a scene from a particular vantage point. They require a pre-determined dataset of known locations within that scene. This method compares differences in features known to be at specific positions, from successive pictures of the same scene.

Figure 2.16 Scene Analysis

3 Proximity

An object can also be determined by sensing when it is proximate to a known location, using a physical phenomenon with limited range.

There are three methods to proximity sensing:

3.1 Direct Physical Contact – Contact between the object and an *in-situ* sensor.

3.2 Monitoring Cellular Wireless Access Points – When a device capable of wireless communications is within range of one or more access points. Its position can be determined by knowing the cell geometry (“radius”) of each access point, and their intersections.

3.3 Observing Automatic ID Systems – The object’s position can be inferred by observation of phone records, credit card transactions, and identification tags such as toll systems, barcodes, bluetooth or even scanning super-distributed RFID tags in the floor (Bohn and Mattern 2004).

2.1.6. Software

Software is evidently necessary to allow all the different technologies “talk” to each other. Microcontrollers need to know how to process sensor signals, when to send information and when to stop controlling actuators, among other processes.

Ubiquitous computing has special properties which differentiates it from other paradigms. Therefore requires a diverse range of software to enable access to those singular properties (networks, location), as well as software intended to refrain events from happening (energy optimization and privacy).

Within the last years new digital devices started to emerge. They are neither simple like a digital watch nor complex like a PC. A lightweight Operating System (OS) is targeted to those specific low-performance devices, with fewer capabilities in order to use fewer resources (energy, memory, processor). Symbian is an example of lightweight OS, it started on the “low-tech” side, originally designed for the first mobile phones and has been upgraded since to accommodate new, with more capabilities. WindowsCE/PocketPC and embedded Linux started on the complex side of the spectrum and are now leaning to lower performance systems. All of them have a GUI, networking and storage capabilities (ESTO 2003)
For future ubicomp devices, personalized software may have to be designed, depending on the complexity range covered as well as their purpose. It may just be a small network-capable information gatherer, or fully interactive clothes displaying context-aware information to its user.

GRID Computing consists of interconnected computers intended to be accessed and used by the community as easily as the electrical grid. Information processing and storage is already happening over the internet in applications such as Google Docs, this is called “cloud computing”. Cloud computing is slightly different from grid computing. The former implies the supply of applications to millions of end users, while the latter is similar to a utility that can be tapped, turned on or off as required (Rubens 2008)
Until now, grids have been constituted by clusters of universities’ computers and (voluntarily) by household PCs and entertainment systems (Playstation3), in scientific projects: Large Hadron Collider, Protein Folding, SETI@Home. As the internet becomes faster and platforms develop, companies and people will be able to rent their processing power, memory and bandwidth to users from anywhere in the world. Even more computational-intensive projects are expected to appear: high quality 3D image and animation rendering, realistic physics simulations or complex mathematical model simulations.

Networks are becoming increasingly more complex and unpredictable. Peer-to-peer (P2P) and ad-hoc networks are an example of this trend. This kind of networks has defining properties (ESTO 2003):

- a large number of nodes
- extremely variable load
- extreme variability in topology (nodes joining or leaving the network)

Special software will be required to manage future dynamic and ubiquitous networks. Some research about self-organizing architecture is based on biomimicry. By studying apparently unpredictable natural systems (social insect colonies, evolutionary systems, mammalian nervous systems, immune networks), researchers might infer how they behave and organize, and translate that into software (e.g., using Genetic Algorithms). This approach consists of autonomous agents with simple behaviors (Nakano and Suda 2005).

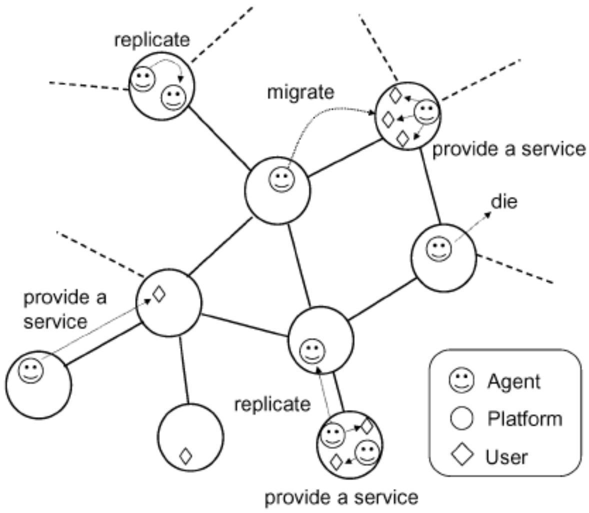

Figure 2.17 Network service provided by a group of autonomous agents with simple behavior. (Nakano and Suda 2005)

Nodes should also be easy to find. Peter Morville defines "ambient findability" as "a world at the crossroads of ubiquitous computing and the Internet in which we can find anyone or anything from anywhere at anytime."

But in a network of potentially billions of similar objects, that task can be humanly impossible. Also, automation of processes depending on that may be desirable. Machines do not yet possess the "intelligence" to do so by themselves without specific human guidance.

Steps are being made on the web to organize information, a concept called "semantic web" which is poised to become Web 3.0. The concept revolves around classification and

relationship between data as well as automatically generating meta-data for any content on the web.
According to Morville, this meta-data is the path to findability for all content across all formats and all devices, by “bringing together things like tags and taxonomies, not keeping them apart”. (Morville 2008).

Ubiquitous computing will need additional software-related development: for personalization, behavioral data mining, for embedded systems, standardization, among others.

2.2. Bottlenecks

One of the reasons why ubicomp-enabling technologies are so highly developed is the fact that they weren’t created originally with ubicomp in mind. They were created before and while the vision was growing. By the time ubicomp became a well-known research topic, the technologies were already mature enough to allow it to happen.

While they are sufficiently advanced to theoretically permit some kind of ubiquitous computing world, some of them are still considered a bottleneck if the objective is to completely realize Mark Weiser’s vision (i.e., transparent interaction).

In order to understand ubicomp’s dependence on technology, experts were asked about technology fields that could potentially be considered as bottlenecks Figure 2.18.

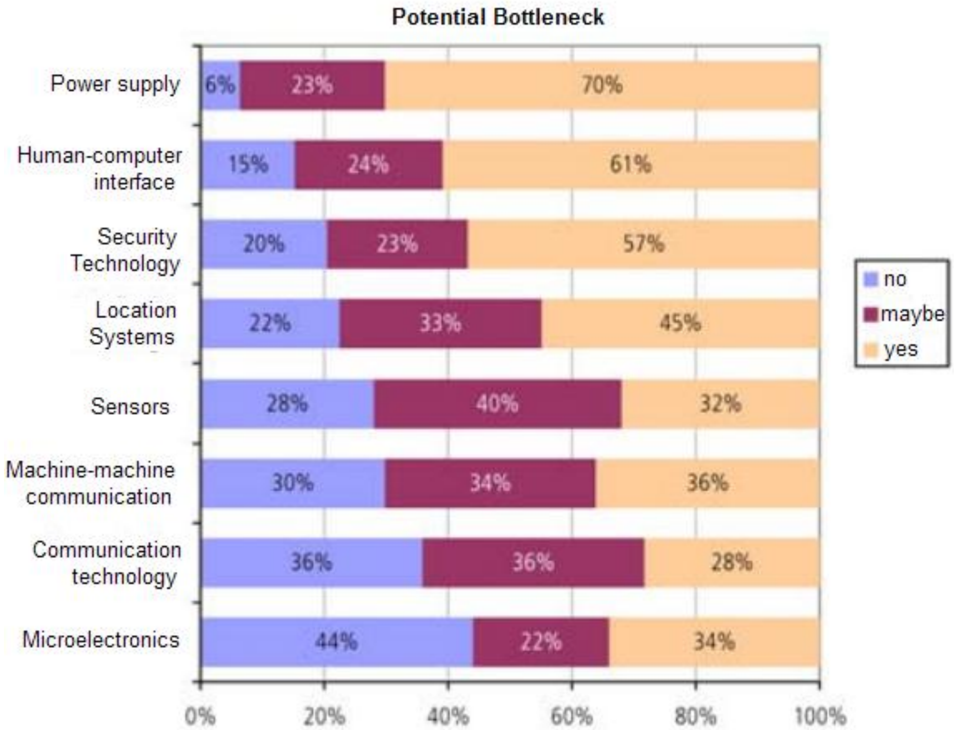

Figure 2.18 Potential ubiquitous computing bottlenecks (BSI 2006)

Experts have considered energy supply, lack of adequate human-computer interface and security as the most likely limiting factors to overcome.

Overall, microelectronics, sensors and location systems are considered mature technologies. They do not pose significant bottlenecks for ubiquitous computing. Some exceptions exist such as nanotechnology - although not sufficiently advanced, is only meant to be used in niche applications. Even though communication technology is widely available only in some areas, which may geographically limit some applications, experts show more concerns about the development of IPv6 and Mobile IP.

Energy supply is, despite their high availability, the most relevant bottleneck. Experts refer increased capacity, reduced self-discharge and especially energy harvesting, as the most relevant developments to overcome supply problems (BSI 2006).

Humans will interact in a truly ubiquitous world of computational objects. Many of these interactions may be implicit, as devices won't necessarily provide feedback. Nonetheless, users must have the choice to control them, by means of an adequate human-computer interface.

3. Interaction

3.1. Natural Human-Computer Interaction

People should think of a computer interface less as a tool and more as an extension of themselves or as extension of their mind.
Austin Shoemaker, CTO, Cooliris

As stated by Mark Weiser himself, the ubiquitous computing concept is about making computers unobtrusive and human interaction with electronic devices a much more intuitive, seamless, fluid, even enjoyable experience.
In order to achieve those desirable characteristics, new kinds of interactions must arise, different from the current desktop computer model. Even before 1991, research was done to develop intuitive physical interfaces. In 1963, Ivan Sutherland designed a system that allowed a user to sketch directly on a computer display with a pen (Sutherland 1963). This not only enabled drawing lines effortlessly (without having to type coordinates), but made it a more natural process.
HCI has since grown and evolved. The technologies available today enable a wide range of possibilities, many already in development, perhaps more still unknown. HCI has traversed the boundaries of computer science and is now an interdisciplinary field, comprising different areas such as psychology, design or sociology.

One of the most important factors which is conditioning the user experience when interacting with computers is the interface. The interface provides a means to “translate a conversation” between two different entities. A machine interface can encompass a method for input, a method for output, or both. Output allows the computer to transform signals/data and enable it to communicate in a “human language” (e.g.,: through visual displays with text or images, sounds). Input allows humans to communicate with the computer in their own terms, which the system translates into signals/data for the computer (e.g. B letter in a keyboard, moving the mouse).

Notably, there is a parallelism in function between humans’ and computers’ input and output systems. In some cases humans have a greater sensing range and resolution (tongue, nose) and

other cases computers can sense better (microphone, temperature) or even sense outside human range (magnetic sensor, UV sensors).
Some examples are shown in Table 3.1.:

Table 3.1. Human / Computer analogy

Human Inputs, Outputs	Computer Inputs, Outputs
Voice	Speakers, headphones
Muscular movement	Motor
Eyes	Camera, visual spectrum sensors
Skin	Pressure, temperature sensors
Nose, tongue	Chemical sensors
Ears	Microphone
Inner ear	Accelerometer, gyroscope, tilt sensor

Similarly, the machine's input is activated by means of a user's output, and the machine's output is received by the user as an input for their CPU, which is the central nervous system.

Interaction therefore can be seen as a continuous Stimulus→Change→Response cycle between users and computers.
A human-computer interaction model can be schematically described as follows:

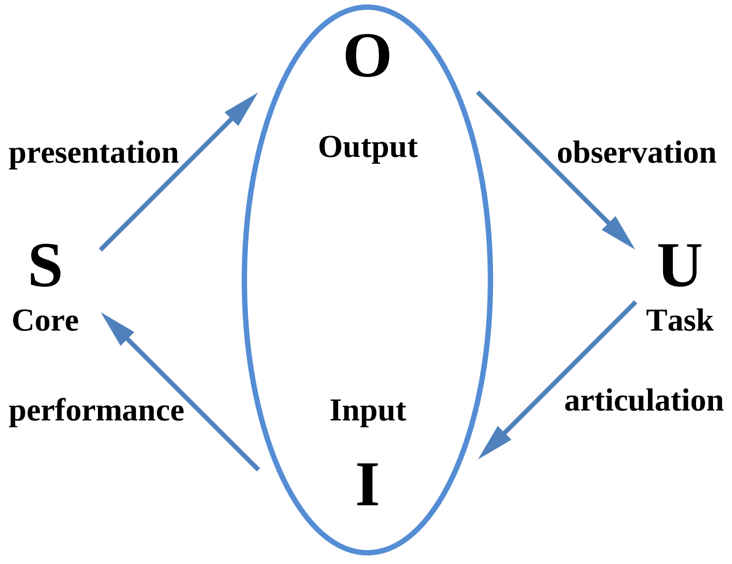

Figure 3.1 Abowd and Beale's interaction model.

Natural interaction is a desirable paradigm: people should focus on the task, rather than on the tool. In the real world, interactions with objects and people typically involve two or more sensory modalities. To simulate the real world is important for technology to have this ability. Also, tasks should be accessible to everyone. Ideally, interfaces meant to be used by a large, undetermined group of people (public information access points, ATMs) should have more than one interaction mode. Multimodal interfaces are able to receive more than one mode of input at the same time (e.g.: speech and gestures), providing a richer interaction.

3.2. Emerging Input and Output Technologies

Today the distinction between display and input devices is being blurred. We are seeing the emergence of interactive surfaces capable of sensing rich gestures encompassing multiple touches of multiple fingers from multiple hands of multiple people on multiple objects.
-Bill Buxton, Principal Researcher, Microsoft

To achieve natural interaction, several technologies already exist. They don't share the same maturity - while some of them are recent or still being developed, a few others already exist for some years, but only now they start to be applied in whole new contexts of interaction. According to Bill Buxton: "any technology that is going to have significant impact over the next 10 years is already at least 10 years old".

Input devices are sensors that can detect a user's action. They can be digital (discrete values) or analog (range of continuous values). The most important characteristics of an input system are its ability to locate an action in space and detect selection (or absence thereof) in that location.

Output devices are usually visual displays, acoustical or mechanical. Unlike color, which requires a combination of 3 primary colors, taste and smell exist in thousands of different combinations or thousands of primary molecules and are therefore very difficult to synthesize. Odor delivery systems exist though.

The following technologies can be regarded as input, output or both, simultaneously integrated. They are described in an interaction framework.

3.2.1. Computer Vision

Computer vision can be described as a way to acquire information though images. Images can be in or outside the visible spectrum, as computers aren't limited by it (e.g. IR detection).

It relies on algorithms to process the detected image. Relevant parts of an image are selected by feature extraction techniques such as edge, motion or blob detection (for example separating contrasting images)

Used mostly for people and object recognition, detection is possible with the aid of tags and markers, or without them. Users have the possibility to access information contained in an image; to be recognized (biometrics); or to interact with virtual elements with gestures, which are informative movements, unlike pressing a key.

Tags include 2D codes such as QR code, Semacode which can contain information coded in patterns (Figure 3.2). Body markers facilitate interpretation of human movements by the computer (Figure 3.3) [Video 01]

Figure 3.2. Tag examples: QR code (Kaywa 2008); AR Toolkit marker (HITLab); d-touch marker (Costanza)

Figure 3.3. Tom Hanks motion capture for the Polar Express movie. (Newsweek 2004)

Usually with more complex algorithms, recognition is possible without markers. This includes:

- Facial recognition, which can be used to determine traits, a person's age or identity (by comparing with photos); [Video 02]
- Fingers and hand movement (Figure 3.4), for pointing, controlling virtual objects though movement or gestures; [Video 03]
- 2D and 3D Body movement, as means to affect virtual objects or electronic devices. [Video 04]

For this purpose, humans can be differentiated from their surroundings in two ways:
By detecting specific human traits, usually the face, i.e., eyes, nose, mouth;
By possessing higher body temperature, we emit more IR (thermal) radiation than the environment; skin also backscatters near-infrared wavelengths.
Both these IR signals can be captured by cameras with IR-pass filters. In interaction, IR detection is usually more useful than facial recognition.

Figure 3.4. Zcam (3dv Systems) and Sofkinetic iisu (Softkinetic)

New developments include research on using computer vision to identify objects or people by coupling cameras on the fingers. Especially useful for the blind to navigate, Fingersight (Stetten 2007) transfers visual input to another sense, in this case touch (Figure 3.5.).

Figure 3.5. Fingersight (Stetten 2007)

Computer vision techniques are useful when high accuracy is needed. It can also be inexpensive and less obtrusive as cameras are increasingly cheaper and smaller

Visible spectrum cameras may need some calibration when changing light conditions. Whereas IR detectors work well in dark places, and through darkened surfaces, in outdoor spaces they're not as useful due to constantly changing IR radiation from the sun, throughout the day. Some complex techniques may require higher resolution cameras and computational power, and are therefore less suitable for mobile applications.

Camera-based detection can also be used in combination with other I/O technologies, for instance, haptics, FTIR touchscreens or augmented reality

3.2.2. RFID

RFID, one of the most promising technologies for widespread use, is composed of two elements: a tag and a reader. Tags consist of a chip which contains information and an antenna, necessary to transmit it to a reader as radio waves (Figure 3.6). There are passive tags, semi-passive tags and active tags. Passive tags consist of only the chip and antenna, transmitting only when near a reader, which powers the tag by inductive coupling. Active tags are battery-powered (both chip and antenna) and can send and receive information. In semi-passive tags only the chip is powered.

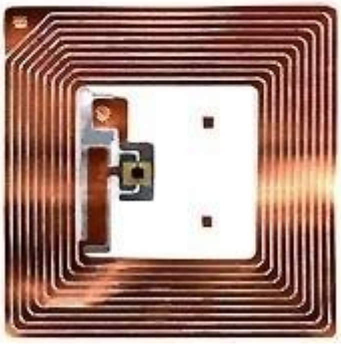

Figure 3.6. Passive RFID tag

They're used for information as well as location purposes: locating objects (inventory, finding a book in a library), animals (pets, cattle), people (active badges), acquiring info on our (tagged) surroundings, automatic payment (tolls, octopus card). [Video 05]

Currently chips can be as small as 0.15 x 0.15 mm in area and 7.5 μm thick (Gingichashvili 2007). The problem is that the antennas still need to be relatively large, about 200 times bigger than the chip.

RFID enables previously manual processes to be automatic and contactless, consequently much faster. They are becoming increasingly ubiquitous (e.g: the Octopus card is used in almost every transaction in Hong-Kong, from shopping to public transportation).

Passive tags are becoming cheaper, already costing less than $0,10 each (Creative Systems - private communication 2008). It is believed that the threshold price for using tags in every product is $0,05. By lacking battery, the signal is weaker, meaning their range is shorter (Figure 3.7), and quality of information transmitted is more error-prone than active tags.

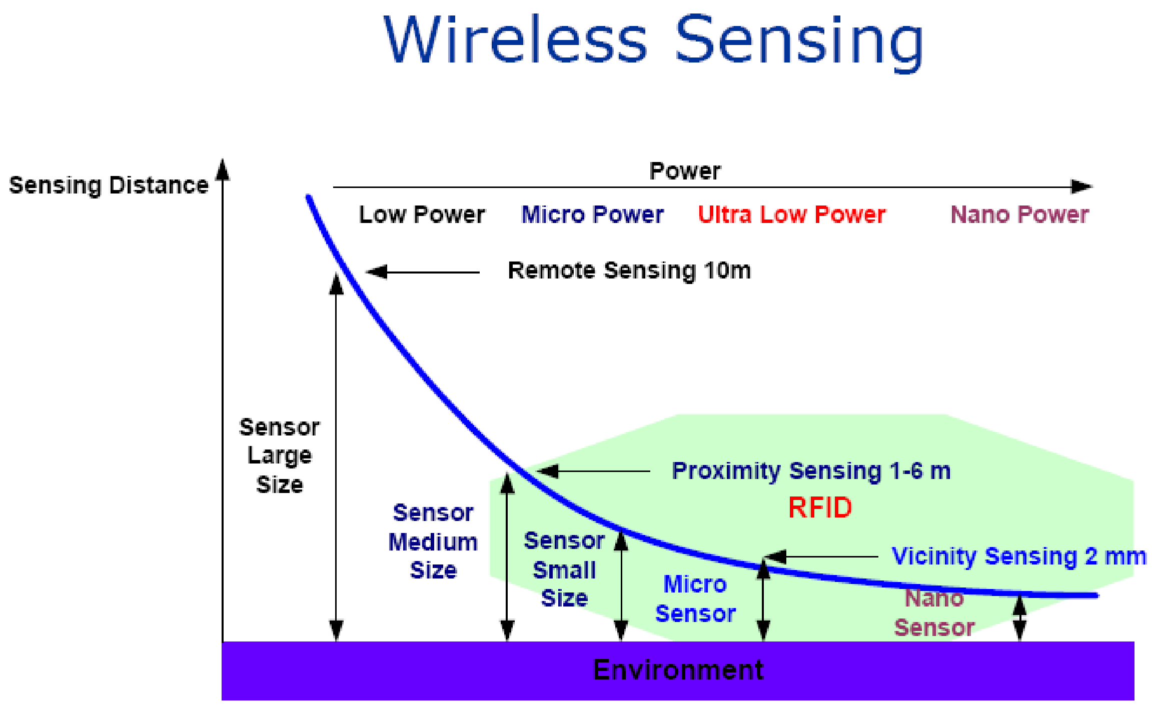

Figure 3.7. RFID Power vs Sensing distance (Vermesan 2007)

Active tags have the disadvantage of being bigger and more expensive. Contrarily to traditional barcodes both of them they don't need to be in the line-of-sight of the reader. Being thin and flexible, they can be adapted onto any surface configuration, and read in any orientation (Joshi 2000). They don't have a way to display information, therefore making difficult to instantly track credit and expenses, without having to resort to a reader.

3.2.3. Remote Sensing

Remote sensing considers contactless sensing concerning distances over 10m (Vermesan 2007).

While in most cases the interface between the task and the user is preferably near to the user (usually to allow him/her to receive instant feedback of their actions), some cases require a more remote sensing. When users want to use their own location as input information, over large areas, the best way to do it is by means of Global Positioning Systems.

The user needs to have a GPS receiver, linked to at least 3 satellites in order know the exact location via triangulation (see "Location Systems").

User’s position can be of use especially for mobile applications. Due to extensive use of GPS for non-military purposes, it has become increasingly cheaper. The technology is not new, but by allowing general public access, it has given birth to original uses, namely location-based services, games and art.

Services may include finding the nearest gas station, bus stop or healthcare facility. [Video 06]

Games range from requiring simple receivers to complex mobile phone games. They may be singleplayer (geocaching and other treasure hunt games) or incorporate several players cooperatively or competitively (Undercover2).

New forms of art are emerging: virtual drawings made by walking, driving or flying in predetermined paths using a receiver with the ability to plot trackpoint data (Figure 3.8).

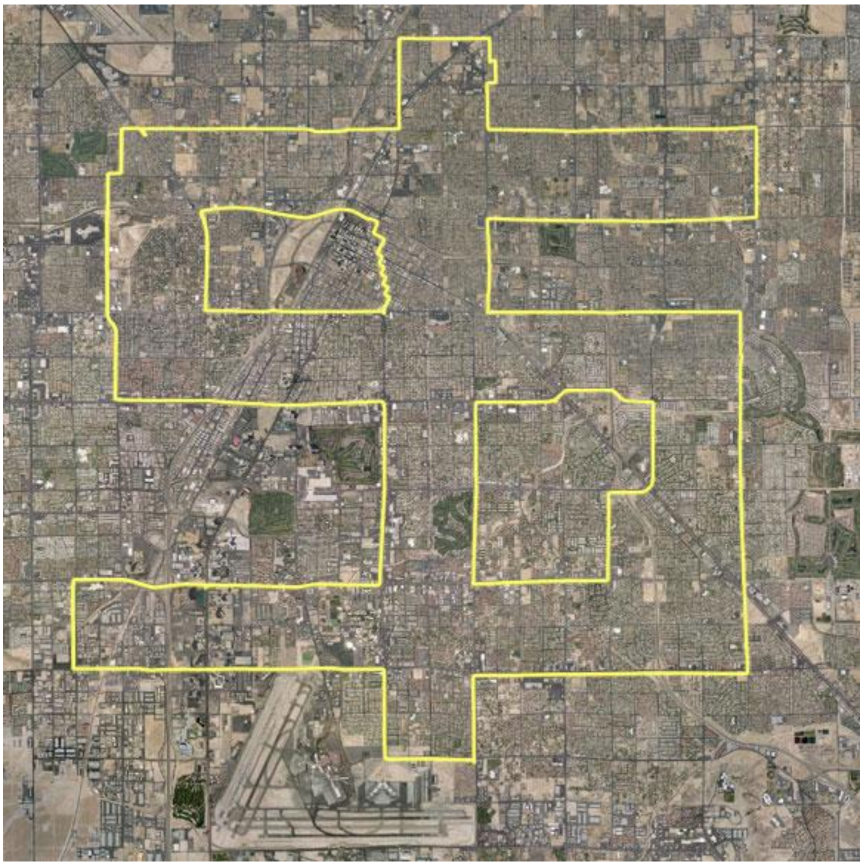

Figure 3.8. 13km dollar in Las Vegas. Retrieved from Wood, 2008.

Receivers tend to be too big to become wearable or otherwise unobtrusive. A possibility is to use GPS-enabled mobile phones (which people would carry anyway), but presently these can be somewhat expensive.

This technology, although mature, lacks the proper infrastructures to reveal its full potential: there are still few commercial products using this technology except for driving support applications. To provide ubiquitous LBS, stores, objects, places need to be georeferenced and specific software need to be developed to integrate all this information.

3.2.4. Paper Augmented Interfaces

Writing is probably the most intuitive and ubiquitous technology humans have. It is so integrated in our everyday lives that we don't even regard it as such. Literate people can read (and write) as effortlessly as they walk or breathe.

Stylus-based interfaces have existed for some time: lightpens (Ivan Sutherland), digitizing tablets (Wacom), touchscreens (handheld computers). But these never felt like normal writing, there were always trade-offs. A user either had to stay close to a computer screen, write without having a feedback on the digitizing surface or carry the device which necessarily has a small interface, occlusion problems, turning the stylus into a selecting tool, instead of a writing one.

New stylus-based interfaces include Livescribe's smartpen or Logitech io pen (based on Anoto's pen technology), when used with Anoto's paper. Microsoft's "universal pen" also works in similar way (Huang 2004).

The paper is printed with an almost invisible microdot pattern, and while the user writes, the camera embedded in the pen takes more than 50 pictures/second, determining the pen's position and saving that information (Figure 3.43.9). That data can be afterwards transferred to the PC and used as an image or transformed into digital text via character recognition software.

Digital documents can also be printed over the paper and annotated, followed by synchronization between paper and digital documents (Guimbretière 2003). Commands can be written in the paper, in special portions of the paper recognizable by the pen (to send information wirelessly, for instance), or by special gesture (Liao 2005), as to not be confused with regular writing.

Figure 3.4 Pen & Paper interface (Anoto)

This input technology is especially useful for people less knowledgeable on modern tools. Everyone, even illiterate people can use a pen. This technology can be useful in situations such as e-voting, where all that is needed is a cross or a simple sketch. Asian markets can also benefit, as asian-language characters are numerous and tedious to type on a keyboard.

Paper has the benefit of not needing backlight (less strain on the eyes) and can be used in a variety of environments

The downside is that without the special printed paper this technology won't work. Paper can become expensive to archive, and is a fairly static medium (unupdatable, unsearchable). Mobility depends more on how much paper is needed, its easiness of transportation or availability on the destination, than carrying of the device (pen) itself, although the pen needs to be powered. Nevertheless, sheets of paper are still much more mobile than other inflexible media. [Video 07]

3.2.5. Brain-Computer Interfaces

Brain-computer interfaces (BCIs) have been studied for several decades, mostly for medical purposes, as a mean for disabled people to sense or control the outside environment. Ubiquitous computing is primarily paradigm change to affect as many people as possible, therefore I will only consider general-use BCIs, i.e., non-invasive interfaces.

There are two ways to detect neuronal activity as input signal:

Electroencephalography (EEG) – Electrodes are placed on the scalp and are used to monitor electrical activity produced by the brain.
EEG-based BCIs attempt to measure user’s voluntary intentions and decisions. They can detect brain activity that correlates to visual stimuli, gaze angle, voluntary intentions and cognitive states (Lebedev 2006).
Electrodes can also be used to measure eye movement (electrooculography) and muscle cell contraction (electromyography), as both activities create an electric potential differential.

Functional Magnetic Resonance Imaging (fMRI) provides an indirect measure of neuronal activity. As brain activity increases in a particular area, neurons consume more oxygen. fMRI measures the signal differences in the concentration of deoxygenated hemoglobin (Weiskopf 2004). As brain activity increases in a particular area, the blood flow increases, bringing more oxygen with it and increasing the signal strength.

Commercial BCIs are EEG-based, usually take the form of an headband with electrodes (Figure 3.5 3.10). They differ on the number of electrodes which translates into different resolutions, and capability to sense activities like ocular or head movements. Emotiv EPOC has 14 electrodes (Emotiv Systems 2008), while OCZ NIA only has 3 (OCZ Technology 2008).
By differentiating brainwaves’ wavelength, EPOC can measure discreet emotional states, detect conscious thoughts and identify facial expressions in real time. In gaming these signals are used as a substitute for keys and mouse, allowing users to control character’s movement and shooting. There are plans to use them in varied other areas such as medicine, security or interactive television. Thought-to-speech interface is described in “Speech Recognition”.

Figure 3.5 Left image: OCZ NIA (OCZ Technology 2008); Right image: Emotiv EPOC (Emotiv Systems 2008)

In development are devices using functional near-infrared spectroscopy (fNIR) which detects oxygen changes in hemoglobin, in a similar way to fMRI. NIR light between 700 and 900nm, which most of the tissue is transparent to, except hemoglobin. Oxi- and deoxi-hemoglobin have different levels of backscattering and can therefore be differentiated (Izzetoglu 2005).

Muscle signals are stronger that brain signals (Tan 2008), and are the easiest to control, but are also a problem due to their interference with other signals. Also, outside electrical interferences may occur, namely electric chargers and adapters in the vicinity.
The lack of analogy with natural, real-world interaction processes such as grabbing or pointing, makes the learning curve steep - more than 30 minutes of training to start using, and several days to perfect (from exaggerated muscular movements, which are tiresome, to using small movements and focusing thoughts) and thoughts may vary from person to person. This makes it unsuitable for public occasional use.

Non-intrusive BCIs have the potential of becoming one of the most unobtrusive and intuitive input technologies in the future, provided signals can be measured and allocated to the right thought for everyone. Price ranges vary from $20 (Neurosky, B2B only) to $300 (EPOC) (Gingichashvili 2007)

EEG is currently the most promising interface due to its temporal resolution, ease of use, portability and cost. But they are limited in spatial resolution due to travelling through brain tissue and bone, causing signal strength loss and overlap from different cortical areas. Current EEG-based techniques also have limited bandwidth, typically 5–25 bits/s limiting its potential uses (Lebedev 2006).

fMRI techniques have a much greater spatial resolution, in the millimetric order of magnitude (Peplow 2004) and can detect activity in deep brain structures. Nevertheless they are not suitable for everyday use: their temporal resolution can vary from minutes to several seconds (Weiskopf 2004) and fMRI machines are too large to carry. fNIR devices are much more affordable and portable (wearable), when compared to fMRI. [Video 08]

3.2.6. Eye-tracking

Eye tracking can be described as a technique that allows a computer to know where a user is looking at, and to measure eye's movements. Eye gaze is often associated with thoughts, intentions. Many distinct movements are used to infer on what the user is feeling or focusing on Blink rate and pupil size can indicate fatigue and effort (Ball 2005). Movements encompass fixations and saccades (jumps) or their sequences, scanpaths (Poole 2006).

Some detection techniques include electrooculography (measuring electric potentials around the eyes) and wearing special contact lenses (Glenstrup and Engell-Nielsen 1995) both require wearing devices and can be considered obtrusive.

Point-of-regard detection can now be done unobtrusively by means of infrared light reflected by the cornea. The sensor consists on a camera next to the display, with an infrared LED pointed at the user's eye. The light creates reflections, turning the pupil into a bright disk and creating a corneal reflection (also known as first Purkinje image) (Figure 3.6 3.11).

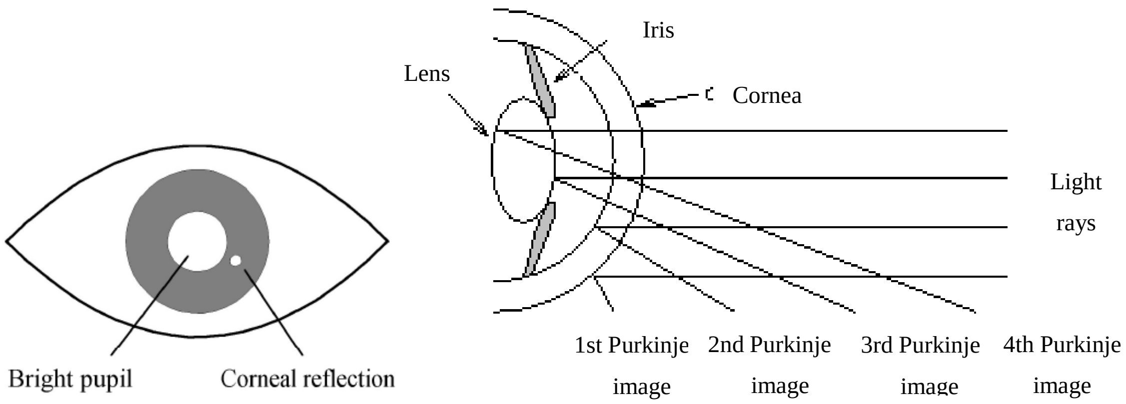

Figure 3.6 Corneal reflection and bright pupil as seen by the infrared camera

Once the image processing software has identified the centre of the pupil and the location of the corneal reflection, the vector between them is measured, and, with further trigonometric calculations, point-of-regard can be found (Poole 2006).

Point-of-regard could be determined by just tracking the corneal reflection, but since one of the major problems with eye tracking is the dissociation of eye and head movement, by measuring the relative position of the pupil and reflection, they can be distinguished (Poole 2006).

Selecting can be determined by blinking, which is unnatural and has to be done consciously, and difficult to distinguish from normal blinks (a long blink is impractical because it distracts the user from the scene); gaze dwelling on the target (150ms) as not to be confused with quick glances (Sibert e Jacob 2000) or using another input, which implies a different action and takes more time.

This method of interaction has the advantage of being one of the most natural, requiring little conscious effort.

It can be useful not only as input for navigation, pointing and selecting, but also to collect data for usability testing and market research, e.g., if the interface or advertisement are working as intended. For instance, too many regressions when reading a text can be a sign of confusion (Poole 2006).

This system is especially useful for disabled people and hand-busy applications, possibly allowing multitasking. [Video 09]

When looking at large displays, real-time image rendering could be localized at the point-of-interest. Peripheral areas could have less resolution, increasing performance without sacrificing quality.

Detection can be harder when users wear glasses or contact lenses because they can make pupil identification difficult and change the reflection's path.

The balance between gaze dwelling and a glance may be difficult to accomplish. Many eyes movements are involuntary and can be considered by the system as a selection when in fact that wasn't the intention. A solution would be to use a multimodal input system, adding voice, for instance (Kaur 2003).

3.2.7. Speech Recognition

Besides movement, the other human output is sound. Sound can be generated by mainly by our hands - clapping, knocking or hitting something – and our mouth - whistling, blowing, screaming or talking. To recognize a sound as an input, microphones or piezoelectric sensors can be used. Different frequencies, intensities, durations and other properties can be allocated to different commands.

Even if by recognizing a wide spectrum of parameters a computer could perform a multitude of tasks, humans can't produce accurately (and therefore don't use) a complexity of sounds.

The only sound humans have coded is spoken language, which is a composed of different combinations of basic sounds (phonemes, syllables) to form words and phrases with meaning. Bushmen (khoisan) language is composed of clicks, but they still have meaning.
Musical notes, despite being able to be mixed, usually require an instrument, knowledge on how to play it, and especially, some meaning had to be given to those combinations, therefore can't be considered as a natural input method.

In order to control a computational device with speech it needs an input system and recognition software to identify its meaning. Input devices are usually microphones which convert sound vibration to electrical signals. Unvoiced speech information can be inferred by detecting the activity of muscles associated with speech by means of electromyography. There are 3 exterior movements: pursing the lips, lifting the corners of the mouth, and opening the jaw (Figure 3.7 3.12). With this method vowel recognition accuracy exceeded 90% (Manabe 2003). Image processing could also be used to catch lip movements, but in a less accurate way as video can't capture tongue movements

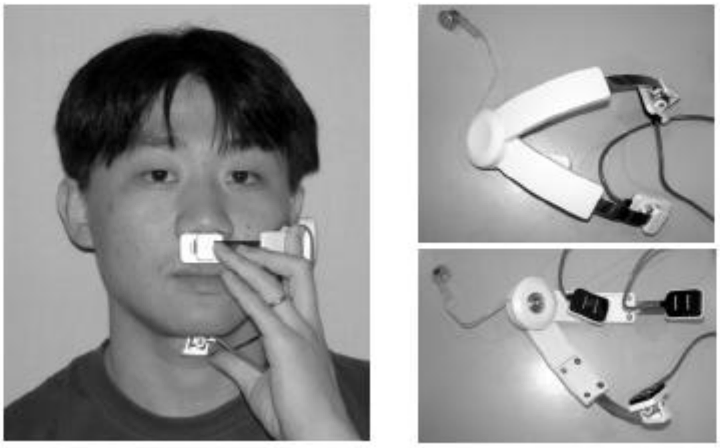

Figure 3.7 3-channel EMG configuration (Manabe 2003).

Other systems (e.g. The Audeo) consist of sensors placed under the chin and on the side of the Adam's apple to pick up "[nerve signals and patterns that] arise when reading or speaking to oneself with or without actual lip or facial movement" (Jorgensen 2004). [Video 10]

Ideally, voiced or unvoiced signals can afterwards be processed sent to a speech synthesizer, write text or used to control a virtual or real object.

Transcribing spoken sentences into text is already possible with acceptable error rate. According to Raymond Kurzweil "systems can recognize fully continuous speech on a 60 000-word vocabulary, with accuracy levels comparable to a human typist" (Kurzweil 1999 cited by ESTO, 2003). Results may vary depending on accents and tones, and system training is required to achieve a good performance. [Video 11]

Unvoiced speech recognition, when based on word recognition, suffers from high error rates. The most promising approach is to recognize phonemes (Manabe 2003). With this technique, a 32% word error rate is already possible with a 108-word vocabulary (Jou 2006)

The real challenge now lies on actual meaning recognition. Computers' artificial intelligence (A.I.) isn't sufficiently advanced to understand natural speech (as humans do). Spoken language has many subtleties, leading to fundamental differences including lack of adaptation and incorporation of new words, and difficulty understanding nonsense words when lacking context or changing topic (Lippmann 1996). The World Wide Web consortium (W3C) developed a grammar standard to help developers specify words and patterns for speech recognizers (World Wide Web Consortium 2004) to allow vocal browser navigation.

Noisy environments can severely impair voice recognition, unless good algorithms are developed and applied to separate user's voice from background noise.
Unvoiced systems don't have to address the cocktail party effect because they aren't influenced by sound. They also have the advantage of being an aid to people without vocal cords and aphasics. Even for people without disabilities they can be of use: mobile phones are creating a social problem in public places (transportations, libraries, restaurants) (Manabe 2003). This technology can help both ways: by reducing ambient noise and keeping user's privacy at the same time. Other particular situations will benefit from it such as underwater communication (divers) or workers in loud environments.

3.2.8. Acoustic

An object or gesture can be detected by their acoustic properties and effects. Their coordinates may be detected on a surface (2D) or in the air (3D).

The two main in-air localization techniques are Time Delay of Arrival (TDOA) and Doppler Effect (Tai-Chi Consortium 2007).

TDOA works in a similar way to Time-of-flight, but compares time differences between sensors. Each receiver pair knows “how far” the source is, but doesn’t know the direction, therefore it can be anywhere on a hyperboloid (De Sanctis 2006) surface around them. It needs 4 receivers, only by intersecting 4 hyperboloids can a single point be located in 3D space.

The Doppler Effect is a change in wave frequency (in this case, acoustic) that occurs when the source and the receiver are in relative motion. When they are closer the sound wavelength is shorter, when the distance between them increases, so does the wavelength. This effect can be used to track a moving acoustic source

Other methods exist such as acoustic holography (Figure 3.8 3.13) – a three dimensional sound pressure field reconstructed from the actual 2D field recorded on a photosensitive plate (Rolshofen 2006) or even an ultrasound transceiver which simply detects interference on the sound’s path (unable to pinpoint the location in 3D space but enough for proximity detection).

Surface detection is based on how waves propagate on a two-dimensional rigid surface. Solid surfaces allow for a better wave propagation than liquid or gaseous media. Contact points can be a tap with the finger or nail, or a continuous movement. Location can be detected by TDOA and Location Pattern Matching (LPM).

In this case, TDOA only needs 3 (coplanar) sensors from which to compare the difference in the time each of them received the signal and locate the impact.

LPM may only use one sensor to record the acoustic signal pattern. This technique consists of a cross-correlation between that pattern and other prerecorded reference patterns.

2D acoustic holography can also be used, requiring only measurements on a plane by a linear array of sensors (Pham 2005).

Other techniques for surface detection have been developed (Tai-Chi Consortium 2007): Time Reversal, Multi-Sensor Tracking through the Reversal of Dispersion, and in-solid (2D) acoustic holography. [Video 12]

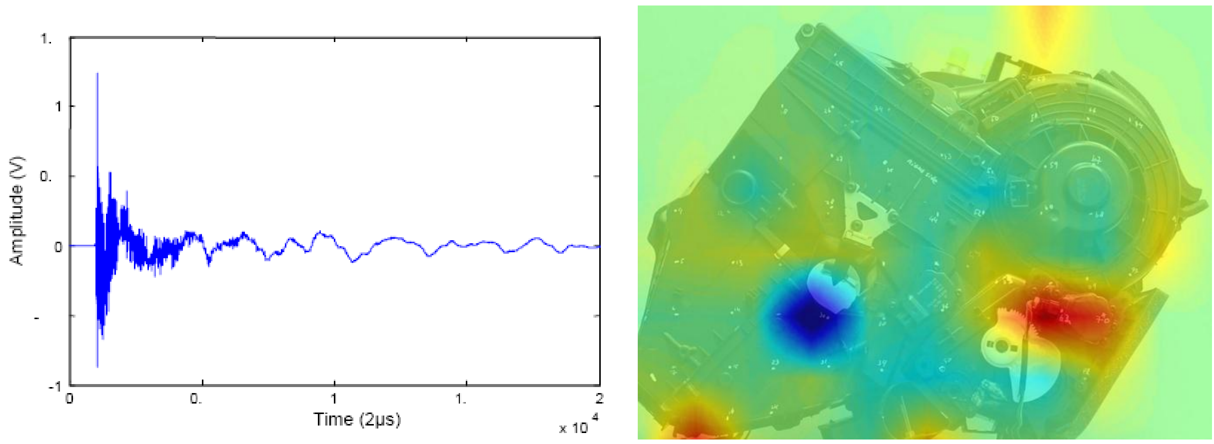

Figure 3.8 Left: Typical acoustic signal pattern. (Pham 2005); Right: Acoustic Holography (Microflown Technologies)

Acoustic detection has the advantage of being unaffected by the existence, absence or changes in light levels (unlike computer vision), but is always dependant on the homogeneity of the propagation medium, especially surface but in-air as well: detection can't have any obstacle between the source and receivers.

By using the surface itself to transmit information to the sensor, there is no need for an overlay over the area, to make it sensitive.

TDOA technique has a quick response time and simple computation requirements. LPM needs less sensors, making it easier to configure, but in turn requires recording a longer signal, which makes it slower (Pham 2005).

In-air and in-solid acoustic holographies still need improvements in speed, spatial resolution and reliability to be successfully used in real-time interaction.

3.2.9. Touchscreen

A touchscreen is an input/output surface which can sense a touch of a finger or stylus on top of a display. The touch detection acts as a substitute for a mouse, lightpen or other active pointing devices. Although finger pointing may seem much better than using a stylus, especially in small devices, using fingers can occlude the screen and making it difficult to touch a small soft-button for example. Outputs are usually regular (i.e., LCD, CRT) displays or projections over a surface or screen, preferably rear projection over a screen that can retain light (e.g. DNP holoscreen), due to occlusion.

Devices usually only detect where they were touched, but other aspects' detection have been developed in some systems such as pressure sensitivity (usually by sensing the finger's area growth), continuous dragging, finger/screen angle, finger rotation (Buxton 2008) and ability to differentiate each finger or each user, in the case of multi-point/multi-user devices.

There are several technologies and techniques to sense touch:

Resistive touchscreens (Figure 3.14) use two layers of a transparent conductive material (indium-tin oxide) separated by a gap with spacers, which act as isolation by preventing them from touching each other. The top layer is flexible so that when a touch occurs both layers connect at the point of contact, allowing the powered layer to transmit voltage to the other.
One layer measures the X axis and the other the Yaxis. By sensing the percentage of the total applied voltage at the point of contact each coordinate can be pinpointed. The voltage percentage over the horizontal axis is measured by the top and bottom terminals and the vertical coordinate by the left and right terminals.

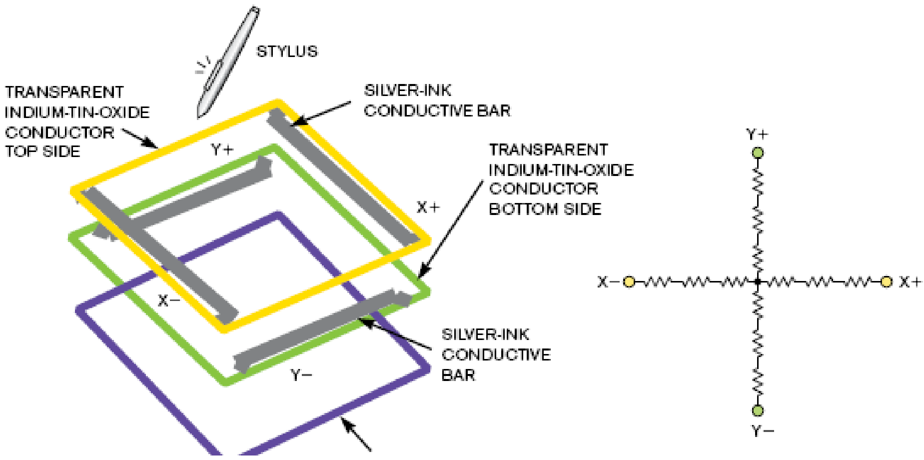

Figure 3.14. Resistive touchscreen schematic (Baker 2007)

Surface capacitive touchscreens have a small voltage applied to the four corners of the screen creating a uniform electric field across the layer. When it is touched by a finger or other conductive object (stylus) some of the charge is proportionally drawn from the corners and transferred to the user (Figure 3.15). The circuits at the corner measure the percentage of charge decrease and, by comparing their differences, the point of contact can be calculated.

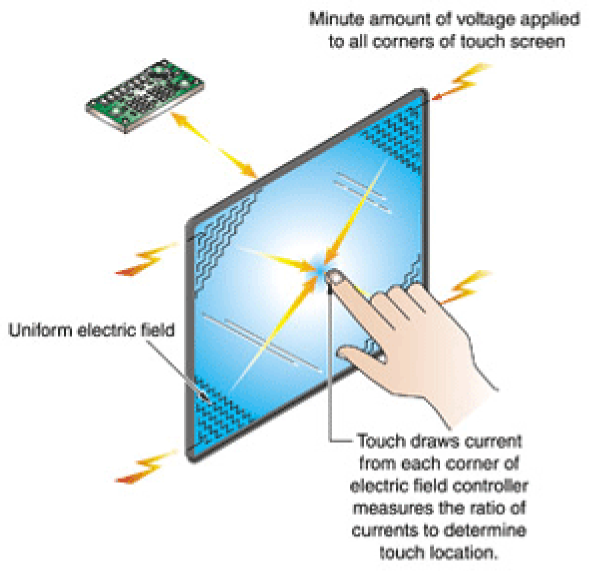

Figure 3.15. Capacitive Touchscreen (Electrotest)

Projected capacitive touchscreens have a grid of wires behind the screen which generate an electric field, and a controller on one of the edges. A touch draws current, causing changes in the electrostatic field. The point-of-contact is determined by measuring the distribution of the change in signals between the X and Y electrodes on the grid (Figure 3.16).

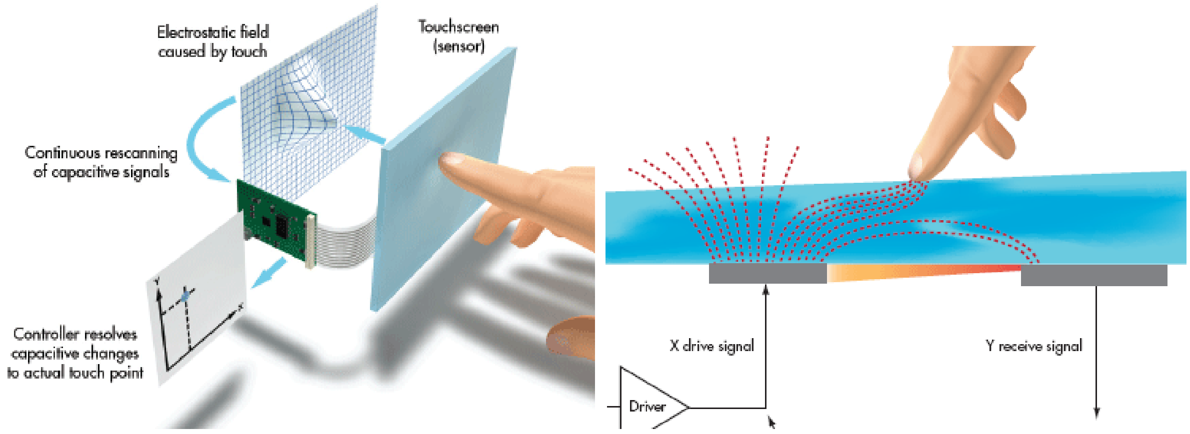

Figure 3.16. Projected Capacitive Touchscreen. (Electrotest)

Surface acoustic wave (SAW) works by means of ultrasonic waves travelling on the surface of the screen. It consists of 2 (X and a Y) transmitters and X and Y receivers at each side of the screen. 2 reflector arrays direct the transmitted waves throughout the screen, while the other 2 arrays reflect them back to each corresponding receiver transducer. When a touch occurs the waves are absorbed, unable to reach the other side of the screen (Figure 3.17). By comparing received signals before and after, the touch can be located.

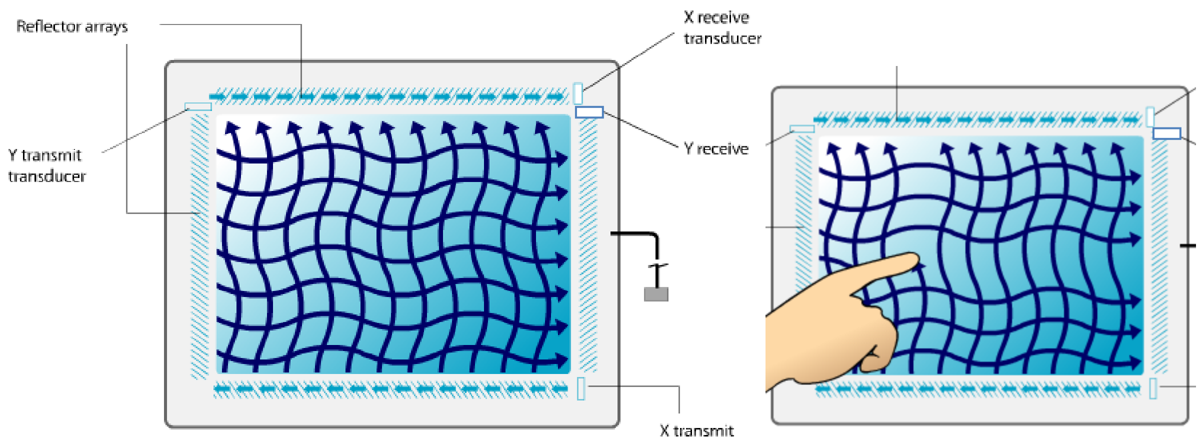

Figure 3.17. SAW before (left) and after a touch(right). (Elo Touch).

Acoustic pulse recognition (APR) and Dispersive signal (DST) work by means of surface acoustic techniques (see "Acoustic" interfaces), both are different from traditional touchscreens because they passively wait for a signal (Figure 3.18), instead of emitting a field which has to be interrupted. APR detects by TDOA and DST by LPM.

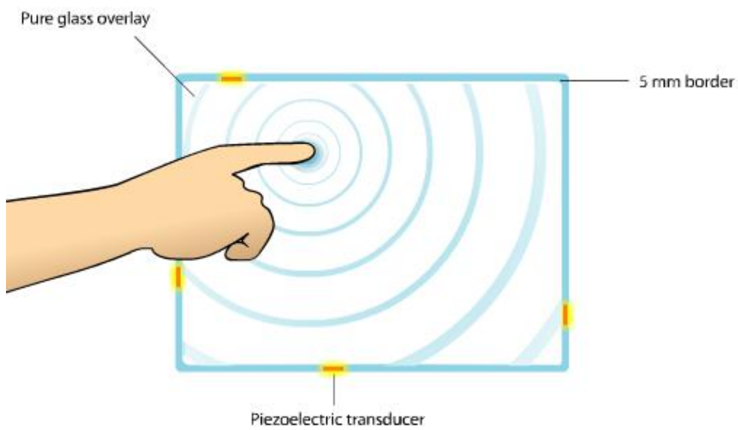

Figure 3.18. Acoustic surface detection. (Elo Touch)

Optical techniques also exist, by using cameras and/or IR light.

Infrared touchscreens have IR light emitted by several LEDs which are receiver at the opposite side of the screen, defining a grid. When the screen is touched, the matrix is interrupted at the touch coordinates (Figure 3.19).

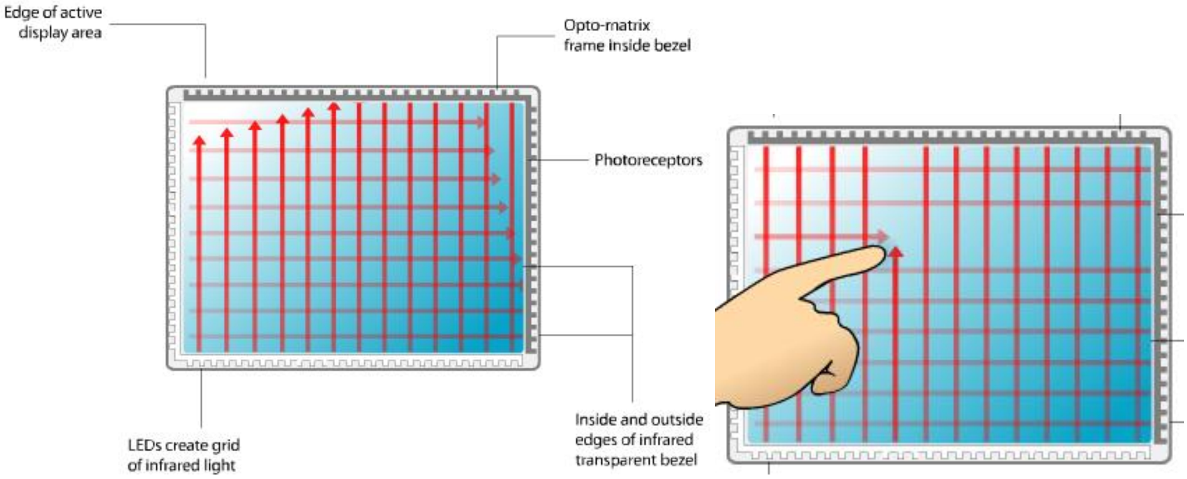

Figure 3.19. IR touchscreen - active matrix (left), touch interrupts matrix (right). (Elo Touch)

Another IR-based technique uses an optical effect called “frustrated total internal reflection” (FTIR). The system emits an infrared light into a medium (e.g., acrylic, $n_1 \approx 1,49$) with an index of refraction bigger than the one of the media (e.g., air, $n_2 \approx 1,00$) around it. When the light reaches the interface between the two media at a certain angle (θ), where, according to Snell’s law:

$$\theta > \arcsin\left(\frac{n_2}{n_1}\right)$$

light is reflected internally (total internal reflection). When the acrylic is touched by a finger (skin, oil,sweat) the difference in the index of refraction between the two media is reduced and the reflection is frustrated, causing the light to escape out the opposite side (Figure 3.20) (Smith 2007). The light is then captured by an infrared camera which is then able to recognize touch locations. [Video 13]

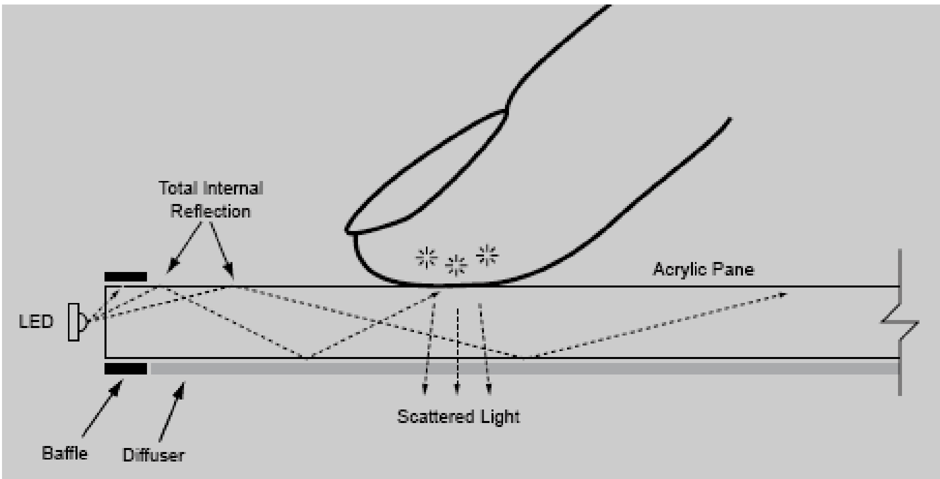

Figure 3.20. FTIR schematic (Han)

Touch location can also be inferred by directing IR light at the user and using two or more IR-sensitive cameras at different angles to capture the reflection (Wilson 2004) or one camera, by comparing the previous frame with the current one and assuming different pixels' center of geometry as the touch location. These setups can detect an in-air "touch", even before a surface touch actually happens, which may be an undesirable feature. In this these cases selection can be defined by a knocking on the display (microphone) or a small time interval on which the user has to stop movement. [Video 03]

Touchscreens can also locate and sense touch by supporting the screen with four force-measuring strain gauges at the corners of the screen. The gauges can measure different levels of force which are exerted unevenly over the four gauges. With this information both the location and the pressure of a touch can be sensed.

Touchscreens allows for a more intuitive interaction, they allow for direct selection over the screen. Direct selection can have a disadvantage, especially on small screens – occlusion. Screen occlusion may be lessened by using a pen, but at the cost of having to use both hands, carry a pen and pick it up before pointing, which can be time consuming especially short intermittent tasks.

Some touchscreen technologies can sense more than one touch point at the same time, e.g., FTIR, layers of capacitive sensors, while others cannot, e.g., strain-gauges.

Screen positioning is also important as vertical screens can be tiresome for long-term uses causing sores and cramps ("gorilla arms"), but are good for sporadic uses because they can be placed at eye-level. Horizontal screens can cause neck discomfort due to users constantly looking down, but is better for the arms, although resting arms can sometimes be confused by the computer as input.

Resistive technology is cheap and can be used with fingers (gloved or not), stylus or other hard obects. It has a high resolution and is unaffected by dust, dirt and light but also has disadvantages: mechanical weakness, only 75% light clarity and potentially damageable by sharp objects (Mass Multimedia 2008).

Capacitive screens have also a high resolution and a much bigger clarity (90%), and because they can be sealed, they are resistant to water, dirt and dust and work even if the glass is scratched. Touch can be detected though 18mm thick glass (Elo TouchSystems 2008). Projected capacitive often require no user or factory calibration. Capacitive screens have to be touched by a finger or other conductive input.

SAW screens don't need layers, meaning they have the highest durability and highest clarity. It also has higher resolution. It has to be touch by a finger or soft object (Trident 2008). The setup is usually one of the most expensive.
DST is unaffected by contaminants and operates with static objects on-screen (resting hand or cup) and any object can be used to activate it (3M 2008).

IR touchscreens don't rely on substrate or overlay to register touch, so even if the screen is damaged, input detection is unaffected. FTIR is highly responsive but performance can be degraded when the user's hands are dry (Smith 2007).

3.2.10. Augmented Reality

The world we perceive is real, but our senses can also be deceived into perceiving something as real, when in fact it's an artificial, computer-generated virtual reality. Milgram et al propose viewing reality and virtuality not as antithesis but as a continuum represented in Figure 3.21 (Milgram 1994).

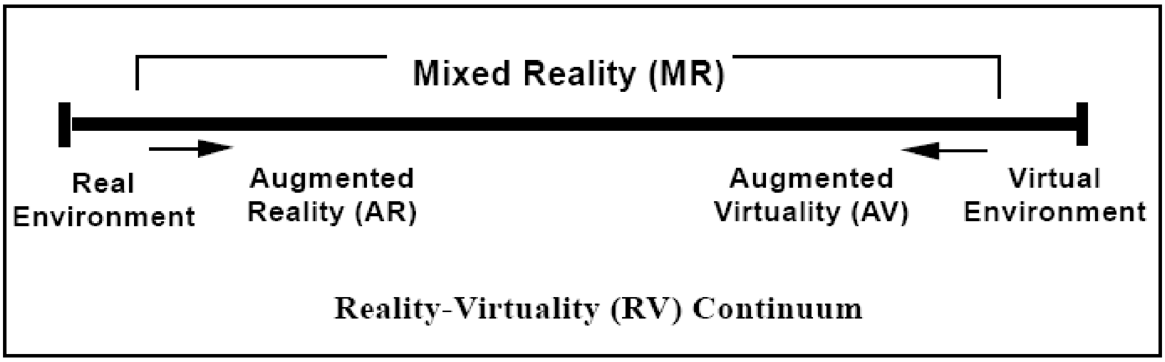

Figure 3.21. Reality – Virtuality Continuum (Milgram 1994)

Reality is the world environment bounded by the laws physics and composed of atoms. Virtuality is an environment totally composed by computer-generated elements (image, sound, touch, smell, taste). Between these extremes, a mixed reality (MR) exists, a combination of both realities. When the "world" is composed primarily by virtual elements and a few real entities, it is called augmented virtuality, when the opposite occurs, when we perceive reality with some virtual changes, we have augmented reality (AR). These changes are additions or subtractions of images sound and/or touch, which are obtainable by partially clouding our senses and feeding a mix of virtual and real elements.

Of the non-reality possibilities, AR is the most desirable for ubicomp. Because ubiquitous computing is essentially the opposite of virtual reality – computers inside a world of people instead of people inside a world of computers. AR can bring seamless augmentation superimposed on the real world.

In order to mix both types of information two components are required: an input to sense information from the real world (e.g. direction facing, image feed) and an output to convey virtual information to our senses, previously mixed or not with reality.

Most augmented reality applications are visual. To view AR information there are two basic choices: video and optical.

In video the real-world information is obtained by a camera and other devices such as tilt sensor, compass or GPS and subsequently combined with virtual information. That combination is then showed to the user through monitors. Monitors can range from closed-view head mounted displays (HMD) to wearable or big screens. Bigger screens usually don't need positional information because they're not portable (the information is not location sensitive).

Optical devices are see-through HMDs which also use location and positional information from the user and renders virtual information, but unlike video devices, doesn't capture and combine optical information. The visual information is observed directly by the user through glasses. Those special glasses are optical combiners (Azuma 1997) and allow only a percentage of optical information to pass because they're half-mirrored in order to reflect, and thereby combine, the projected virtual image with the directly observed one.

A different type of AR display is the Virtual Retinal Display (VRD). Unlike others, it isn't a flat panel display - the image is scanned directly onto the retina. VRD consists of: a light source (red green and blue lasers); a modulator, to determine the intensity of the picture; vertical and horizontal scanners to draw the raster pattern and control the FOV; and imaging optics to focus the diverging light beam, in order to present an undistorted scan with good focus at the retina (Tidwell 1995).

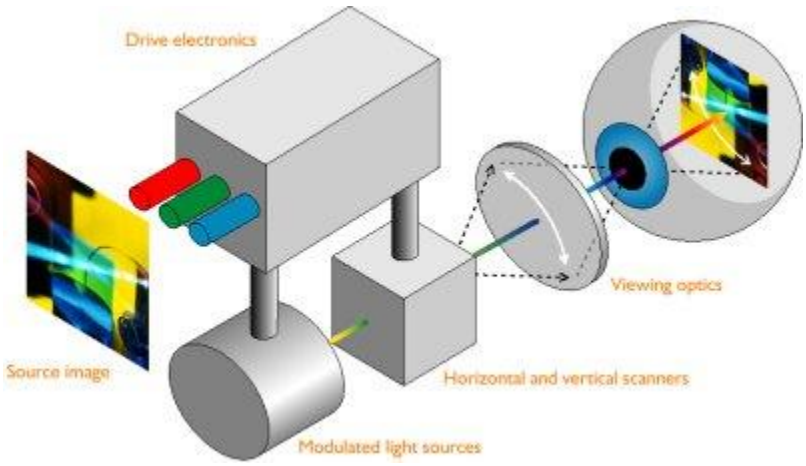

Figure 3.22. VRD schematic (Microvision)

An example of AR could be: a user in a music store looks at a CD, the song names would appear in mid air, while a sample track starts playing. This is a somewhat passive interaction, simply displaying information. Already in development are ways to interact with the virtual component (e.g.,YDreams' SimVideo, uses collision detection). Used in the previous example, this would allow users to select another track to play, or search for similar songs within the store. [Video 14]

These principles can also apply to other senses: haptic devices exist which could, theoretically, take the form of a glove and convey touch, totally overriding real touch information or allowing some to be sensed ("feel-through") and for sound, headphones which can also be completely immersive and impervious to outside sounds, or "hear-through", the same way a DJ mixes the music currently playing on speakers with the one only he/she can hear.

Superimposed virtual information should be proportional in size and should also relate to the object we are looking at. Because artificial intelligence is still at its infancy, to allow the composer software to recognize these real parameters, one must use artifices. These can take the form of fiducial optical markers for computer vision (Figure) or RFID tags embedded in objects which stay invisible. A markerless option is to model the environment in 3D and georeference the model. The user would have accelerometers, tilt sensors, GPS, compass to define its orientation and location relative to the environment and referenced object in order to allow a correct information overlay. Mobile phones with increasingly new features, including some of the aforementioned ones, and better processors, cameras and image quality, already allow mobile AR visualization, including Geotagged information (Wikitude for Android phones). [Video 15]

AR has a multitude of applications, from daily life to specific uses, for example medical, military, manufacture or entertainment. An example is demonstrated in the following picture:

Figure 3.23. Collaborative AR application using HMD

Using tags has the disadvantage of requiring the actual tag to be where we expect, which is not guaranteed to be, and in order to detect and gain access to the information we must be relatively close to it. We also need to already have the information pertaining to each different tag, except for RFID and 2D barcodes which generate the information instead of retrieving it from the system memory. Nevertheless they are cheap and can be ubiquitously distributed.
3D models have the disadvantage of having to be built and georeferenced which are effort- and time-consuming processes. They also need to be previously integrated in the software prior to arriving at the actual place.
They allow for a much better positioning of the information and don't require target proximity or even direct line of sight. Not using tags also keeps the aesthetic of the locale.

Most HMD are still bulky, but that's expected to improve due to miniaturization. Lumus managed to build a see-through HMD with a form factor near to regular eyeglasses, but still bigger, to accommodate all the hardware (Lumus 2008). Apple has filed a patent for an optical HMD which keeps all the hardware in a box that can be clipped to the belt (Tang 2006). Contact lenses are being developed to include electronics and work as a see-through display with microLEDs (Parviz 2008).
With new emerging display technologies such as transparent OLEDs and miniaturization of VRDs, HMDs could take less space in front of the eyes.
HMDs have the advantage of being more visually immersive than wearable or big screens are, due to peripheral vision.

3.2.11. Haptics

Haptics is a type of interaction focused on sense of touch. Haptic devices can be both input and output. While not necessarily controlled by a computer, every haptic input device can be considered to provide some output by way of the tactile or kinesthetic feedback that it provides (Buxton 1999). A stylus, touchpad or mouse can be considered as haptic input because they can sense touch and pressure, but their form doesn't change to, or represent in a tactile way, the virtual information and actions we perform. Good haptic devices create a link between their physical form/feel and the action being done, current state of the system or other relevant contextual information (e.g. bending a real paperclip bends a virtual clip in the same way). Haptic interaction is almost always multimodal, either used to reinforce what we see or hear or to allow the performance of different tasks at the same time. Haptic feedback may therefore be applied to any other static input.

The skin and muscles have sensory organs which can sense pressure and distortion (mechanoreceptors), temperature changes (thermoreceptors) and pain (nocioreceptors). Stimulus can be created by several different means (Pasquero 2006), (Berkelman and Hollis 1995), (Iwamoto 2008): electrostatic, rheological fluids (which can change their viscosity), electromechanic, air jet, thermal, electromagnetic, pneumatic, electrocutaneous, ultrasound.

These technologies are used in four different distinct ways (Hayward and MacLean 2007): vibrotactile, force-feedback, surface displays and distributed tactile displays.

Vibrotactile is currently the most common haptic feedback. Its outputs are vibrations, felt by the user. Vibrations can be achieved, for example, by a loose motor spinning an eccentric mass or a “tactor”, a magnet vibrating due to current passing through a coil (SKERI 2008) or using air pulses. Vibrotactile sensations are used to provide silent alarms or a change in the state of the system (e.g. injury or death in a video game).

Force Feedback applies forces on the user. The encounter with a virtual object is determined by collision detection and the motor exerts a force (dependent on the vectorial forces between the two and others such as drag) so that the user has the perceptual experience as real as possible of encountering that object. Force feedback is able to provide large forces capable of stopping the user’s motion, for example when colliding with a virtual wall (Laycock and Day 2003) if the user is, for example, using an exoskeleton such as Cybergrasp (Immersion 2008).

Surface displays simulate the existence (or surface) of a virtual object. It allows for a user to feel its shape (Hirota and Hirose 1993). This can be achieved by rolling a small surface on the fingertip as the user “moves along the object’s surface”.

Distributed tactile displays allow more complex haptic communication. They provide spatially distributed sensations directly at the surface of the skin, usually the fingers because they are highly sensitive, but also the tongue, mouth, thighs and torso. Tactile displays generally create an indentation on the skin with arrays of pins that rise out of a surface to create a discrete representation of a texture or a small-scale shape

Despite advancements in speech synthesis, Braille code still is an important access medium for visually-impaired people. This technology is especially useful to display long text (originally digital or not) without occupying a large space – a book in Braille doesn't fit in a table because physical space does not allow scrolling as screens do.
In addition to motors, other employed actuator technologies include shape memory alloys (SMA), piezoelectric ceramics, pneumatic valves, rheological fluids, electrodes, and others (.

The Novint Falcon is a 3 DOF device. It tracks in 3 DOF (right-left, forwards-backwards, and up-down), and gives forces in those same DOFs. Magnetism can also be used as a means to achieve haptic interaction: Magnetic Levitation Haptic Device has a levitated handle to grasp, with and can control a virtual object in 6 DOF. The handle is controlled so that the user can feel the motion, shape, resistance, and surface texture of simulated objects (MSL 2008). [Video 16]
Some use cameras: the haptic lens uses a flexible elastomer that can be deformed like clay (Figure 3.24). The image captured is lighter or darker depending on the pressure, and the grayscale converted to height value (like a bump map).

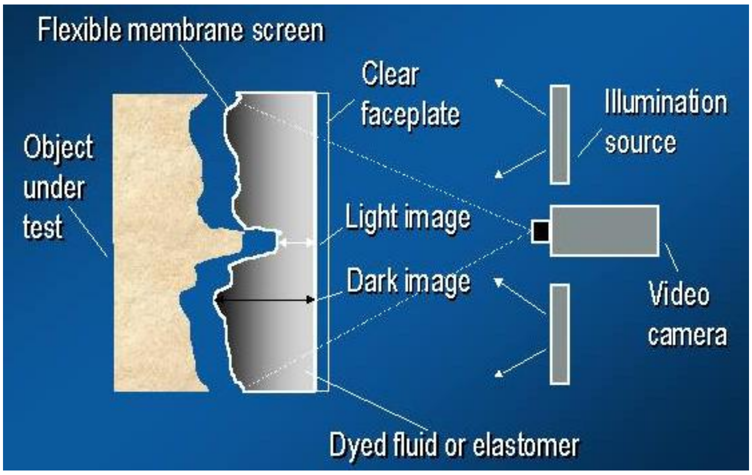

Figure 3.24. The Haptic Lens (Sinclair 1997)

Cameras also can provide information about the surrounding objects and transform it into tactile feedback. For example, Touch Sight has a flexible Braille sheet which displays a 3D image by embossing the surface. The Optacon device scans printed material and converts it to Braille. Also, haptic feedback is starting to be added to touchscreens to emulate the sensation of pressing a key (Nokia cited by Red Ferret 2008). The airborne ultrasound tactile display, based on a nonlinear phenomenon of ultrasound- acoustic radiation pressure, provides free space haptic feedback. It can create 20 Pa at 300 mm from the radiation surface (Iwamoto 2008). Is especially useful if combined with 3D displays in CAD applications for example. [Video 17]

Skin has limited spatial resolution and all resolutions vary according to the place where touch is sensed (finger, arm) and can differ from person to person. Fingertips can sense, in average, two points 2,5mm apart, and the palm, 11mm.. Fingers can sense and pressures of 0,2 N/cm^2 and temperature changes of 1ºC. Single-point vibrations at the fingertip can be sensed at a bandwidth of at least 300 Hz (Laycock and Day 2003), for frequencies over 20Hz (Gunther 2002). These characteristics can be considered limitations or benefits (big spatial resolutions are easier to simulate) depending on the device, technologies used and design.

The advantages and disadvantages of numerous haptic technologies are described in (Pasquero 2006), (MSL 2008) and (Iwamoto 2008).

3.2.12. Audio

Sound systems are very mature and evolved in terms of technology and methods to prevent loss of quality (e.g., correct positioning in a theatre, materials chosen for the walls). They excel at filling rooms with high quality sound. In a ubiquitous computing environment, the problem lies in the size needed to provide that quality, which makes them too big to be hidden from sight; and for some applications (such as various interactive devices with different audio in the same room) the ability to fill rooms with sound can be more of a hindrance than beneficial.

Controlling the final position of sound is normally obtained by means of headphones, which are small loudspeakers placed at the ears and speaker domes, a parabolic reflector to focus sound the same way a mirror focus light. Binaural audio allows an apparent positioning of the source. With these methods only the source or the final position of the sound can be controlled, but directional sound can do both.

Directional sound happens when sound is emitted in a narrow space. In order to direct soundwaves, the source has to be much bigger than the wavelength it produces, or sound will propagate omnidirectionally. Since audible soundwaves vary from a few centimeters to about 20m (EPCC 2006), in order produce a narrow beam from audible waves, the source would have to be several meters wide, an impractical solution. If the source needs to be small, to overcome this problem the wavelength must be even smaller- ultrasounds.

Directional ultrasound was developed to use in communications, but the receiver needs a demodulator to be able to hear it. Directional sound is now possible by using modulated ultrasounds which can change to hearable frequencies (20-20 000 Hz) after being emmited. This is done when ultrasound is passing through air, which behaves nonlinearly, effectively acting as a demodulator (Holosonics 2002) (Pompei 2002).

This technique (sound from ultrasound) enables sound waves to travel in a narrow (cylindrical) space, much like a light from a spotlight (Figure 3.25). The lighting analogy is so helpful that words like “shine”, “project” and “shadow” often apply to sound. Indeed sound can be projected against a surface, and depending on its material (foam, brick wall) it can be absorbed or reflected/scattered (Pompei 2002). It can be directed at a user (only the person in front of a painting in a museum listens to the explanation). Nevertheless source placement is a very important aspect - as with lighting, anything or anyone that stands in the path of the beam will interrupt its progression. Possible applications can include headtracking to direct the beam if the user moves. [Video 18]

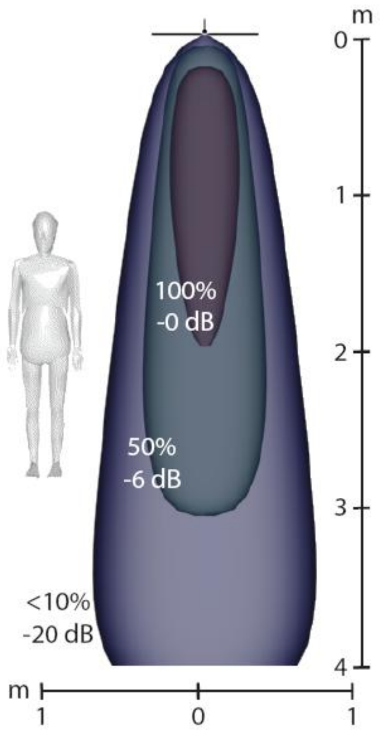

Figure 3.25. Sound field distribution (Holosonics 2002).

There are cases when omnidirectional sound is sufficient or even desirable and the objective is to hide the speaker or make a surface the sound source (e.g. window, table). To accomplish this effect, a transducer (e.g. SolidDrive) can be placed in contact with a solid surface. It uses permanent magnets and two symmetrically opposed motors to emit acoustical energy through a rigid surface (such as glass, wood, drywall or stone), from which sound radiates (Induction Dynamics 2007).

Since every material has different wave propagation levels, it must be equalized in order to emit an undistorted sound. The surface is the speaker, so there's no risk of blocking the sound (as could happen if a beam was reflected on the surface to create the illusion that it came out of it). A transducer, when hidden behind big surfaces, leaves the user unable to pinpoint the sound source, leading to a bigger sense of immersion. [Video 19]

Hidden speakers may also be selectively accessed as in the case of Paper Four's flat loudspeakers which can be placed behind a sheet of paper. It has capacitive sensing electrodes printed on the paper with conductive ink in order to activate the speaker. The user touches the paper in order to listen (Mittuniversitetet 2007). [Video 20]

3.2.13. 3D displays

In real life we can perceive if an image is three dimensional or not from a variety of signs, most importantly stereo parallax (seeing a different image with each eye) and movement parallax (seeing different images by moving the head).

Commonly when 3D images need to be displayed, using special glasses is mandatory (e.g., red/cyan glasses to see anaglyphs). Although glasses provide stereo parallax, having to use glasses to sporadically look at images does not translate into a seamless experience.

Autostereoscopic displays allow the user to see 3D images without the use of glasses or other device. In order to do this, different perspectives (different images) of the same scene have to reach their corresponding eye, as demonstrated in Figure 3.26. The basic principles used to achieve that are head-tracking and two- or multi-view.

Two-view displays divide the horizontal resolution into two sets. Both images are transmitted by alternate pixels. As Figure 3.26 shows, multiple viewing zones exist at an appropriate distance, but there is a 50% chance that the user will be at the wrong position and see a pseudoscopic image, therefore they don't provide movement parallax (Dodgson, 2002). This constraint can be overcome by increasing the number of views or using head-tracking.

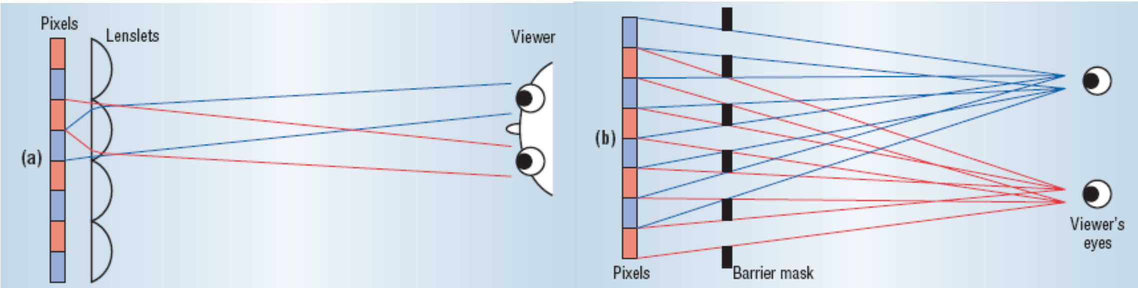

Figure 3.26. Two-view spatially multiplexed display builds. Left image: lenticular; Right image: parallax barrier. blue = right eye, red = left eye. (Dodgson 2005)

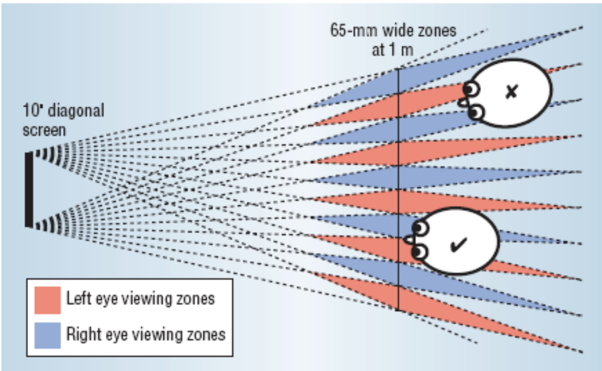

Figure 3.27. Two-view multiple viewing zones (Dodgson 2005)

By tracking the user's head, only two different images may be displayed because they can be directed to the appropriate zones. Even if the user moves, images can be swapped to show correctly, or the display moved accordingly. Head-tracking generates a specific image, it only works for one person.

Multiview displays show multiple different images to multiple zones in space. As long as the user has both eyes inside the lobe, a 3D image will be perceived. Figure 3.28 (left) shows a four-view display. Each of the lobes contains the same set of four views. So long as a viewer's head is within one of the lobes, a 3D image will be perceived. A sixteen-view display creates a bigger, continuous lobe (Figure 3.28 (right)). It accommodates several viewers, each seeing a 3D image from his/ her own point of view. Multiview displays are more expensive and difficult to build because it has to generate all the views simultaneously, whether someone sees it or not.

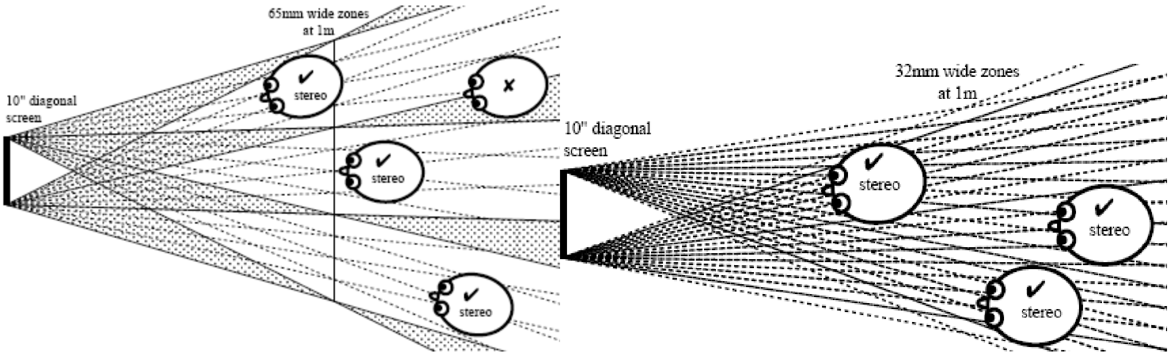

Figure 3.28. Left: 4-view display with three lobes. Right:16-view display with one lobe (Dodgson 2002)

Autostereoscopy can be delivered by devices using essentially two technologies: spatial multiplex or multiprojector. Spatially multiplex using parallax barriers and lenticular sheets are used to divide the resolution in two or more views (Figure 3.26). Spherical lenslets are used to create parallax in both dimensions, but this requires an extremely high resolution display as every lens has to transmit the whole image (integral imaging) (Martínez-Corral 2005).

The constraints on pixel size and resolution in traditional liquid crystal and plasma displays limit horizontal multiplexing to four views, which is barely sufficient for a multiview display (Dodgson 2005). Cylindrical lenticular sheets also cause dark zones between viewing slots. Parallax barriers cause significant light loss for more than two views, (Dodgson 2005) but allow switching between 2D and 3D modes as the light barrier is constructed from a layer of liquid crystal which can become completely transparent when current is passed across, allowing the LCD to function as a conventional 2D display (ReviewSpring 2008). Some companies (such as Phillips and Newsight) already have commercially available lenticular displays.

Multiprojector technology uses two or more projectors to indirectly project different images to the user (light is first reflected by a half-silvered mirror and then by a retroreflective screen before reaching the eyes). Another method consists of projecting onto a special double lenticular transmissive screen as shown in Figure 3.29 (left). Having one projector per view significantly increases the cost of the display, and images have to be precisely aligned with one another (Dodgson 2005)

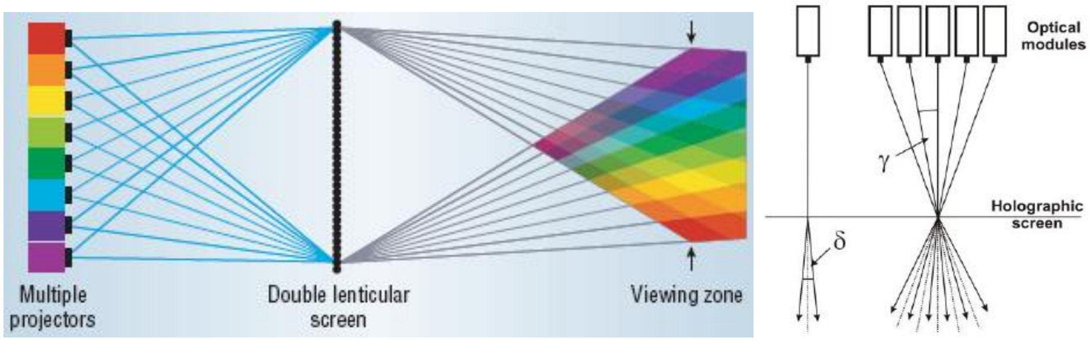

Figure 3.29. Multiple projections over a double lenticular screen (left) and over a holographic screen (right). sources: (Dodgson 2005), (Holografika 2006).

In HoloVizio technology, light beams generated in the optical modules hit the screen points in various angles and the holographic screen makes the optical transformation to compose them into a continuous 3D view. Each voxel can project multiple light beams (different intensity and colors) in several directions simultaneously, as seen in Figure 3.29 (right) (Holografika 2006). [Video 21]

Virtual Retinal Displays (with headtracking) have the ability to project different images to each eye, forming a 3D Picture (Schowengerdt and Seibel 2006).

3D images can also be displayed by other means, sometimes called “volumetric displays” (Chatterjee and Chen 2006).
Holograms use monochromatic light beam(s) - one as reference and other to reflect on the object. The interference between the two beams is recorded in an holographic film, and then decoded again, by emitting monochromatic light through the film.

360º light field display uses high-speed video projection (5000 images/s), over a spinning mirror covered by a holographic diffuser. The rendering algorithm can recreate scenes with correct occlusion, perspectives and shading) (Jones 2007). [Video 22]

Some displays accept projection of video or images in free-space. By ejecting atomized condensate air, a non-solid particle cloud screen can be created (Dyner 2003). Images are planar but can have three-dimensional appearance since there is no physical depth reference (IO2 Technology 2007).

Free-space display of 3D images consisting of dot arrays. The dots are made of air plasma which is induced near the focal point of strongly focused infrared laser beams (AIST 2006). [Video 23]

These systems have practical uses in application in which depth perception is important. This includes scientific (military, medicine, geographic visualization) or computer games and advertising. Humans are good at interpreting 2D images, so there are many other applications where parallax is irrelevant (Dodgson 2005)

3.2.14. E-paper

Electronic paper is a new kind of display with the appearance of real paper. They are, similarly to printed paper, thin, flexible, lambertian (matte) surfaces and depend on an external light source to be readable.

Electrophoretic displays (EPD) is the widest used e-paper technology It is based on e-ink – microcapsules containing white, positively charged and black negatively charged particles in a fluid medium. The principle used to move the pigments in order to display an image or text is electrophoresis, a method already used in chemistry to separate charged particles. In this case the microcapsules are between two layers of electrodes which change their electrical field at defined places to allow the migration of the oppositely charged particles to the top of the EPD (Figure 3.30). The resolution is not dependent on the number of microcapsules but on the precision of the applied electrical field. Color can be obtained by using white particles suspended in different layers of primary-colored oils. [Video 24]

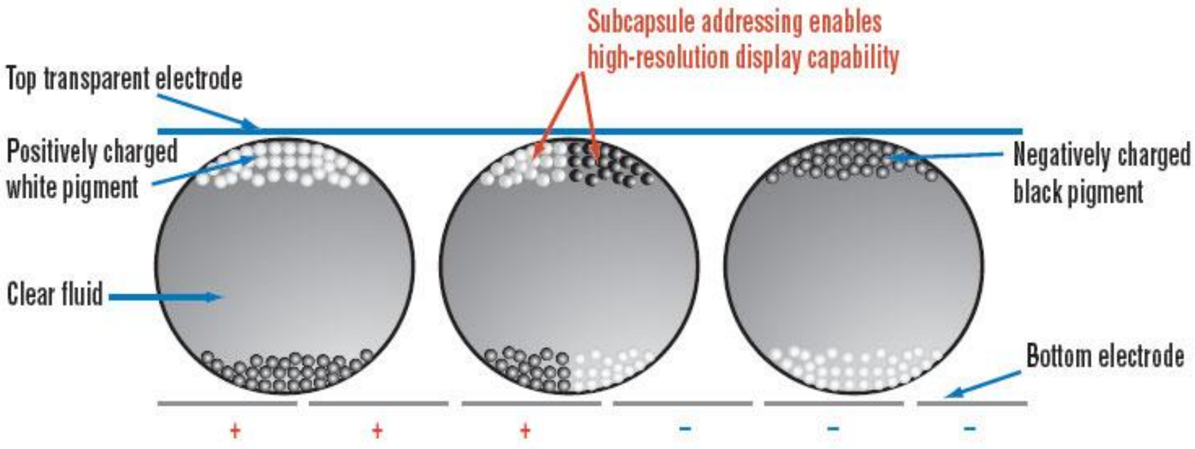

Figure 3.30. Cross section of electronic-ink microcapsules (E-Ink)

Cholesteric Liquid Crystal Displays (ChLCDs) are composed by three liquid crystal layers (blue, green, red) 0,8mm thick (Figure 3.31).

Each layer reflects at a specific wavelength. Resultant color of red/green/blue mixture is determined by additive color mixture principle.

Liquid crystal molecules are formed in a spiral like structure. They are normally aligned vertically. In this state they reflect light (Figure 3.31).

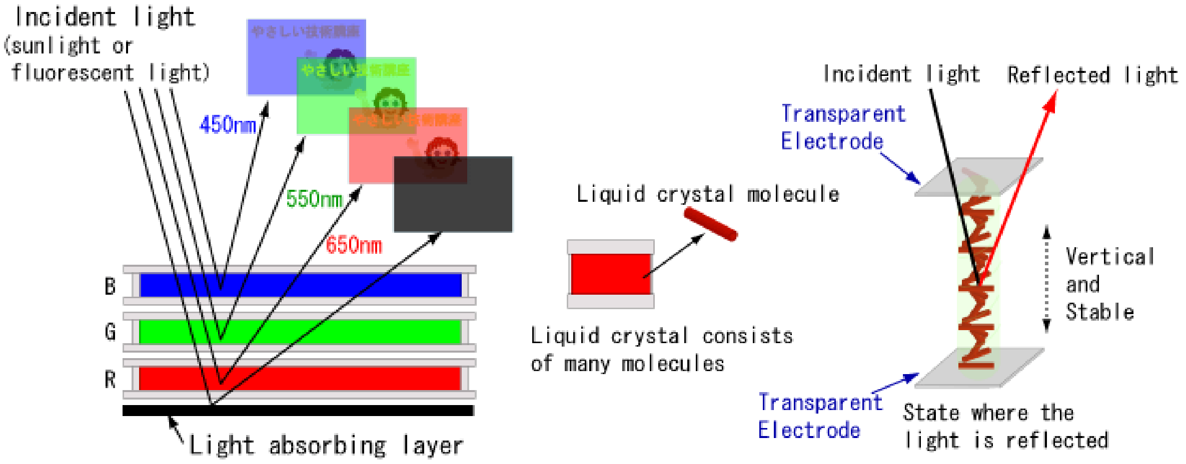

Figure 3.31. Left image: Layers. Right image: Vertical crystals reflect light (Fujitsu)

When low voltage is applied the molecules turn horizontal, losing their reflective property, allowing incident light to pass through. Horizontal molecules are also stable; no energy supply is needed to maintain their state.

When reflection is needed again, higher voltage is applied. The horizontal crystals stretch and when voltage is turned off, they kickback, reverting to their original configuration (Fujitsu Laboratories 2006).

Another technology used is Interferometric Modulator (IMOD). Each pixel consists of 3 subpixels each one with MEMS reflective membranes. When light hits the structure, it is reflected both off the top of the thin-film stack and off the reflective membrane below (Figure 3.32). Depending on the height of the gaps between the surfaces, both wavelengths reflected will be slightly out of phase. This will generate interference between wavelenghts which can be constructive, amplifying color (red example) or destructive, cancelling themselves (green and blue examples). To generate black, voltage is applied causing the MEMS membrane to collapse, which results in constructive interference at ultraviolet wavelengths (black to the human eye) (Qualcomm 2008). [Video 25]

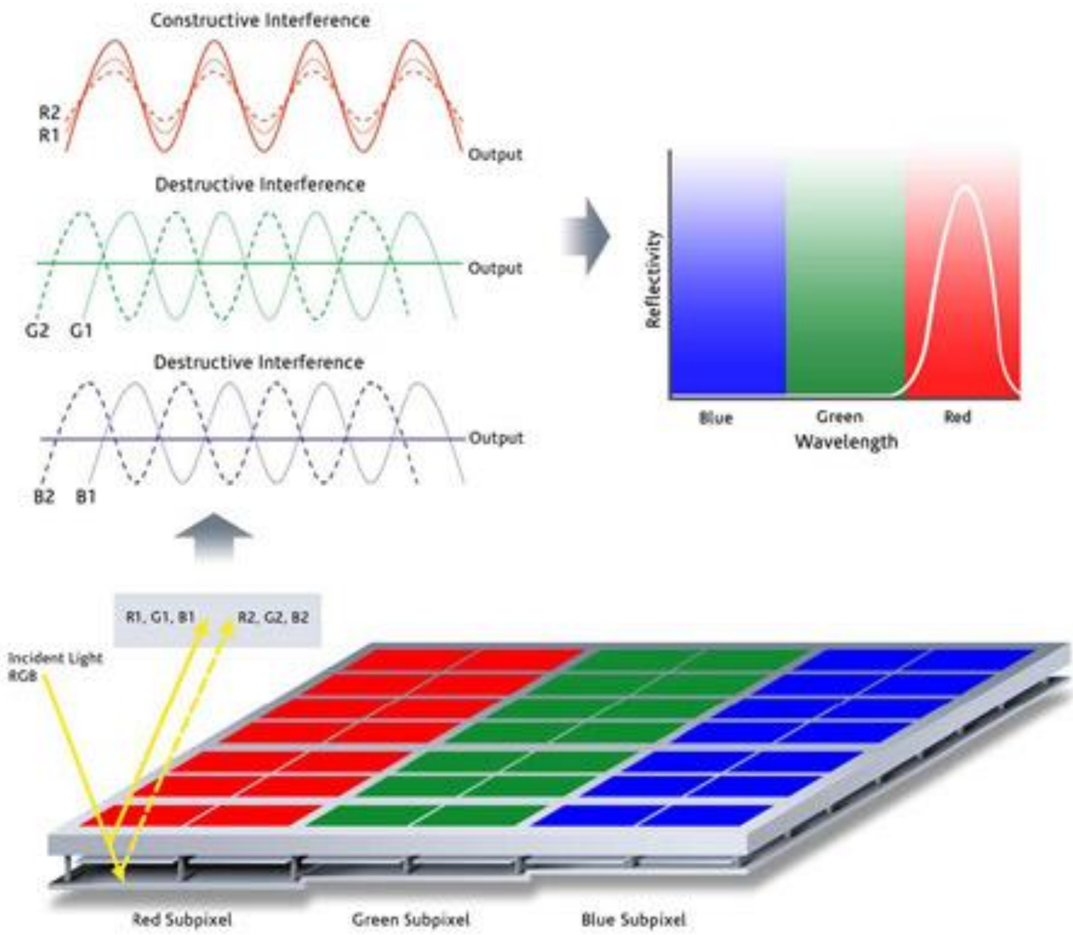

Figure 3.32. Interferometric Modulator technology (Qualcomm 2008)

A recent technology involves using photonic crystals, "P-Ink". Photonic crystals are materials with a nanostructural regular pattern which affect the movements of photons.
Crystals are made of silica beads measuring 200nm which are embedded in a electroactive polymer Figure 3.33(left). When a voltage is applied, an electrolyte fluid is drawn into the polymer composite, causing it to swell, thereby changing the space between crystals Figure 3.33(right). The controlled spacing defines which wavelengths are reflected (Arsenault 2007).

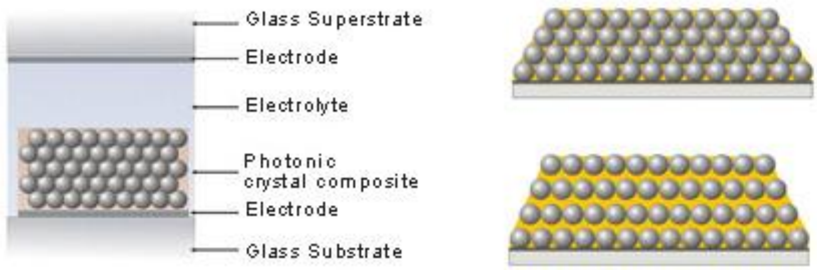

Figure 3.33. Left image: P-Ink Structure; Right image: Swelling of the polymer composite

P-Ink's each individual pixel area can be tuned to any color, unlike most other technologies which divide the pixel in 3 subpixels (equally reducing color brightness). Photonic crystals can display all visible spectrum, UV and IR wavelengths too. Color change depends on the applied voltage. This technology is also reflective and bi-stable. A new version of P-Ink, dissolves the silica spheres with an acid, leaving electrolyte in direct contact with the porous polymer. The liquid now fills the polymer faster, so P-Ink can change color in a tenth of a second (Patel-Predd 2009).

Next generation e-paper technology will allow not only flexible (using plastic electronics), but foldable e-paper. Flexibility allows using them in columns and uneven surfaces, and by rolling them, increased portability. The ability to bend and fold can make them one of the most desirable portable displays.
ITO is starting to be replaced by CNTs as transparent conductive layers (Unidym 2008), which are more resistant to physical and chemical stresses, and more abundant in nature, contrary to indium which is becoming a scarce resource.

E-paper is reflective, making it easier to read than conventional displays, as it doesn't need backlight which causes train on the eyes. It's also readable in bright light environments in various angles, thinner and lighter. The other main advantage is that they are bi-stable,

meaning that once they have been switched to a state, they will hold that state without requiring power. These features make them suitable for applications such as signs and electronic books which don't need to be updated often, nor constantly powered to keep crystals in a state. Updating can be as low consuming as an RFID tag activation.
EPDs and ChLCDs have a low refresh rate (500 and 1000ms respectively) making them unsuitable for video and sophisticated interactive applications. IMOD is the only technology with fast enough refresh (1ms) to allow it without flickering (Qualcomm 2008).

3.2.15. OLED

Organic light emitting diode (OLED) is currently the most promising emissive display technology to substitute LCDs and lamps (illumination). Its basic principle is electroluminescence.

It consists of layers of organic material between a cathode and an anode. Organic layers are usually two: emissive layer and conducting layer (Figure 3.34).

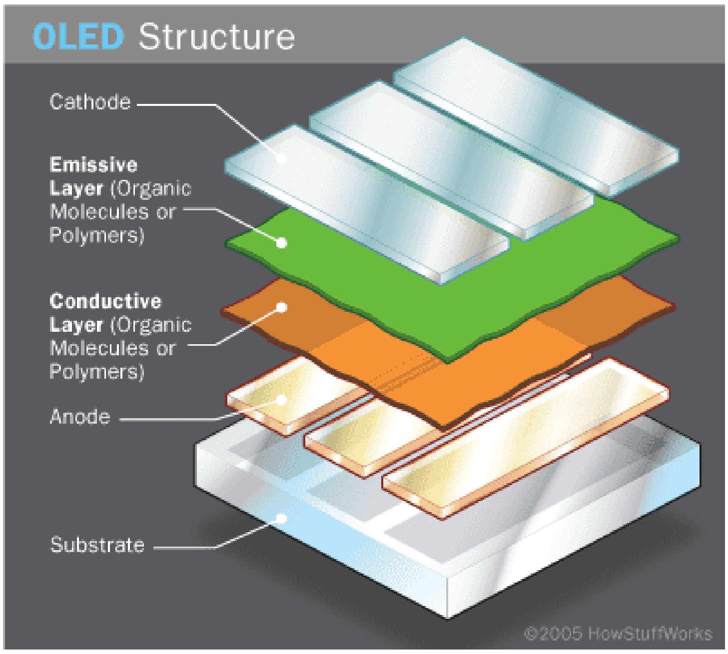

Figure 3.34. OLED structure (HowStuffWorks 2005).

The substrate is usually glass or polyethilene for flexible devices, the anode (150 nm) is an ITO layer (it has to be transparent so that the emmited photons can exit) and the cathode (200 nm), calcium or aluminum (Antoniadis 2003). Organic layers (80nm -120nm) can vary, depending on the objective (e.g., PPV, Alq3) (Nuyken 2006)

As electricity flows from the cathode (-) to the anode (+), it passes through the organic layers. The cathode gives electrons to the emissive layer, and the anode removes electrons from the conductive layer. In in solid state physics removing electrons is equivalent to giving “electron holes” (absence of electrons), so electricity can be considered as a stream of electrons (e^-) moving in one direction, it can also be considered a stream of their holes (h^+) moving in the opposite direction. The emmissive layer is negatively charged and the conductive layer positively charged (Antoniadis 2003).

In organic materials the holes move faster than electrons, so electrons and holes meet in the emmissive layer (Strassler 2008) the electron. They recombine to form an excited state (exciton) which is followed by a drop in the energy levels of electrons (from higher orbital to ground orbital, producing photons. Colors can by achieved by placing several types of organic films on the OLED, each emit photons in different frequencies (R,G,B). The intensity of the light is depends on the amount of electrical current applied.

OLEDs can be categorized into passive-matrix and active-matrix displays.

Passive-matrix OLEDs (PMOLEDs) have anode rows and cathode columns (Figure 3.35). The pixel is formed by their intersection, and the external circuits can apply current selectively to turn pixels on, off, and with different intensities.

Active-matrix (AMOLED) display consists of pixels that have been deposited or integrated onto a thin film transistor (TFT) array to form a matrix between full layers of cathode and anode. AMOLEDs have a continuous current feed. The active-matrix TFT backplane itself acts as an array of switches that control the amount of current flowing through each OLED pixel.

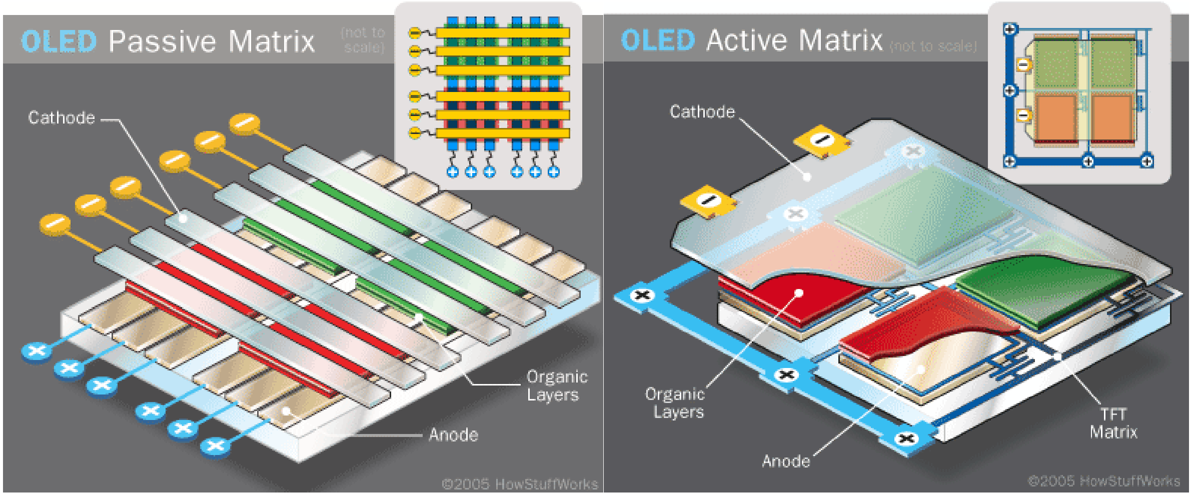

Figure 3.35. PMOLED and AMOLED structure (HowStuffWorks 2005)

PMOLEDs have fairly simple structures to design and fabricate, but consume more power than AMOLEDs (the TFT array requires less power than external circuitry). Consumption exponentially increases with the display size, resolution and brightness. Power analysis show that PMOLED displays are most practical in sizes smaller than 2” (Yi 2008).

Several new OLED technologies exist to enhance performance and broaden its uses:
PHOLEDs use phosphorescent materials and are useful due to their high luminous efficacy, notably for illumination purposes (white light OLEDs). PHOLEDs can achieve energy efficiencies up to 102 lm/W (Universal Display Corporation 2008), five times more than incandescent light bulbs (20,7 lm/W).

Flexible OLEDs can be built on very thin plastic or metal foil substrates. This allows their implementation on curved surfaces as well as resistance to breakage which happens often with glass.

Top emission can be obtained by using a transparent cathode and opaque anode. Light is directed away from the TFT, rather than through. In this way metallic foils and certain opaque polymer films with very desirable performance characteristics can be used (Universal Display Corporation 2008)
Total transparency is achieved by using transparent cathode, anode and substrate. TOLEDs are useful for see-through applications such as HMDs, new screens for collaborative environments or even interactive windows. [Video 26]

A significant advantage of OLEDs over conventional displays is that they don't need backlight. Therefore they are more energy efficient and can be thinner than LCDs. They also have lower production costs, higher flexibility, and a maximum viewing angle (Nuyken 2006). OEDS have the potential to be brighter than LEDs because they use organic layers, much thinner than inorganic. They also don't need to use glass which partially absorbs light.
Despite these advantages OLEDs have experienced slow acceptance in the industry: they have a relatively short lifespan and as power/brightness increases, the lifespan is reduced dramatically, especially for the blues, which lose their color balance over time. The organic materials are susceptible to degradation by water and air (oxygen), so during manufacture they need to be encapsulated and sealed, adding significant cost and complexity to the process (Qualcomm 2008). [Video 27]

3.2.16. Chromogenic Materials

Some materials when exposed to certain external effects such as light, electricity, heat, pressure, change in pH among others, have the ability to physically or chemically change color. Usually those materials change color/transparency only while exposed to the specific change, reverting back to their original state after, but some have "memory effect", the ability to stay in the different state for some time.

Of all the chromic phenomena, the most likely to be useful as displays are electrochromics, thermochromics and (perhaps) photochromics.

Photochromism is a phenomenon relative to materials that undergo a reversible change between two chemical forms with distinct colors, when in the presence of certain electromagnetic radiation wavelengths. Spirooxazine molecules are a photochemical specie used to tint glasses when exposed to sunlight (UV radiation), and revert back to a transparent state without UV (Figure 3.36). Other materials make a one time permanent change, but can be defined to change after one second to one month of UV exposure

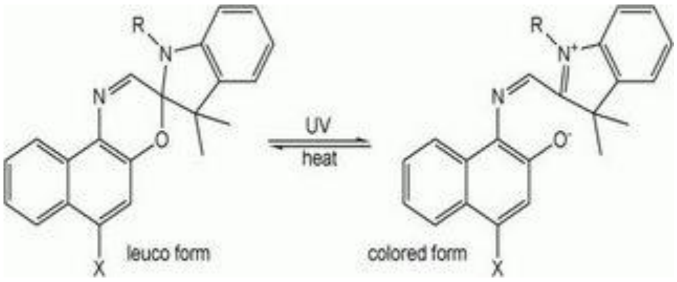

Figure 3.36. Spiro-mero photochromism – when exposed to UV light, the bond between the spiro-carbon and the oxazine breaks (colored form), when the UV source is removed, the molecules gradually relax to their ground state (colorless form).

This is useful in eyeglasses, and sometimes in glass windows (while they are good in the summer to prevent excessive heating inside the house, they also darken in warm sunny days in winter). Photochromics are not as versatile as other materials in a natural interaction context because they cannot be easily controlled and its performance requires controlling solar radiation. Nonetheless they are useful for static displays (for signs, clothes), including phosphorescent displays which provide a distinct light in the dark (TEP 2008) or interactive installations using a laser or flashlight.

Researchers in Germany have recently developed a screen consistent of a chemical layer between plastic sheets, transparent under normal light but fluorescent when hit by IR light lasers. The chemicals "upconvert" light, i.e., absorb light of shorter frequencies and emit at higher frequencies. The laser quickly scans across the screen to produce a fast moving image (Miteva 2008). [Video 28]

The need to have a laser scanning the screen makes this technology is "too bulky and power intensive to be useful in consumer electronics" (Sheridon 2008).

Thermochromic materials respond to temperature changes. The two main types of thermochromic materials are Leuco Dyes and Liquid Crystals.

Leuco Dyes, like the spiroxazine in Figure 3.36, are conjugated compounds that vary between two states (one colored, other colorless). Thermochromic dyes are comprised of a mixture of leuco compounds, a weak acid and salt dissolved in a (usually solid) solvent, protected by a process called microencapsulation. At lower temperatures the leuco dye exists in its colored form (broken ring), but at higher temperatures the solvent melts, dissociating the salt which reacts with the weak acid, increasing the pH (this is a reversible reaction). The pH change

closes the ring, and the molecule returns to its colorless state. As this reaction is reversible, when the temperature is lower again, the leuco dye will be in its colored form.
Dyes change color back and forth with fluctuating temperatures of about 3ºC, so they aren't used in applications requiring accuracy. Several colors are available between -5ºC and 65ºC, including 31ºC for body-heat activation (when touched or worn) (CTI 2008). Although they only change between colored and colorless states, they can be mixed with colored inks. For example, a blue leuco dye can be mixed with a yellow ink, resulting in green ink when in colored state, and yellow when colorless (Kelly Chemical Corporation 2008)
Uses include packaging which may need specific low or high temperatures, interactive products and safety signs (e.g., color change below just the pain threshold temperature).
Leuco dyes' life span is shortened by UV exposure, very high temperatures and contact with aggressive solvents (Homola 2003)

A liquid crystal (LC) is composed by polar molecules. They align themselves when the negative parts of the molecules are attracted by the positive parts of other molecules. When heated, the molecules line up in different ways, changing the LC's structure. As the temperature increases, the layers of molecules move further apart. This causes the LC to refract the light in different ways, producing various colors, each for a different structure (see ChLCD displays in "E-paper" section).
Thermochromic LCs are very difficult to work with and require highly specialized printing and handling techniques but allows for accurate measurements (e.g. thermometers) and full spectrum of colors. LCs turn from clear (or black if a black background is used) to red at a given temperature, and as it increases color turns in sequence (orange, yellow, green, blue, violet) before turning colorless (black) again at a higher temperature (Parsley 1991).
Color bandwidths may range between 1ºC and 7ºC, and the activation temperature may be a value between 0ºC and 50ºC. As an example of a body-heat activation ink with 5ºC bandwidth: Red starts at 25ºC, green at 26ºC, blue at 30º and clear again at 44ºC.

Both types of materials require microencapsulation. The capsules (5-10µm) being larger than normal pigments, require adjustments to printing and manufacturing processes which makes the process more expensive (Gem'innov 2008).
Thermochromics are best used to measure absolute temperatures. They may be useful in an interaction context when the body temperature is different from the environment. Controlling

color is difficult to achieve if a product is not calibrated for every geographical region it is in. Even in the same place, there is also the problem of temperature fluctuations during the day/night and seasons. Touch interaction is possible but for a short amount of time, as the ink reverts back to their default color after the heat source is gone.

The way turn this technology to a more complex display is by means of selective electrical resistance (TEP 2008). This is achieved by placing wires with high electrical resistance (e.g. nickel and chromium alloy) behind a surface painted with thermochromic ink. When connected to a battery or other power source, current passes through the wire, heating it, and the ink on the other side changes to a different color along the wire. Electrical resistance is proportionally dependent on the thinness of the wire. If sufficiently thin (e.g., 0,1mm) they can even be used in flexible displays (Liu 2007). Wires may be arranged in patterns which effectively act as pixels, and selectively turned on and off (matrix-like, or the 88:88 in digital clocks). [Video 29]

Electrochromic systems involves electroactive materials that show a reversible color change when an electric field is applied. The system is composed by three layers between two glass/plastic panels and two transparent conductive layers (ITO) on each side (Figure 3.37): electrochromics layer (polyaniline or WO_3 for example), ion conductor/electrolyte (salt) and ion storage/counter electrode layer (Li or Zn ion suppliers).

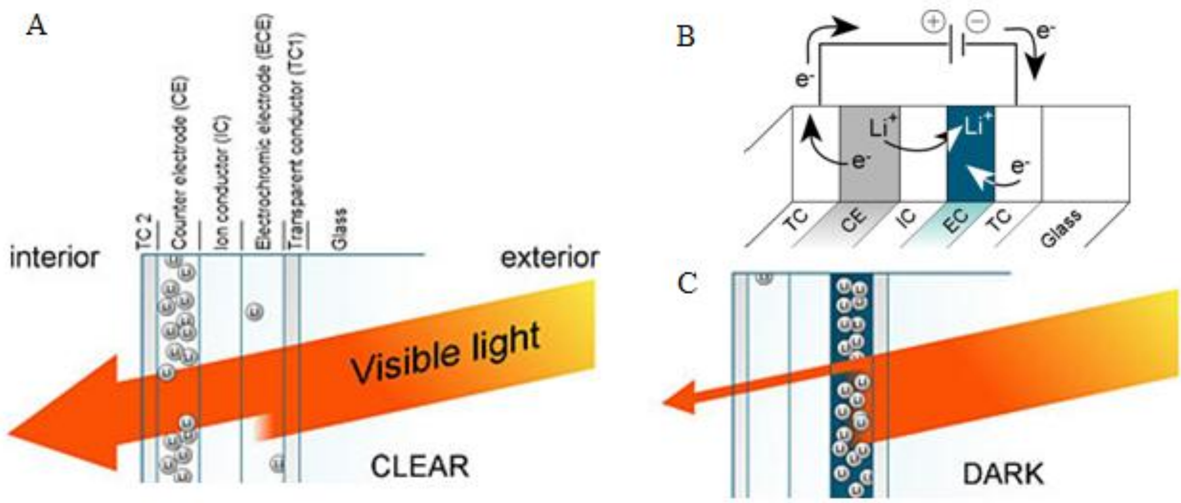

Figure 3.37. Window electrochromic system (A- before; B- ion transfer; C- after) (SAGE Electrochromics)

When a low voltage (1-5V) is applied to the conductive layers, electrons are removed from the counter-electrode/ion storage, causing ions to be driven across the electrolyte (which provides only ionic, not electronic conduction), and into the electrochromic layer, where the charge compensating electron is being inserted. This changes the electrochromic material into a state which absorbs and reflects light in a different frequency.

$$WO_3 + x(Li^+ + e^-) \rightleftharpoons Li_x WO_3$$

colorless blue

Figure 3.38. Example of an electrochemical redox reaction

The system may change from a colorless state to an opaque state, from colorless to colored, or between two colors if the counter electrode is also electrochromic (Rosseinsky and Mortimer 2001). Upon completion of the redox reaction, the cell will retain its color (memory effect). Reversing the voltage polarity causes the ions and associated electrons to return to their original layer, the counter electrode, consequently reverting it back to its original color. [Video 30]

There are other electrically-driven systems for achieving darkening: suspended particle devices (SPDs) and polymer dispersed liquid crystals (PDLCs). Their default state is one of random distribution/orientation, which scatters light. When sufficient voltage is applied the particles/crystals align parallel, and allow the light to pass through. Both devices require constant power to keep the translucent state.

Electrochromic hydride materials are being developed to behave in a different way, reflecting light instead of absorbing it. For example, Ni-Mg films normally are specular (mirror-like) surfaces but can become transparent on reduction in alkaline electrolyte. [Video 31]

Active-matrix addressed displays have been created in a flexible substrate, paper (Figure 3.39). The electrochromic material used is Poly(3,4-ethylenedioxythiophene) (PEDOT) doped with poly(styrenesulfonate) (PSS). In this matrix, each pixel is obtained by integrating the electrochemical transistor (a stripe of PEDOT:PSS), used for conductance switching, with the electrochromic display cell (two adjacent films of PEDOT:PSS electrodes covered with an electrolyte). Pixel addressing is made possible by placing them in cross-points of a conductor matrix. In a process similar to TFT LCDs/OLEDs, the transistor, which controls the flow to and from each display cell, allows for unique addressing of individual display cells by suppressing cross-talk with other display cells. By keeping the transistors in the first row in the on-state while the transistors of the other rows are “off”, only the display cells in the first row can be updated by applying the appropriate voltages to each individual column line. This procedure is then repeated for the other rows (Andersson 2007).

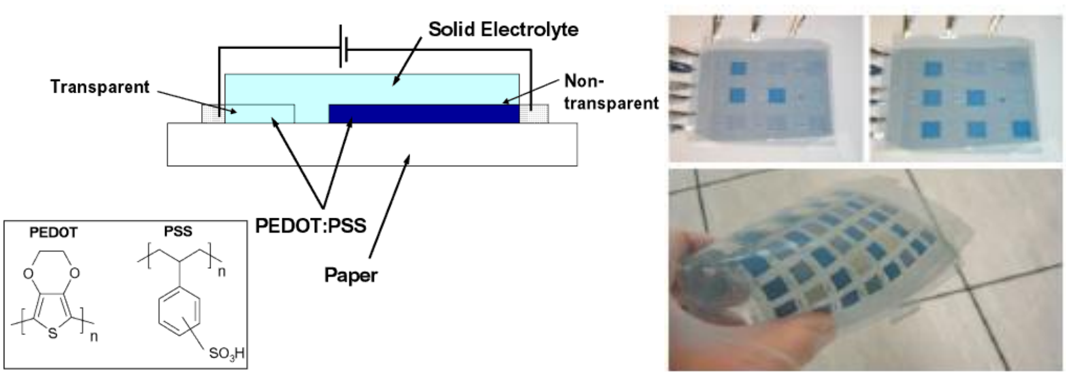

Figure 3.39. Electrochromic paper display. (Acreo 2008)

Electrochromism allows a greater flexibility over when and what is displayed. Any number of sensors could be used to control it. For instance, when used with a photoelectric or/and temperature sensor, windows can reduce a commercial building’s energy by “30 to 40 percent” (National Institute of Standards and Technology cited by ToolBase 2008).

Chromogenic displays have the advantage of being easier to manufacture (printing) and being cheaper than other displays, e.g., PaperDisplay costs 0,005€/cm^2. This is a promising technology for interactive (disposable) systems such as packaging or updatable billboards.
They may lack the resolution and versatility of other pixel matrix displays, but for some applications requiring only change between a few images that may not even be required - they can be printed into any desired shape. In disposable electronics updating speeds become less important when compared to factors such as low environmental impact materials, power consumption and cost. One step towards disposable electronics is the cellulose-based transistor which is as competitive as oxide-based TFTs, but much cheaper and disposable (Fortunato 2008).

3.3. Guidelines for a Primary Choice of Input Technologies

There is great variety of input and output technologies nowadays. While many input technologies may have the same functionality, they probably cannot be used interchangeably. Not because one is better than another – all of them are good for something and bad for something else – but due to their limitations relatively to the environment and context in which they are used. Many factors may influence that choice; some of them are in the following tables.

The tables are intended to be used on the “coarse grain”, 1st level choice when picking an input. As it is generally restricted by the aforementioned constraints, the guide is made as to allow the designer to rapidly decide those he/she can’t use, being ultimately presented with a smaller set, of one or two, to choose from.

This guide does not attempt to convey a quality/price selection (“finer”, higher level choice). Prices are changeable and the quality needed is entirely dependant on their objective - this would obviously translate into countless possibilities, undesirable for this guide.

Displays aren’t mentioned due to rarely being limited by the environment (except conditions of very low/high brightness and loudness). Also, the choice is usually straightforward considering the needs (size, resolution, flexibility, number of dimensions, power consumption) and the differences among the described displays. For most objectives only one or two are appropriate. In the same way, they don’t include inputs whose specificity and uniqueness makes their choice immediate, e.g., speech recognition, BCI.

Table 3.2. Free-space presence, movement and object recognition (✓ = yes/good, ✗ = no/bad)

	No Markers			Passive Markers		
	Visual Camera	**IR Reflectivity**	**Acoustic Reflectivity**	**Visual Camera**	**IR Reflectivity**	**RFID**
Works w/ background physical movement	✗	✗ [2]	✗	✓	✓	✓
Works w/ background projected movement	✗	✓	✓	✓	✓	✓
Ambient light effect	✓[1]	✗	✓	✓[1]	✗	✓
Ambient sound effect	✓	✓	✗	✓	✓	✓
Line-of-sight objects effect	✗	✗[3]	✗	✗	✗[3]	✓

1 – Reflections and glare spots may affect outcome

2- If b.g. mov. is IR reflective = ✗

If b.g. mov. is IR absorbing/transmitting = ✓

3- If LoS objects are IR reflective/absorbing = ✗

If LoS objects are IR transmitting = ✓

Table 3.3. Surface (touch) recognition (✓= yes/good, ✗= no/bad)

	Acoustic			Optical			Electrical	
	TDOA	**LPM**	**SAW**	**FTIR**	**IR**	**“In-air”**	**Resistive**	**Capacitive**
Finger	✓	✓	✓	✓	✓	✓	✓	✓
(Non-conductive) Pen	✓	✓	✗	✓[1]	✗	✗	✓	✗
No ambiguities w/ obstructions	✓	✓	✗	✓[1]	✗	✗	✗	✗
No problems w/ surface damage	✓	✓	✓	✓[1]	✓	✓	✗	
Number of sensors	3	1	2	1	Many[2]	1, 2	1	1
Ambient lighting effect	✓	✓	✓	✓	✗	✗[3]	✓	✓
Multitouch	✗	✗	✗	✓	✗	✓	✓	✓

1 – Depends on index of refraction

2 – Depending on needed detection resolution

3.4. On New Media Design

In a time when people constantly rely on technology, and even trust it with their lives (airplanes, robotic surgery), the interface design is ever more important. For being so common, not much attention or significance is given to interfaces. The truth is, a well designed interface isn't noticed, it fades into the background; a bad interface can, in a worst case scenario, be responsible for the deaths of people (for example, in an emergency situation when a decision has to be made or a button pushed in a few seconds).
They aren't just used in critical situations. Buying a ticket, making a call, having fun on the computer, writing this text could not be possible without an interface. In these cases, a bad interface "only" results in productivity/money/time loss.
Whatever the use may be, the designer has a responsibility to make sure it works as intended, which is to say, as good as possible.

Designing an interface is no easy task. Every person is different and the interface should accommodate every user. The biggest difficulty to overcome is the fact that the designer(s) aren't statistically representative of the users, especially in ubicomp. More often than not, the interface is to be used by people completely different from the ones who designed it.
Development can be expensive, but if poorly designed it can render a device useless, no matter how good the functionality and content are. If well designed, it can define the success of the device (e.g., Nintendo Wii, iPod). Success is accomplished when a system allows the user to better perform tasks – it is defined by usability (easy, effective, safe) and overall user experience (pleasant, fun to use) criteria.

Designing an interaction for ubicomp, better yet, an experience is an even harder task. Real world environments and activities are much more dynamic and complex than the ones possible in the desktop computing environment.
User Experience (UX) design is a new discipline which draws from various other fields such as ergonomics, interface design, information architecture, or psychology. A major part of the experience is subjective and different for each person, the other part is objective and easier to quantify. For example using the mouse can be objectively (through common sense or usability statistics) determined as an easy way to communicate with a computational device, but some

people may never adapt to it. It may seem too complex, they may lack hand-eye coordination, or even have a physical impairment that prevents them to interact in such manner.

The physical design of the user interface, the flow of the interaction, the context involving that interaction, they all affect the final experience. In most cases usability contributes to overall UX, but sometimes compromising has to exist between the two (e.g., a fun to use missile launcher?).

Ubiquitous computing is new and different from everything we were used to until now, essentially from personal computing, therefore, the best way to design for it is by means of iterative design.

3.4.1. Iterative Design

The iterative design methodology is based on a cyclic process and is defined by constant refinement with each iteration. The cycle's main stages are Requirements, Design, Implementation and Evaluation, linked as represented in Figure 3.40.

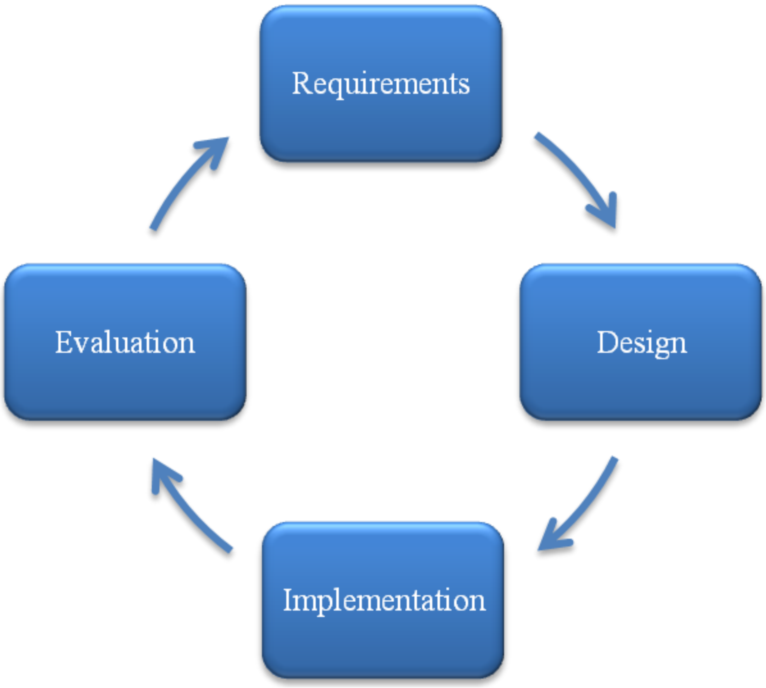

Figure 3.40. Iterative design cycle

The following table summarily describes the iterative design process: The four phases and their description (through key activities), and methods used to accomplish them.

Table 3.4. Iterative design process

Phase	Key activities	Methods and Techniques
Requirements	Identify user's needs, problems and context. - who users are; - what they do; - how and where they do it; - what they use; - what they need to know. Create problem scenarios (based on task analysis)	Task analysis: - Questionnaires; - Interviews; - Observe and Record; - Study documentation and similar products Select relevant tasks
Design	Develop alternative designs Conceptual models: - System model (how the system works) - Interface model (how the system will present itself to the user) - User model (how the users think the system works) - Design model (what the designer intended for the interface to convey) Activity scenarios (based on conceptual models, new ideas)	Metaphors – transpose user's previous knowledge into the design Norman principles: - Affordances – know what the system does based solely on its design - Constraints – restrict user's alternatives - Mapping – relation between controls and effect - Visibility – no need for labels or experimentation - Feedback

Implementation	Producing an interactive version of the design Sketches (to explore design concepts) From low-fidelity prototypes to high-fidelity prototypes (to test design concepts) - Horizontal prototypes (more tasks, less functionality) - Vertical prototypes (less tasks, more functionality)	Interaction scenarios Videos/animations Storyboards Paper prototypes Physical prototypes Wizard of Oz
Evaluation	Evaluate the prototype: - functionalities - interface impact (usability) - system's problems Evaluation by experts, when user tests aren't possible: - Heuristic Evaluation - Predictive models User tests (requires working prototype) Statistics	Heuristics: - Nielsen's 10 principles - Tognazzini's 17 principles Predictive models: - GOMS (Goals, Methods, Operators, Selection rules), - KLM (keystroke level model), Fitts' law User tests - Observe and Record; - Think aloud; - Questionnaires; - Interviews; - Physiological monitoring;

In order not to make this process impossible due to time and budget issues, the initial set of ideas should preferably be sketches, which are cheap, disposable, purposely appear as unfinished (as to suggest new iterations), and plentiful to prevent attachments and bias towards a specific idea.

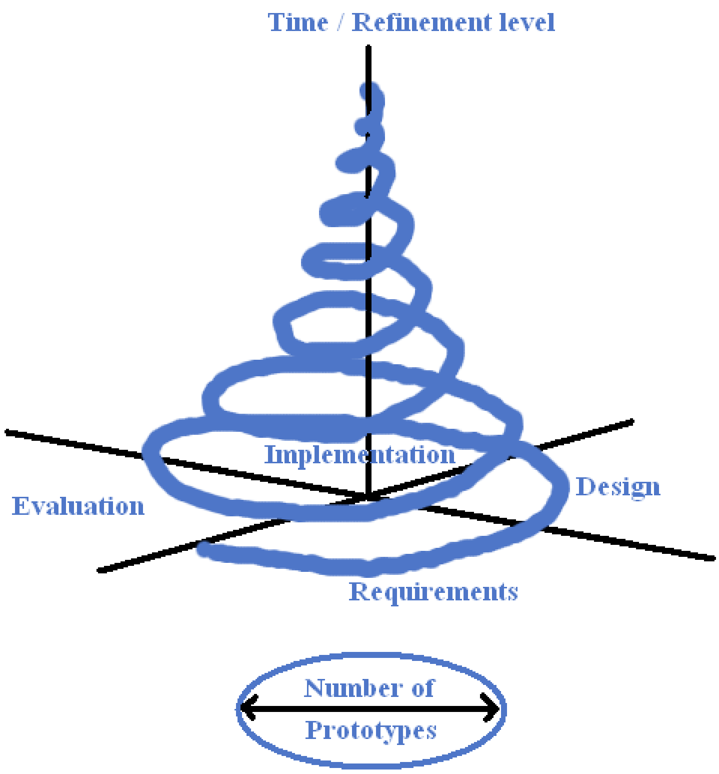

Figure 3.41. Sketches and prototype "pruning" throughout the design.

In a development continuum, the multiplicity of sketches/ideas is “pruned”, in a process much like natural selection, until only one or a few ideas emerge. These turn into low fidelity prototypes which are evaluated, some of them are discarded, others further refined and prototyped in an increasingly perfected way (while lessening in number). Prototypes are more specific, used to describe and test, until one final product is obtained.

3.4.2. Considerations

No matter how good the design process, we must always assume it is not perfect, and with that in mind, always design for error.

Even the mouse, unveiled in 1968 by Douglas Engelbart, which had an extensive design revision and usability testing (he finalized the first mouse design in 1963), isn’t perfect. Using the mouse is unintuitive and unnatural (albeit easy to learn) and time consuming. Nicholas Negroponte stated that, while writing, if a person wishes to point at something on a screen, four steps have to be taken (Negroponte 1984):

1st – Stop writing and find the mouse,

2nd – Move mouse to find cursor on screen,

3rd – Move cursor to the desired location,

4th – Click mouse button.

In contrast to finger-based interaction, which “people don´t realize how important that is” because they “don’t have to pick them up”. Touch is rapidly becoming the preferred method of input. Consumer products using touchscreens are growing, and many patents have been filed concerning future mobile phones, PCs and other electronic devices that could benefit from it. Touch interaction is more intuitive, but it also has drawbacks, such as occlusion, “gorilla arm” or neck discomfort. The latter can be potentially ameliorated by placing the screen at an height and angle which would allow the user to rest their arms while interacting but not as horizontal as to cause neck problems.

To allow touch without any auxiliary object (pen), and still reducing the occlusion problem, essentially four methods exist:

- Use oversized targets, which is impractical for smaller screens, not to mention inaesthetic.
- Offset the cursor. The problem is, users don’t have visual feedback until they touch the screen, and have to estimate the offset and correct the finger’s position. If the offset is, for instance, upwards, it would render targets on the bottom edge of the screen unreachable.
- For small targets Shift (Vogel and Baudisch 2007) creates a callout showing a copy of the occluded screen area and places it in a non-occluded location. The callout also shows a pointer representing the selection point of the finger.
- Lucidtouch and Nanotouch use pseudo-transparency. A technique creates the illusion of device transparency, by overlaying an image of the user’s hand onto the screen. This way user’s can control it by touching the back of the device.

Despite existing technologies and design methods, not every developer dispenses as much effort on the interaction, as they do on the amount of content. While there are some very well-thought and designed interfaces (many of the previously mentioned are examples of it), there are still badly designed ones, both physical and graphical.

Innovation exists to overcome problems and increase functionality. When badly implemented can cause more problems than it solves. This should not be mistaken by flawed interaction due to underlying technology maturity – for instance, the impossibility to have a large number of remote participants interacting haptically in a shared virtual space, due to the high bandwidth requirements.

Some examples of not so good designs are described in (Marentette 2008). Many desktop computing applications have visibility and feedback problems, even including OS (Windows' tabs) and visualization applications (Citegraph). Also, many mundane interfaces lack proper design, (e.g. digital clocks, light switches rarely have decent mapping).

Passive RFID cards, without a reader lack visual feedback on their current state. This is especially problematic in RFID cards with credit. The biggest advantages of passive tags are their price and size, so carrying a reader is not an option, it would make their existence pointless. One cannot immediately check, for instance, how much money is available, and risks trying to pay something without credit, probably causing a difficult social situation. This problem could be solved by using a bi-stable thin display technology such as e-paper or OLED. It could potentially be powered by inductive coupling when passing by the reader (on the act of purchase) and updated at that time.

Ubiquitous computing relies not only on the easiness to control devices but also their interconnectivity. Never forgetting that ubicomp is anthropocentric, not technocentric, our rights, needs, and quality of life should always be maintained. Therefore, in order to prevent setbacks, global rules and directives should exist.

Of course, safety, health and environmental compliances already exist for devices, such as laser classes or RoHS. But ubicomp is not made up of individual devices; instead, it's about them working as a whole. That fact may bring unforeseen impacts, if not considered by the designer as being as important as legal conformities.

Regarding the safeguarding of human prerogatives, Greenfield enunciates five principles (Greenfield 2006):

- Ubicomp must default to harmlessness – When systems fail, they must default to a mode that ensures user's physical, psychic and financial safety.

- Ubicomp must be self-disclosing – Users should always know when they are in the presence of informatics systems. Those systems must contain provisions for immediate and transparent querying of their ownership, use, and capabilities.

- Ubicomp must be conservative of face – Systems must not act in a manner which could embarrass or humiliate users, expose them to ridicule or shame in the course of normal operations.

- Ubicomp must be conservative of time – Technology exists to bring simplicity and save time. Systems must not introduce undue complications into ordinary activities.

- Ubicomp must be deniable – Systems must offer user's the ability to opt out, always and at any point.

Needless to say, some of these rules can be hard to comply, especially the last, due to the naturally progressive implementation of technology in everyday life. For example, we may want to keep the traditional lock on our door, so we can open it with a key, in case we forget our card or the body recognition device fails. But aren't the lock and key technologies too? Should their inventor have designed a system which allows doors to be opened without any mechanism? That would render the objective (keep doors locked) itself pointless. The choice to opt out is important, but providing alternatives to reach the same objective is virtually impossible. If every hi-tech information access point had an option to ask a real person, millions of "useless" jobs had to be created for the small percentage of people that wouldn't use that technology. If in the future, every public transportation system adopted a retinal scan and every public or private vehicle had tracking devices for security purposes. If we must have an alternative, then the government would have to create a whole new transportation infrastructure without any kind of new technology, except the vehicles themselves, just for a small percentage of people who would use new vehicles. The other option would be walking several kilometers, which would also violate our prerogatives. Ubicomp like every other technology, sooner or later, is inescapable, and trying to live by pre-industrial standards in a modernized city is impossible. A (bad) example is a bus stop advertisement, in Rotterdam, which weighs people who sit and displays the weight in the ad. It tries to use shame and convince people to work out at a local gym.

In order for interaction to occur fluidly, standards have to be created before technologies are deployed in order to address incompatibility and interoperability problems. Internet 0 (see “Networks and Communication” chapter) promises inter-device internetworking. It’s poised to be an alternative to the current dozens of different device interface standards.

A universal gesture “language” has to be standardized as soon as possible. They should have been before multitouch devices reached the market. If not, each time a person uses devices of different brands, they essentially have to learn a new language. Standardization should be done through an independent, non-commercial organization such as ISO, and not through patents, which is exactly what’s happening at the present time. Companies are trying to patent gestures, and if successful they can stop others from using similar techniques (Figure 3.42). Apple begun filing applications for multipoint touchscreens and gestures over 5 years ago, and was the first to launch a multitouch consumer product on a global scale. Even if the patents are not granted, iPhone and iPod Touch “gestural language” is the first people will learn to use. Other companies’ (later) products will be forced to follow Apple gestures, or risk selling less, not because their interaction techniques are worse, they might even be better, but because people won’t want to learn new “gestural alphabets”. Gestures are simply movements representing a function and should not be patented. These kinds of patents should only be possible if everyone is certain they are as perfect as possible, for all of the world’s population, and this is unlikely to happen on the first attempt. If anything, it will only hinder technology development and dissemination.

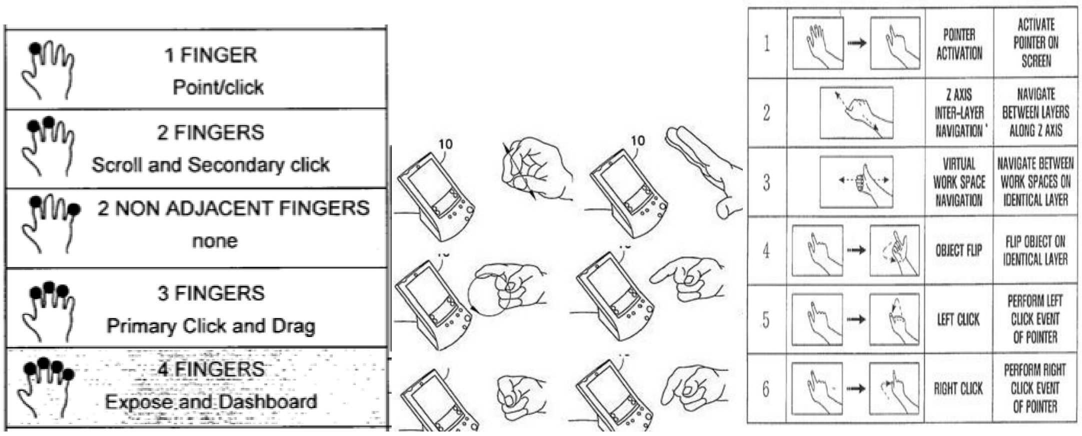

Figure 3.42. Patent submissions containing (A) Apple, (B) Nokia and (C) Samsung gestures. Retrieved from: (Kirk 2008), (Unwired view 2008), (ITsky 2008).

A practical example of lack of gestural interoperability concerns the numerical keypads on mobile phones, ATM, calculators, and computer keyboards, which have a different layout between devices, or even among the same kind of devices, as shown in Figure 3.43.

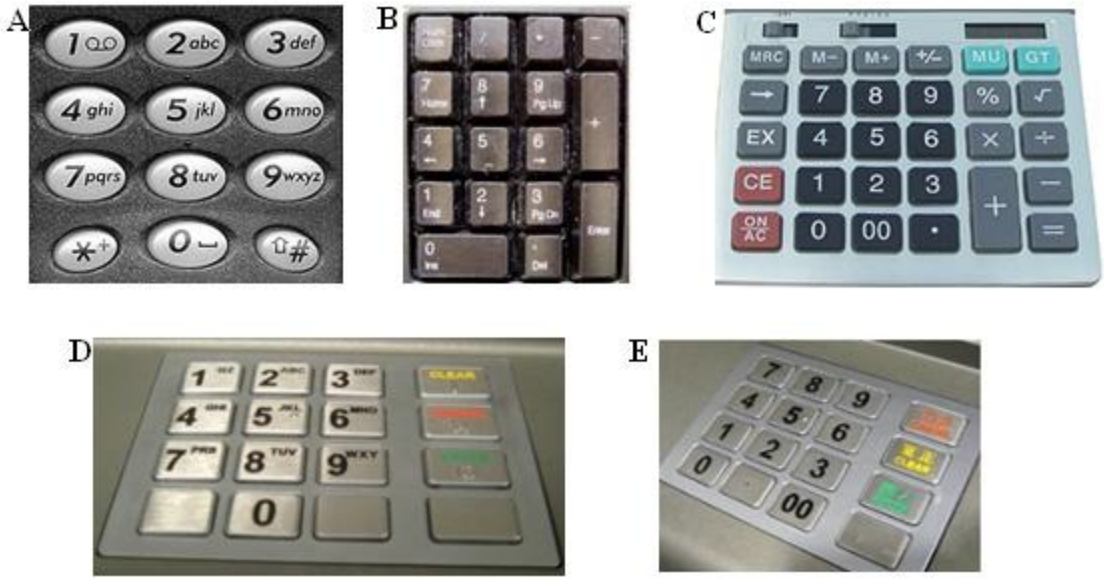

Figure 3.43. Examples of keypads from various devices: (A) Mobile phone, (B) numpad, (C) calculator, (D and E)ATM. Retrieved from: (MacKenzie 2001), (Ikibits.co.uk), (Lakewood Conferences 2007), (Currency Cassette Company), (Hammond 2007).

People often operate such devices without even looking at the keys (e.g., text messaging, calculator). Usually the act of inserting the PIN code is so fast that people tend to do it unconsciously. This example can be illustrative of gestural interfaces: users sometimes don’t even recall the numbers, but the gesture used to type them. If a person uses the same PIN for both mobile phone and ATM they can be confounded. Even by using different ATMs, as evidenced by Figures D and E

Other example, concerning lack of compatibility, is the “7 Colinas” card, an RFID “card on which multimodal tickets can be credited” used in Lisbon’s metro area. The card is an attempt to reduce the different tickets which currently exist in public transportation. It can be used to travel by bus, train, “surface metro”, subway and boat. The problem is, the same card can’t be used on all of these transports. Sometimes can’t even be used on the intra-transportation, for different destinations.

Some operators charge cards with number of travels, others with money. Only after completely using up the travels/money that the card contains, can it be charged by a different operator or for a different destination. This results in the user having to buy and carry several cards, if they use more than one means of transportation. Additionally, all cards look alike (Figure 3.44), further confusing users.

Figure 3.44. Example of the multiplicity of "7 Colinas" cards. Which is which?

The above image is a glimpse of the amount of cards regular person may carry.
Operators/ transportation/destination, from left to right:

- Fertagus / Train/ Corroios-Pinhal Novo;
- Fertagus / Train/ Corroios-Pragal;
- Metro Lisboa / Subway / Lisbon area;
- MTS / Surface Metro / Almada area.

Validating a card becomes a trial-and-error process (a reading error occurs if cards are placed together). Using this system, users are likely to be frustrated, especially considering these are transportation systems, timeliness is too relevant – half minute is the difference between catching and missing a train.

The situations here explained are supposed to be solved before the product or system is completely designed, much less implemented. Companies should talk to all stakeholders before committing to a final design, more so when their use isn't optional, and will affect many people.
The designer has a decisive role: to take into account all the potential effects and use them to design ubiquitous computing systems properly, as well as humanly possible.

4. Impacts

To appropriately assess a future technological vision, we have to deal with great uncertainties, namely:

- To what extent ubiquitous computing will go, in both breadth and usage;
- How fast it will develop and reach large numbers of people
- How it will affect the world.

When ubiquitous computing permeates our environment, negative as well as positive impacts will emerge. Consequences need to be predicted and linked to its causes before any action is made. The interconnectivity and complexity of this new paradigm makes any prediction attempt more of an educated guess.

The expected effects were structured in a conceptual structure that distinguishes between 3 levels:

Table 4.1. Impact and opportunity levels (EITO 2002)

First order	Second order	Third order
Impacts and opportunities created by the physical existence of ICT and the processes involved. This includes the design, manufacture, operation and disposal of ICT.	Impacts and opportunities created by the ongoing use and application of ICT	Impacts and opportunities created by the aggregated effects of large numbers of people using ICT over a medium to long term

Impact orders dynamically interact with each other and aren't mutually exclusive, they can overlap.

ICT has great potential as a force for development, but it should always be sustainable. New ICT will bring positive effects, but there might be negative ones as well. Despite being error-prone, they should be deduced and considered as soon as possible, as to maximize the positive and mitigate the negative.

Ubiquitous computing has the potential to influence everything: the atmosphere, hydrosphere, lithosphere and biosphere, which includes human society. Although these spheres are part of a whole, to more easily understand its effects and causes, they were separated by distinguished fields of study.

4.1. Society

Social impacts influence the human population, its intra-relations, lifestyle, education, health and other services. Social sustainability implies an increase (or at least maintenance of) base human values such as justice and equity.

4.1.1. First Order

Job creation

Opportunity:

More and new jobs will be created to build and maintain ubiquitous computing, and those jobs will create even more, necessary throughout the whole product lifecycle.

Risk:

The ICT industry is constantly evolving. Many jobs will require specialized people constantly upgrading their skills. There is a risk of marginalization of lower skilled workers (EITO 2002).

Regional digital divide

Opportunity:

Cheap, as well as intuitive products (e.g., OLPC, RFID Post-Its) will be available to empower poor countries and contribute to reduce the digital divide.

Risk:

Many technologies will be expensive, and lack of infrastructure (such as internet access) to operate some of those technologies, may further contribute to the existent digital divide.

4.1.2. Second Order:

Access to technology and information (apparent)

Risk:

The wide range of new “intuitive” interfaces being developed, when deployed, may confuse users. They might have to interact with two or three devices in just a few minutes period, and each one can have a completely different interaction mode.

Also, ubiquitous computing may become invasive computing. Some people, especially older people, not accustomed with technology and lower learning aptitude, may become overwhelmed with technology and new information. The inability to access information, when “everybody else can”, may convey a sense of frustration. In an extreme case, they might self-exclude, fearing not being able to engage with technology needed in common activities such as using and buying an RFID ticket or making a phone call.

Access to technology and information (effective)

Opportunity:

Around 78.6% of the world’s population is illiterate (United Nations 2007). New interfaces could make information reachable without a need for writing or reading.

Multimodal interfaces will allow people with disabilities to access information. Intuitive interfaces reduce the learning curve and bridge the digital gap.

Information is accessible everywhere.

Risk:

If the interface has only one mode of interaction, and that corresponds to a person’s disability, it can’t be used by him/her.

In an informatic world, people’s freedom of choice is limited. Most likely people won’t be able to avoid using/being subject to ICT in their daily life, even if they want to.

Information quality and quantity

Opportunity:

Access to information will be possible anywhere, anytime, and its quality will be better. The user will have even more than today with the internet. It will be context-sensitive and location-based.

This will also enable organizations to provide people with better services.

At the same time, information previously unavailable, is already gaining access to the general public: health knowledge comes from a variety of sources, allowing individuals to take greater responsibility for their own health (EITO 2002); democracy pressures governments to be more transparent; technical subjects are available for autodidactic people, education surpasses schools.

Risk:

The user can be flooded with information. The conscious attention of the user will become even a scarcer resource. Advertisers will fight hard to commercially exploit this resource (Hilty 2004). In the context of healthcare, misinformation can be particularly dangerous. Healthcare professionals disagree over the extent to which self-diagnosis and treatment should be encouraged (EITO 2002).

As with the internet, information can be inaccurate. When the source is unknown, there is no independent entity which guarantees any information to be trustworthy.

Security

Risk:

Ubiquitous computing will allow new forms of computer crime, but with even more meaningful consequences. Systems not only process information but can also control physical processes. Unauthorized influencing of systems can take place (Hilty 2004): by reprogramming components; by means of radio waves; influencing through networks.

Safety and privacy

Opportunity:

Surveillance can be cheaper, more effective and invisible. Effectiveness can increase with new ways of identifying people (biometrics, behaviometrics).

Objects will have traceable tags and other identification systems to prevent theft.

Risk:

The technology used to detect criminals also includes innocent people. Being identified everywhere they go, being forced (by their employer or by social convention) to wear active badges or use any other locating object, might be seen as a violation of privacy. There is also the risk of personal and behavioral information to, willingly or unwillingly, reach a third party entity. Effects range from simply a nuisance (advertising company), to serious threat, if a person's daily behavior information reaches criminal's hands.

Causation and Accountability

Risk:

In a network of sensors, databases, devices of all sorts, data can travel freely. Due to the complexity inherent to ubicomp, it will be difficult to attribute responsibility to an entity, if confidential information is misused or when a device doesn't work properly. How can one trace an information leak to its source? Whose responsibility is it, when something doesn't work as intended? Problems can have a multitude of origins: could be an electronic malfunction, original data error, network problem. If a smart device starts buying unwanted products because it "thinks" its owner need them, users won't be able to know, much less perform a diagnosis, until it's too late. A complexity point is coming, when humans cannot effectively have total control of their own technology.

Automation and efficiency

Opportunity:

Almost every process which is now done by humans can become automatic, given the technology exists to do it. Comparatively, humans are limited, especially at the speed they perform certain tasks. Simple, repetitive tasks can easily be improved by automation, namely information gathering, transmitting, and sometimes processing and acting on it. This frees people to work on other subjects, allowing a greater contribution to society.

Risk:

Loss of jobs such as cashier, postman, and some jobs based on monitoring (home nurses, security).

Automation may replace working people to the point where only one is needed to control several automated tasks, generating solitary *in-situ* or tele-working. Social isolation may become a problem.

Persuasive Computing

Opportunity:

Human beings respond to cues in the environment, especially to things that seem alive in some way (Reeves e Naas, 1996 cited by Fogg, 2002). Computing devices can express social presence through attractive hardware design, or software design (e.g., Tamagotchi, interactive plushes). If a CGI “person” gives instructions to the user, they’re more likely to be followed than if they were text written in a box. Research confirms that people respond to computer systems as though the computers were social entities that used principles of motivation and influence. Praising technology can transmit a sense of reward for successfully doing what the designer intended. People feel better about themselves, heighten their mood, and are more likely to work with it again (Fogg 2002). This influence can be used to better convey and make people follow social norms, laws, local rules (“Don’t smoke here please”), increase productivity and general well-being.

Risk:

With persuasiveness comes a risk of transmitting wrong ideas or values into people. As Arthur C Clarke said: “Any sufficiently advanced technology is indistinguishable from magic”. Ubiquitous computing new interfaces will undoubtedly convey that sensation. People interacting with technology beyond their comprehension tend to assume their creators are much more intelligent, and therefore, technology is flawless. This way of thinking induces people to blindly trust technology (even more if it is pleasant to the user) and follow its instructions. Malicious instructions can vary from influencing the user to buy a certain product, be and act in a wrong way or reveal passwords or other personal information.

4.1.3. Third Order:

Urbanism

Opportunity:

Augmenting space by displaying of virtual, dynamically changing elements, over the reality we experience.

Change of lifestyle and architecture - our urban environment will have information about themselves and their surroundings, which may, or may not be used without human intervention (e.g., vehicle-to-vehicle communications). They’ll also have the ability to anticipate people’s actions, and automatically act accordingly (e.g., opening doors upon owner’s arrival) .

In a security point of view, urban areas are currently “battlespaces” in which terrorists and insurgents are largely indistinguishable from the wider urban background. According to the U.S. Department of Defense (DoD), current “intelligence, surveillance, and reconnaissance (ISR) capabilities are inadequate for many tasks that emerge in asymmetric warfare. More intimate, 21st century ISR is required, composed of elements like tagging, tracking and locating capabilities.” (DSB 2004) This kind of aware environment will provide a better homeland security.

With locative data, new forms of art arise, providing data visualization for all sorts of information (traffic, people’s emotions, GPS drawings). Urban spaces are also a preferred setting for augmented reality games (ARGs) and location-based games (LBGs), interactive storytelling and forms of massively authored artistic projects.

Risk:

Things which are not tagged start to be considered dumb. Amongst those things may well be people. There is a risk of undermining of unwired people, if “connection level” becomes a relevant social characteristic. (Graham and Crang 2007)

The DoD wants to “develop intrusive, close in, networked systems, with an operational focus sufficient to introduce these systems to the user community in the near term” (DSB 2004). If that becomes a reality, entire populations’ privacies may be compromised.

New virtual communities

Opportunity:

Virtual communities are groups of people with shared interests, which would not for in real space due to dispersion. As with the internet, new virtual communities will arise, but without the constraints of being on an internet PC. It also makes faster for them to share information about an event or place with geo-referenced, real-time feed of information (e.g., video of a political speech, a music concert, or human rights violation). This may empower common citizens and give them leverage to reclaim their rights, promote public participation, or just a better way to share their thoughts.

Risk:

Virtual communities are appealing, but can replace social contact. Already today there are serious cases of people isolating themselves, “immersed” in virtual worlds (namely games) for several days straight, even dying because of that. Being able to access the virtual world anywhere and everywhere will probably increase the trend to addiction (Schauer, 2002 cited by L. M. Hilty, 2004)

Cultural homogeneity and diversity

Opportunity:

Widespread new media can bolster small communities, reaching for people who share the same language and cultural background. This is important as a means to maintain local cultures and dialects. Emigrant communities can have access to various informations, from their original community, in their own language, anywhere they are.

Risk:

Some software and interfaces support several languages, but still, many non-romanic scripts such as Arabic and Chinese are not supported, local dialects even less. The predominant language in software and interfaces is English, which cause an even faster growth of globalization. The detrimental impact on culture and diversity is undetermined, but if English comes to dominate almost exclusively, the potential for non-English speakers to be marginalized would be a serious concern (EITO 2002).

4.2. Economy

Economic sustainability means economic growth without unjustified demands on human or natural resources.

4.2.1. First Order

New companies and types of company

New companies and markets arise, such as RFID and location-based services (LBS).

With the inherent complexity of ubicomp products and services, many companies, especially SMEs, will outsource more. This will originate new types of specialized companies, continuing a trend already visible, e.g., programming companies in India. This is beneficial to both the outsourcer company, by spending less money, and the outsourced company (and its country) due to an income of more, valuable money.

Risk:

Some market segments are more volatile than others, and ICT is no exception. A situation like the "Dot-com Bubble" burst could happen again.

Investment in Research and Development

Opportunity:

Governments, companies and institutions are relying more on ICT. They understand the potential in ubiquitous computing, and continue to invest large amounts of capital into their R&D budgets. This development translates into direct benefits for the companies responsible, but it also has wider benefits for the economy and society as a whole (EITO 2002). Studies suggest that the social return from R&D is at least twice as big as the private return due to spillover benefits (Woodall 2000).

World ICT Market

Opportunity:

The World ICT market is expanding across the World. In 2005, both the ICT market and the World's GDP growth were equal, at 4,9%. But this is steadily declining: in 2007/08 the World's GDP grew 5,2%, contrasting with an ICT growth of 3,8% (EITO, 2007 cited by ITD Hungary, 2008), (CIA 2008). Due to its "everywhere" dimension, ubiquitous computing could significantly reinforce ICT market and allow growth rates equal or superior than GDP rates. In addition this would reflect in, among other things, employment in the ICT sector.

4.2.2. Second Order

Application within companies

Opportunity:

Using ubicomp within businesses can be a big asset in terms of efficiency. Available human and economic resources could put to a better use if, for instance, products in a shop or supplies in a factory are tagged. This would save potentially millions of dollars each year

(Accenture 2002), free employees' workload, and speed up processes such as locating products within a store, item inventories, and selling.
Ubicomp could also promote information transparency (Joshi 2000), and help reducing the bullwhip effect - when small changes in demand amplify along the supply chain and ultimately result in either excess production (and associated storage costs) or sudden interruptions to supply (and associated missed sales) (Bohn, et al. 2004).

Risk:
If all companies along the chain operate with minimum stock, one unexpected interruption in supply would be enough to completely stop the whole chain (Bohn, et al. 2004).
When replacing people, automation in companies can lead to two situations: job transfer or unemployment. The transfer may not always be to different task inside the company and some companies see automation as a means of saving money, by relieving employees.

Application outside companies

Opportunity:
Monitoring can be done in order to find consumer patterns and their willingness to pay (WTP) for a product (Skiera and Spann, 2002 cited by Bohn, et al., 2004). Prices can be adapted according to individual's behavior (insurances) and WTP, creating a better economy.
Shopping could be done automatically, without the need of human intervention. Accenture calls this "silent commerce" the next competitive differentiator. This can increase customer satisfaction, providing payment easiness and speed (Accenture 2002).

Risk:
Monitoring people always raises concerns about the right to privacy.
Individual prices can be regarded as an injustice, as some would have to pay more than others for the same goods/services
Silent commerce could be dangerous. Automatic shopping should depend on human approval.

Business-consumer relation

Opportunity:
Advertising can be personalized (referring people by their name, suggesting adequate products) and be made in innovative ways, to better influence people.

Easiness of information access about a company can empower consumers into making a more conscious choice, when buying products. They can know about the whole product life-cycle and its environmental impacts (e.g., wood vs plywood) and human/social impacts (e.g., child labor). Having this information shown to consumers would also make prices reflect their social and environmental values, which presently in the great majority of cases, aren't.

Risk:

Advertisements can become annoying or invasive (always popping up in personal devices). Even outdoor advertisements can be a constant interruption, if they actively try to make attention to themselves.

4.2.3. Third Order

Globalization and sustainable growth

Opportunity:

Ubicomp will have a significant role in modern economy, enabling services to be delivered efficiently and further binding the global economy together, reaching a wider spectrum of people and countries. With technology at the economy's core, it may be possible for economic growth to finally be de-coupled from growth in consumption and resource use, creating a context in which the goals of sustainable development can more easily be achieved. (EITO 2002). Ubicomp would make the TechnoGarden scenario much easier to achieve. This scenario consists on market and technology being used to improve the reliability and supply of ecosystem services. It is based on ''natural capitalism'', i.e., working with nature is advantageous for both individuals and society (Hawken 1999), and by means of technology improvements, aims to reduce the amount of material and energy required to produce goods and services (MA 2005).

Some ubicomp products and services require few and inexpensive resources and may not depend on an existing ICT infrastructure. These can be an important factor to boost developing countries' economies.

Risk

People's little experience of non-human nature in conjunction with technological failures can have serious negative effects (MA 2005)

Uneven distribution of technology may further contribute to the lack of competitiveness of developing countries and deepen the digital divide.

4.3. Health

This section explores the effects ubiquitous computing may have on health. These effects can be direct, by contact, or indirect, as a result of ubicomp applications. This area's importance must be addressed. The ubiquity and range of electronic devices has the potential to affect people's health in very different way than the current computing paradigm does.

4.3.1. First Order

Non-ionizing radiation

Risk:

Non-ionizing radiation (NIR) is used in many ubiquitous computing applications, for wireless data transfer. This radiation includes radio-frequencies up to 30GHz. Nowadays many people are concerned about the risks of telecommunications radiation, due to proximity with base stations and mobile phones/WLAN devices. Ubiquitous computing would increase both exponentially. Health damage can arise from thermal effect of high NIR exposure, above 100W/kg. Therefore the highest Specific Absorption Rate limit for mobile phones is 2W/kg (L. M. Hilty 2004).

The most debatable aspect is on non-thermal effects. Some reports suggest increased risk of cancer, changes in brain activity, reaction times (indirectly causing traffic accidents), and sleep patterns. There is also the possibility of electromagnetic interference with medical devices such as pacemakers, and aircraft electronics. According to the World Health Organization (WHO), "No recent national or international reviews have concluded that exposure to the RF fields from mobile phones or their base stations causes any adverse health consequence" (WHO 2005). Investigations continue in order to better assess the risks associated with this radiation.

Physical contact with materials

Opportunity:

Carbon nanotubes (CNTs) are a new material with many desirable characteristics and different commercial expectations, from implants to displays (Field Emission Displays). In particular, singlewalled carbon nanotubes (SWCNTs) demonstrate unique electrical properties.

Experimental results and mathematical models demonstrate that neurons can grow on SWCNTs and electrical interactions occurring in SWCNT–neuron hybrid systems can directly stimulate brain circuit activity (Mazzatenta 2007).

Risk:

With more wearable devices, direct contact between skin and microelectronics, (usually polymers with addictives), and metals from batteries will have allergic and toxic effects on the skin and lungs. As more people work in the microelectronics industry, the neurotoxic exposure to solvents will grow (WHO 1994).

Tests suggest that CNTs, upon reaching the lungs in sufficient quantity, produce a toxic response. Nanoparticles enter the human body more easily and can be more biologically active because of their larger surface area per mass unit compared with that of larger particles (Oberdörster 2005). Some nanoparticles, such as TiO_2 can pass through the air-blood barrier and enter the bloodstream. This pathway cannot be excluded for CNTs. Dermal contact with CNTs demonstrates increased cell apoptosis and necrosis (Helland 2007).

4.3.2. Second Order

Monitoring

Opportunity:

Real-time monitoring capabilities can inform people about the quality of the environment they're on, allowing them the possibility to move to another place if there is a health risk. Monitoring physiological parameters can improve patients' comfort, by staying home instead of being in a hospital, and allow people take conscious decisions about their daily lifestyle. When there is a health problem, detection speed is greatly improved, even before symptoms show up. In some cases this might be crucial to stop a disease in time. It can also help by allowing an efficient emergency medical response if an older person falls (Songdo city) or if a firefighter needs help (YDreams I-Garment).

Risk:

A concern exists about monitoring being used "for exceeding the capacity of the human body for a short time, taking a calculable risk" and "give rise to a new kind of doping that could be called e-doping." (Hilty 2004)

Leaving people's health to depend only in machines can dehumanize healthcare and psychological effects can occur on the patient. It can also be dangerous if machine intelligence isn't sufficiently advanced and "bug-free".

Persuasive computing

Opportunity:

Computers can help persuade people into a healthier lifestyle. One example is the interactive Virtual Personal Trainer (Davis 2000) in which a virtual Army Drill Sergeant offers positive feedback ("Good job!" and "Keep up the good work!") or negative feedback ("Get moving!") according to the user's movements, motivating them into exercising.

Risk:

There is a risk that some applications or games might negatively influence users. Some people are easily influenced by inadequate games. Not only concerning violence, but also unhealthy lifestyle. An online game, Miss Bimbo, aimed at girls between 9 and 16, has already attracted more than a million. Its objective is to embrace plastic surgery and extreme dieting in the search for the perfect figure, buying lingerie, diet pills and having breast enlargement. At that age children are easily influenceable and could be lead to believe that weight and body size manipulation is acceptable (Bird 2008).

Many people tend to believe in everything technology "tells" them. If a future game would be created which could, like the Virtual Personal Trainer, receive input from the user's actions and biometrics, it would be even more dangerous, influencing people into actually taking diet pills and be thin, causing acute eating disorders such as anorexia and bulimia.

Automation in daily life

Opportunity:

Automation leads to extra-time people can use to become healthier by exercising.

Risk:

The need for a person to move is becoming increasingly lower. The human population is more sedentary than ever before. If a person (present and future generations) spends all day sitting or lying down, legs are rarely moved. As various studies show, the rates of heart disease, diabetes and obesity are doubled or tripled in people who sit for long periods of time (Hamilton 2008). At the long-term this can cause muscle groups could become weaker, or in an extreme case, even atrophied by lack of use (alike astronauts in zero-gravity).

Ergonomics

Oportunidades:

Input devices such as the mouse, when excessively used can cause carpal tunnel syndrome or other medical conditions. New interfaces, e.g., based on speech recognition and computer vision, can prevent such injuries to occur.

Risk:

Present, newer input devices, such as the Nintendo Wii remote can cause tennis elbow and other conditions collectively called “wiiitis” (Nett 2008). Poor ergonomics increases the chance of future interfaces (especially gestural and touch) to cause muscle or tendon strains and sores.

4.3.3. Third Order

International medicine

Opportunity:

Monitoring of physiological parameters, and how they relate to specific diseases, can facilitate medical diagnosis of people in another country or place lacking doctors. If monitoring becomes inexpensive, it can be useful in poorer countries. Data can be transmitted to countries with more doctors to help with the diagnosis and treatment. This also holds true with telemedicine. Data mining can also be used to automatically compare similar symptoms and provide a diagnosis and treatment, already done before by a better qualified doctor, in the same way “common law” works in the legal system.

Risk

Automated medicine can be a risk without the common sense human doctors possess, some diseases with similar symptoms may have different treatments.

4.4. Nature

Although the environment can encompass the previous subjects, this topic mostly covers impacts over the non-human part of the environment, which has repercussions on both humans and the rest of the natural world.

Environmental sustainability means to maintain or improve natural resources and ecological functions, safeguarding them for future generations.

4.4.1. First Order

Manufacture

Opportunity:

If designed for the environment, future ubicomp may require less material resources (compared with an equivalent present technology) or use different materials, more abundant and with smaller impacts on the environment upon gathering. Technological advances such as the use of paper as interactive medium or the continuing trend for miniaturization can be a benefit. Advancements may be primarily moved by a reduction in manufacturing costs, but in some cases, the increased efficiency is accompanied by a reduction in negative impacts.

Risk:

The scale on which of ubicomp will appear, will most likely cause bigger resource depletion than the current desktop model. Minerals are non-renewable resources. The mining process and the extraction of raw materials from ore have significant impacts, even after closing (UNEP 1998): they require energy, leave toxic waste material behind, and may cause serious and long-term local soil and water pollution, leaving the land inhospitable and unusable.

Besides toxic and scarce resources, electronics also require large quantities of water, mainly for washing. One chip factory can use between 4.5 and 13.5 million litres of water a day (Atlantic Consulting 1998).

Miniaturization can lead to increased consumption and consequently, increased manufacture (Hilty 2005). Ubiquitous computing may simply be an increase of electronic equipment, not a replacement for PCs. Their appearance and functionality may be different, but everyone will still want to have their own, personal computer (whatever form they may take).

Energy

Opportunity:

Ubicomp small, low-consuming objects, e.g., WSNs, can be powered by energy harvesting technologies (Table 2.5). Energy harvesting technologies can help to reduce the current unsustainable demand for energy, largely based in fossil fuels.

For the EU15, in 2000-2020, overall energy consumption could decrease by 17% and CO_2eq emissions could decrease by 29% on a best-case scenario, (Erdmann 2004). Emissions value can lower, depending on the energy mix, which is expected to rely more on renewables. Without the expected development of ICTs, both values would be higher, therefore, it has a decreasing effect on total future energy consumption and GHG emissions (Erdmann 2004).

Risk:

Energy consumption has several consequences, including non-renewable resources depletion, disturbances in ecology and landscape, soil water and air pollution. It is one of the most relevant environmental impacts, since one of the effects of energy production is global warming.

It is estimated that 50 to 85% of the total ICT environmental impact is due to the energy consumption in the use phase (Stevels 2004 in Jørgensen 2006).

In 1999, the energy used to build and operate networked and standalone chips and computers added up to 450 billion kWh/year of demand (about 13% of total U.S. demand in 1999) (Mills 1999). With the ubicomp advent, that value will most certainly increase. As an example, Esquire published a magazine with e-paper on its cover, and its ("loosely estimated") carbon footprint increased by 16% when compared to a typical print publication (Kamenetz 2008).

In 1999, 100 million nodes on the internet added up to 290 billion kWh/year of demand. At that time there were approximately to $1{,}9 \times 10^9$ allocated addresses (Huston 2008). IPv4 allows for $4{,}3 \times 10^9$ total addressable nodes, which are expected to be exhausted by 2010-2011. Therefore, one could roughly project that, by 2011, in a BAU scenario, demand would rise to about 676 billion kWh/year. IPv6 allows for 3.4×10^{38} addresses which, even if, theoretically,

use existed for them, and devices were low-consuming, current energy producing technologies could not sustain them.
This projection is overestimated and considered as a worst-case scenario. BAU scenarios are rarely used in technology due to constant changes: today's growing number of laptops use about 10X less power and the LCDs that replace CRTs use 2-3x less power (Koomey 2007), at the same time memory and CPU also increase in number, power (in accordance to Moore's law) and energy consumption. There is also an exponential increase in mobile devices which are substantially different from computers energy-wise. Estimates on ICT energy have been very polemical. It is impossible to reach a percentage without data such as the number of ICT equipments in the world, which are still working and for how long, their specifications or their energy efficiencies. Some, such as Koomey from US EPA, even doubt the 13% mark calculated by Mills in 1999, claiming a much lower 3% (Koomey 2000)

According to Gartner Consulting, in 2007 the ICT industry accounted for 2 percent of global CO_2 emissions (Gartner 2007). Electricity consumption is expected to grow 1,3% annually (Kohler and Erdmann 2004).
Ubicomp can bring efficiency gains to technology, but these individual gains can be overcompensated by the multiplication of technology that surrounds us.
For the EU15, in 2000-2020, energy consumption could increase by 37% and emissions by under 32%, in worst-case assumptions (Erdmann 2004).

End-of-life

Opportunity:

Due to short innovation cycles and software incompatibility problems, products are constantly being discarded after a service life of only 10–50% of their technically possible lifetime (L. M. Hilty 2004) even if they are at full functionality. Ubicomp devices will be fabricated at great quantities. Being a new "kind" of technology, they can be designed from the beginning to be almost completely recyclable, to reduce the impact on the environment. New technologies such as paper transistors can help achieve this goal.
Their end-of-life can also be extended by transferring "outdated" technology to other people in the same country (through network movements such as Freecycle) or other countries for free or a small price.

Risk:

Although measures already exist such as the Battery, WEEE (Waste Electrical and Electronic Equipment) and RoHS (Restriction of Hazardous Substances) Directives in Europe, Electronic waste is going to have even bigger negative impacts in the future. As the trend rises to embed microprocessors and other electronics into the everyday objects, the number of “electronic objects” will rapidly grow, increasing pollution from hazardous materials (e.g., lead, mercury, cadmium, brominated phenyls) which in some cases are bioaccumulable, toxic and carcinogenic (Directive 2002/95/EC). If clothing becomes embedded with electronic, a typical developed country can have, per year, up to 0,82kg/cap of wearable and 100t of batteries waste

Miniaturization does not necessarily mean reduction, it can be accompanied by a significant increase in the number of consumers, leading to a rise in e-waste (Hilty 2005). In addition, there is a trend for disposable electronics. When RFID are used in every product, as substitute for UPC and EAN, they will potentially turn every package into electronic waste.

New materials can be prejudicial. Once taken up by humans or other species, CNTs can cause various problems such as cell damage, performance reduction and long-term pathologic effects. They are bioaccumulable and may change properties during their lifecycle, exposing the biota to different types of CNTs (Helland 2007).

Transferring technology to other countries can have adverse effects. Their recycling can be managed by informal businesses which do not comply with environmental (or other) regulations (Streicher-Porte and Yang 2007), therefore posing a significant risk. When electronic objects change hands, so does responsibility for its waste. One cannot assume that it will be properly disposed of in the future, if the country doesn’t have acceptable waste legislation. [Video 32]

4.4.2. Second Order

Monitoring and process automation

Opportunity:

Environmental monitoring can become pervasive. WSNs can be deployed everywhere to monitor all kinds of pollution, especially air, water and sound, which are more chaotic and mobile than soil. It can also be used to monitor fauna, flora and water levels. Monitoring equipments and human activities (e.g.,traffic) can help to increase efficiencies (e.g., thermal insulation), and inform people (e.g., reinforcing awareness about household resource consumption) ultimately resulting in reduced CO_2 emissions, water spent or nitrate pollution, among other wastes.

Automation effectively acts as a multiplier of laboring power, in some cases possibly with a smaller ecological footprint than a human performing the same task.

Risk:

Such a massive quantity of sensors and actuators would require a bigger spenditure of materials and energy to build and operate, and would eventually turn into waste.

Automation, by improving efficiency, causes mass productions originating more waste.

Dematerialization and demobilization

Opportunity:

Value is increasingly being created by ideas and information, which have little impact on the environment. The replacement of "physical goods or processes by virtual services can contribute substantially to increasing resource productivity" (Kohler and Erdmann 2004).

E-books allow a reduction of books' paper, glue and transportation. In a similar fashion, compression of digital files make them easily distributed in the network, and could result in the production of less physical storage devices.

Supported by available information about objects' condition and place, virtual services and projects like Freecycle or online auctions could be improved, thereby extending product lifetimes though their reuse.

By allowing information everywhere and anytime, ubicomp will reduce the need for physical presence of persons and objects. By reducing the need for transportation, GHG emissions in this sector would decrease. It presently accounts for 14,4% of global GHG emissions (CAIT 2008).

Risk:

A rebound effect may occur. Reducing transportation (and its emissions), can cause an increase in other, potentially damaging activities, depending on what people choose to make of their time. In addition, by reducing traffic, people can be more tempted to drive instead of using other, environmental-friendlier means of transportation.

Rematerialisation is also possible, virtual information is downloaded and then is burned onto a CD, printed in paper or polymers (ABS plastic) in the case of 3D printers.

Environmental information

Opportunity:

Information, especially environmental information, will be enhanced by ubiquitous computing. It will be more complete and reliable (finer monitoring), location-based, and accessible to more people than with previous technologies. This will give more resources to researchers and help citizens to participate in environmental actions. A wider environmental public conscience can press governments to take action on the subject.

Public knowledge about services and products' life-cycle impacts will be possible when choosing which to buy. A consequence of this aspect is corporate accountability. When facing a total transparency situation (services, products and the company itself), they will most certainly change their *modus operandi* to a more sustainable one.

Environmental persuasive computing

Opportunity:

Computing and interaction with computers has been shown to have persuasive effects on people (Fogg 2002).

Displaying contextual information can be used as an advantage to convey environmental information at the right time. Persuasive tools can be embedded in the built environment, particularly in public or semipublic places, to reach a maximum amount of people. It can teach good environmental practices to people, and show them how taking an environmental-friendly action can be better, saving also time and money.

For example: the sink can display the water being spent (in volume and currency units); a person could be informed about the destination of a nearby driver, and carpool.

People don't like big changes, but incremental ones (Evans and McCoy 1998). Also, curiosity makes people choosing, something new, thereby having a different behavior, e.g. interactivity to attract people into using a staircase instead of an elevator (Mathew 2005).

To follow environmental advice, even if not for the "right" reasons, can eventually change people's behavior towards it. Environmental persuasion can work the same way advertising does, but on a moral level.

4.4.3. Third Order

Decoupling growth from energy and materials

Opportunity:

Through dematerialization, a greater decoupling may be achieved between economic growth and energy/resources. Already the World's CO_2 intensity of economy (CO_2/GDP) has declined almost 25% from 1990 to 2004 (Figure 4.1), while at the same time, one important change in the economy is the growing use of ICT. However it is difficult to determine if it is in great part due to ICT application or other factors (EITO 2002).

Dematerialization would also reduce countries' ecological footprint. Work, school, health, aided by new forms of communication will allow settlements to be established outside urban centers, preventing rural exodus and its associated impacts, increasing quality of life.

Risk:

Dispersion of settlements means a less efficient use of space (e.g. more infrastructures per capita). This change has increased demand on natural resources and other impacts on the environment (EITO 2002).

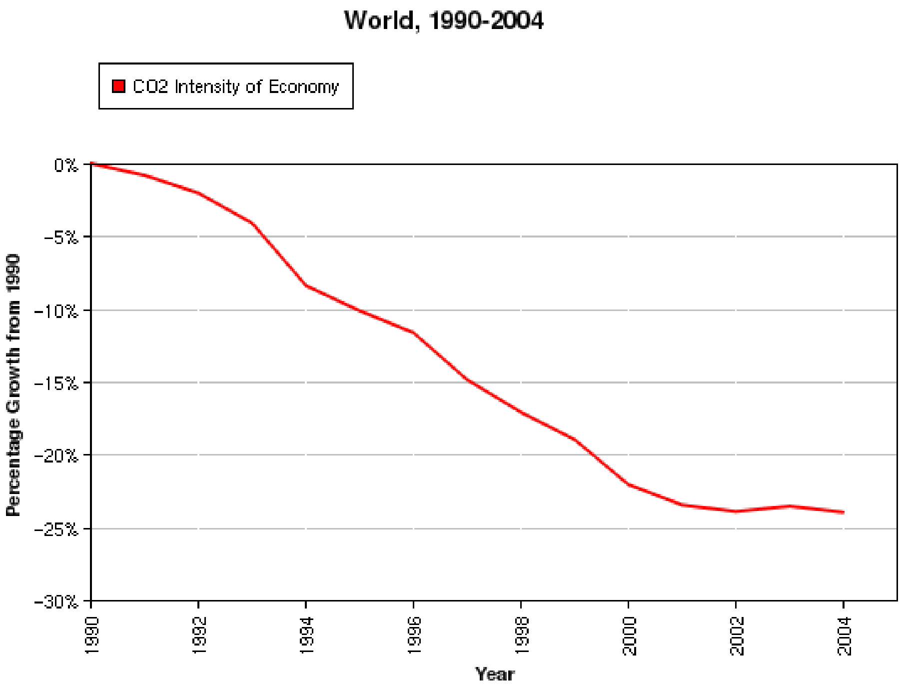

Figure 4.1. Carbon intensity of the World's economy. (CAIT 2008)

4.5. Towards U-World

Views about ubiquitous computing and how it will affect the world vary. Some claim it will allow for an almost utopic world, some say it will create a dystopia. Probably something in between.

Though hard to predict at a large scale due to its intricacy, common sense and past experiences with technology allow some level of deduction. Inferences are always accompanied by errors but are important to avoid undesirable consequences.
When impacts are unpredictable, science should not be allowed to "develop at any cost", the Precautionary Principle should be used whenever necessary. Some ubicomp applications will have profound consequences, so advancements should be stopped in order to prevent what might be an irreversible damage to individual people, the society, or the environment. Many of the underlying technologies can be created and used with good intent (e.g., tracking and profiling people with their consent, to improve their life). But as history show us, they can also become harmful. (e.g., hacker gaining access to confidential information).

But even with the best intentions, some technologies eventually have unforeseen developments (an example is the evolution from ARPANET/CYCLADES to the current internet). Ubiquitous computing, if it becomes truly pervasive in our lives, may be responsible for great changes, shifting the balance of political and economic power (Bohn, et al. 2004), social structure, the way we perceive our surroundings and interact with it.

There are obstacles which are likely to appear. Many can be avoided with proper planning.
In a U-World, William Gibson's quote "the future exists today - it's just unevenly distributed" will probably still apply, as politics and economies are major driving forces. Communication and power infrastructures aren't present in many countries. Poor countries, still struggling to provide basic needs, have other priorities. In some, leaders consider information as a threat to their control over the population. Factors such as these constitute a hindrance on the implementation of ubicomp.

In countries where ubicomp does become a reality, people already take some requirements for granted, therefore have higher expectations. One of them is their freedom of choice. Using or being subject to ubiquitous computing should be optional, without compromising the user's wishes. That choice should be available without any relevant energy, time or money loss to the person.

They also expect technology to enhance their lives, not to damage the environment and their health. As a tool, ubiquitous computing should not get in the way of the task; interaction must take place as transparently as possible.

Social interactions evolve: physically proximate social contact may be seen as unnecessary and inefficient. Given already existing technologies, one can maintain several conversations simultaneously, with the enhancing benefits of multimedia content. The main communication forms (vision and audio information) can be transmitted as data, as can touch, in a less degree. The only senses which require a person to be *in situ* are smell and taste, secondary for the majority of social interaction.

Advancements in technology make information exchange possible anywhere, anytime. And while performance grows, size keeps decreasing. In 1985 Richard Feynman wrote: “it seems that the laws of physics present no barrier to reducing the size of computers until bits are the size of atoms and quantum behavior holds sway.” (Marinescu 2005). Indeed, enabling technologies are expected to be developed within the next decade (BSI 2006).

The growing number of connections made possible by this development will be virtually limitless. In a linked world, connections will rise in a geometric way by means of the mathematical progression:

$$A_n = n\left[\frac{n-1}{2}\right]$$

in which n is the number of nodes, and A_n is the number of possible connections established by those nodes.

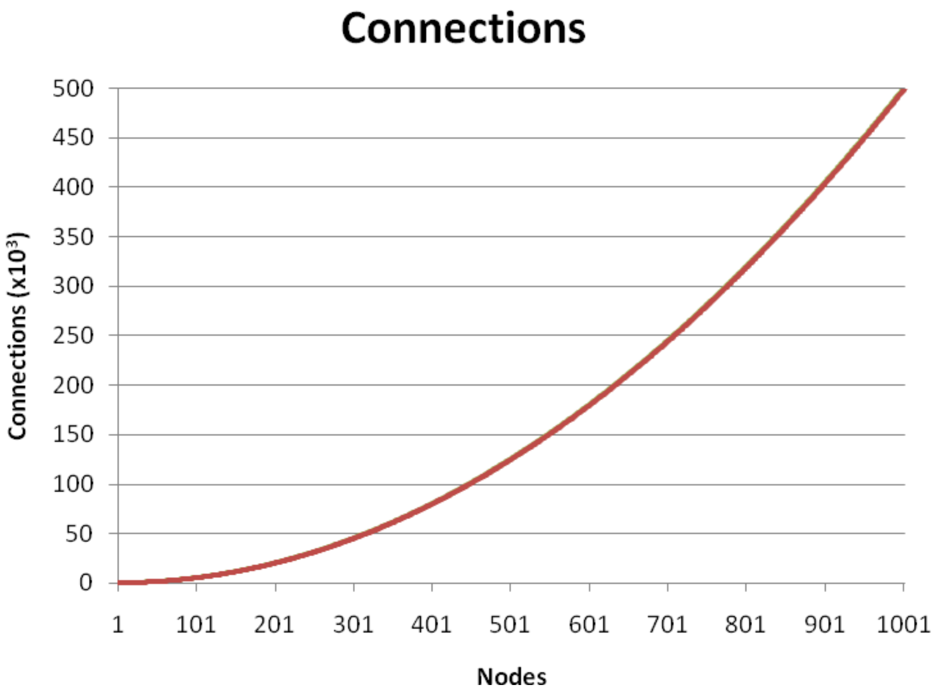

Figure 4.2. Evolution of the maximum number of potential connections between smart objects.

In the future, technology has to be able to support many connections. Theoretically, in a world which could connect $3{,}4x10^{38}$ objects (IPv6), up to $5{,}8x10^{76}$ different connections would be possible. With an ever-increasing number of connections, we can easily loose track of data.

People expect their privacy to be kept. Privacy and security is the main reason for dystopian concerns. Constant monitoring can be seen as a form of control by unknown entities, and as RFID and other identification devices are starting to be used in a variety of purposes, the amount of connections raises fear of uncontrolled propagation of personal information.
Interconnected devices are a liability in two ways:

- Collected data (by one device) is transmitted (copied) to many, making it easy to loose track of data and difficult to track the source;
- Malicious users can more easily reach their goal from a remote area, from anywhere in the world, which difficults their identification.

While some devices (e.g., RFID-based driver's licenses), lack security (Albrecht 2008), measures are already being taken, at the legislative (Washington Bill 1031), standardization (ISO 14443) and research levels (Tang, et al. 2006) to prevent information theft. Ubiquitous computing will increase profits and start new business models – which may include using its complexity to deceive people. There are already examples of companies providing a false sense of security using new technologies (Reuters 2008).

Interfaces will enable people with disabilities to work as fast as anyone else, reducing job-related discrimination. Information will be ubiquitously available. People will be able to receive information wherever they are, and education will be accessible to even more population segments, such as isolated, less literate people.

5. Ubicomp for Environmental Information

Information is now equivalent to empowerment. Ubiquitous computing will act as the tool to provide that empowerment to more people than ever before. Pervasive connectivity, sensors and displays will enhance teaching, learning and essentially every way to convey and receive information.

One type of information that could greatly benefit from these technologies is environmental information. Environment, due to its wide breadth, inter-relations and inherent subjects, often yields a massive amount of information. That information needs to be grasped by a wide spectrum of people, with different backgrounds and varying levels of environmental knowledge.

Environment is becoming an ever more important topic, now that we know the extent of implications our collective actions may have.

The Nobel Peace Price 2007 was awarded to Al Gore and the Intergovernmental Panel on Climate Change (IPCC) “for their efforts to build up and disseminate greater knowledge about man-made climate change, and to lay the foundations for the measures that are needed to counteract such change” (Nobel Foundation 2007). This is highly indicative of importance of environmental information.

5.1. Aarhus Convention

The 1998 Aarhus Convention grants the public rights regarding access to information, public participation in decision-making and access to justice in environmental matters.

The obligations related to environmental information in the Aarhus Convention consist of two parts: ensuring public access, and establishing certain means for collection and dissemination.

The following lists some of the Parties’ obligations and implementation elements, contained in article 5, concerning “collection and dissemination of environmental information” (UN 2000):

- Faster provision of information. Keep and update information “as soon as possible”, in electronic databases which can easily be accessed through public telecommunications networks.

- The right of access extended to any person. Accommodation of members of the public with special needs, such as disabilities, different languages, or lack of certain equipment;

- Make information accessible in a user-friendly form that reflects the needs and concerns of the public

- Efficient use of complex information systems, such as geographical information systems, that can produce information in a variety of forms.

- Requirement to disseminate legislation and policy documents

- Establishment of a coherent nationwide system of pollution inventories or registers on a structured computerized and publicly accessible database, completed through standardized reporting.

- Mechanisms for disseminating environment-related product information to consumers, so that they can make informed choices

- Possess and update environmental information, about proposed and existing activities which may significantly affect the environment and information which could enable the public to take measures to prevent or mitigate harm

- Provide sufficient information - Type and scope, terms and conditions, and process used to obtain environmental information

- Establish a record-keeping and reporting system for operators

- Establish monitoring systems with regular reporting. Require public authorities and operators monitor emissions and environmental quality

- Encourage certain operators to inform the public directly (e.g., impact of their activities and products)

- Public authorities need to have a reliable system for collecting and updating environmental information

- Encouragement of the development of national meta-information systems

Under the Convention, access to environmental information ensures that members of the public can understand what is happening in the environment around them. It also ensures that the public is able to participate in an informed manner.

Each party must inform the public concerned, by public notice or individually, about the proposed activity, the nature of possible decisions, the envisaged procedure and possibility of participating, and the place where information is being held. They must also guarantee that the public can submit comments, either in writing or at hearings or inquiries.

Ubiquitous computing may represent important tools to ensure the aforementioned obligations are carried out in a simple and effective way, for both authorities and public.

5.2. Information

Information is conveyed by means of communication, a flow of information from the communicator to the audience. It is essential for education, which happens when that information is assimilated by a person, becoming knowledge.

Education has traversed the confinement of school years, and is nowadays a lifelong process, more so if subjects are as complex and rapidly evolving as HCI or environmental science. It is composed by two distinct but interconnected processes: teaching and learning and the objective is to ultimately benefit our society, by modifying our behaviors. Environmental education in particular uses environmental information to develop skills, knowledge and values, in order to change certain behaviors which are prejudicial to the environment and/or instill those that are beneficial, to contribute to a greater sustainability.

Education is not confined to formal schooling. It also occurs in a wide range of non-formal education settings and activities (European Comission 2001), as described in Table 5.1. According to OECD (OECD 2008):

- Formal learning is typically provided by an education or training institution. It is always organized and structured, and has learning objectives. From the learner's standpoint, it is always intentional, i.e., the learner's explicit objective is to gain knowledge, skills and/or competences;

- Non-formal learning is rather organized and can have learning objectives. Such learning may occur at the initiative of the individual but also happens as a by-product of more organized activities, whether or not the activities themselves have learning objectives;

- Informal learning is never organized, has no set objective in terms of learning outcomes and is never intentional from the learner's standpoint. Often it is referred to as learning by experience or just as experience.

Table 5.1. Educational structure and setting/activity examples

Education	Settings	Activities
Formal	School, Research Organizations, other educational Institutions	Conferences, Classes
Non-Formal	Local learning groups, Home, NGOs, Dojo	Talking, Classes, Educational Visits, Field trips, Internships
Informal	Bedroom, Forest, other cultural, entertainment and leisure settings	Jogging, Playing, Visiting urban or rural areas, Taking a stroll, Shopping

5.2.1. Information Roles

The educational methodology is leaning towards an active learning approach (learn by doing, sharing, communicating) as opposed to a passive approach (learn only by watching and listening). This is especially true when the educational information concerns the environment, a highly practical and experimental subject. Environmental information and environmental education will be henceforth referred as “information” and “education” respectively.

In the 21st century, the climate change debate fueled our awareness and engagement in a global issue – our role as individuals, societies and global community in managing the environment.

In order to further pursue this issue, three key challenges have to be addressed. The need to collect more and better information, convey environmental knowledge in new ways and persuade people to change their behaviors.

Information has to be handled differently according to its objective, source, and target audience. There are several levels of information, depending on the level of aggregation of the original data:

Table 5.2 - Aggregation levels of environmental information

Type	Description	Unit example
Primary data	Raw information manually or automatically gathered as a result of monitoring or other information gathering process. Parameters can be precisely measured or evaluated. Maximum detail.	$kgCO_2$, ppm, gCH_4/m^3
Analyzed data	Parameters are analyzed, relevant data is extracted and arranged to evaluate certain aspects of the environmental system.	gCO2 eq, TPE
Indicators	Data is selected and combined with other relevant data, to communicate environmental systems’ state and performances	gCO_2/capita trends, days above the threshold
Indices	Highest level of aggregation. Indicators are further merged, and units changed to allow the information to be easily perceptible. Minimum detail.	Colors, 0-5 scale, Good

Depending on the intended audience, each type of information has a different role, represented in Figure 5.1. Raw data is collected by technicians, and used by technicians. They treat it so that decision-makers and information disseminators can understand it and then use it communicate it in a simpler way to the general public. Despite the loss of detail, indicators and indexes gain clarity and operativeness, and are the best approach to communicate complex information to laymen.

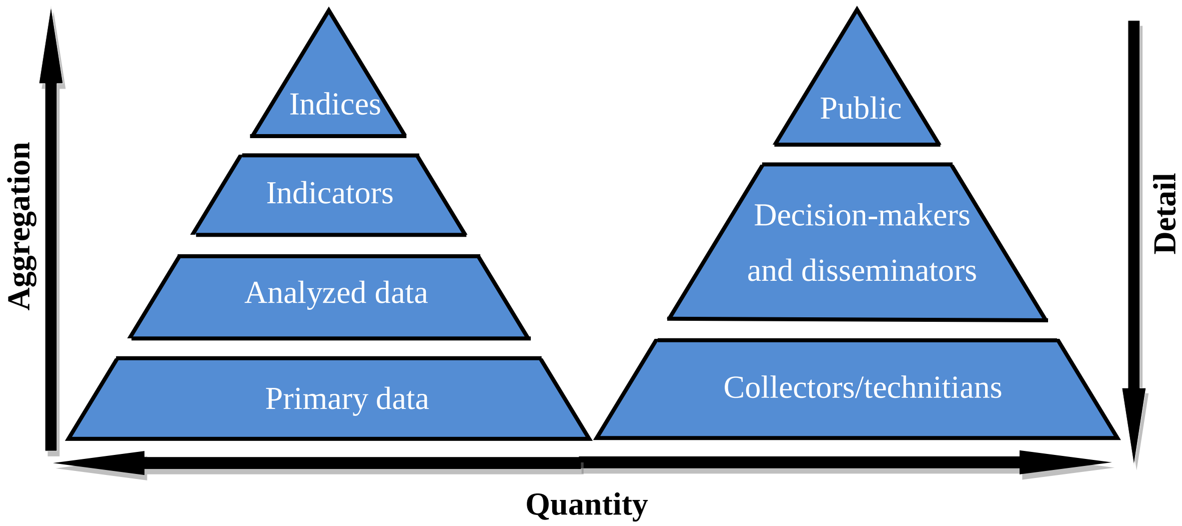

Figure 5.1. Information levels according to their intended audience. Adapted from Direcção Geral do Ambiente, 2000.

5.2.2. Role of Technology Regarding Sustainable Behavior

Education is the basis for social development and economic growth (Spellings 2006), but education without information is useless, and vice-versa. Therefore, means need to be constantly developed, to gather that information, allow its transmission and facilitate its reception. An example of this importance is the chalkboard, which better supported teaching and demonstrating to the group, rather than the individual, and enabled timely support material to be displayed in the visible periphery (Buxton 2008). More recently, classrooms are being equipped with computers, internet access and interactive whiteboards. Recent developments in ICTs emphasize the learning centered model, rather than the teaching centered one. These technologies enable fast and easy knowledge sharing. They also allow learners to use different types of media, i.e., audio(visual), interactive applications.

Ubiquitous computing can contribute by taking objectives even further. Given the goal of sustainable behavior, new technologies will act as:

Intermediaries - They allow easy input of information and facilitate access to it. This will be possible due to the wide range of natural I/O systems and better overall design.

Amplifiers – Information technology amplifies the potential to attain sustainability, by enabling humans with tools, making us capable of determining previously unreachable and undetected knowledge. This includes mass distributed sensors or geo-located information, for instance.

Space and time traversers – Cheap and portable objects, in conjunction with future networks will allow information to be sent and reached from anywhere. Communication can happen immediately (even without needing human intermediaries), or saved for later inquiry.

Persuaders – Technology is designed in such a way that it can influence people towards ecological behavior. This may be accomplished by humanizing it (either by designing it with a human form factor or human-like communication mode) or by means of subtle environmental cues, implicit interactions, which gradually change our culture and mentality.

5.3. Adversities

Environmental information is extensive and encompasses many other types of information. But despite intersecting other subjects, environmental information has characteristics, as well as special requirements and implications that define it as such (Table 5.3):

Table 5.3. Environmental information peculiarities

Characteristic	**Example**
Exterior settings	Sea, forest, desert
Wide areas and distribution	Atmosphere doesn’t rule itself by geographic boundaries
Localized information	Pollution from pig farms in Ribeira dos Milagres
Complex visualization	Urban/Land management, fluid modelling

Automatic sampling	Air pollution
Constantly changing variables	Tropospheric ozone levels, home energy consumption
Mobile, linear sources	Traffic, train pollution
Point sources	Noise from a construction site
Nonpoint sources	Polluted runoff from agricultural areas into a river
Chemical/biological analytes	Chemicals and bacterial presence in drinking water
Heterogeneous audience	Directed at different levels of education, age, sex, culture
Money-saving	Energy efficiency measures
Public Participation	Stakeholders express their opinions about a project
Cooperative	Various persons, with various jobs, from various places
Life cycle	Every man-made product

When thinking about difficulties regarding information, intuition tells us that the most important thing is to have that information in our possession, to collect it. This is obvious because first and foremost, we always have to gather it.

What may not be as obvious is that, even if sufficient information exists, other problems may render it less valuable, or even useless. A general example is, for instance, web 2.0. In this current anarchy, everyone writes their knowledge in their blogs, social networks, wikis, personal webpages. Information is now so divided, exists in so many "places", that finding the exact, relevant information we seek becomes more confusing.

Regarding environmental information, many contemporary problems have been identified. The US EPA gathered stakeholder's information needs and access preferences. Stakeholders are representative of users of all information roles. They include industry, government, news media, community groups, NGOs, students, educators, librarians and researchers (EPA 2008). Overall, the main problems appointed by the stakeholders are:

Finding information

- People are not aware of the environmental problems that affect them, therefore they don't know what to look for. They rely on information from information intermediaries/disseminators.

- Problems finding relevant information. Even if people know what they need, they often don't know where to go for it. People express frustration using interfaces, and information is not adequately categorized.

- People need timely information, but don't have the time or ability to search for new and updated information (or may not even know of its existence)

Understanding information

- Offering a one-size-fits-all approach on information doesn't fulfill the level of detail required by both technical and everyday people.

- People need context for the information they find. To understand complex data, they need the proper ecological, politic, economic context. They also need trend data, geospatial data, pollutant information, and information on organizations that affect the environment.

- To understand information, people need better descriptions about the data and information found: better explanations and documentation of data quality, information on where and how the data were collected, reasons for collecting the data, intended use of the data, level of certainty about the data, when the was it collected.

Using information

- There is a need for improved tools. Needs include: clearer instructions for how to use available informational resources, easier user interfaces, ways to extract data from databases, and additional tools to facilitate data analysis.

- Many people seeking environmental information are not active users of cutting-edge technologies. They tend to access information in conventional formats such as printed paper.

- Lack of collaborative environments. It is difficult to connect users and experts or people with the same interests.

Noticeably, stakeholders did not complain about lack of information. Indeed, the problem is not quantity, but quality and lack of proper infrastructure to facilitate its access, understanding and usage.

In the near future measures have to be taken to overcome the problems expressed by users.

5.4. Solutions

Tell me and I will forget. Show me, and I may remember. Involve me, and I will understand.

-*Confucius*

Present day solutions to these problems will require expending more money publicizing more environmental information, provide better education for people, use better designed web pages (e.g. better search and GUI), expend human and economic resources to create a hotline and other personal information services. Experts will have to improve data collection, metadata and information classification. Web tools have to be created to support the delivery of updated information and facilitate data extraction and use. Wikis and social networks could be created to join people with common interests so they could share information and debate.

Ubiquitous computing will play a relevant part, as it will transform our surroundings, enabling with intelligence. It will be able to connect people, communicate and integrate contextual information and more easily than present technologies can. Technology will develop to allow ubiquitous sensing, complex simulations, virtual environments and a variety of other yet unknown tools.

On the other hand, as ICT becomes the center of scientific education, scientists and researchers will have to be even more computer-savy. This fact should have an enormous impact on present education policies, because current and future students are going to be the ones using it. In this regard, gaming proves to be important as an entry point for children, into starting to know and interact with computing tools.

5.4.1. New Media implications in the Learning Process

When TVs and VCRs and other audiovisual tools where adopted by teachers, they were expected to preponderantly change the way education worked. Instead, classes continued mostly oral and written, they used it as a complement, not really a remarkable change in teaching and learning (Moran 2008). Students retention rates vary in accordance to the medium used to convey that information. Disparity in information retention exists because different sensory information is allocated as different types of long-term memories. For example, visual stimuli are explicitly stored and retrieved - explicit or declarative memory, while practiced actions and motor skills, rather than being consciously stored and recalled, are based on implicit learning – implicit or procedural memory. The latter will yield a much higher retention rate. As the old saying goes, “it’s just like riding a bike”.

The NTL Institute for Applied Behavioral Science created the Learning Pyramid, containing the average student retention rates for different learning methods:

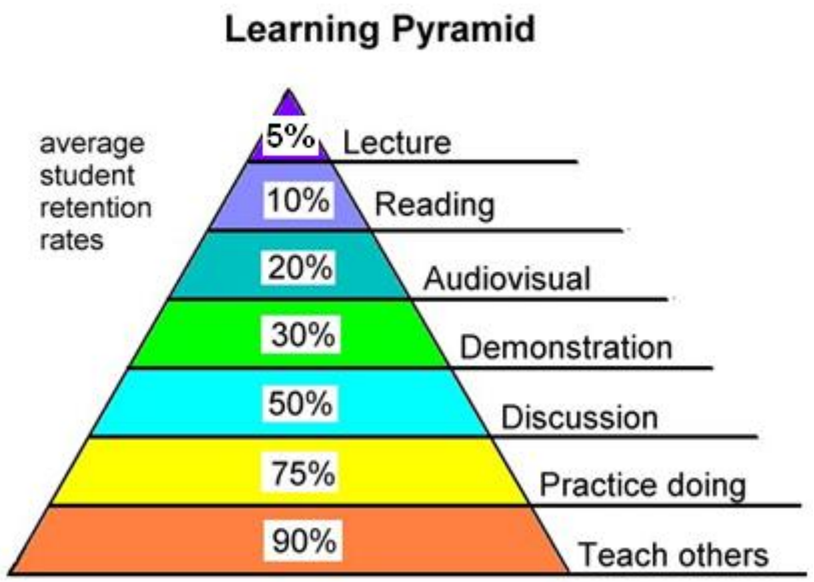

Figure 5.2. The learning pyramid, representing average retention rates following teaching or activity by the method indicated. Source:(National Training Laboratories for Applied Behavioral Science)

In this pyramid, we can verify that learning by using human outputs is much better than learning by using human inputs, which is precisely the way we do it nowadays.

Ubicomp will undoubtedly change the educational paradigm, not only it will empower students with tools that allow them to learn in a variety of ways and places, but, by using the tools themselves, students will have an enjoyable experience while learning. Especially if physical computing and other interactive elements are used, people will have higher information retention rates.

New interfaces work in a different way than traditional tools, they use natural interaction methods. Since actions are natural they will be stored as implicit memory. In addition, interactive applications' output is also audiovisual, which further contributes to information retention.

In the same way audiovisual retention is better than only seeing or hearing (Figure 5.3), by using interfaces that are audiovisual and physical/gestural at the same time, people will relate actions with visual and echoic memories when remembering (see & hear & do). Studies about haptic memory are scarce, but some have shown that vision-and-haptic trials had better performance than the vision-only trials, which demonstrates that the touching of an object improves a subject's recall. They also conclude that recall for real objects were better than recall for high-imagery nouns, i.e., better than reading or listening (Stadtlander 1998). Retention will be even higher for multimodal input interfaces, e.g., speech + gestural. Interaction with such devices would correspond to the lower part of the pyramid (human outputs) combined with the higher part (human inputs).

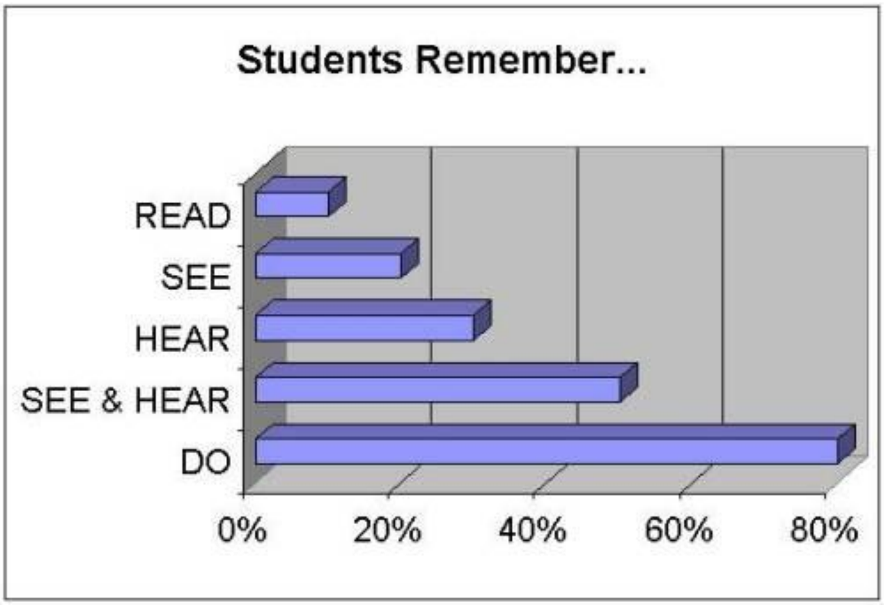

Figure 5.3. Retention rates according to each actions performed by the student. (Bayston 2003)

The way information is presented is also important. Visually appealing information is usually preferred – interactive, colorful, and intuitive (Price 2007) (EPA 2008).

Colors have to be carefully chosen to maximize legibility. The eyes' cones are unevenly distributed, they are more sensitive to mid-spectrum colors (green, yellow, orange) and have smaller red and blue absorption values, consequently these colors have to be brighter. Blue should not be used for small objects which need to be focused, or they will disappear (the fovea doesn't have blue cones). Additionally, colors can be used to convey sense of depth – shortwave colors appear in different depth from longwave colors.

Games also make information more appealing and are indeed a valid approach to learning (Futurelab 2004).They are immersive, require the player to make frequent, important decisions, have clear goals, adapt to each player individually, and involve a social network. Games are inherently experiential, engaging multiple senses, and for each action there is a reaction. Users test hypotheses and learn from the results (Oblinger 2006). Playing can even be considered the most natural way of learning. Many mammals, from felid cubs to baby humans, play in order to experience the previously mentioned aspects, thereby learning.

New generation games, with augmented realities and virtual environments, cause a greater sense of immersion and fosters "situated learning" (learning that takes place in the same context in which it is applied). Serious games, which use game technologies to produce more than just entertainment, include edutainment applications and realistic simulations for professionals.

5.4.2. Projects

Several technological projects and devices exist, intended to improve information dissemination and education in general.

Mobile Learning is a growing area, with several successful projects, for instance EULER (Environment of Ubiquitous Learning with Educational Resources) uses RFID, Internet, cameras, mobile devices, embedded systems and database technologies (Tan 2007), others use mobile phones and computers in a wireless network (Wessels 2006) (Hill 2005) (Pachler 2007) to enable access to scholar materials anywhere, anytime.

Formal learning institutions, e.g., campus, classroom, are places where ubiquitous computing can make a difference (Weiser 1998). Several projects intended to augment the classroom with interactive technologies have been done (Abowd 1999). Research includes usage of tangible artifacts, augmented reality and interactive whiteboards. Technologies are now being deployed in the classroom, starting with personal computers, internet access, and more recently interactive whiteboards and multitouch tables.

They serve as the basis for novel learning methods, for instance, CSCL (Computer Supported Collaborative Learning). Ubiquitous computing can also be developed and deployed to greatly benefit the museum educational experience (Hall 2006). Studies show that technologies motivate students to learn and improve the effectiveness of learning. Student creativity is also improved as well as the ability to explore and absorb new knowledge and solve problems over that provided by traditional learning methods.

Some projects are starting to apply new technologies, connecting it with environmental information, in a step towards ubiquitous computing.

Some of those are used by technicians, as information “collectors”. Crossbow Technology provides solar powered wireless sensor networks to monitor soil moisture and temperature, ambient temperature and humidity. There are various projects which include biosensors to monitor waste phenols (Rosatto 2001), genotoxins, pesticides (Boulet 2004) or methanol from organic wastes (EPA 2003). Pigeonblog is a project that aims to both collect and divulge information. Chemical sensors are carried by pigeons, to monitor CO and NOx levels, and the data is georeferenced and made available to the public, via Internet.

Other projects have been done pertaining urban air quality and participatory urbanism (e.g. Eric Paulos and Urban Atmospheres).

Technology can take information a step further and promote sustainable behavior changes (Tawanna Dillahunt 2008) The Botanicalls project make users care for plants. It personifies plants sending a Twitter message to their owner, asking for water. Another project uses technology to empower people to easily gain an awareness of their surroundings, thereby promoting participatory urbanism, citizenship and ultimately, environmental change (Paulos 2008)

Mostly directed at energy savings, Wattson and HomeJoule are displays used for "self-information", to make one's behaviors visible. A similar concept is present in FLOW, also geared to increase awareness, in this case, towards domestic water use.

Environmental education is also benefiting from new technology. For instance, "Environmental Detectives" (Klopfer 2008) is an AR game created by the MIT. Directed at high school and university students, they play the role of environmental engineers that have to find the source of a toxin spill. A location-aware Pocket PC simulates the spread of a toxin in the groundwater, and students' water sampling.

Another example is "Ambient Wood" (Rogers 2004), an outdoor learning experience augmented with digital content. In this project, kids were encouraged to explore the woodland and discuss among themselves. They were given a range of mobile devices that provided them contextual information during the exploration.

Mobile computing can also be used in a similar way, as a guide for self-guided tours, providing information on predefined POIs (Ruchter 2007)(Katja Schechtner 2008).

5.5. A World of Possibilities

Although projects are increasing, they are still not enough (in quantity and deployment level) to tip the scale. Stakeholders are still expressing problems and needs regarding information. Ubiquitous computing together with improved methods can ameliorate those problems, or even eliminate them altogether:

Natural user interfaces will make information access much less frustrating; new displays will allow display of electronic data in previously improbable places and proper software will help information organization and retrieval.

Table 5.4. Main problems and possible technological solutions

Informational Problems		Technological solution
Finding	People express frustration using interfaces, and information is not adequately categorized.	NUI and better information architecture
	People are not aware of the environmental problems that affect them, therefore they don't know what to	Displays embedded in, or near the problem, with contextual

	look for.	information
	People don't have the time or ability to search for updated information (or may not even know of its existence)	
Understanding	A one-size-fits-all approach doesn't fulfill the level of detail required by both technical and everyday people.	Better designed interfaces and visualization techniques
	People need context for the information they find. To understand complex data, they need the proper ecological, politic, economic context. They also need trend data, geospatial data, pollutant information, and information on organizations that affect the environment.	A variety of sensors will collect the necessary data. Information will have more and better metadata, and reality mining will help retrieve relevant and contextual information
	To understand information, people need better descriptions about the data and information found: better explanations and documentation of data quality, information on where and how the data were collected, reasons for collecting the data, intended use of the data, level of certainty about the data, when the was it collected.	Self-disclosing objects, "spimes". As the cost and size is reduced, more complete systems with a variety of sensors, allows them to simultaneously gather more than one information at a time
Using	Easier user interfaces and additional tools to facilitate data analysis.	Natural input systems coupled with new displays and better information visualization
	Many people tend to access information in conventional formats such as printed paper.	E-paper, OLEDs, interactive paper, will be fitting replacements for the look and/or feel of conventional paper
	It is difficult to connect users and experts or people with the same interests	Increasing CSCL and CSCW tools will make connecting easier

Most of the problems referred by concerned stakeholders are also valid for other types of information. However, there is also the possibility of using ubicomp to enhance rather than simply correct previous problems. As was seen in Table 5.3, environmental information has many specific traits. If ubiquitous computing technologies are applied, most information gathering and dissemination can be enhanced.

Table 5.5. Ubicomp enhancements regarding specific traits

Characteristic	**Ubicomp technologies**
Exterior settings	Ubicomp can be used in any setting. Energy harvesting possible in outdoor environments.
Wide areas and distribution	Smart dust is small enough to remain suspended in the air, water
Life cycle	RFID may have information on impacts and be constantly updated throughout a product life-cycle
Localized information	Data can be geo-referenced with GPS/ cellular network assisted GPS
Complex visualization	Tangible interfaces, new media allow tridimensional information visualization and manipulation
Automatic sampling	Ad-hoc sensor networks preprogrammed or controlled in real-time
Constantly changing variables	Super-distributed WSN constantly sending information
Mobile, linear sources	
Point sources	
Nonpoint sources	
Chemical/biological analytes	Biosensors allow faster and cheaper detection
Heterogeneous audience	Natural, multimodal interfaces encompass a wider range of users
Money-saving	Monitoring resources and displaying consumption in an effective way increases awareness
Public Participation	Ubicomp allow people to communicate anywhere, and make it easy to do so (e.g. telepresence).
Cooperative	

Despite the environmental-oriented benefits, research projects only scratch the surface of future applications.

Ubicomp, especially at the interface level, has innumerous possible applications for environmental information purposes, in both formal and informal settings. Its potential is better put to use in situations concerning general public information access. Nevertheless, it will also be extremely useful for technicians to manage and visualize information under different conditions, one of which is the potential to do it on the move, in the field, in a timely fashion.

Information access may be static or dynamic. Static information implies that the display is fixed, even if the information gathered is dynamic (e.g. WSN in a river). This means that the user has to stay in the same place to access it. It may be indoor (home classroom, store, museum) or outdoor (kiosk, street furniture). When access is mobile, it is location-independent. The user may be moving while accessing, or even as a means to get information (e.g., LBG). The user or information is preferably geo-located.

Mobility varies due to the current state of some interface technologies, but in the future all of them will be mobile.

The following table presents next-generation interfaces and an example scenario of how they could be useful in the context of information.

Table 5.6. Possible scenarios where natural interfaces could be of use, regarding environmental information (✓= already mobile, ✘= not yet mobile)

Interface	Possible application scenario	Mobility
RFID	RFID used in every product, containing life cycle information. It would influence its acquisition	✓
Remote sensing	Tracking mobile sensors and use it to geo-reference the collected data	✓
Paper augmented interface	Biologists can draw flora and fauna, and annotate in the field	✓
Brain computer interface	Tetraplegic people may control wheelchairs and visit national parks by themselves	✘
Speech recognition	Laymen are able to interact and record information in public participation processes	✓
Acoustic	Interact with outdoor environmental information	✘

	kiosks	
Touchscreen	Easily access to environmental RSS contents, in a mobile device	✓
AR	People visiting a city can see, through AR glasses, its evolution through time: an animated layer composed by several sequential aerial photos of the same area	✓
Computer vision	Integrate real kids in virtual environments, planting virtual trees	✓
Haptics	Blind people have access to weather information before leaving home	✘
Audio	A museum exhibiting a continuum of different biota. Different ambient sounds can be heard, as the visitor walked from one to another	✘
3D displays	Geographical information visualization: terrain relief and urbanized areas become more apparent by adding height dimension	✘
E-Paper	Self-guided tour in the woods. A portable display, easy to read in direct sunlight, during long periods of time.	✓
OLED	House windows as displays using TOLEDs. Windows can display information about pollen levels outside	✓
Chromogenic Materials	Electrochromics used as small displays when coupled to biosensors, changing color as CO values rise. The system can be placed in public places – color changing would act as indices to bystanders	✓

Direct sensorial experiences provided by these interfaces create immersiveness, the feeling of being there, directly manipulating information. This experience may add persuasive impact to the traditional communication methods like speech or text. Taking information a step further may motivate people enough to attain the crucial objective – change towards an environmentally responsible behavior.

In a future worst-case scenario, if individual people shall have to change their behavior as a mandatory rule (a plausible possibility if major players don't commit themselves to reduce GHGs in time), ubicomp may be useful. Ubiquitous measuring of individual consumptions would increase people's awareness or send information to authorities in case of infringement. Like present exposure of tax debtors over the internet, ultimately people with bad environmental habits could have their performance displayed to public scrutiny (e.g., shown in their clothes - wearables) to make them change. Noticeably, this would go against one of Greenfield's fundamental principles and should only be applied as a last resort.

Ubiquitous computing will empower people with knowledge, help them identify and choose environmental-friendly alternatives and create positive attitudes intended to change behavior.

6. cUbiq

In order to integrate the aspects presented in this thesis - ubicomp's concept of transparent interaction, enabling technologies, interface design and environmental information – I have designed and prototyped an interactive system, "cUbiq".

Figure 6.1. cUbiq prototype.

cUbiq is a tangible user interface (TUI) which can be used to access and interact with virtual elements, in this case, environmental information.
Users interact with a cube, and depending on the side they choose, different (types of) information will be displayed in Flash.
As a TUI, it is a physical object that connects the real world with the virtual world, and the state (rotation) of the cube has direct implications on which information is displayed. [video33]

It complies with interface design guidelines:

- Metaphor: Children's game to insert a shaped solid into the corresponding hole;
- Affordances: Based on the metaphor, how it works becomes evident, even without previous experimentation;

- Constraints: The frame prevents misplacing of the cube, and every possible rotation is accounted for;
- Visibility and Mapping: each (labeled, drawn or painted) side of the cube correctly maps to the information on it
- Feedback: Instant feedback is provided

The system is composed by a matrix of 9 pushbuttons, activated by the cube. The communication to Flash is done using Arduino, an open-source electronics prototyping platform. The microcontroller receives digital and analog sensors' inputs and has the ability to control a variety of actuators. The code used to make Arduino "talk" to Flash was based on the open-source code provided (and constantly improved) by members of the Arduino community.

cUbiq uses a cube with different indentations on each side, to press different combinations of buttons, thereby controlling instances in Flash.
Detection is done through the opposite side's shape. Users read the description on any side of the cube, and naturally place it facing upwards. This happens because the moment they read it, it is facing upwards and they don't rotate it vertically before placing the cube, also, logic determines that the label read on the cube, while it is placed, is the theme they will access on the screen. When side 1 is up, side 6 presses the switches (see appendix).

Table 6.1. cUbiq, choices and effects

Side up	Description
"Water"	Displays information about water pollution
"Soil"	Displays information about soil pollution
"Life"	Plays an animation about life
"Air"	Different horizontal rotations, reflect different "sides" of the same subject, e.g., global warming, ozone layer depletion, acid rain
"News"	Connects to an environmental news website
"Video"	Plays a wildlife video

cUbiq is an easy to use, intuitive interface, that allows anyone to be informed, especially for those who can't use the mouse/keyboard and would otherwise be unable to access its contents.

It may even be used with children, for edutainment purposes, as it resembles a simple toy (insert each shape into its respective hole). The cube may take other forms, a picture of a bee on a side of the cube could play a wildlife educational video, for instance.
Other future developments may include side detection via RFID or camera, which would allow a smoother solid, without indentations.

Pushbuttons allow a DIY possibility, of each person doing their own interface. The information disseminator might allocate virtually infinite pushbutton combinations to several pieces of information, only limited by the desired matrix size. Using modeling clay/plasticine users would make their own customized shapes, and access a variety of information. The shape itself can even be related to the information available through it, e.g., a star-shape only allows information about space. In a street setting, someone might approach it and use a specific shape to access political news, then reshape it to see train schedules, local air quality etc. This option would augment the TUI with limitless possibilities.

7. Summary and conclusions

In this dissertation, the emergence of ubiquitous computing as the next paradigm was explained, special emphasis was made according to its true meaning: transparent and unobtrusive interaction.

Trends were analyzed, concluding that technology is evolving towards a state in which humans aren't necessary to operate them, instead, objects are proactive. They will have the ability intercommunicate without intervention, while humans and their behaviors are subject to computer analysis. Applications are becoming mobile, always connected, and being developed for specific situations and large groups of people.

The word "emergence" is used, because only now technologies are starting to have the required properties, and being used holistically towards one objective – to fulfill Mark Weiser's (and now also our) vision. In the last few years research work is getting out of the labs and being turned into products. At the same time, major industries/military become aware of this paradigm, its potential, as the future and fund more research. Microelectronics are getting smaller and more powerful; sensors are also decreasing in size while increasing the range of measurable parameters; energy supply is becoming wireless and the harvest of renewable sources is advancing (in part due to environmental requirements), computing is becoming less energy-intensive; wireless networks are widening in range and bandwidth, even starting to use already existing infrastructures, power lines; location systems are also aided by existing cellular wireless access points, super-distributed RFID tags; lightweight OS are created for specific, mobile applications and artificial intelligence to recognize complex patterns, learn and act.

While it is virtually possible to start a rudimentary version of ubicomp now (if every state-of-the-art research suddenly became commercial products), some technologies are still considered bottlenecks. In order to fully realize it, current energy supply methods will have to rely less on the grid, additionally, interfaces and interaction need to be more coherent, usable and intuitive.

The concept of transparent interaction is only recently being seriously explored. I reviewed the most promising input and output solutions (the line dividing technologies into both categories is blurry), and present advantages and disadvantages for each one.
They are at various levels of maturity: for instance, RFID, touchscreens, directional audio are thoroughly developed and usable technologies, while BCI, AR, haptics, 3D displays need further development to be less obtrusive and effectively "live up to its name".

In order to sort among the variety of input systems now presented as an alternative to the keyboard/keypad and mouse, I have elaborated a table containing the main obstacles encountered when using each one. This table's purpose is to immediately choose which options are suitable, depending on mandatory constraints, context and environment.

The iterative design process is emphasized and its phases explained so that industries and independent designers may know about it and adopt it. It is the best method to prevent a flawed system, and despite being more costly (in money and time) than working only the first ideia, it is better than implementing a defective system and afterwards having to correct it (assuming it wasn't a total failure). Moreover, cheap and fast prototyping techniques exist which soften the associated costs.

Touch is rapidly becoming the preferred interaction method, mostly because they allow users to interact with (pre-)existing, single-point GUIs. It is a paradigm most people are used to, and is easier to implement. Multipoint technology exists, but most of the software (e,g, WIMP style) is not yet adapted to take full advantage of the rich gestural vocabulary and potential that multitouch allows. Several companies are trying to patent gestures, and each use a different "language" to control their products. If multitouch devices from different brands are to coexist, gestures should be standardized to promote interoperability and avoid confusing users. Interoperability/design problems already exist among numeric keypads, and recent "ubiquitous" RFID systems.

The existence of ubiquitous computing will be full of positive and negative impacts, albeit to a varied extent.
Ubiquitous computing will provide unprecedented access to information, to a wider variety of people. Ubicomp will be taken for granted and, as humanity, culture and technology grow

around it, eventually it will be indispensable. Depending on how it will evolve (well designed/cheap or not), ubicomp may also contribute to further deepen already existing gaps.
In a world where any object can be monitoring something, strict rules have to be applied, to identify sensitive/interactive devices from common objects. Technology has to be able to support many connections. Theoretically, IPv6 can connect $3{,}4 \times 10^{38}$ objects, up to $5{,}8 \times 10^{76}$ different connections would be possible. With an ever-increasing number of sensors and connections, we can easily loose track of what is being sensed and where data is being sent to. Privacy has to be legislated in advance.
Our cities will be dynamic, lifestyle and communities changed. Novel products and services will be provided, with them, new job opportunities, but also job loss due to process automations. Ubicomp makes possible distance health services, but, as electronics multiply, they may pose a health risk due to radiations and toxic substances used. This is also an environmental problem, due to resource exploration and deposition. Regrettably, the countries where both processes will occur the most, are generally the ones lacking proper environmental regulations. Energy consumption is also expected to grow, and with it, nuclear and climate change problems. This growth is expected to be mitigated by more efficient technologies, and dematerialization/demobilization. Ubicomp is expected to further decouple growth from energy and resources, reducing the carbon intensity of the world's economy.

Future environment depends on every one of us acting sustainably. The new paradigm is poised to become the best vehicle to convey environmental information, educate us and assist us on living sustainably without losing comfort. It will be used to successfully implement the directives from the Aarhus convention and solve many of the current problems regarding environmental information. It will help at every stage:

Collection – Biosensors and WSNs small enough to travel by air and water, while monitoring and transmitting information. Mundane objects may become environmental sensors without losing their original purpose.

Treatment – Novel data visualization methods, data mining, displays will allow computing while in the field, on the move; visualize and work with large amounts of data, display fully tridimensional environments.

Dissemination – With natural interfaces information will reach virtually every person. Ubiquitous connectivity will allow telepresence, submission and retrieval of information anywhere, anytime.

Environmental education will greatly benefit from new interfaces. In addition to being different and appealing, they encourage new learning methods and experimentation, resulting in higher retention rates, which ultimately may lead to sustainable behavior.

The cUbiq TUI makes information dissemination much easier: it represents a novel, natural way to interact with information which may be aimed at people of any age, education or previous technological experience.

Considering its extensive influence and impacts, ubicomp may be seen as a two-edged knife. It’s up to us, as society and designers, to make sure it is adequately applied.

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Appendix

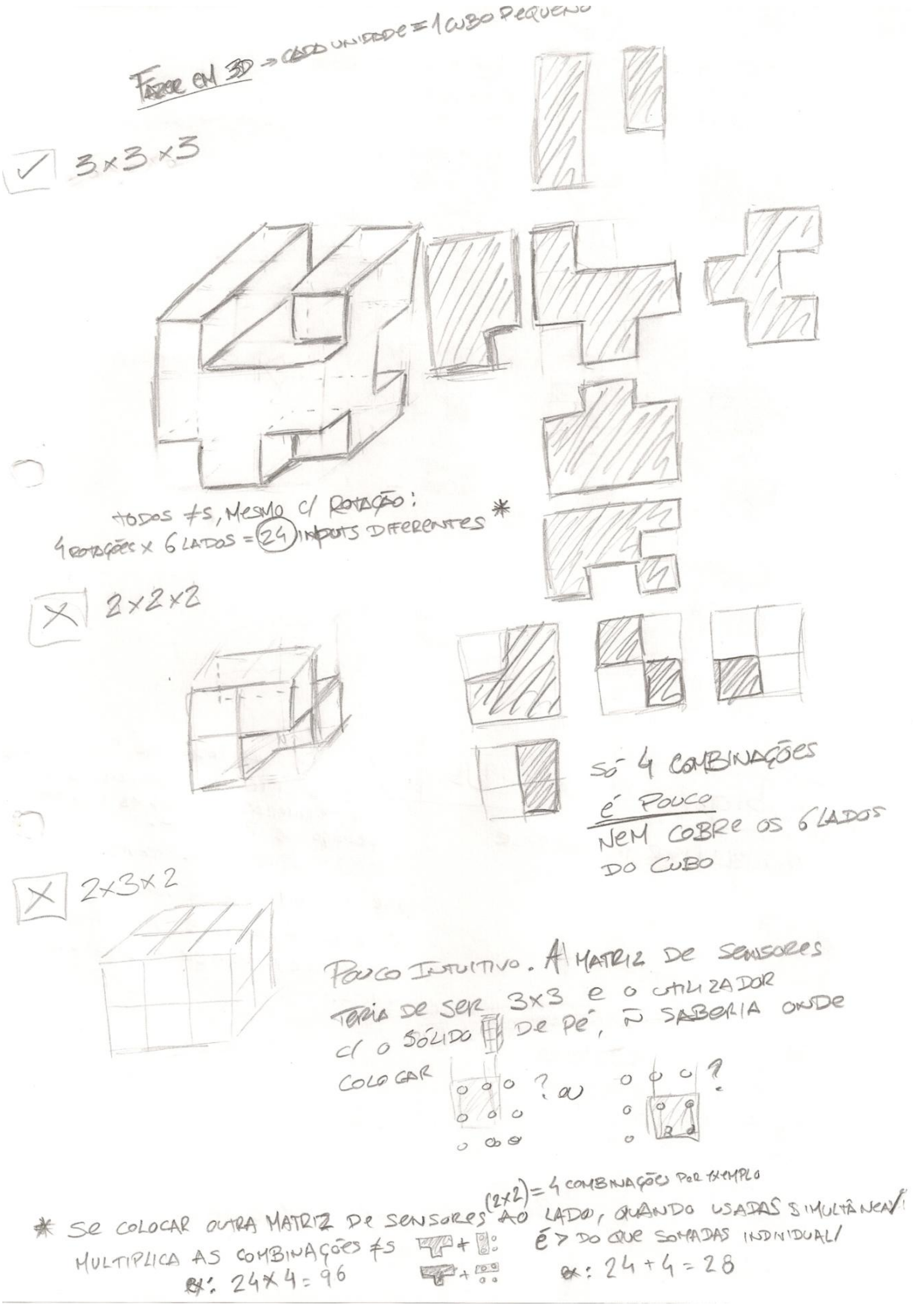

Figure A.1. cUbiq initial designs. Determining feasibility and number of inputs.

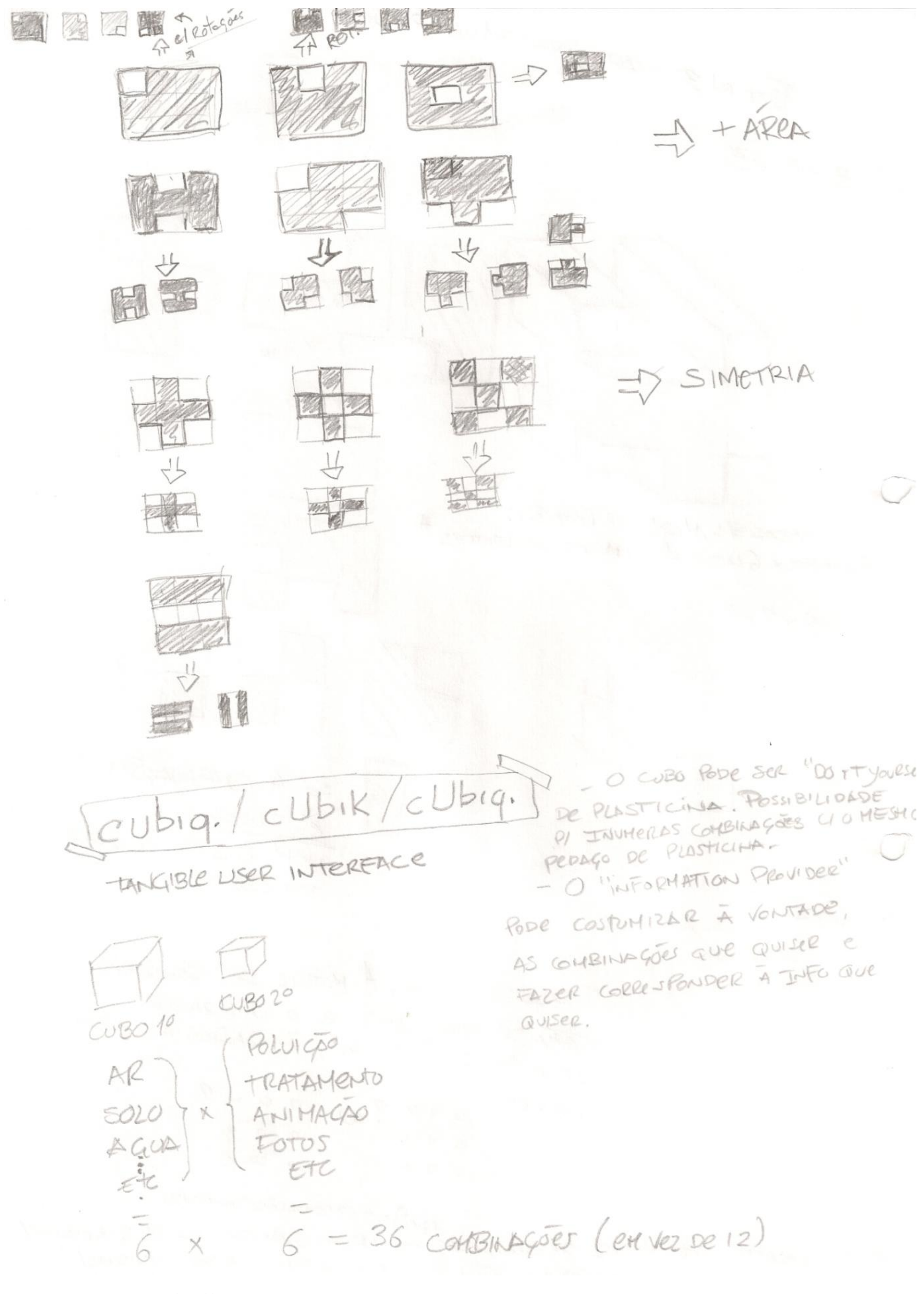

Figure A.2. Study of different input combinations and side shapes.

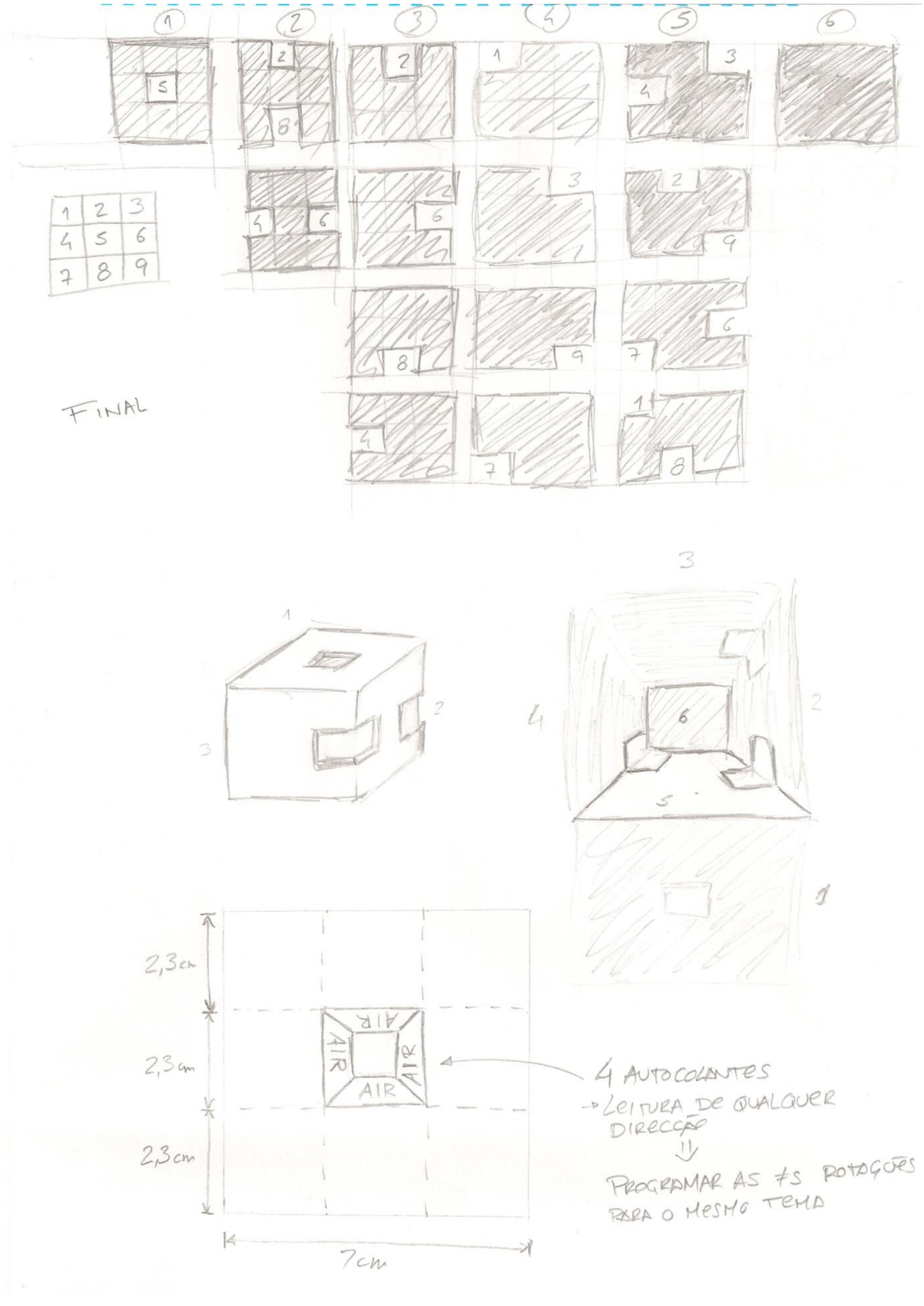

Figure A.3. Final version design and integration