Interaction with our electronic environment

an *e*-cological approach to physical interface design

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We are surrounded by technology, the result of a long history of technological developments. The latest stage of these developments, the digital computer, can be found not only as a box on one's desk but also infiltrated into many older technologies. It is embedded, pervasive, ubiquitous, the computer is disappearing while it is everywhere at the same time. However, when the *interface* disappears too we will loose touch with this technology and not be able to interact with it and through it. In this ubiquity lies an opportunity. By approaching the design of the technological environment as a whole, the computer can become the unifying factor. Trying to make computers more intelligent at this early stage of development may lead to a situation where many 'little big brothers' appear. Due to the invisibility of digital technology, which is increased by miniaturisation, networking and embedding, the need for a well designed interface and increased interaction-bandwidth is bigger than ever.
At present there are big tensions between our technological and natural environments, which can particularly be seen in the mismatch between people and computers. A lot of unnecessary frustration is caused by technology, but there is great potential. This Cahier discusses an *e*-cological approach which regards the design of the interactions with our technological environment as a whole.

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Interaction with our electronic environment – an e-cological approach to physical interface design

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Ingredients

In perspective – a preface

We are surrounded by technology. Everyday we interact with man-made technological artefacts, from a door handle to a car, from a light switch to a mobile phone. The evolution of the design and developments of these interactions, originating from technical, cultural and economic motivations, reveal a potential to extend ourselves physically, cognitively and socially[1]. Yet it is clear that the development of our surrounding technology is increasingly out of control.

Traditionally technology needs human intervention in order to be repaired, improved and upgraded, as if we are merely the reproductive organs of the machine[2]. There are predictions that the cognitive supremacy of the human race will soon be rivalled and even surpassed by the technological systems that we create. Complexity can lead to intelligence, evolving through *interaction* with the environment, not in isolation. To invent its own successor may be seen as the ultimate goal of a species, but to be taken over by technology prematurely is a Frankenstein scenario.

One of the clear symptoms and pitfalls of the so-called machine intelligence at present is the pseudo-control of automation, which is an inadequate substitute for interaction[3]. With an appropriate interface, designed to keep the human central, we are able to convey our intentions to the technology. We actually have a chance now to augment our minds in such a way that, as it where, an external fourth brain may emerge[4]. This is a result of an human-machine symbiosis[5] rather than the current human-machine mismatch.

Preceding every chapter in this book there are sections presented in a more personal style. These writings are meant to further illustrate the content or as an intermezzo.

The CD contains several QuickTime clips, to accompany the reading of this book with *techno-wallpaper*. The images focus on the elements and interactions from my own technological environment, and are meant to support, illustrate and illuminate the text.

Further information can be found on *www.bertbongers.com*.

1. Introduction

So here we are, surrounded by all these technologies we created, technologies that are very complex and increasingly (but not necessarily) out of control. How to seize back the power? If there was a simple answer, the question wouldn't be worth asking.
This Cahier focuses on issues and approaches based on the physical interaction between the natural and the technological environments. It is not going to be a cookbook of how-to recipes for preventing the world from being taken over by technology, rather a book about cooking (to continue the metaphor) and by no means the only one[6]. It is not an attempt to provide pre-made answers, but rather a framework and inspiration to create ones own solutions.
More specifically, after advocating a holistic approach by taking the whole interaction into account between the human and the technological environment in the first chapter, chapter 2 looks at the interaction loop in parts and levels. Then through further deconstructions of the interface technology undertaken in chapter 3, chapter 4 looks at the higher levels of communication of information. In chapter 5 the whole deconstructed view will be put back together in a meaningful way from a human point of view, and end on a positive foot.

1.1 The disappearing computer

The desktop computer, which has become common over the last twenty years in our working environments such as the office, design studio and the living room, is disappearing. Two main reasons for this tendency are the increasing *networking*, and the continuing *miniaturisation*.
Computers, peripherals and other electronic gadgets communicate more and more through the networks, such as local area networks (LAN's, through cables or wireless), the Internet, USB and Bluetooth. Therefore we can think of systems not as insular boxes but as whole networks, not centrally organised such as the mainframe systems in the 70's, but distributed. Due to the miniaturisation appliances can become so small that we can barely hold them in our hands, let alone operate them. The physical presence of the appliance has shrunk to a point where all that remains is the *interface*, or even beyond that, which means that we can't physically control the technology anymore. It is this concern that led to the writing of this book.
The notion of Ubiquitous Computing or the disappearing computer is about the idea of the computer as a networked omnipresent system rather than a specific box. At the current stage of networking and miniaturisation, it can be said that the computer virtually *has* disappeared. Observe for instance a laptop computer or mobile phone, its physical presence consists of the screen and the keyboard or keypad, and not much else. What is left of the disappeared computer seems to consist entirely of the interface.......

1.2 The computer has disappeared, now what?

The danger is, as has been shown by other technologies in the past that have been miniaturised away, that when the computer disappears also the interface will disappear. To make things worse, there is the tendency of manufacturers to omit mechanically moving parts such as sliders and dials because of the costs. The effect of miniaturisation can be seen with the mobile phones, which are becoming so small that they can hardly be used anymore. However, there are other tendencies. For instance, computer manufacturers recently started to change the tendency of making laptop computers smaller and lighter - in order to accommodate a 17" screen they had to become bigger. This is an example that shows that the dangers signalled can be changed into an opportunity. After all, the interface technology is extremely malleable and interfaces can be shaped taking the human (in)capabilities (both physically as well as mentally) as a starting point rather than the technology. More than ever, form can follow function - not the technology.
It is sometimes said that the ideal interface has to be invisible (or disappeared?), but this is mainly a sentiment that stems from the frustration caused by interfaces that are badly designed (if at all) and

are seemingly getting in the way. Too often computers don't do what the user wants, but what the engineers and designers think the user wants, or what the engineers and designers want the users to want. When the computer becomes ubiquitous the danger is that this misunderstanding also becomes ubiquitous. The need for a solid and understandable interface in the case of ubiquitous computing is therefore bigger than ever.

1.3 Technology needs an interface

Whether it is an internal-combustion engine, a complicated piece of software, or an electronic circuit board, we can enjoy the technology for itself - the smooth motion of the pistons, the speed with which an algorithm calculates a complicated formula, the density of patterns on a circuit board. However, to make technology usable, to be in control of it, to work or play with it, technology needs an *interface*. In this book I will argue that the interface is therefore the most important part of technology in general. The simplest and most effective way to make technology more efficient, to get the most out of the horsepowers, algorithms or dense circuits, is by designing and developing an optimal interface.

An interface is a connection between things. In its simplest form, it can be seen as a line - the line that separates one thing from another. In order to be meaningful however, it will stretch itself and reach out into both domains on either side of the line, and link things together. Interface literally means the face-in-between. This could refer to our own face, through which a lot of communication with the outside world takes place and which is certainly not a thin line. The (beauty of the) interface is more than skin deep, and faces two ways. Through an interface, *interaction* can take place. Interaction is a two-way process of two things or entities acting and reacting upon each other, from the switch that turns on the light (strictly speaking rather reactive) to navigating in a complex computer generated 3D environment.

Of course, our natural ability to adapt means that we can learn to use almost any interface, even a bad one. Technology gets away with bad interfaces, but it could get much further with a good one.

1.4 Technological stages and their interfaces

In order to manipulate an object, or a process inside a machine, an interface needs to be present, linking the possibilities of the machine or object to the capabilities of the human.

Over the course of thousands of years humans have developed all kinds of technological artefacts. These artefacts needed to be manipulated, controlled, interacted with, *used*. For the science of measuring and study of the human factors of machine usage the term *ergonomics* was introduced around 1945, but of course the issue is as old as the invention of the first technological artefact. When the cave-man picked up a stone to make a tool or weapon, we imagine he made one that did the job best (for instance a sharp edged piece of flint stone) but also made it to fit his hand best[7]. In the following 100,000 years we perfected this craft, accumulating knowledge and skills to a high level of complexity.

Below is a categorisation of artefacts developed by humans over time, in stages of development:

manual (objects)	tools like a knife or a hammer	stone age
mechanical (passive)	levers, cogs, gears	
mechanical (active)	powered by steam, combustion engine	industrial age
electrical	electricity, power and communication	
electronic (analog)	modulating of electric signals (vacuum tube, transistor)	information age
electronic (digital)	integrated circuits (IC's or 'chips')	
computer	software	digital age

Each of these categories has its own kind of ergonomics, from the physical aspects in the earliest stages to cognitive ergonomics dealing with the mental layers of the interaction with interactive systems. There is often a lot of overlap, and the issues dealt with in each successive technology are accumulating. Generally the knowledge of each technological stage is needed in the next, for instance, to design the shape of a handle for a machine one can apply the knowledge of grip design of a hand tool. Every technological stage brought about their own interface elements, not always consistent with previous stages. For instance to open a tap we have to turn the knob *anticlockwise* (due to the underlying mechanics of the standard thread) while the volume knob on audio device turns *clockwise* to make the sound louder (through a potmeter).

Interface elements can be of another nature than the underlying technology. An example of this is the digital watch, which now can have an analog display and dials instead of displaying the time in digits.

In the development of these technological stages over time there are two clear and very important tendencies. First there is the *increasing complexity* and the development of a potential for interaction rather than a simple mechanical reaction, from the early designs for a mechanical computer around 1840 (The Difference Engine of Charles Babbage) and the analog electronic computers in the 1960's, to the digital computer which can be programmed through software. At the same time another tendency, a trend of *decreasing visibility*, is taking place over the years. It is relatively easy to understand the workings of a mechanical device by just looking at how the elements move and interrelate, the carriers of power (leather belts, cogs) or information can be seen. In electric and electronic systems the power and information itself is invisible, except for the trained engineer with his specialist tools[8]. In the case of the computer it is impossible to understand what it does by just scrutinising the inside of it.

The problem is that the tendency of *increasing complexity* (and therefore potential for interaction) and the tendency of *decreasing visibility* develop inherently at the same time. The more complicated the machine, the less visible its workings are. For the computer a whole new way of visualising the workings of the machine had to be developed, and the need for a good interface is bigger than ever. Fortunately, the flexibility of the elements of design for the computer interface (both in hardware and software) enables a solution.

1.5 The evolutionary nature of technological developments

Technologies evolve, they add and accumulate as illustrated above. We may think that we *create* technology, but we don't really; there is such a high level of complexity in design and development of technical systems since the industrial age, involving many people, teams, approaches and other factors which influence the end result. Like the biological evolution in nature, developments are stacked on top of each other, in an incremental way, rudiments and vestigial elements showing traces of earlier stages in the development and not necessarily leading to an optimal end result.

Take for instance the car which, although being among the more advanced tools man created, is not that different in appearance to the carriage when the horses were first taken off about 120 years ago. We still sit in a box with a similar volume, facing forward in rows of 2-3, with the driver on the right hand side of the car so that he can wield his sword or hold his lance[9]. The motor cycle can be considered to be modelled on horse riding, actually with a rather more elegant interface than the car – all controls are within the driver's hands and feet. It always surprised me that to drive a car one often has to move ones limbs around in order to take action, introducing a delay even in a vital action such as braking.

The car is a good case study in evolutionary and incremental design, stacking technologies from the (electrical) spark plug that made the (mechanical) combustion engine useful, to the latest addition the (digital) navigation system, to upcoming additions such as guided driving. Each new technology gets tagged on, and it takes time to get integrated in the whole system, if at all. An interesting example is the car radio, with its controls traditionally far removed from the main car interface that the driver deals with (the steering wheel and pedals). Over the decades it grew in complexity by the addition of cassette and CD playing capabilities and the relaying of traffic information, demanding more interactions with the user who should rather keep its attention to the prime task (driving) than

fumbling with little keys tucked away under the dash board. Finally in the last years some of the controls of this system have been moved to more easily reachable spots on the steering wheel.
So, the occasional re-design can be quite useful, particularly from an ergonomic point of view. But the more complex the systems, the more difficult it becomes to fundamentally redesign it. This is even more the case with systems that are under a strong influence of a fast stream of technological developments, which is the case with the computer. When the current interface paradigm with windows, icons, mouse and pointer was developed in the early seventies at Xerox PARC, this was based on thorough research on *how people do things*, how they act, and as such it was a strong example of matching the technology to the human[10]. However, it was the technology of that time and since then screens have become bigger, sound and speech are used as interaction modalities, 3D vision and multiple degree-of-freedom input devices are available, haptic feedback addresses our sense of touch, processing power went up dramatically, and also our knowledge of the human factors and interaction issues has increased. But the 2D desktop metaphor is still the same after twenty years. The limitations of the paradigm are hindrances for further developments. Rather than muddling on and adding bits and pieces, 'interface-lifting', it would be very interesting, rather obvious even, and I would even argue essential to start all over again. What is needed, and is researched in several labs around the world, are new paradigms for human-computer interaction. Unlike in nature, which progresses in the relatively slow pace of the biological evolution, technological evolution is not only faster but allows bigger steps to be taken and can re-iterate. Could it start from scratch at an appropriate moment with new interaction paradigms?

1.6 *e*-cology: the electronic ecology

The *e*-cological approach, as put forward in this Cahier, advocates to treat the interaction with our technological environment as a whole, rather than the wide variety of separate interactions with all different technologies currently taking place[11]. This variety is due to the fragmented technological inheritance of the artefacts, from the simplest hand tool to the complexity of the digital computer.
The computer, as the most complex artefact ever developed by mankind, is not only present as the beige box getting in the way on the desktop, but is also embedded in everyday appliances. Computers can be found in lifts, cars, telephones, the barcode scanner at the supermarket till, a credit card reader, coffee maker, air traffic control systems, the washing machine, et cetera.

Studying the natural environment has brought about the notion of ecology – entities, animals, systems, not regarded in isolation but in relation with each other. When technology and nature meet, there is a clear tension between them. This can be seen in technologically advanced urban surroundings, such as the centres of big cities, or a country like Holland where even the nature is man-made. However, it is possible to model our inventions on nature - but not in a literal way. For example, today's pathological 'information overload' is not caused by the amount of information *per se*, but by the way it is presented. It is an artefact of technological systems. Our natural surroundings are full of information, yet we are not easily overloaded by it (though we can be overwhelmed by it – imagine the Dutchman visiting the mountains). In the natural environment, the information is presented in a largely implicit way, based on *tacit* knowledge. One often has to look for it, it is a relationship between the animal and the surroundings that create the abstract idea of information[12].

The *e*-cological approach regards the design of the interactions with our man-made technological environment as a whole, inspired by our natural environment. It is therefore hoped that this will lead to a better match between our natural and technological environment, more effectively applying our existing (tacit) knowledge about interaction. I am not pretending that this is new – even though I decided to make up another "*e*-" word for it, inspired by common terms like e-mail, e-commerce and e-motive architecture[13]. The term is already been used for some other ideas, from the internet as an electronic ecology (which is too limited to my sense) or web site design for environmental initiatives.

This *e*-cological approach becomes more necessary, and at the same time is made possible by, the tendencies of increasing miniaturisation and networking of current technology, leading to the embedding of systems and a general sense of ubiquitous computing. This enables the computer to disappear, to become ubiquitous, only the interface is left (hopefully!). It is the interface that facilitates *interaction*.

The ergonomics of musical instruments

It is interesting to illustrate the technology categories as discussed in this Cahier with examples of musical instruments. The oldest instruments were *objects*, things that make a sound when banged on - still existing in drums, in fact all percussion instruments including the xylophone. The rest of the instruments in a symphony orchestra are in fact members of the second category, *passive mechanical*, and are taking the sensitivity interface to an extreme. The basis of most of the instruments, where the tone is excited, is often an object (a string bowed, hit or plucked, the mouthpiece of a brass instrument or flute). The tone is then further manipulated through mechanical constructions of valves, keys, pistons and levers of the interface which is extremely well fitted to the human player. The ergonomics of such an instrument design are quite straightforward and visible, highly elaborate (though constrained by the physical processes). They are controlled using the most dexterous and sensitive elements of the human effectors, the mouth and the hands, and with their output and feedback they address the ear and the sense of touch. The carillon is an interesting example. The performer plays with the fists, hitting pegs that stick out of a sort of 'keyboard'. The movements of the pegs are transmitted via metal wires strung to the top of the church tower where bells are hit through a lever and clapper. This is hard work of course, and therefore in the industrial age instruments were invented that were driven by external power sources.

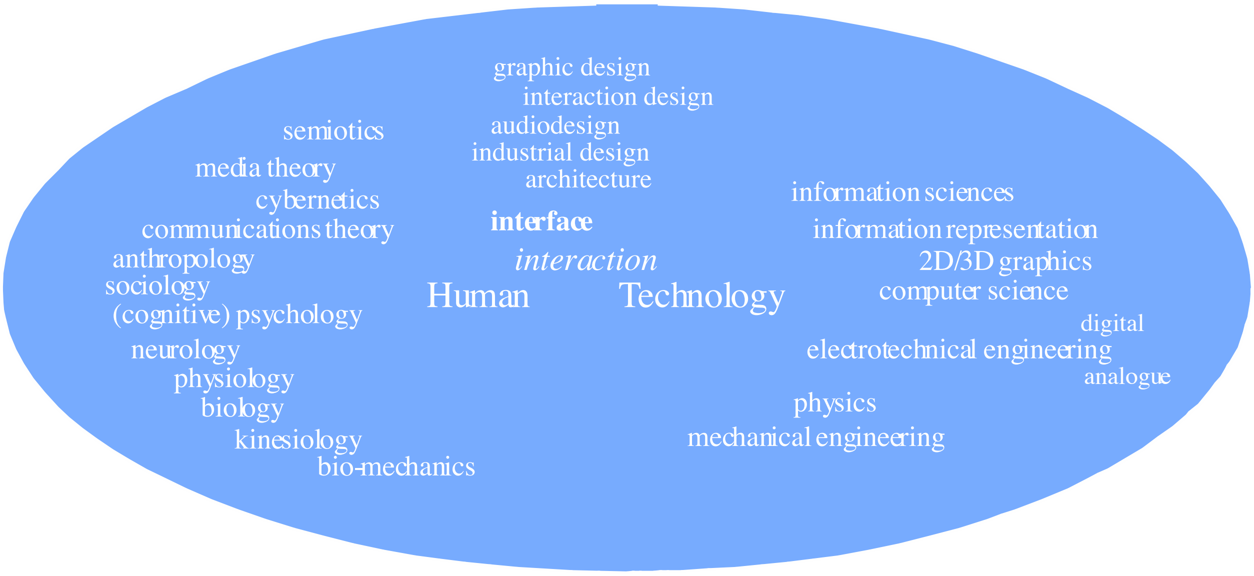
The *interface* of instruments since the industrial age were often copied from the previous musical instruments, particularly the chromatic keyboard from the harpsichord and piano, in for instance the church organs, completed with handles and levers for timbral control. The feet are often used as well, with a large scale foot keyboard. This was also the time when the use of electricity became more widespread, and the most interesting example from an ergonomic point of view is the Thereminvox. This instrument, named after its Russian inventor who brought it to the western world in the 1920's, was played without touching it. Two antennas that were directly coupled to the circuitry inside the box influenced pitch and volume of a tone when the player waves the hands around them. This instrument is often copied and still very popular (it can be heard on the melody in the intro of Good Vibrations of the Beach Boys, and more recently in many techno and trip hop music, for instance Portishead). After this exciting start things started to change, partly due to the invention of the record player and the tape machine in the 1950's. The focus of the field turned to the inside of the machine, and got lost there for a long time. Although it produced a lot of interesting music the emphasis was often on the processes inside the machine rather than on how to control them. The ergonomics of tape machines and record players are interesting in a way, and in fact the turntable became the other example of a new instrument in the hands of DJ's in the last decades.

The trend of adapting existing instrument forms to newer technologies persisted, so most examples of electric, analog electronic and digital electronic instruments (called synthesisers as they electronically synthesise the sounds) are controlled with a keyboard interface. The ergonomically interesting bits are in the extensions, such as the wheels, joysticks and ribbon controllers on synthesisers or the whammy bar on the guitar. The electric guitar was invented in the fifties which opened a whole range of new sounds and playing techniques possible, such as effectively demonstrated by for instance Jimi Hendrix who took the instrument to another level altogether. Players started to further influence the sounds of the instrument with electronic additions, often controlled with the foot such as a wah-wah pedal. Today's stunt guitarists such as Steve Vai or Joe Satriani have taken the electric instrument to the extreme.

Meanwhile, synthesisers started to become more modular and the separation of the interface from the sound source, accelerated by the introduction of the MIDI protocol for communication between the elements, brought new possibilities for interface designers[14]. In the last decades a lot of new instrument forms have been invented, such as gloves and more abstract forms such as webs. Any form is possible and the freedom for an instrument designer to apply all ergonomic knowledge to fit the instrument to the human are vast. Too vast in fact, there is so much freedom in the design that common new instrument forms and shapes have not yet emerged. Most of the well known inventions so far, like the several hand controllers such as The Lady's Glove of Laetitia Sonami and The Hands of Michel Waisvisz are quite idiosyncratic, that is, fitting these particular composers, and have not become widespread.

2. Interaction

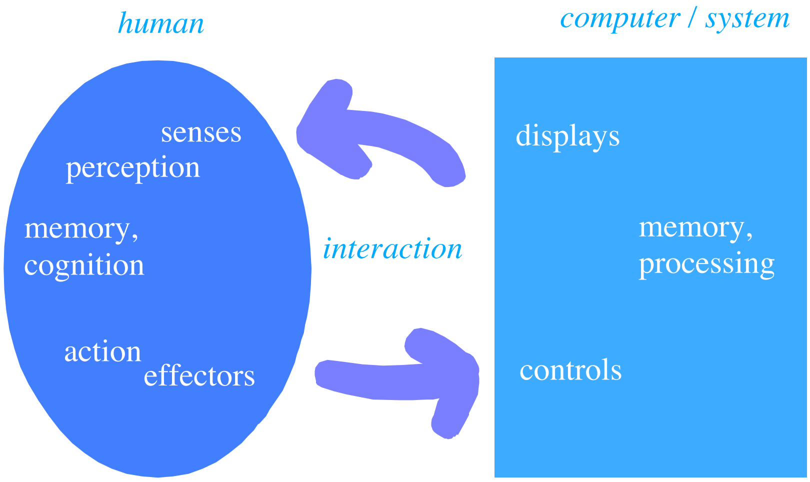
Human-Computer Interaction (HCI) can be defined as the research field that studies, and develops solutions for, the relationship between humans and the technological environment. In this chapter layers of interaction will be described, from the physical to the more mental layers. These layers are reflected in the historical development of interfaces, from the grip of the pre-historic stone tool to the data-glove. Knowledge about interaction accumulates and can be applied in each successive technological stage.
The study of interaction between humans and the technological environment is of a very multidisciplinary nature, drawing knowledge and inspiration from a wide variety of fields. In the diagram below a 'map' is shown, not pretending to be totally inclusive but to give an overview of the disciplines grouped in the human sciences (left), engineering sciences (right) and design (top). They all meet in the middle in a muddle.



There are three main approaches, coming from computer science, cognitive psychology and interaction design. Each of these disciplines have their own approach, and seem to have brought about their own version of HCI.
When interactive media started to emerge, it took a while before the transition within the design discipline was made from static, graphic and industrial design, to dynamic design, under influence of the tradiononally time based media such as music and film, and subsequently interaction design.
More than ever, design is not something that can be ‘slapped on’ at the end of the product development cycle[15]. In software engineering there has been a tendency to think that programming the user interface is not the core job, but in the case of interactive media the need for an interface that is thoroughly integrated is bigger than ever. With the current state of developments on the technical side, and increased knowledge on the side of the human sciences, the design disciplines can (and are undoubtedly eager to) introduce new paradigms of matching humans and technology.

2.1 The interaction loop

The figure below shows the basic aspects of the interaction between a human and a computer, with a focus on the physical aspects of the interaction. Interaction is a two-way process of control and feedback, and is shown in the diagram by the large arrows in the middle.



When two entities interact, both will change state during or after the processes taking place at both sides. In order for two entities (people, systems, computers) to interact, they must both have the ability to *act*, and have internal processes of some degree of complexity that can change. Strictly speaking, most 'interaction' with computers is merely 'reaction', due to the asymmetrical capabilities between the two parties involved (the human and the computer). The computer in the diagram is of course not necessarily a single box, it can be an embedded system, and it can (and often is) a system expanding over networks – worldwide. Likewise, the human side can (should) consist of multiple people.
The human user can control the system by using their **effectors** (for example, manipulating with the hands, speaking with the voice) which will be taken in by the system through its **controls** (input devices). After processing, the system can output a result through its **displays** (screens, loudspeakers, motors) which can then be perceived by the user through their **senses**. The user can process the information, and continue the loop.
It is important to be aware of the relation between the parts, they are not to be studied in total isolation. For instance, perception is often not a passive process; we move our eyes or our hands to actively explore the world[16].
There is more interaction taking place, not shown in the diagram above. People can (and increasingly do) interact with each other *through* technology. Also the interaction with whole (natural) environment influences the interaction with the technology shown in the diagram.

2.2 Modalities

The term modalities is used to discriminate between different flows of information and to describe the interaction or communication. For instance, the visual modality concerns our ability to see things (such as the information displayed visually on a computer screen) or the haptic modality through which we feel the things that we are manipulating. Different forms of communication can exist within a modality, depending on the bandwidth of potential communication. For instance, within the sensory modality of vision we can discern a linguistic modality (reading of text), recognition of non-verbal information and signs, see chapter 4.
Multimodal interaction refers to the situation where the interaction takes place using several modalities at the same time. For instance, a combination of visual, auditory and haptic feedback addressing the human senses[17], or a combination of manipulation and speech. Multimodal interaction can make use of the human ability to carry out several activities at the same time (multitasking). Most interactions with our natural environment are in fact multimodal.

2.3 Levels of interaction

In order to understand the interaction between human and technology, it is useful to discern various *levels of interaction*. At the higher level an action is usually initiated in order to achieve some goal or intention, which has to be prepared and verbalised, and finally presented and articulated at the lowest levels of the interaction through physical actions and utterances. The presentation and feedback by the computer passes through several levels as well before being displayed, possibly in various modalities including the haptic, in order to be perceived by the user. The actual interaction takes place at the physical level.

In the standard literature often three interaction levels are discerned: *semantic* (the meaning of the message), *syntactic* (the syntax), and *lexical* (the elements), but for more specific cases more levels can to be described. Nielsen's virtual protocol model is example of a more extended model, specifying a *task* and a *goal* level above the semantic level, and a *alphabetical* and *physical* level below the lexical level[18].

Norman makes a useful explicit discrimination between input and output flows of information in *stages*[19]. Users have to accomplish their goals through the physical system's action through two processes, having to bridge a Gulf of Execution and a Gulf of Evaluation by the flows of actions in various stages. Garett's Elements of User Experience is an example of a more recent model, developed to include and contrast approaches from design and engineering, particularly in the case of web site architectures[20].

2.4 Human senses

Of the traditional five senses (seeing, hearing, smelling, tasting and feeling) only two or three senses are actively (but limitedly) addressed by the current computer interface. In order to establish a better match the human senses need to be studied in more detail, as has been done in the field of the psychology of human perception. However, a lot of this research is based on stimulus-response paradigms in fixed laboratory conditions, while in the context of HCI research we need to take into account the whole loop, and preferably study them in more complex situations. Generally, in real life perception and action are closely linked.

Lumped together under the fifth sense of feeling (or the bodily senses) are in fact a number of senses. Consider, one can feel pain, motion, gravity, acceleration, pressure and so on, which are all very relevant in the context of the physical interface. Our sense of touch has three sources: the signals from the mechanoreceptors in the skin (our cutaneous sensitivity) informing our *tactile* sense, the mechanoreceptors in the muscles and joints (our proprioceptors) inform our *kinaesthetic* awareness of the location, orientation and movement of body parts, and the efferent copy signal that occurs when a person is actively moving by sending signals from the brain to the muscles. *Haptic* perception involves all three channels, which is usually the case when a person manipulates an object or interacts with a physical interface[21].

The reason why Aristotle's division into five senses does not hold is the omission of the notion of self-perception or *proprioception*. When interacting an individual is inherently active, and therefore aware of it. There is an internal feedback loop that guides the control of the act, for instance when focussing the eye, articulating speech, moving around and guiding manipulation. It makes a difference if a stimulus is imposed or obtained (as in the difference between tactile and haptic). The internal feedback often goes together with feedback perceived externally, which in the case of technology has to be provided by the system and explicitly designed, built in or programmed.

2.5 Human action

At the physical interaction level we can influence our surroundings. The progression of technological stages as introduced above enable new human output modalities to be applied in the interaction, such as speech recognition and reading neural signals directly from the brain. For a machine interpreting and understanding speech and other complex signals is difficult though. First of all it is necessary to establish a solid basis – the physical level of the interaction. If one wants to jump, it is easier to do that from a solid surface…

Any movement and orientation of a movable object can be described in its Degrees-of-Freedom (DoF's), three of which describe the position in three-dimensional space (along the X, Y and Z axes) and three describing the rotations around the X, Y and Z axes.
As an example it is interesting to look a bit closer to our hand. We count four rotational degrees of freedom for each finger - about 70° for the top joint, about 110° for the middle joint and about 100° for the lower knuckle, which has another degree of freedom: abduction (about 40°). The thumb is more flexible. In total for the five fingers of one of our hands we have 20 degrees of freedom. Then the wrist has two degrees of freedom: rotating left or right (the radial or ulnar deviation) and up or down (extension or flexion). When rotating the hand from 'palms up' or supine position to the 'palms down' or prone position one of the bones in the forearm (the radius) rotates and crosses over the other (the ulna)[22]. The elbow has one degree of freedom, and the shoulder three, which makes the DoF count of just one of our main effectors up to 27.
Applying our ability for fine manipulation in the interaction paradigm can be done through the development of sensitive and responsive *interfaces*.

Modern thumbing - text messaging on the mobile phone

Personally, I was a late adopter of mobile phone technology. I always felt a need for sending and receiving short written messages, e-mail being my main mode of communication rather than speaking on the phone (the other main mode is meeting in real life). So it is not a surprise for me that ten years later SMS (Short Message Service) has become a great hit in mobile phone usage, leading to new social behaviours[23]. SMS was originally invented as a by-product of the GSM standard, intended to enable service providers to send messages to their clients. Its current use was not anticipated, therefore its interface not optimally designed. As usual, also in this case when people really want to get something done they will adapt to the given technology, however hard to operate. Particularly teenagers have developed their own strategies to cope with the main problems of SMS: limited message length (160 characters) and cumbersome input. Words are abbreviated in creative ways, depending on the language, mixing languages and inventing new words. This language is hard to understand for the outsider, and particularly bound to confuse the word completion algorithm T9, which was thought to solve the problem of input (not the problem of limited word length) with predictive text input.

So in the end I got what I always wanted, a tiny box that can send and receive short messages. But the interface is infuriating, of course you can use it but it shouldn't be necessary to do things this way. Even after quite a bit of practice it is difficult. The fact that the characters used most, you know those that are very limited letter value in Scrabble, require the most key presses (two for E, three for O, *four* for S) while the Q and X (many points in Scrabble for these) are only two key presses away. But the worst thing is being paced by the interface, you have to wait until the 'time-out' has passed before entering a new character on the same key. The word 'moon' (6-666-666-66) will therefore take a lot of time to type, and so does the word 'love' (555-666-888-33) but at least it is on all different keys. A useful word like 'damp' however takes the least time to type (3-2-6-7)[24].

Meanwhile, phones got smaller and smaller making it harder for manufacturers to simply extend the interface with a full alphanumeric keyboard, priority is given now to screen size. Half heartedly implemented add-on keyboards didn't solve it, and some phones with full keyboards were never very popular (the Nokia 5510, too big to be cool even with a built-in MP3 player – it was marketed as the first 'mobile entertainment' device, or the newer Nokia 6800 that unfolds a full keyboard in two halves – but too far apart). Chording, an extended technique from the normal keyboard shift and alt keys, as used in for instance the Twiddler device for wearable computing, could be applied to the standard phone keyboard but this requires some persistence due to a somewhat steep learning curve.

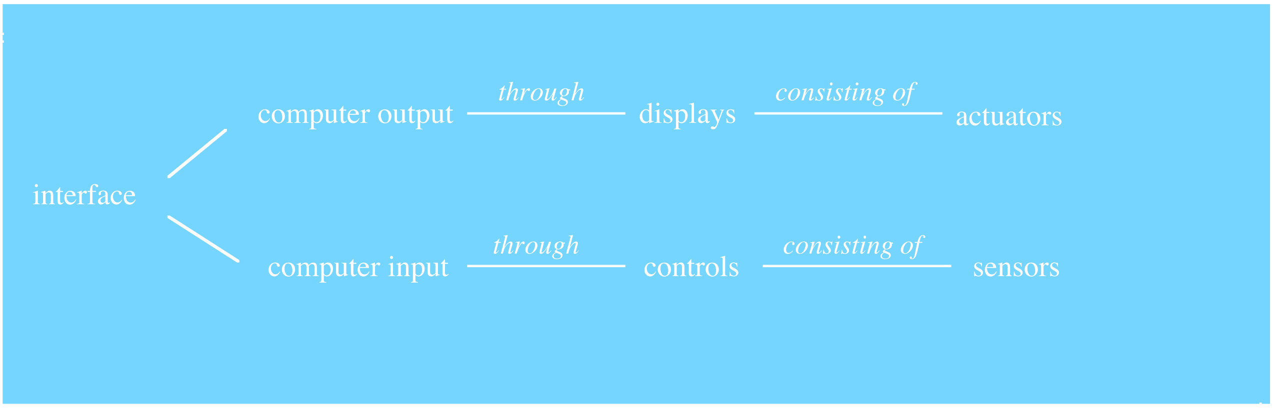
The PDA class of devices which now often include the mobile phone connection technology will probably take this share of this market. The need for usable and elegant text input has been an issue for these devices right from the start, so they have small full keyboards, on screen keyboards, or gesture recognition of stylus moves on the screen[25].

Not one paper presented at a recent conference on Mobile HCI adequately dealt with the problem of text input[26]. Phone manufacturers make small incremental nudges within the idiom of typing text on a numeric keypad, instead of a good solution this is settling with a 'less bad' scenario. What we get now are things we didn't ask for: a built-in camera and larger colour screens, so that we can send each other pictures.

The interesting question which remains is what would have happened if SMS was properly designed for its current usage right from the beginning, before it was introduced to the users?

3. Interface

An interface facilitates the interaction loop. It enables the computer to 'communicate' with its physical environment through its controls and displays, consisting of *transducers*, elements which translate one form of energy (physical quantity) into another. The internal world of the computer is electrical, so the transducers through which the computer communicates with its environment have to translate electrical signals into other physical quantities of the real world (such as light, movement, temperature, or electricity itself) and vice versa. There are two types of transducers: *sensors*, for input, and *actuators* for output.
Generally an interface is a two-way device (or group of devices) which facilitates the two-way process of interaction.



In the process of getting the signals in and out of the computer system more stages can be distinguished, such as the conversion of the analog electrical signals from the sensors into digital signals and various levels of software drivers.

3.1 PIDS: towards a categorisation of interfaces

In order to analyse interfaces further, I have been working on the development of a design space or taxonomy, the Physical Interface Design Space (PIDS). This work is focussing on the physical interface and describing movements of both machine input and output[27].
The approach is to *decompose* a complicated device into its actual sensors and actuators, and then to build it up again in human factors terms. The most accurate level of description of human interfaces is the level of individual sensors, which is not necessarily the most meaningful description from a human point of view. Sensors categorisations are usually based on the physical quantities measured, such as light, magnetic field, sound, force, etc. In the context of the Design Space the working principle of the sensor is not the primary way to organise, instead it is organised in the way the sensor can be applied.
In PIDS, the human input of movement is measured for each degree-of-freedom in the parameters *range*, *precision* and *haptic feedback*. Human movement can be measured on-body or in-space.
The range parameter is plotted on a logarithmic scale, as is often the case with the measurement of quantities on a human scale, and discriminated in the following ranges:

- *intimate*: from isometric, no movement to about 10 cm, within the hand - for instance adjusting a wrist watch or playing a musical instrument
- *body-sphere*: within reach of the arms or legs, up to 1 meter, such as moving the mouse
- *spatial*: locomotion, the scale of a room, up to 10 meters, and beyond – the architectural scale, and for instance gestural control in an interactive space.

The precision parameter of a sensor can partly be expressed in number of bits, starting from 1 bit in the case of a switch. The value of the precision parameter is often difficult to establish as it is dependent on many technical parameters such as the sensitivity of the sensor, the resolution of the A/D (Analog to Digital) conversion, speed and accuracy of buffers and software drivers, etc. It is therefore proposed to include the time factor in it (due to delays or lag) and establish this parameter experimentally in a ratio of the slowest and fastest movement. It would thus relate to the expressiveness of a device.

The haptic feedback parameter is included in order to describe the *feel* of an input device. Feedback can be *passive*, not generated by the system (for instance the feel of a normal mouse, the click of a key), or *active* when the feedback is generated by the system (and therefore might contain information). An action can be isometric, i.e. no movement in which case the force perceived is the normal force, or an action can encounter a certain resistance, or be free moving, or even be pulled by the active haptic feedback (in this case called feed-forward). This can all be plotted on one logarithmic scale, with these ranges.

The Design Space can be used to place individual sensors in a taxonomy, organising them into a classification of operation[28]. A taxonomy of input devices may split the devices up in functional parts which then can be individually described in the parameters of the design space.

In the future it is hoped to include in this description not only haptic feedback but also other machine output modalities. The *visual display* may be described in screen size, resolution (number of pixels), colour depth, refresh rate and viewing angle. In the case of the *auditory display* each speaker may be described in frequency range and sound pressure level.

Developing a taxonomy of interfaces helps understanding the issues we're dealing with, and it may give us insight in how to improve the interaction. It is anticipated that, from the gaps left when a design space becomes more complete, we can identify opportunities and directions for new interaction paradigms.

3.2 The mouse

In its current stage of development the mouse will listen to our movements with two degrees of freedom of movement in the XY plane, one rotational degree of freedom for the scroll wheel and some discrete switches. With this we can point and click, and 'directly manipulate' though there is not much manipulation possible with this limited number of DoF's.

The mouse was invented around 1964 and the current desktop metaphor paradigm was invented in the seventies. At the time this was a great breakthrough, but now it can be considered a straight jacket, stifling further developments in the interaction paradigm. There is no match with our abilities for parallel activities, both physically (the DoF's mentioned in section 2.5 among other things) as well as mentally. The point and click paradigm funnels all our actions through a narrow, one thing at a time channel, only partly helped with the keyboard for text input and keystrokes that act as shortcuts for certain commands. As a result a more complex task leads to endless repetitions in a sequential way, which is a major ingredient from the recipe for Repetitive Strain Injuries (RSI). Even a simple task such as changing the settings of the printer driver to determine the outcome of the printing process will involve a sequence of repeated movements. If this can be changed, in order to have a better match between our physical and mental abilities on the one hand and the computer on the other, a major step will be made to solve the pathological 'mouse-arm'[29].

More elaborate interfaces have been developed in expert fields, such as the electronic arts, games, virtual environments, medical systems and hybrid architecture. For instance for drawing applications there is the standard drawing tablet and pen which have more degrees of freedom than the mouse. The Wacom Intuos reads pen position XY, tip pressure and the angle with the surface in two DoF's. In ergonomic terminology the pen allows for a 'precision grip' hand position rather than the 'power grip' of the mouse grasp.

In the next sections I will describe some interfaces from expert fields from my own practice.

3.3 Expert interfaces in the electronic arts

Composers of electronic music were confronted with a sound world with many parameters, and devised new interface forms that allow many simultaneous degrees of freedom to be mapped to parameters of the synthesising algorithms. Two examples are the Lady's Glove of the French / American composer Laetitia Sonami and The Hands of the Dutch composer Michel Waisvisz, instruments that contain a variety of sensors that measure the player’s movements on the intimate and the body-sphere scale. The Lady's Glove reads 15 continuous Degrees of Freedom and 7 switched DoF's, and each of The Hands has three continuous DoF's and 24 switched DoF's[30].

Another example is the instrument called Sensitive Chords, which was to be played by four performers simultaneously. It consists of a structure pivoting with two DoF's on a pole, with each corner consisting of a joystick like joint with two rotational DoF's translating in lateral movements from each of the corners. In addition each string has a mechanical tension sensor built in. In a current research project a modular interface is developed called the Video-Organ consisting of many elements each with their own set of DoF's and characteristics, for the live performance of audio-visual material[31].

With the ensemble called SensorBand I developed The SoundNet, an instrument of 6 x 4 meters, an example of an interface that operates on the spatial scale. It uses tension sensors with a spring constant of several hundreds of kilos to track the position and movements of the players climbing on the instrument, allowing for a new level of physical interaction[32].

3.4 Interactivated spaces

There are several fields of research and development that deal with interaction on the spatial scale. It is expected that the house of the future will use this as a modality to control the complex and versatile embedded computing systems, as in ubiquitous computing, also combined with mobile interfaces[33]. Many art projects already explore the use of spatial interfaces in interactive installations. In the field of *hybrid architecture* the interaction between virtual and real worlds takes place using sensors for presence and motion detectors[34]. Collaborating with the Dutch architect Kas Oosterhuis, for instance at his ProtoSpace project at the Technical University in Delft, we focus on the parametric design that arises from the use of computers in the building process[35]. Under investigation now is how to meaningful map the measured parameters from the users to the parameters of the models.

In these cases it is important that groups or teams of people work on one model or set of parameters together. This is a major step away from the desktop computing paradigm, that led to a rather solitary use of computers in general. By using large projections, sound and touch feedback we try to open up the tunnel vision inducing paradigm, and by using many sensors it is hoped we can break away from the one-thing-at-a-time nature of the point and click paradigm.

3.5 Mapping

Designing and developing new instruments and interactive spaces is not so difficult. As stated before, the problem of the PC lies in the limitations of the point and click paradigm which is not something that can be changed easily. All commercially available software is tied to this paradigm, so I have turned to other fields of application for inspiration. In the examples briefly discussed above, not only the physical interface but also the *mapping* is free because of the nature of the processes controlled. Mapping is the link between control and display inside the computer. In the PC the mapping is quite fixed, but it could actually be free in most applications. In order to get closer to that, we need to think about *what* might be displayed through all these computer output modalities, what it is we perceive, in order to establish an interaction with all the input modalities. In other words, what is *information*?

Moore’s Law and the user interface

When the first mainstream dual-processor computers came out I thought that we would get one. That is, I thought that we, the users, would get this second processor all for ourselves. One for the computer, one for us. One processor doing the computing (boring) and the other one dealing with the user interface – fantastic graphics, clear and fast, audio, touch perhaps – all things that are only convincing and useful if there is no delay or lag in the system’s response. However, it proved to be a misunderstanding, because both processors were dedicated for ‘computing’ and we had to put up with systems that were sometimes sluggish in appearance when it was attending more important tasks like loading a CD, attending the flatbed scanner, etc. Around that time I worked on a Silicon Graphics workstation, which did put the money were its mouth was to quite an extent – a good bit of its graphics power went to the visual interface. But the network was slow which affected the workstation’s overall performance, and therefore the appearance.

Meanwhile, graphics chips got faster and more powerful and by now have surpassed the power of the actual CPU[36]. So that part seems solved. But a satisfactory user interface is only for a small part depending on silicon.

Even though there is an element of self-fulfilling prophecy, Intel’s founder Gordon Moore’s famous prediction from the early 60’s that the number of transistors on a chip would double every 18 months still holds[37]. What keeps this development under control is the seemingly equally impressive exponential growth of the demands of software. When I buy a new computer and upgrade all my software, say every three years, this balance is shown in the fact that everything seems to happen at the same speed (or slowness) as before. For a while I have been resisting this and found that downgrading was often the solution – old software runs much faster on your new machine, has far less bugs and all the new features most of which I don’t need anyway that replaced other functions that I dearly miss – I can’t add up numbers in the latest version of my word processor, or edit the diagrams that I used to make in it, but it has a ‘paperclip from hell’ and it will automatically make a list when I type my name:

A. J. Bongers
B.

Wonderful. Smart computing? Less stupid first. Now, back to the point of Moore’s Law and the user interface. The size of my screen doesn’t double every 18 months (in fact doubled in 10 years), the mouse now has a scroll wheel which adds 1 (one) degree of freedom (after 30 years) to which the graphical interface responds, my stereo sound doubled in resolution and sampling frequency (in 5 years), and I can shout at the computer and it will talk back. It does play video smoothly and will do 3D graphics, and there is a limited supply of off-the-shelf input devices available.

It is to be hoped that one day the user interface will catch up with the speed of Moore’s Law.

4. Information

In the context of interactive systems and communication it is useful to assume the world around us, with all objects and processes, both real and virtual (computer generated), as *information*. Objects inform the attentive perceiver in many ways, for instance, location, what they are made of, something about their history, what one potentially can do with them and so on. The latter is often described as *affordances*, potentially informing the perceiver about what can be done with the object and how it can be used[38].

4.1 Information signs

Several levels or classes of *signs*, through which information is communicated, can be described. There is the information from objects themselves and what is called their indices or *signals*, information that they cause. Processes are often revealed through their *symptoms*. When manipulating things in the world around us, this kind of information or signs give us feedback on our actions. Living things add further signs to our world, as do human artefacts which are made to convey information. Signs can be mimicking the object which is signified, for instance a pictogram or a gesture that imitates a certain action. These kind of signs are called *icons*, which in the case of the computer interface can have their own behaviour or processes. Abstract signs that have no resemblance to the object or concept it signifies are called *symbols*, such as in written or spoken language or a musical score. Humans are the only animals that created and use symbols. Symbols can be organised in language, such as our speech, which first developed long before it was written down. The first written languages were very iconic, such as hieroglyphs, and later the phonetic alphabet was invented[39]. A language can be verbal as well as non-verbal (such as gestures), or a combination. Non-verbal signs are sometimes uttered unconsciously.

information signs:

- all the things in the world, their affordances, their signals and their symptoms
- icons that mimic and resemble the thing that is signified
- symbols ...... organised in languages (or codes) ...... and written down

4.2 Presentation and feedback

All these signs, of objects, processes, and symbolic languages are applied in the most complex artefact developed by humans so far, the computer. Computer generated phenomena are often called *virtual*, as opposed to real phenomena in the world around us. This difference between a real object and a virtual object, one that is seemingly there but not in reality, is more of a conceptual level. Virtual can be defined as ‘known not to be real’, although the philosophical implications of this are beyond the scope of this Cahier. It has been argued since Plato’s cave that 'real' is a matter of interpretation, as it is in principle not possible to be sure that the phenomena in the world we perceive are really there or that the information from our sense systems is made up[40]. For the moment we will leave this pitfall for what it is, and assume that the computer and its output is really there.

The information the computer displays can be described as *presentation* and *feedback*. Through its displays (visually, auditory and possibly addressing other senses as well) it presents which objects and processes it has to offer. When being used, being manipulated, being interacted with by the user, it should convey information about the process(es) at hand, by feeding back information to the user. Information that is presentation in one moment, can be feedback in another situation or even at the same time, depending on the context of control.

Feedback can come from elements especially designed for that purpose, such as message boxes and widgets that allow manipulation, or from the content itself.

Most feedback is actively generated by the system, but some feedback can come from passive elements of the system. An example of such passive feedback, sometimes also called inherent feedback, is the mouse click felt when the button is pressed - it is useful information but not generated by the system. The system therefore cannot be held responsible for misinterpretations - the click will still be felt even if there is nothing to click on the screen, the computer has crashed, or isn't even on.

4.3 Energy and information

Another useful distinction to be made when analysing the interaction within the electronic ecology is between supplies of energy and information. Looking at our environment from an architectural point of view (the house as a machine to live in as Le Corbusier famously has put it), we can discern flows of *energy*, such as the mains electricity, water, light and gas, and flows of *information* such as the internet connection, telephone, television. The flows of energy and information can have two directions: fresh water in, sewage out; the two directional information exchange over the telephone; or one direction: electrical power in, television information in. They can be continuous, such as the main supply of power and the network connection or television which can deliver a constant stream of information, or intermittent – power stored in batteries or gas bottles, information stored in letters and newspapers. As computer systems increasingly merge into the house, new possibilities for control become possible as shown in domotics applications in the home and office automations systems.

4.4 Transition

Now that we have sufficiently pulled everything apart, interaction, interfaces and information, it is important to start to put it back together again. We need *integration*.

IEEE1394b, or *down with the acronyms*!

How much jargon can we tolerate? It always surprises me when computer users can speak quite fluently in engineering terms. For a long time any PC user would know that C was the hard disk, and A meant the floppy disk, D often is the CD but not always, that there is RAM (Random Access Memory) and ROM (Read Only Memory), as if computers weren't being invented to make our life simpler and better. Users are made part of the engineering conspiracy as it were, particularly exciting for boys it seems. It is as if things escaped from the lab without influence from marketing, ergonomists, usability specialists, or designers. Even a whole new medium surfaced named after the carrier, namely the CDROM. We're so used to it now that we tend to ignore how cryptic its name actually is. The first part is the CD bit, this is something we are familiar with (though it wasn't a very imaginative name, Compact Disc, after the Compact Cassette, guess who invented that). Then the ROM bit, previously only used for memory chips that could be programmed only once. Well, these chips made a lot of progress as there were PROMs, then EPROMS, then EEPROMs, at this time the stacking of contradictions gets pretty impressive: Electrically Erasable Programmable Read Only Memory. When using the term ROM for the disc medium of course the same thing was bound to happen, but now in public: CD-R, CD-RW (recordable and writable read only?).
We don't even see HTTP:// anymore even though it is in our face in the web browser all the time. (My word processor saw it, though ↑). Iomega's Zip disk (E on your PC) was a great hit, firstly because it gave us something we really wanted, it had a cool design and a catchy name. USB, Universal Serial Bus sounds a bit nerdy. In the case of IEEE1394, introduced to replace SCSI and to open new ways for high speed high bandwidth communications, was marketed under a catchy name (by Apple that was involved in the invention of it), Firewire. Or iLink in the case of Sony, this is what happens if too many marketing departments become involved. A shift of nerdy discussions in the shop, now about connecting iLink to Firewire (and yes it is the same as DVout if you happen to ask in the camera shop). SCSI by the way is an example of an acronym that became a cool word, when pronounced as 'scuzzy'. Same with the MIDI protocol musicians invented, I once had a cat which I named Midi. Bluetooth sounds like something you want to have, even though you might not now exactly what it is, and IrDA does not.
Compare this with the situation with cars and motorcycles, that have come a longer way of development, but still the jargon slips in (now often deliberately). We can see labels on cars displaying the number of cylinders, and the total amount of cubic centimetres of them (1100cc!!). Some years ago, when the design of engines changed and the valves were operated in a new way, you would see labels like DOHC (Double Overhead Camshaft, in case you want to know) sometimes even in big signs. Currently one might see '16v', referring to the number of valves which apparently is relevant for the puny European cars. The number of valves is meaningful only in relation to the number of cylinders, a lot of guessing involved here because that is currently not advertised (always four, in line anyway). Point is of course that things like quality and usability are hard to express in numbers. A restaurant may have Michelin stars, but that is only applicable in the high end of the market. A really interesting car may even have no indications whatsoever on it, the idea being that it is all about reputation. Ever seen a Porsche with a sign of its amount of cc's? It doesn't need that, all we need to know is that it is enough.
We now see the same thing happen with computer technology, talking about CPU speed in Megahertz as if they were horsepowers, cache size and bus speed. Yes it all influences the user experience, but that experience itself cannot be expressed in numbers, it has to partly rely on reputation. And compared to more established technologies, like cars, restaurants, musical instruments, the choice is very limited.

5. Integration

So here we are, in the current situation where this complex and powerful computer technology is disappearing, becoming ubiquitous, and (hopefully) gently receding into the background, leaving no traces or hindrances.... and no interface?

5.1 The ubiquitous interface

The interface can be most narrowly defined as a line or plane. An area placed between, and connecting, two worlds, entities or whatever elements that communicate and interact with each other. The human skin is a good example, or the skin of an apple. As discussed before, in order for this interface to be effective it needs to stretch itself out, deeply into both elements. Imagine the roots of a tree, which form the interface between the tree and the surrounding earth, or again the human skin from which the nerves connected to the mechanoreceptors that sense movement reach into the brain to deliver these signals.

A spatial interface, such as used in Interactivated Spaces, is a way of searching for solutions for the problem of how to control an invisible, ubiquitous system. Such an interface can be a combination of speech recognition, gestural control, on-body and in-space sensing, and physical interaction elements.

5.2 Physical interaction

In the current computer interface the physical level of interaction is quite neglected for two reasons, one harder to solve than the other. Manufacturers don't like hardware interface elements because they consider it more expensive and less flexible than the software bit. The public is actively made to believe that hardware interfaces are not what they want, and that software is all you need. There are some examples which prove the opposite, they are rare but very strong. For instance, as Bill Buxton once pointed out, a professional (top-) string player would invest more in the bow - just the bow - than the value of a whole Silicon Graphics workstation[41]. For the musician the only way to get the message across, to enjoy playing, to be a virtuoso, is to have an optimal interface – at whatever cost. However, the interface hardware in the case of the computer, sensors, actuators, and electronic circuits, are still much cheaper. Even specialised hand built electronic musical instruments cost a lot less than that bow.

The other reason for the ignoring of physical interaction is harder to solve. Since the industrial age, with its division of labour for the hands (blue collar workers) and the head (white collar workers), there is a tendency to think that working with ones hands is inferior, and that working with the head is regarded with more respect – nowadays this includes even software development (just about). The skills of the craftsman are seen as useful, but not as crucial[42]. It is as if when one can work with the hands, one can't be good at working with the head[43]. I strongly disagree. It is not mutually exclusive, in fact we know that theory can be developed through practice, and therefore that both the head and the hands are important.

Within the research field of HCI there is finally an increasing interest in physical interfaces. For instance, the notion of the TUI (Tangible User Interface) as successor of the GUI, as supported by Hiroshi Ishii (and his group at the MIT Media Lab)[44], and the notion of 'embodied interaction'.[45]

5.3 A shift in thinking: from devices to functions

The recent tendency in technological developments has been towards the disappearance of devices, the functions of which are then incorporated in the remaining appliances (for example the fax/copier/printer combined device, or an electric toothbrush with a built-in compass). These resulting multifunctional appliances are therefore harder to operate as the 'interaction bandwidth' decreases, there is less room for an interface. The tendency of the increased networking of appliances results in functions disappearing into the network. An example of that is the "voice mail

box", storing messages somewhere in the network instead of on a tape or chip in an answering machine in the home. This has certain advantages, but the problematic issue is that the interface of the old answering machine, which gave access to the functionality of voice mail, has disappeared. Now, the functionality needs to be operated with an interface that was never designed for this - "to delete this message, press 5". This results in cumbersome switching between modes and modalities, instead of just having a "delete" button at hand.
As stated before, in the current society a lot of technology is already ubiquitous. What is needed is an analysis of this technological environment based on functionalities rather than based on the devices, because the devices change and often eventually disappear. In the past, working as researcher for Philips, I have been trying to work out why for example the stop button on a tape deck does something different than on a CD player (which goes back to the beginning). It is necessary to separate functionality and technology. Another example is the telephone. Why has the interface from a wireless home phone ('handset') been for many years so different from the interface of a mobile phone (for instance a GSM phone)? The answer is that they come from different engineering and product disciplines. It takes many years for these differences to iron out. The car, as described earlier, shows inconsistencies in the interface that have to do with technical issues. When technology matures it starts to overcome this.

5.4 Device Parsing

In the context of the e-cological approach to interaction, device parsing is a way of analysing the functionality of a piece of technology. This will be illustrated by an example. The mobile phone (GSM in Europe) is primarily a communication device, it has many functions that have to do with communicating but there are also many other functions. If we parse the functionality of the device we will typically find:

Primary function:	wireless two-way real-time voice communication
	supporting primary function such as a phone book
Secondary function:	SMS, WAP
Other functions:	Scheduler
	Clock (date/time/alarm/timer)
	Calculator
	Games

More generally, we find (and this is supported by the experience of taking the device literally apart, hardware device parsing):

- a communication module
- a power supply (mains, and a battery to temporarily power the device)
- the user interface

Analysing the interface, typically we find these elements:

Input
numeric keys, several function keys, scroll wheel or joypad
microphone
Output
visual display
loudspeaker or earpiece
vibration element

The device has been designed in the first instance to perform well mainly for its primary function. The popularity of SMS, originally intended as a technical niche feature, was not anticipated (but could have been), and as a result the interface of the device is not particularly well suited for text messaging.

5.5 The generic interface

A possible solution to the 'featuritis' that plagues current devices is to go back (in a way) to the one device one function relationship, such as the information appliances[46], with the added benefit of the ability of networking which enables information exchange and seamless interaction. I think that we can go further than this, and the solution may be to think of the interface as a physically separate element[47]. In electronic music a small revolution took place because of the introduction of the MIDI protocol, which enabled the decoupling of the interface and the sound source. Bluetooth has the potential to fulfil the same role in information appliances. Linking the PAN (Personal Area Network) with the local networks and beyond is essential in this approach,

The generic interface is in a contrast with the present situation. Currently, one may be walking around with a mobile telephone (interface: a few buttons, small display), a PDA (very few buttons, pen input, larger display), a laptop computer (trackpad, lots of keys, even larger screen), a walkman or CD player (buttons, dials, headphones), a watch (tiny buttons, small display), et cetera. It is clear that there is a lot of overlap in the interfaces, which is the tradition. The strong point of this is, as seen from the user, that there is a fixed *mapping* between interface elements and functionality. When devices disappear, and a generic interface remains, this mapping needs to be designed and built in a different way, without losing the clarity and transparency.

5.6 Conclusion

Every technology has to mature. From its first careful steps, creating more problems than its solves and raising more questions than it answers, it can be allowed to develop when it is showing promise – often that one 'killer app' or enabling something that wasn't possible before. There are always initial compromises. The promise of being able to communicate at a distance went with telegraph wires strung across the landscape, the promise of covering distance with trains meant that railroad tracks went everywhere and that farmers believed it would make the cows deliver sour milk, the first motorcar drivers had to be accompanied by someone with a flag to warn the public..... The promises of computer technology are vast and far reaching, as it is not just a tool but a whole medium influencing, changing and potentially massively enriching and augmenting the way we work, live and play.

From the historical perspective we might be able to see when a technology has matured. If there is one message that I want to get across in this book it is that computer technology has not reached that stage, not remotely in fact. Computer viruses, bugs, endless upgrades, and bloatware are the teething problems that signal this.

Windows (whether those from Apple, or Microsoft's attempts to keep up – 95, 98, NT, 2000, XP, all these windows) are *not* the end point. It is a starting point. The development has barely begun, in a way, we haven't seen anything yet. Taking the current situation for granted, taking it for an end point, will kill all of the (vast) potential developments.

Having discussed that computers are not only the most complex and most powerful artefact ever invented by the human race, but also being the most invisible kind of technology, and luckily also the most flexible – there is complete freedom to design the interface and mould it therefore to the human physical and mental (in)abilities. This has to be sorted out first, so that when 'intelligence' is added to computer systems there will be the full benefit. Otherwise there is, as discussed earlier, the risk of the computer becoming big brother – or rather, lots of little brothers (wizards who will do the job, or actually *their* job not the one intended). Solid ground is needed if one wants to jump high.

To end on a positive foot, as promised, there is an area of the user interface where Moore's Law *does* hold. The number of research centres, HCI courses taught in universities, journals specialised in interaction topics, conferences and symposia dedicated to user interfaces, books written on the topic – all these seem to go up in number exponentially over the last fifteen years.

The naive outsider (if they still exist – everyone is involved in some way or another with this technology after all) might ask if the current interface paradigm is *that* bad to deserve this increasing amount of scientific and design attention. The answer is yes, by the way, but that is not so interesting. The real question is if there is that much room for improvement. This time, the answer is more yes than ever.
We've barely begun, we've just been scratching the surface of what is possible.

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Notes and references

[1] After all, the subtitle of Marshall McLuhans book *Understanding Media* (1964) is *The Extensions of Man*.

[2] As McLuhan points out in his essay *Motorcar, The Mechanical Bride*, in Understanding Media.

[3] Don Norman writes in *The Invisible Computer* 1998 (p106): "…intelligent help systems, assistants, guides, and wizards […] are bandages on the surface problems of today's systems rather than attempts to eliminate the fundamental causes of the trauma."

[4] after the biological evolutionary stages represented in the brain, first the central nervous system, later the limbic system and most recently developed cortex, described for instance by P. A. Vroon, *Wolfsklem, De Evolutie van het Menselijk Gedrag*, 1992.

[5] as Brenda Laurel calls it, in *Computers as Theatre*, 1991

[6] To name two general HCI books: Alan Dix, Janet Finlay, Gregory Abowd and Russel Beale, *Human-Computer Interaction*. 2nd Edition 1998, and Jennifer Preece, Yvonne Rogers and Helen Sharp, *Interaction Design – Beyond HCI*, 2002

[7] Why homo sapiens have always had such large brains we still don't know but it did come in handy.

[8] To the trained engineer the layout of the discrete components can tell a lot about the workings of the apparatus. This is part of what is called 'reverse engineering', an approach sometimes needed when the original design plans or circuit drawings and manuals have been lost (or never existed - such as in the case of the human brain). Having the machine run in order to see how it behaves is an important element in this approach. When confronted with a piece of technology this is what we often try to do, in order to understand how it works and what it can do for us preferably without having to read a manual or follow a course.

[9] Napoleon reversed this scheme in order to confuse ze enemy, and ever since on the continent we drive on the right hand side of the road.

[10] Alan Kay, *User Interface, a Personal View*, in Brenda Laurel (Ed.), "The Art of Human-Computer Interface Design". 1990. pp. 191 – 207.

[11] It was first mentioned in my short paper and presentation, *Interacting with the Disappeared Computer*, Physical Interaction Workshop on Real World User Interfaces, at the Mobile HCI Conference, Udine Italy, September 2003.

[12] This ties to the notion of 'affordances' from the ecological approach to perception, which be discussed in chapter 4.

[13] As Kas Oosterhuis calls his approach, described in his book *Architecture Goes Wild*, 010 Publishers, 2002.

[14] Musical Instrument Digital Interface, introduced around 1985.

[15] In the Dutch language we have two separate words for the two meanings of the word 'design'; one is *ontwerpen* which refers to the act of planning, outlining kind of design and the other word is *vormgeven*, 'shape-giving'. Indeed, design needs to be about both.

[16] As described in for instance *The Ecological Approach to Visual Perception* by J.J. Gibson (1979)

[17] Bongers, A.J., Eggen, J.H., Keyson, D.V. and Pauws, S.C. *Multimodal Interaction Styles*. In: "HCI Letters Journal", 1(1), 1998. pp. 3 - 5.

[18] Jakob Nielsen, *A virtual protocol model for computer-human interaction*. In: "The International Journal of Man-Machine Studies", 24, 301-312, 1986

[19] Donald Norman, *Cognitive Engineering*. In: Norman and Draper, "User Centered System Design", Chpt. 3, 1986

[20] Jesse James Garrett, *The Elements of User Experience*, 2003. See www.jjg.net.

[21] Described in more detail in A.J. Bongers, *Palpable Pixels: A Method for the Development of Virtual Textures*, Proceedings of the "Touch, Blindness and Neuroscience" conference, Madrid October 2002

[22] Stephen Pheasant, *Bodyspace, Anthropometry, Ergonomics and the Design of Work*. 2nd Edition, 1996.

[23] Richard Harper, *People versus Information: The Evolution of Mobile Technology*. Keynote speech and article in the Proceedings of the Mobile HCI conference, 2003.

[24] See for a more thorough analysis of text entry on mobile phones (without reference to *Scrabble*) I. Scott MacKenzie, *KSPC (Keystrokes per Character) as a Characteristic of Text Entry Techniques*. In: Proceedings of the Mobile HCI conference, 2002

[25] Research has been done to optimise keyboard layout, such as the Fitaly one-finger keyboard, introducing the old discussions of Dvorak layout versus Qwerty of normal keyboards to mobile devices. For gestural text input, thre is the now standard language Graffiti which is based on simplified characters of the alphabet, and the further developed language Quikwriting which allows stringing letters together in words with one single (compound) gesture.

[26] *Human-Computer Interaction with Mobile Devices and Services* – 5th International Symposium, Mobile HCI 2003, Udine, Italy. Also a recent book by Hiltunen, Laukka and Luomala, *Mobile User Experience*, (IT Press, 2002) devotes a whole chapter on text entry, a good summary but no solutions.

[27] Around 1990 some seminal work has been carried out in the field of organising interfaces in a design space, reflecting the state of the field of physical interface developments of that time. See Mackinlay, J.D, Card, S.K. and Robertson, G.G. *A Semantic Analysis of the Design Space of Input Devices*. In: Human-Computer Interaction, Lawrence Erlbaum Ass., Vol. 5. 1990. pp. 145 - 190.

Foley, J.D., Wallace, V.L. and Chan, P. *The Human Factors of Computer Graphics Interaction Techniques*. In: IEEE Computer Graphics and Applications, 4/11, 1984. pp. 13 - 48.

Baecker, R.M and Buxton, W.A.S. *The Haptic Channel*. In: Readings in Human-Computer Interaction, Morgan Kaufman, San Mateo CA, 1987. pp 357 - 365.

The PIDS has been described in (early version) Bert Bongers, *A Survey and Taxonomy of Input Devices and Haptic Feedback Devices*. Philips Technical Note TN-298/97, 1997 and a more recent version in: Yolande Harris and Bert Bongers, *Approaches to Creating Interactivated Spaces, from the Intimate to Inhabited Interfaces*, Organised Sound Journal, Cambridge University Press, 7/3, 2002 pp. 239-247

[28] Bert Bongers, *Physical Interaction in the Electronic Arts, Interaction Theory and Interfacing Techniques for Real-time Performance*. In: M.M. Wanderley and M. Battier (Eds.) Trends in Gestural Control of Music. e-book, IRCAM, 2000. pp. 41 - 70.

[29] Again, it is not so much the mouse that is the cause, but the whole paradigm and other factors around it that complicate the situation. RSI is the popular term, which I use here because of its emphasis on the problem of the repetitiveness, but there are better terms such as Work Related Upper Limb Disorder (WRULD) and Work-related Musculoskeletal Disorders (WMSD). See Stephen Pheasant, *Ergonomics, Work and Health*, 1991.

[30] See www.sonami.net and www.steim.org

[31] Bert Bongers and Yolande Harris, *A Structured Instrument Design Approach: The Video-Organ*. In: Proceedings of the Conference on New Instruments for Musical Expression, Dublin Ireland, 2002

[32] www.sensorband.com/soundnet, and Bert Bongers, *An Interview with Sensorband*. In: Computer Music Journal 22(1), 1998. pp. 13 - 24.

[33] See for an overview Bert Bongers, *Interactivated Spaces*. In: Proceedings of the International Symposium on Systems Research in the Arts, Baden Baden Germany, 2002

[34] Peter Zellner, *Hybrid Architecture, New Forms in Digital Architecture,* Thames & Hudson, 1999, or Kari Jormakka *Flying Dutchmen: Motion in Architecture*, IT Revolution in Architecture, Birkhauser 2002.

[35] Kas Oosterhuis, *Architecture Goes Wild*. 010 Publishers, 2002.

[36] See for instance *The Next Intel, How Graphics Powerhouse Nvidia Is Transforming the Chip Game* (Nvidia is maker of the GeForce graphics chips or GPU), Wired July 2002, pp. 101 – 103

[37] Michael S. Malone writes in Red Herring, February 2003: “Forget Moore's law because it has become dangerous. It is a runaway train, roaring down a path to disaster, picking up speed at every turn, and we are now going faster than human beings can endure. If we don't figure out how to get off this train soon, we may destroy an industry.”

[38] The notion of affordances is originally thought out by J.J. Gibson in the sixties, and was already present in the ideas of the Gestalt psychologists, later made popular in the context of HCI by Donald Norman (*The Psychology of Everyday Things)* and further developed for instance by Bill Gaver (see W. Gaver, *Technology Affordances*, Proceedings of the CHI’91 Conference).

[39] See Karl Rosengren, *Communication, An Introduction* (2000) or Stephen W. Littlejohn, *Theories of Human Communication* (2002).

[40] Daniel Dennet refers to 'the brain in the vat' in a thought experiment in *Consciousness Explained* (1991)

[41] W.A.S. Buxton, *The Importance of Ubiquitous Media*. transcript of his talk at the 1st Doors of Perception Conference, November 1993, Mediamatic CDROM.

[42] See for a discussion of the historical aspects in relation to the current technology the book by Malcolm McCullough, *Abstracting Craft, the Practiced Digital Hand*. MIT Press, 1996.

[43] In the first chapter of his book *When Things Start to Think* (1999) Neil Gershenfeld reports his struggles in university and early professional stage with the fact that it was not accepted to work in the 'machine shop' as well as being involved in developing conceptual and theoretical development.

[44] B. Ulmer and H. Ishii, *Emerging Frameworks for Tangible User Interfaces* IBM Systems Journal, vol. 39, nos. 3&4, 2000.

[45] as Paul Dourish calls it in his book *Where the Action Is, the Foundations of Embodied Interaction*, which actually also does discuss the old but relevant philosophical debate of the mind / body relationship

[46] As proposed by Donald Norman in *The Invisible Computer*, 1998.

[47] The Pebbles project has shown the strength of such an approach, based on handheld PDA devices. See Brad A. Myers, *Mobile Devices for Control*. In: Proceedings of the Mobile HCI Conference, Pisa Italy, 2002. The Philips *Pronto* is an example of a commercially available device, but again the physical interface is limited to a touch screen.