Interactivation

Towards an *e*-cology of people, our technological environment, and the arts

A. J. Bongers, Vrije Universiteit Amsterdam, June 2006

SIKS Dissertation Series No. 2006-12

The research reported in this PhD thesis has been carried out under the auspices of SIKS, the Dutch Research School for Information and Knowledge Systems.

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ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad Doctor aan
de Vrije Universiteit Amsterdam,
op gezag van de rector magnificus
prof.dr. T. Sminia,
in het openbaar te verdedigen
ten overstaan van de promotiecommissie
van de faculteit der Exacte Wetenschappen
op dinsdag 4 juli 2006 om 13.45 uur
in de aula van de universiteit,
De Boelelaan 1105

door

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geboren te Den Haag

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Contents Overview (short)

Preface

This thesis is based on the two methodologies of scientific experimentation and artistic exploration. My approach to the field of Human-Computer Interaction (HCI), as described in this thesis, is to look at the interaction between people and technology in general in order to make contributions to the field of HCI. My inspiration comes from the fields of artistic expression such as music, video art and architecture. The thesis describes an iterative process of the mutual influence of art, technology and people.

The following contributions are proposed:

A. *four frameworks for describing and analysing (and possibly extending) interactions:*
   - A1. *a categorisation of technologies and their functions, relevant for HCI*
   - A2. *a framework for describing interaction styles*
   - A3. *a design space for physical interfaces and a taxonomy of interface elements (sensors)*
   - A4. *a classification of media*

B. *an approach to study human perception and action in the context of multimodal HCI, to firmly include the somatic senses, and the research question of whether haptic feedback can improve interaction.*

C. *a design approach based on bringing together and in harmony our natural and our artificial environment through the embedded interactive computer technology (ubiquitous computing), forming an electronic ecology or e-cology.*

D. *the proposal of Interaction Appliances as distributed and modular facilitators to support the e-cological design approach of thinking in functions rather than devices.*

E. *a research agenda for further study and developments.*

The interaction between people and the relatively new technology of computers is less far developed than the interaction with the other and older technologies, yet the possibilities are much bigger. This is why I look at other technologies, and other fields, as a reference and inspiration by the rich forms of interaction found there. Another reason is that computer technology permeates our whole environment. My aim is to broaden the field of HCI to include the other technologies, to study the interaction between people and their technological environment as a whole.
The frameworks I have developed are meant to support the application of multiple interaction modalities, enriching and improving the interaction. It gives directions for further research.

I am discussing the historical development of technological artefacts and environments, particularly the technologies we physically interact with. I will identify the main functions of technology and describe the successive technologies in these terms (A1). The latest technology, the digital computer which facilitates interaction and behaviour, is not only present in isolation but also permeating other technologies due to miniaturisation and networking. This leads to a technological environment that is interactive and that we are all part of: the 'electronic ecology' or *e*-cology (C). This is not meant as a strict method, but as a design approach to treat the interaction with our technological environment as a whole.

In order to study these interactions in more detail, I describe the fields of musical instruments and architecture as specialist areas where particular interactions take place. The field of music illustrates the importance of an intimate, sensitive and rich interaction through the instrument, from the earlier mechanical constructions to current day digital electronic instruments some of which I have developed. The framework for describing technologies mentioned above is based on instrument developments. The field of architecture has always dealt with the spatial interaction between people and their technological environment. Recent developments in dynamic architecture are relevant for the field of HCI, particularly the work on 'interactivating' architecture and my contributions to it.

From these experiences, and from studying other research projects in the field of HCI, I have developed a framework to describe the rich, multimodal, multilayered interactions between people and technological environment (A2) (current or possible). Furthermore, I will introduce a taxonomy for describing and categorising physical interfaces (A3). Many existing frameworks take the current 'mainstream' interaction paradigms as a starting point, which may make them limited in their application for developing new interfaces. I have developed the frameworks based on what would be possible, firmly based on practical experience. Inspiration and knowledge comes from the aforementioned arts fields.

In order to improve the interaction between people and technology, a thorough knowledge and understanding is needed of human (and generally natural) factors such as studied in the fields of psychology, physiology, biology, ecology, bio-mechanics, sociology etc.

The field of psychology is a great contributor to the field of HCI, however we cannot find answers for all the problems. Particularly the psychology of perception has most attention to the modalities of vision and audition, while for HCI the somatic senses including the haptic sense are increasingly important. The field of HCI has therefore developed their own research methods and scientific approaches, also because it has to deal with complex situations were many parameters influence each other. In this HCI field I carried out a number of experiments in order to acquire knowledge about the physical interaction between people and technology. This was done in particular to address the question (B): Can haptic feedback improve the interaction? I am not developing psychological or physiological knowledge as such, but applying and putting together existing knowledge for design purposes in HCI.

Analysing recent and relevant developments in the history of the arts, particularly in artistic expression and representation, lead to a proposed framework to categorise media from static, to time based and interactive (A4). Various *roles* in this process will be identified, which can be applied in other design processes. In order to test and further develop the framework for interface design I will apply it to the development of new interfaces for artistic expression, such as a novel instrument for the live performance of audiovisual material. This includes the addressing of the architectural and natural environment. In another project the interactions with the distributed nature of computer technology is researched, adding a layer of interaction between performers.

All this leads to a design approach for interaction with the electronic environment (C). I have developed several novel interaction styles for general HCI and interactive architecture, which further informed the development of the frameworks (A). These frameworks will be described, illustrated and partially validated. Generalising the knowledge and experiences from the electronic music world on how to deal with distributed functionality (eg. the separation between controller and sound source, facilitated through the MIDI protocol), a shift in thinking for the design of interactive products and environments is becoming clear: *from devices to functions*. The devices will disappear in the electronic ecology, and the way to control the environment is through *interaction appliances* (D). Using the frameworks (A) it is possible to deal with the complexity of the (potential) interaction through the analysis and description of the interactors and context, enabling a modular approach.
The thesis ends with proposals and directions for further research, such as a new form of interactive medium (the video book), a paradigm to include unconscious processing, and a proposal for information radiation (E). Like all scientific work, developments lead to new questions and research directions.

I am deliberately presenting this work partially as a narrative, a search of in total over 15 years rather than the 4 years of a common PhD research project. It is more generalist rather than specialised. However as a PhD thesis in the field of HCI the emphasis is on the core chapters (4,5, 6 and 8), describing the research carried out since the year 2000.

The audience of this text is not only the scientific community of HCI research, but it is written in such a way that readers with a background in communication sciences, media studies, design, architecture, and the arts are also addressed.

Interactivation connects us to our electronic environment, extending our nervous system, supporting memory and cognition, augmenting our senses, and expanding our actions. We become part of an electronic ecology, the *e*-cology.

Structure

The structure of this thesis is in five parts and in total ten chapters, with a preface, list of references, and CV.
The main text is accompanied by an undercurrent of footnotes. I haven chosen this structure to keep the main text more legible, with the references and further elaborations (including sometimes more personal comments) separately from the current of the main text. This structure has helped me to avoid just throwing in references, but through the added layer of footnotes force myself to give some background about the references. It is also a way of keeping references to web sites, magazine articles, internal reports etc. out of the list of references at the end of the thesis.
In the final lay-out of the thesis the footnotes will all appear on the same page or at least very near the main text.
There are diagrams, and many pictures to illustrate the projects described. The illustrations only have figure captions if it is not clear from the preceding text what is shown, to avoid doubling of information.
In addition to the illustrations, there is a lot of audio and video material which will be added in the final version of this thesis, either through a built-in video screen and speakers controlled by sensors (see 10.3) or on a separate CD or DVD linked to the book and controlled by the sensors in it.

The Parts: from stepping stones to foothills, explorations, and onwards

This thesis is divided in thematic parts. Part 1 is a general **Introduction** to the issues of interactivation in the electronic ecology and technology in general. I describe in Part II the **Stepping Stones**, projects I have been involved in as a developer that inspired and informed the early research and directed the approach to the matter. To continue the metaphor, from there the mountains are in view and the **Foothills** in Part III are my recent research and developments, describing the multimodal interactions. Then the **Explorations** in Part IV are about new spatial and multimodal interaction paradigms for multimedia systems, as well as for various art forms - collaborative, electronic, and multi-disciplinary (or rather, *non-disciplinary*). In the last part, **Conclusions and Aims,** I round off with concluding remarks about what has been achieved so far and further describing the vision of the electronic ecology. This is further illustrated with some examples of current research. Described here is also where I want to go next, there are no precise instructions as I am not pretending to know the way. The exploring will continue knowing the directions and aims but not the end goal.

The Chapters

This thesis reports the research and developments in a field that studies the interaction between people, the technological environment, and the arts.

The first chapter described various technologies in *stages*, as developed over time from the first use of artefacts by pre-historic man, to the interactive technology at present which contains its own intelligence. An ecological approach to the interaction between people and technology is described. There is an electronic ecology or *e*-cology due to the fact that the computer with its ability to interact has permeated our technological environment, increasingly invisible and increasingly networked.
In the second chapter musical instruments are described as examples of sensitive, precise, and intimate interfaces, including the importance of the sense of touch. A brief historical overview is given, in the terms as introduced in the first chapter, and the new instruments that I have developed or have participated in developing are described and discussed.
The third chapter describes the spatial interaction with the architectural environment. Some historical examples are given, and the projects I have been involved in as interaction developer are described.
In the fourth chapter the human is described, as a multimodal being that interacts with its technological environment using multiple and concurrent modes, modalities, and layers. A framework is introduced to describe multimodal interaction.
Chapter five is about the human sense of touch and how this is addressed by interactive technology through haptic feedback. Several experiments that I carried out are described and the results presented and discussed.
The sixth chapter introduces my framework to describe the physical interface, as interrelated parts. This design space consists of the parameters range, precision, and haptic feedback, and is illustrated with descriptions of existing interfaces, new interfaces from my own practice, and individual components.
In chapter seven the relation between art and technology is investigated. A historical overview is given, and several of my own projects are described. These projects illustrate an approach to electronic art that is non-disciplinary, based on rich physical interaction, using multiple modalities and media, and addressing the architectural space.
Chapter eight reports two of my recent research projects into multimodal interaction styles for the *e*-cology.
In chapter nine I propose to approach the interaction with the electronic environment by functions rather than by the devices.
Chapter ten rounds off with descriptions of my current research directions, and proposals for further investigation and development to facilitate the interaction between people, technology, and the arts.

Acknowledgements

The work described in this thesis is based on many experiences, and over 10 years of structured research. The variety of places and institutions where this research was carried out is reflected in the diversity of the work.
The early work on musical instruments was carried out particularly at STEIM, the Studio for Electro-Instrumental Music in Amsterdam since 1987, at the Sonology department of the Royal Conservatory in The Hague since 1989, and in several free-lance projects. At Sonology I started working on haptic feedback and developed the Tactile Ring in 1994.
The architectural work have been carried out since 1997 in free-lance projects with the design offices ONL and NOX (both in Rotterdam), in the last years also with the Hyperbody Research Group at the Architecture Department of the Delft University of Technology. Some of the research in this area has been carried out with the Metapolis Institute for Advance Architecture in Barcelona in 2001 and 2002.
The research in multimodal interaction, including the use of haptic feedback, took place at the Institute for Perception Research at the Eindhoven University of Technology when I was working for the Philips company in 1996 - 1997. At Philips I also started working on a taxonomy of input devices.
When working at the Rijksakademie, the post-graduate artist in residency institute in Amsterdam, in 1997 and 1998, I researched the relationship between art and (new) technologies, further developed the categorisation of input devices. The taxonomy described individual sensors and was illustrated with the musical instruments and other art and architecture projects.
At the Engineering Design Centre of Cambridge University I did the research on using haptic feedback in computer interfaces for Motion-Impaired people, in 1999 - 2000. Here I developed a tactual mousepad and loudspeaker based vibrotactile feedback.
Working as an independent researcher in Barcelona from 2000 onwards I developed the taxonomy further into what became the Physical Interface Design Space, and developed the set-up and experiments into Palpable Pixels and virtual textures. In this period I also intensified the research-by-performing into developing instruments for live music and video. Together with Yolande Harris I developed for this purpose the Video-Organ, addressing the architectural space in performances (most notably Inside Out, which interactivated a building), and eventually as a portable instrument for the Video-Walks. Part of this work was carried out in and around the Metronom Lab in Barcelona which I set up in 2001, and at the media space of Nau Côclea in Catalunya in 2002. Meanwhile I kept developing the ideas on group performance with the multidisciplinary group the Meta-Orchestra, co-founded in 2000 as a European project.
The ideas about multimodal interaction and physical interaction driving an approach for HCI teaching, has been applied in many courses taught in several communication, multimedia and product design schools and universities in the Netherlands, and in workshops (also on instrument design) in England, Spain and Denmark. This teaching enabled me to refine and further develop the ideas.
The research into the *e*-cology was supported by the Academy for Digital Communication in Utrecht.
Since 2003 I have carried out research in tactual articulatory feedback in gestural control of interfaces at the Vrije Universiteit (VU) in Amsterdam in the HCI,

Multimedia and Culture group. Some of the *e*-cology ideas were further developed at the VU as demonstrators, such as the InfoZphere.
Since early 2004 part of my research and most of the writing has been done in our own 'MaasLab', a studio on the river Maas in Maastricht.

I want to thank all the numerous colleagues, musicians, composers, artists, architects, crafts people, researchers, reviewers, designers, dancers, cooks, managers, directors, writers, students, professors, motorcycle engineers, friends and family for all their support, encouragement, and sharing their knowledge with me. I would have been nowhere without this.

All the photographs in this thesis are made by myself, unless otherwise indicated.

Glossary

In this thesis there are many specific terms, often made up by me to describe the ideas. Below an overview is given, with a reference to where in the thesis the topic is described in more detail. They are divided in general terms and self invented terms[1], roughly in order of appearance in the thesis.

General terms

Interaction
The mutual influence of two (or more) entities, leading to a change of state in all parties involved (human or machine).

Interface
The part of the machine through which it communicates with its environment. It consists of actuators that make displays (machine output) and sensors that make controls (machine input). The interface facilitates interaction. (Chapter 6)

Modality
A communication channel.

Communication
Transfer of information, knowledge and / or facts

Medium
Facilitates communication.

Mixed Reality
An environment which is a mixture of the real world and virtual worlds. Also known as Hybrid Space or Augmented Reality.

Gesture
A meaningful movement of a human.

Articulatory feedback
Feedback from the system on the human's action when manipulating the interface, facilitating articulation of the human movement.

Tactual
Referring to all the senses involved in the sense of touch together, including tactile, haptic, cutaneous etc. (Chapter 5).

General terms occurring in this thesis

Interactivating
Turning an object or environment in an interactive system.

Technological stages
The development of technologies over time, from the earliest mechanical stage to the latest interactive computer environments (Chapter 1.2).

***e*-cology**
The electronic ecology, in which people interact with their technological environment (Chapter 1.4).

MIS
Multimodal Interaction Space. A design space to describe the interaction between people and electronic environment in the dimensions of *sensory modalities, modes,* and *layers of interaction* (Chapter 4)

PIDS
Physical Interface Design Space. A proposal to describe the interface in terms of *range*, *precision* and *haptic feedback* (the feel of the interface). The range is expressed in a logarithmic scale of *intimate* (eg. within the hand), *bodyspere* (around the body, about 1 metre), to *spatial* (the architectural space).
Interaction Architecture
A mixed architecture of real and virtual environment. The Interaction Architecture is described in palettes: a palette of human modalities, a palette of system parameters to interact with, and the interaction palette of interaction styles (Chapter 8.2).

Interaction Appliance
A device or set of devices to enable interaction between a person and the electronic environment. It consist of an interface, with a certain amount of sensors matched to human output modalities, linked to specific system parameters. It can also facilitate system output, through displays addressing the human senses (Chapter 8). A protocol needs to be developed to describe the meaning of interactions throughout a distributed system.

Specific terms occurring in this thesis

Palpable Pixels
Feeling the pixels on the screen, translating pixel values into touch through the tactile explorer mouse with added vibrotactile feedback. This way widgets, boundaries and other visual (or non-visual) elements of the visual interface can be felt, including textures: tangible textures (Chapter 5)

Haptic Finder
The visual interface of the computer enriched with haptic feedback and presentation of information, paraphrasing the *Sonic Finder* of Bill Gaver in the late 80s (Chapter 5)

Tactile Ring
At Sonology I developed a ring with built in electromagnetic actuator which creates tangible cues to the wearer, for articulatory feedback (Chapter 5)

Movement fingerprint
The idiosyncratic way of moving of individual people, both in whole body expression as well as in the way objects are manipulated (Chapter 5)

SonoGlove
A glove outfitted with sensors for rich control of sound sources. Ideally combined with built in actuators, so that the hand of the player can mould the sound like clay, SonoPutty (Chapter 2).

Interface-lifting
Referring to the tendency of incremental improvement of an interface, patching and upgrading instead of re-designing it. (This term is already used elsewhere, often with different meanings).

Remote touch
Feeling at a distance, for instance with the set-up with the laser pointer and camera traking with tactual feedback (In Dutch: afstandstast) (Chapter 8.3)

Device Parsing
Analysing a device or its interface, including actually taking it apart, in order to reveal its functionality (Chapter 9).

InfoZphere
The information electronically radiated by an object or building, revealing details about itself. It is a demonstration of the *e*-cology (Chapter 10).

Little Brothers
All the bad interactions with our environment, instead of one Big Brother interfering with our lives (Chapter 9).

Neo-Cartesian split
Referring to the separation of virtual (computer generated) world and the real world, as in Virtual Reality (VR). This is similar to the mind/body dualism, and equally unwanted.

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[1] Googled and Yahoo'ed., generally new terms.

Contents

Part I
Introduction

In this first part I give a general introduction to the topic of interaction with our electronic environment. The technologies that we interact with are described in the historic stages of development. Our technological environment changes due to the increasing pervasiveness of computer technology. The computer becomes ubiquitous in our environment, embedded, networked, miniaturised, omnipresent yet increasingly disappearing. When the computers are disappearing we don't want the interface to disappear as well, and it can be seen that this is currently happening. The development of the 'interaction bandwidth' is lagging grotesquely behind the increase in computing power and memory sizes following Moore's Law. Therefore an *ecological approach* is introduced, and developed further in this thesis.

1.
The e-cology
Interaction with our Electronic Environment

In this chapter the historical developments of technologies that we interact with are described in stages. It discusses the incremental and evolutionary nature of technological developments, and it is argued that a holistic approach to design may lead to better integration of the interactions with our technological environment, unified by the electronic layer. We are part of an electronic ecology or *e*-cology.
If it is true that we, as a human race, are inventing our own successors, we must not underestimate this task. At present, a man-machine symbiosis is the best to strive for. This approach is keeping the human central and in control, by *augmenting* the human abilities rather than the adaptation of humans to technology.

In order to understand technology better it is put in a historical perspective, starting from the first man-made artefacts over two million years ago. Since then several technologies have been developed, and the most relevant in the context of human-technology interaction are described here. The main functions of technologies are identified, having to do with the *generation*, *processing*, *translation,* and *storage* of both information and energy. The technologies described are the mechanical, electrical, chemical, magnetic, optical, and the most recent development of programmable digital computer technology including the role of software. Often the technologies around us are compound, integrating for instance electrical and mechanical systems.
The computer meanwhile has become smaller and smaller, and is integrated or embedded in many other technologies and systems, taking over the control functions through automation. The computer is disappearing and at the same time becoming omnipresent, networked, ubiquitous, and increasingly more powerful. However there is a danger that the *interface* also disappears and with that our ability to be in control of the technology.
At the same time the increasingly ubiquitous nature of computers offers new opportunities. This is one of the main topics of this thesis, describing developments that contribute to the research into new interaction paradigms for a ubicomp environment. An ecological approach is followed, proposing to treat our technological environment as a whole. Our technological environment is permeated with computers so that we can speak of an electronic ecology or *e*-cology. The interaction paradigms are therefore less task based but more environmentally based.

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* of this technology.

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 devices can become so small that we can barely hold them in our hands, let alone operate them. This can for instance be seen with appliances such as the mobile phone and the wrist watch. 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.

The notion of *ubiquitous computing*[1] (or *ubicomp* in short) 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.......

1.1.1 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.

1.1.2 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 horse powers, 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.

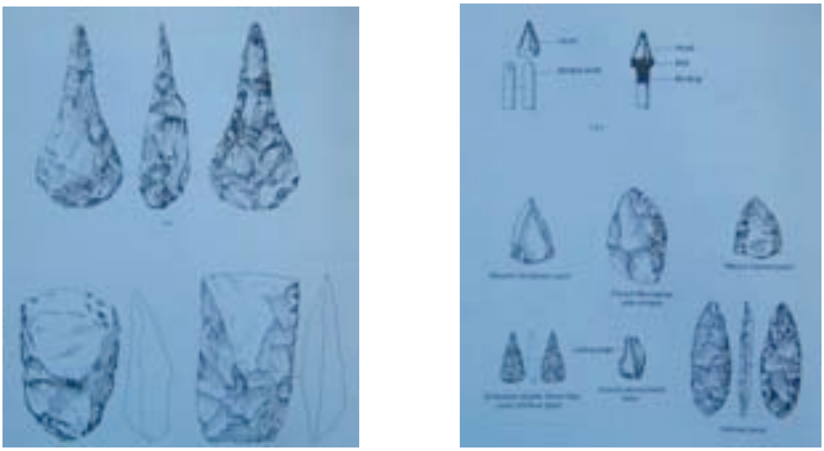
Of course, our natural ability to adapt means that we can learn to use almost any interface, even a bad one. Technology gets away with bad interfaces, but it could get much further with a good one.

1.2 Technological stages and their interfaces

In order to manipulate an object, or a process inside a machine, an interface needs to be present. The interface links the possibilities of the machine or object to the capabilities of the human. The nature of the interface depends on the kind of the underlying technology.

Interfaces connect technology to humans. Internally the human as a living organism operates electrically and chemically. For the connection with the outside world interactions with these categories of technologies do occur (for instance an electrical shock, or medicine) but often interactions take place through mechanical or other translations. The human senses are based on receptors for chemicals (for instance in the mouth and nose), light (eyes), and mechanical changes (skin, ears). Human effectors are mainly based on the mechanical system. This will be described in more appropriate detail in Chapter 4.

Over the course of hundreds of thousands of years humans increasingly 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. In the last 2,000,000 years this craft was perfected, accumulating knowledge and skills to a high level of complexity.



some prehistoric hand tools[2]

This development can be called the *technological evolution*, following (and running alongside) the much slower *biological evolution*. The biological evolution of life started with the first one cell organisms around 3.5 billion years ago, and culminated in the hominids (*Hominidea,* including ape like animals) about 5 million years ago. The hominids descended from the anthropoids, although the common ancestor is still not found as not many fossils remain of this critical period of between 10 and 5 million years ago[3].

There are several theories about why the hominoids started to live in the plain fields rather than the trees, started to walk upright and developed large brains (which consume a lot of energy and were not intensively used until much later). The reason for the descent from the trees into the savannah is like the chicken and the egg problem, but it can be said that due to the lack of natural 'tools' like claws or sable teeth other strategies were employed which were highly successful. Walking upright enabled the *Homo erectus* to see further (thus seeing opportunities for prey or, for the taller males, keeping an eye on the females), and cover larger distances in search for food – the hunter-gatherer species were essentially nomadic. The genus *Homo*, from about 2 millions ago, is particularly well suited for endurance running as a recent study proves, through a number of essential anatomic features including muscular, bone and other adaptations[4].

Another feature is the multi-purpose assembly of teeth that enabled far more efficient pre-processing of food, and a the wider variety of diet. Finally, the use of the large brains was a success factor for the Hominids, enabling stone toolmaking which is about 4 million years old and symbolic thinking which started around 50,000 years ago. Examples of tool making of other animals are rare, and often don't indicate sophisticated planning behaviour. Chimpanzees use sticks or straws to pick up insects, and there are some reports of them shaping their tools.

The brains of the *Homo erectus* had increased rapidly in size, and the Neanderthals (*Homo sapiens neanderthalensis,* living from 120,000 to 25,000 years ago) were the first species to think symbolically: they buried their dead, used some kind of language[5] and were able to make fire.

Homo sapiens sapiens appeared about 100,000 years ago and is the only remaining species from the *Homo* genus[6]. The massive development that followed will be described focussing on our species.
After the development of tools and use of fire, the most important breakthrough was the development of symbolic thinking about 60,000 to 30,000 years ago[7]. This will be discussed in chapter 4.2 about human communication.
Since about 10,000 years BC in Mesapotamia and Egypt agriculture, and farming of animals, the first villages and eventually cities start to appear. Other inventions came about, such as the potters wheel, weaving, the wheel, sailing, boats. Often this period is called the Neolithic revolution or the birth of civilisation[8]. With the development of symbolic language and more particularly of writing, the subsequent developments (including the *cultural* evolution of mankind) became better documented[9].

The further technical evolution of mankind is best described in the technological stages that can be identified. Historically the development of the various technological stages often happened concurrently. To describe this development, and its relevance for this thesis, it is essential to organise it in technologies and functions[10]. Every technology brings about its own kind of interfaces. The underlying technologies in a system have an influence on the way we interact with it.

Technologies
- Mechanical (object, passive mechanical and active mechanical)
- Electric (electrical, analogue electronic and digital electronic)
- Software (the programmable computer)
- Chemical
- Magnetic
- Optical

These technologies will be described in the next sections (1.2.1 – 1.2.6), giving a short historical perspective and analysing the functions of each technology.
In addition to the general use of technologies as tools there are more functions to discern. First, it is useful to distinguish energy in the categories of power and information. These energies can be transported, processed, stored, and converted. These main functions are summarised in the list below, and further described in the next sections in relation to the technologies.
For interfacing between humans and technology *translating* of information is a very important function. In Chapter 6 this will be described in more detail for the case of electrical technology. Sensors and actuators connect the electrical inside of the current technology to the other forms of technology around it.

Functions for power:
- *Transportation* of power
- *Storage* of energy (to be used at another time)
- *Conversion* of power (from one energy form to another)
- *Supply* or generation of power

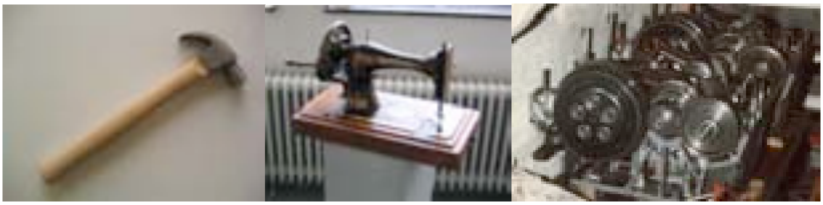
Functions for information:
- *Communication*, including the coding of information for transmission
- *Storage* of information

- *Translating* of information (from one form of energy in the other, for sensing or display)
- *Processing* of information

I will describe the issues in more detail in the sections below, the terms are placed in italics when they occur.

1.2.1 Mechanical

For the category of mechanical technology it is useful to make a distinction between objects, passive mechanical and active mechanical (ie. with an external power source). As described above, the earliest tools mankind interacted with were objects – stone hand axes, cleavers, spears. The ergonomics of objects and tools is still applicable in grip design for hand tool, door handles, hammers etc.[11] Later more complicated tools were developed for instance for agriculture and transport, including the application of levers, the invention of the wheel, leading to passive mechanical machines.



some examples of mechanical systems

Energy could be *stored* in a tensed bow (to shoot an arrow) or in a spring. Later energy sources were added, this is the category of active mechanical technology.
Mechanical ways of *storing information* and *communicating* are through writing, first on stone and clay tablets, later on papyrus[12] and paper, further sped up by the invention of book printing in combination with the movable type by Guthenberg in Mainz, Germany, in 1452.
Early examples of *communication* can be found in mechanical systems: clocks, church bells, semaphore (flag) signs, and wires strung along railroads to operate signals at a distance. *Information processing* occurs with mechanical calculators and even computers, such as the Difference Engine and the Analytical Engine designed and partially built by Charles Babbage between 1830 and 1850[13]. New ways of *storing information* mechanically appeared around 1900, for instance in the wax roll of Thomas Edison and subsequent gramophone players, and even amplified and displayed by mechanical means.
Active mechanical technology includes an energy source. The first energy sources were animals such as horses or oxen, later the power came from wind mills or water mills, and even later steam engines followed by the combustion engine and the electromotor. Pneumatic and hydraulic systems are active mechanical, in certain cases capable of *processing* information.

1.2.2 Chemical

The earliest example of the use of chemical technology is fire, since about 400,000 year ago. It is used for *supply of power* and *storage of power*. As an energy source by burning wood[14] or coals to transfer into kinetic energy with the steam engine, or by exploding gassified petrol in the internal combustion engine. Today we still use fire (for instance by burning gas) to heat our houses.
Fire (and smoke) has been used for *communication*, transmitting information over larger distances.
Drugs and medicine are another example of the use of chemical technology, directly influencing the chemical balances in the human body.

Chemical *storage of information* occurs by using paint, and in photography. Using chemical changes under the influence of light (see under optical below), an image is captured on film and later reproduced on paper, or by projection. This process was first stationary (photography) and later moving (film).

1.2.3 Optical

Optical technology plays an important role in photography and film. Lenses are used both in the process of capturing light images on chemical film (see above) as well as the projecting of the (moving) image.
In the last few decades fibre optic cable is used for *communication* of digital data with a very high bandwidth, and optical computers are in development for *processing information*. Optical *storage* is widespread since the invention of the Compact Disc, and later the DVD. In all these cases Laser light is used[15].

Infrared light (invisible to the human eye, see chapter 4) is often used for short range *communication*, such as the IrDA protocol between digital devices or the RC2 codes for controlling home equipment.
Light is used less for energy storage or generation. Solar panels are used for *conversion* of light into electricity Heat can be stored energy in water or other substances.

1.2.4 Electrical

Currently, electricity is the most widespread technology, used for *storage*, *transmission*, and *processing* of both power and information, easily converted into other energy forms and vice versa. It is useful to make a distinction between electric and electronic (capable of changing signals) technology, and the latter further distinguished in analogue electronic and digital electronic technology.
Electricity has been known in nature in forms such as lightning[16] and static electricity, the latter in particular was seen in combinations of material such as rubbing glass and silk. This effect, called the triboelectric effect, can be seen also in amber, a well known material to the ancient Greeks and the name electricity indeed comes from the Greek word for amber, elektron, via the Latin word electricus introduced in 1600. The first apparatus in the 17th century that created electricity were based on the static effect, such as Otto von Güricke's friction generator around 1650 and later followed by inventions such as the Wimshurst machine in 1832 and the well known Van de Graaff generator in 1912. Chemical reactions were discovered that could *store* electrical energy, such as the Leyden jar[17] in 1746 which was a capacitor, and later *generate* electricity starting with the invention of the 'voltaic pile' by Alessandro Volta in 1800[18].
When the relationship between magnetism and electricity was discovered, it became possible to build generators and motors based on this principle. When an electric conductor (for instance a cupper wire) is brought in an magnetic field a current will be induced, while a current flowing through a conductor will result in a magnetic field around it. Using lots of cupper wire, in spirals in a coil, accumulates this effect. Based

on this principle are for instance the electromotor, the generator, the loudspeaker and microphone.
Practical application of electricity for *communication of information* did not occur until the 19th century, with the invention of the electric telegraph in 1837 in combination with the Morse code in the same year.

The wireless telegraph was the first radio, as a *communication* medium and developed in the 20th century into mass media for both audio and video (television).
Since the invention of the valve or vacuum tube at the beginning of the 20th century it became possible to modify electrical signals, this is the category of analogue electronic technology. The first occurrence of the CRT (Cathode Ray Tube) as a commercial device for *displaying information* was in 1922.
In the fifties the transistor made of silicon (and sometimes germanium, but this is rare now) was invented, allowing electronic circuits with a much higher density and lower power consumption. Integrating transistors in larger quantities on the surface of silicon led to the development of IC's (integrated circuits) or chips. The first digital electronic IC's was introduced in the sixties.
Transistors were used to create analogue computers, while the first digital computers were made with vacuum tubes, such as the ENIAC in the US and the EDSAC in England around 1945, and later made with transistors and IC's leading to the current state of the computer. A computer can store, process and display information; it can be *programmed*. Its functions depend on software, stored in the memory of the computer.

1.2.5 Magnetic

Magnetism is mostly used in combination with other technologies, as mentioned above particularly in the combination with electricity.
The compass is an example of a mechanical system that uses magnetism for orientation by detecting the earth magnetic field. It *translates* magnetic energy into mechanical energy, displaying the magnetic field through mechanical means.

Magnetic *storage of information* has been used since the invention of the tape recorder around 1900 (although it became only widespread after decades of the gramophone system, until 1940), first analogue (audio, video) and later also for digital data on tape or discs (floppy disks, hard disks).

1.2.6 Computer and software

As mentioned before in the section describing electrical technology, the unique feature of a computer is that it can be *programmed*. It works with abstractions and numbers, currently internally with the binary (base 2) system. The result is that software technology is invisible, in fact not directly perceivable at all. Inside the computer resides a virtual world, which will be described later. It is not possible to interact with it directly, so for each task or function, from the most basic to the most complex, the interaction needs to be designed. This is an important subject in this thesis.

1.2.7 Relationship between technologies

To summarise, focussing on the technologies that we interact with most directly, below is a categorisation of artefacts developed by humans over time, in stages of development:

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

This distinction is proposed because 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 analogue display and dials instead of displaying the time in digits.

It is important to realise that most technological systems are *compound* systems. For instance, the car is a combination of mechanical, chemical (the fuel burning), electrical (the ignition system, lights), electronic and computer technologies. What is currently happening is that the computer technology is getting increasingly embedded in our environment, intertwined with the other technologies. This leads to an electronic ecology or *e*-cology that we are all part of.

Technologies are often combined to achieve new functionality. I already mentioned that the combination of magnetic and electric technologies has lead to the invention of many energy converting systems, and in further combination with mechanical technology to systems such as the motor and the microphone. The application of electro-mechanical systems on the scale of the silicon chip (from a micrometre to one millimetre) has lead to micro system technology or microelectromechanical systems (MEMS). This technology is currently used for making sensors (acceleration, gyroscopes, pressure) and actuators.

One step smaller is the nanotechnology, operating on the scale of molecules, between 1 and 100 nanometer[19].

1.3 Technological evolution

The technological stages as described in the previous section mainly concern the last few thousands of years of technological development, after the pre-historic phases of Stone Age, Bronze Age, Iron Age etc. Due to the accumulation and increasing complexity, it seems as if technology and its impact on society develops in a logarithmic way. After the phase of industrial revolution which was particularly based on mechanical systems, came the phase where electrical systems were added, and finally the electronic systems that brought about the information society. These developments have been reflected upon by many thinkers, such as Lewis Mumford starting early in the twentieth century, Marshal McLuhan in the sixties, and Neil Postman in the end of the century. Postman describes three cultures: *tool-using cultures*, which still exist but rarely on their own, *technocracies*, and finally the *technopoly* which he argues only exists (or starting to exist) in the US[20]. A main characteristic of a technopoly is that it seems to strive to take over humanity, it is alienating, and not in harmony with culture. This is something already warned for by Mumford, who described *megatechnics*, an approach where technology and capitalist drives are considered to be leading[21]. Mechatechnics was opposed to what he called *biotechnics*, an organic, self organising form of technology. (Not to be confused with 'biotechnology', the application of technology using biological systems or organism.) It seems that Mumford's biotechnics is very close in spirit to what I advocate with the term electronic ecology.

1.3.1 Complexity and (in)visibility

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. This can be seen in the early designs for a mechanical computer around 1840 and the analogue 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 possible 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 of 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[22]. 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 inherently develop 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.

This development is still going on. Fortunately, the flexibility and total malleability of the elements of design for the computer interface (both in hardware and software) enables many solutions[23].

1.3.2 Moore's Law and the User Interface

Even though there is an element of self-fulfilling prophecy in it, 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[24]. What keeps this development under control is the seemingly equally impressive exponential growth of the demands of software. When one buys a new computer and upgrade all software, usually every three years, this balance is shown in the fact that everything seems to happen at the same speed (or slowness) as before.

The real point is that Moore’s Law doesn't hold for the user interface, not even remotely. The size of my screen doesn’t double every 18 months (in fact it doubled in 10 years), the mouse now has a scroll wheel which adds *one* degree of freedom (after 30 years) to which the graphical interface responds, my stereo sound doubled in resolution and sampling frequency (in 10 years), and I can talk at the computer and it can talk back. It does play video smoothly and does 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.

1.3.3 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 all of 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 it is 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[25].

relative similarity of car designs[26]

The motorcycle 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 audio-cassette and CD playing capabilities and the relaying of traffic information, demanding more interactions with the driver who should rather keep the 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, such as the computer. When the current interface paradigm with windows, icons, menus and pointer (WIMP) 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[27]. The knowledge applied from human behavioural research was related to Jean Piaget's studies on the development of learning behaviour in the 1920s, where he found that children are going through several distinctive intellectual stages during their development from birth through maturity. He identified a *kinaesthetic*, a *visual* and a *symbolic* stage. In the 1960s, this work was extended by Jerome Bruner who came up with a conception of multiple separate mentalities, linked to the stages as identified by Piaget, respectively called *enactive*, *iconic* and *symbolic* mentality. At Xerox PARC, the Palo Alto Research Center set up by the Xerox Imaging company in the 1970s to do research on 'the office of the future', researchers used these ideas to come up with a new paradigm for interacting with computers. Taking these learning phases as separate mental stages in any interaction of humans with their environment and applying this knowledge to HCI, the research looked at how people are actually doing things and perform tasks, and tried to come up with a paradigm that facilitated these mentalities (informally described as *doing*, *image*, and *symbolic* mentality). The interaction between humans and computers until then had taken place in a *symbolic* (textual) way. Using enabling technologies such as the bitmapped display and the mouse, an *enactive* part (pointing with the mouse) and an *iconic* part (or figurative part, the windows and icons) were added. This WIMP paradigm can still be found in the current GUIs such as the Apple MacOS, Microsoft Windows and XWindows.

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 can address our sense of touch, and processing power went up dramatically. Also our knowledge of the human factors and interaction issues has increased. But the 2D desktop metaphor is still the same after thirty years. The limitations of the paradigm are hindrances for further developments. Rather than carrying on by 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 indeed researched in many HCI 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?

1.4 *e*-cology: the electronic ecology

The *e*-cological approach, as put forward in this chapter, 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[28]. 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. As stated before, this leads to the Ubiquitous Computing paradigm, or also called Pervasive Computing (the computer diffused into our environment)[29], or Sentient Computing (the computer's focus is on sensing and interpreting the environment)[30]. The emphasis of the research is on how to interact with the computers in the environment. The European initiative of the Disappearing Computer led to many projects looking into new interaction paradigms[31]. The research field of Ambient Intelligence brings together intelligent environments and interaction[32].

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 often by the way it is presented. It is an artefact of technological systems[33]. 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[34].
The *e*-cological approach regards the design of the interactions with our man-made technological environment as a whole, inspired by (and combined with) our relation with the natural environment. It is therefore expected that this will lead to a better match between our natural and technological environment, more effectively applying our existing (tacit) knowledge about interaction. In that sense the *e*-cology is going further than the ubicomp approach and other pervasive technologies. I therefore decided to make up another "*e*—" word for it, inspired by common terms like e-mail, e-commerce and e-motive architecture[35]. I am fascinated by how all systems interact in relation to the interaction between people and their technological and their natural environment, now that they increasingly merge.
Using the ecology terminology is already been used for some other ideas, but in a more limited way. For instance, the Internet has been called an electronic ecology but limits the boundaries of the ecology to the electronic world. There are also web site design companies for environmental initiatives that use the term electronic ecology. Researchers from the Risø Laboratory in Roskilde, Denmark, have labelled their approach also after this strong notion of the ecology. They, too, are inspired by the work of J.J. Gibson[36]. Their Ecological Interface Design (EID) emphasises the importance of the context of use, the application and its environment, particularly in complex situations such as nuclear power plant control rooms and airplane cockpits[37].

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, while only the interface is left (hopefully!). The interface facilitates interaction.

In this chapter I have proposed a framework for describing and relating technologies that are potentially all part of the *e*-cology. In order to develop new interaction paradigms, the human side of the interaction needs to be explored in more detail. What are the modes, modalities and layers (from mental to physical) in the interaction? This is discussed in chapter 4. To give this some grounding, I will first look at two fields where interactions between humans and their artefacts or environments take place which can be part of an *e*-cology. In the next chapters I will describe interaction paradigms on the intimate scale of the musical instrument, and on the spatial scale of architecture. These are two traditions with vast knowledge about interaction, on the two scales mentioned. In the later chapters there will be examples of *e*-cologies such as the Video Walks (chapter 7.3.2), interaction in the Protospace environment (8.2) and other projects.

[1] The notion of ubiquitous computing has been developed by Mark Weiser and his team at Xerox Parc in the early nineties, see for instance the seminal article in the Scientific American [1991].
Ubicomp is not strictly the same, argues Bruce Sterling in *When Our Environments Become Really Smart*, a chapter in the book *The Invisible Future* [Denning, 2002, pp. 251-275]. Sterling takes ubicomp away from the technological roots of ubiquitous computing, "Ubicomp is what ubiquitous computing might look like after sinking deeply into the structure of future daily life" and that ubicomp is "something that Joe Sixpack and Jane Winecooler can get down at their twenty-first hardware store, cheap, easy, all they want, any color, by the quart".

[2] The picture is taken from an archaeology book [Fagan, 2001].

[3] A recent find of a remarkably complete 13 million years old fossil is thought of as an ancestor of the anthropoids and hominoids, and named *Pierolepiththecus catalaunicus* after the location near Barcelona, Spain [Moya et al, 2004], although there is some disagreement about the conclusions as summarised by E. Culotta in the same volume (pp. 1273-1274).

[4] See the cover article of Nature of November 2004, *Born to Run: how evolution got us up to speed*. [Bramble and Lieberman, 2004].

[5] The archaeologist Steven Mithen, the author of *The Prehistory of the Mind, a search for the origins of art, religion and science* [1996], is currently working on a book in which he postulates that the Neanderthals had a kind of 'musilanguage', a musical language rather than a grammatical language [2005]. See also the interview with the scientific editor Hendrik Spiering of the Dutch newspaper NRC “De Zingende Neanderthaler”. *M Magazine*, NRC Handelsblad, September 2004.

[6] Although the recent discovery [Brown et al, 2004] of a small descendent of *Homo Erectus* at the Indonesian island Flores, *Homo floresiensis*, has lived until at least as recently as 18.000 years ago and there is anecdotical evidence that this species has been around even more recently. In fact, there are many legends and stories in Indonesia of 'little people'. The scientific editors of the Dutch newspaper NRC, announcing the discovery of *H. floresiensis*, posed the question that if we would encounter this species alive would we put them in the zoo or in a hotel?

[7] Most evidence, in the form of artefacts such as flutes, art objects, beads etc. that have been found date from this period which is often described as a revolution or 'big bang' in the development of human cognition [Mithen, 1996]. There are other theories however, recent discoveries of older artefacts suggest earlier development of symbolic thinking, not surprising if one considers that the brain capacity has reached a sufficient level about 150,000 years ago.

[8] But again, revolution shouldn't be taken too literally, as something sharp and sudden but as a transition that took a longer time, as described by the historian Fernand Braudel. His fascinating, posthumously published book (translated from French, *Les Memoires de la Méditerranée* in 1998 after a manuscript originally written in the late sixties) about the history of the Mediterranean, appears in a hardcover version *Memory and the Mediterranean* , while also published as paperback *The Mediterranean in the Ancient World* [Braudel, 2001].

[9] See for instance *A Brief History of Western Man* [Greer, 1968].

[10] Often writing and mathematics etc. are called technologies, or language as a 'device'. While I agree with the terminology, I focus here on technologies that we physically interact with, and explore the language and communication in Chapter 4.

[11] See for instance the chapter on Hand Tools in the ergonomics book of Erwin Tichauer [1978].

[12] Which gave the Romans and important advantage over the Phoenicians, who were primarily relying on the sea for transport because they communicated through clay tablets, while the Romans applied the much lighter papyrus which was an important factor in their success occupying great areas of land. Through the papyrus as a communication medium transportation over large distances over land became possible, as pointed out by among others Marshall McLuhan [1964].

[13] Babbage only managed to build a small part of his Difference Engine no. 1, now in the Science Museum in London. The Analytical Engine he designed, was never built. The much simpler but still highly complicated design for the Difference Engine no. 2 was not carried out

until around 1990, by the Science Museum thus proving that the design would have worked. Thinking along these lines, the writers William Gibson and Bruce Sterling [1991] wrote a Science Fiction novel taking place in the past, ie. the past that *could* have happened if Babbage machines were built, the fax machine (indeed invented in the first half of the 19th century) would have been become more widespread, and with the telegraph added to the mix they portray a world of ICT about hundred years before it actually happened.

14 Partially burning wood under low oxygen conditions result in charcoal, an ancient way of *storing* energy.

15 I leave the laser guns and other weapons out of this description, because they mainly exist in SF movies, such as the neo-western George Lucas' Star Wars.

16 Whether Benjamin Franklin really flew a kite in a thunderstorm in 1752 to catch the electricity or not is a historical debate. He did prove that lightning was an electrical phenomena, but described his method poorly – others who tried got electrocuted.

17 Invented by Pieter van Musschenbroek at the University of Leiden in the Netherlands which gave it its name. The discovery was published to the academic world, and the name stuck although a German inventor independently developed a similar device slightly earlier. But then, Laurens Janszoon Coster may have invented the printing press and movable type before Johann Gutenberg. 1-1.

18 The name 'battery' was coined by Benjamin Franklin, referring to the electric shock one would get which felt like a beating or a 'batter'. The word accu was later used to indicate the ability to store (accumulate) electric energy. In the Dutch language this distinction is still made, ie. a 'batterij' for the device that delivers stored electrical power and 'accu' for the device that stores and re-stores it (ie. a rechargeable battery).

19 The potential and possibilities of nanotechnology have been described in the book *Engines of Creation, the coming era of nanotechnology* by Eric Drexler [1986] (the contents of this book are available on line at www.foresight.org/EOC/).

20 See the book *Technopoly, the surrender of culture to technology* [Postman, 1992]

21 Mumford describes the Megamachine, which in fact can exist of people. See for instance the chapters *Technics and Human Development* and *The First Megamachine* from the two volume book *The Myth of the Machine* completed in 1970 and reprinted in the Lewis Mumford Reader [Miller, 1986].

22 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.

23 As John Heskett puts it: "Theories about form being a reflection of function have been demolished by the dual effects of miniaturization in printed circuits and astonishing increases in processing power encapsulated in computer chips. Processes are no longer visible, tangible, or even understandable, and the containers for such technology have become either anonymous or subject to manipulations of form in attempts to create fashion or lifestyle trends." In *Design, a very short introduciotn* [Heskett, 2005], p52. This book has been previously published in 2002 as *Toothpicks and Logos: design in everyday life*

24 Originally announced in the sixties, see [Moore, 1965]. 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.”

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

26 The photograph on the right is from a poster made by COMA (Marcel Hermans and Cornelia Blatter) called *Car Silhouettes*.

[27] See the article by Alan Kay, who led the team [Kay, 1990]. It can be found in *The Art of Human-Computer Interface Design*. [Laurel, 1990] as well as in the Multimedia Reader [Packer and Jordan, 2002].

[28] The *e*-cology was first mentioned in a short paper and presentation at the Mobile HCI Conference in Italy [Bongers,2003], and further worked out in a little book [Bongers, 2004]

[29] IBM started using the term Pervasive, see www.research.ibm.com/thinkresearch /pervasive.shtml, but other academic institutes use it too, see for instance MIT's Oxygen project www.oxygen.lcs.mit.edu. There are conferences and journals on Pervasive Computing. The word Pervasive has a similar meaning to Ubiquitous, but one could say that it emphasises the fact that it is *active* a bit more.

[30] This term refers to the ability to sense, emphasising the importance of systems becoming aware of their environment and being able to have a rich connection to the real world (although system output modalities should be included for that too). Sentient Computing is the term used by a group of researchers led by Andy Hopper in Cambridge in England, first at the Olivetti lab which has later become AT&T when I visited it in May 2000. The research now takes place at the computer science department of Cambridge University (of which Andy Hopper is the head), see www.cl.cam.ac.uk/Research/DTG/research/sentient/.

[31] More information can be found at the project web site: www.disappearing-computer.net, and the research led by Norbert Streitz at the Fraunhofer institute in Germany, see www.ipsi.fraunhofer.de/ambiente/english/index.html and the special issue of the Communications of the ACM, March 2005, and a chapter in the *HCI in the New Milennium* book [Streitz, 2001]

[32] Researchers and designers from the Philips company in the Netherlands have introduced this term, to emphasise the combination of system behaviour and user control. There are several articles and books on the topic [Aarts & Marzano, 2003], and conferences such as the European Symposium on Ambient Intelligence (www.eusai.nl).

[33] This is emphasised also in the notion of Calm Technology, as put forward in the mid nineties by Ubicomp researchers at Xerox PARC Mark Weiser and John Seely Brown.

[34] This ties to the notion of ‘affordances’ from the ecological approach to perception, which will be discussed in chapter 4.

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

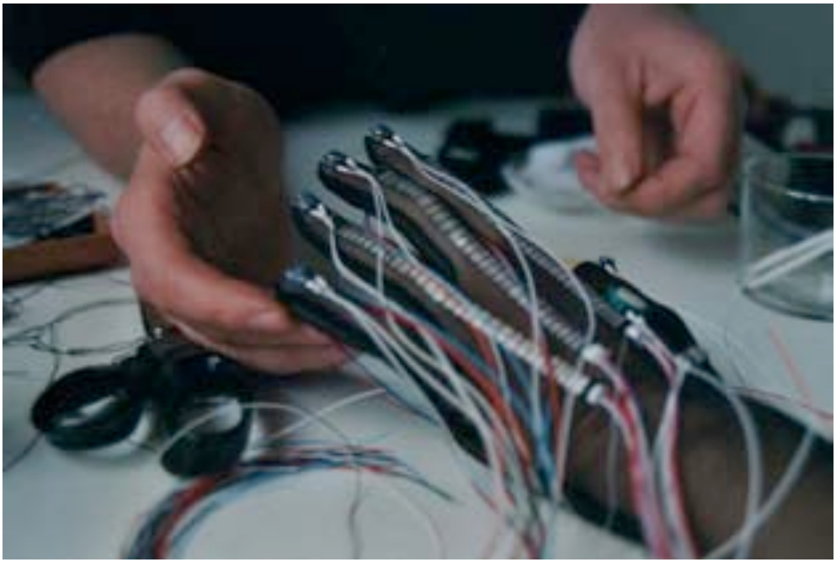
[36] See for instance the book *The Ecological Approach to Visual Perception* [Gibson, 1979], and chapter 4 of this thesis.

[37] There are several articles published about EID by Jens Rasmussen [1989] and Kim Vicente [2002], and recently also a book by their former PhD students [Burns and Hajdukiewicz, 2004].

Part II
Stepping Stones

The field of study of Human-Computer Interaction (HCI) is relatively new and very complex, as introduced in Part I. It is even more complex when we take the whole technological environment into account. One way to deal with this complexity is to look at other fields of complex interactions, such as aeroplane cockpits, medical equipment, biological systems, sailing boats or racing cars.

There are two fields that I have personal experience with as a developer: *electronic musical instruments* dealing particularly with the intimate scale of interaction, and *interactive architecture* which deals with the spatial scale. A number of projects helped me to define my approach to the field of HCI, and I regard these as *stepping stones* for this development. In Part II of the thesis I describe these projects from the two fields: Chapter 2 emphasises the *intimate* scale of the interaction, and Chapter 3 describes interaction at a *spatial* scale.



2.
Musical Instruments
the intimate interface

This chapter emphasises the intimate and precise interaction a player has with musical instruments, and the potential relevance for the design of interfaces in general. It first illustrates technological stages as introduced in Chapter 1 with various musical instruments. The role of recording media is described, which made it possible for the first time in history to capture, store and replay music. This had a great impact on how we approach music.

Some recent new electronic instruments are described, starting from hand held or worn interfaces such as a glove, to bigger scale instruments. All these instruments facilitate a rich interaction, through an intimate connection between player and sound source. I draw this knowledge from my experience as a builder of electronic musical instruments in the nineties, from my 'electronic luthier period'. Primary examples are the new interfaces which I have developed together with some of the main pioneers in this field such as Michel Waisvisz and Laetitia Sonami. Another category of new instruments are those that augment traditional instruments with electronics. An example of such a *hybrid* instrument is described, the Meta-Trumpet I have developed for Jonathan Impett.

A relevant lesson to be learned from musical instrument design is the importance of the role of the sense of touch. This has been the subject of my research since 1993. The sense of touch is described here in the context of musical instruments, and further discussed in the context of HCI in Part III (chapter 5).

As examples of larger scale instruments, two instruments are described which I developed with Atau Tanaka, which extend the scale of intimacy to the architectural or even global scale. This links to the next chapter, about interactive architecture.

2.1 Electronic musical instruments

Musical instruments are extreme examples of precise, expressive and versatile interfaces. Played by a skilled musician, profound and complex interaction can take place. Traditional instruments are a great source of inspiration for making electronic interfaces more sensitive and effective, but there are differences too.
With the transition to the use of electronics as a sound source, a new type of instrument was needed that was not primarily mechanical. The limitations of the mechanical systems (ie, the length, thickness and tension of a string is directly related to its pitch and timbre) have also gone, which means that there is almost total freedom in the design of the instrument. In fact there is so much freedom that new guidelines and approaches to design for this complexity have not yet been established. With the introduction of the communication protocol MIDI in the mid eighties, the *control surface* or interface was increasingly detached from the *sound source* – splitting the 'instrument' in two as it where. In the last twenty years many developers have worked on creating new instruments, both new interfaces as well as new forms of sound synthesis. These instruments show that it is becoming possible to create new instrument forms, unrestrained by mechanical limitations, fitting to the player at the close, even *intimate* level[1]. It is at this level that an *e*-cology starts.

2.2 Technological stages of musical instruments

To give some historical background on musical instrument design, examples of instruments will be described in the next sections based on the technology categories as introduced in Chapter 1 of this thesis[2]. In the table below some examples are given, which are described in more detail in the further sections.

technological stage[3]	*example of instrument*
objects	drums, cymbals
mechanical (passive)	saxophone, flute, piano, guitar
mechanical (active)	church organ
electric	electric guitar
electronic (analogue)	Theremin, Moog synthesizers
electronic (digital)	digital synthesizers and samplers
computer	Max/MSP, Cubase

As most instruments are combinations of (successive) technologies, it is not easy to classify them. I think that not only the sound source is important, but also the way it is controlled, and in some cases the way the signal is transduced.
Instruments are often also grouped by their appearance, particularly of their ways of control (their interface). So there would be keyboard instruments (organ, piano, harpsichord, synthesizer), plucked instruments (guitar, lute, electric guitar), etc.
The common system to categorise musical instruments does not place the electric, electronic and further developed instruments very well. The traditional way to classify musical instruments, as organologists such as Curt Sachs have done in the beginning of the 20th century, organises instruments by their way of producing sound. In the Hornbostel-Sachs model from 1914 they are divided in *idiophones*, *membranophones*

(these two fit in my class of objects, things that are hit in order to make them sound), *chordophones* (things with strings) and *aerophones* (based on vibrating air)[4]. To cover this new class of instruments the Hornbostel-Sachs model was extended with the *electrophones* in 1961. However, I think the distinction between electrical and electronic is too important to ignore[5], and the further development of digital and computer based instruments with their inherent freedom for the design of the interface.
As discussed before, musical instruments are like other systems often compounds of various technologies. The ‘electric guitar' is therefore actually much more than just the guitar, with all its extensions it is compound instrument that includes many technological categories: the instrument itself is *passive mechanical*, the transducing of the vibration of the string is *electric* (coil and moving field of the magnetised string) and *electronic* for the amplification and the effects machines that were first *analogue*, later *digital electronic*. I think the essence of the instrument is the way the vibration is picked up, which is electric, and which influences the way it can be played including various extended techniques.
In the sections below I follow the classification of technological stages.

2.2.1 Objects and mechanical instruments

The oldest musical instruments (after the voice, presumably) are flutes made of animal bones, which have been dated back to 60,000 years ago[6]. The simplest instruments are *objects*, such as things that make a sound when hit or struck. This category still exists and evolved over the years, for instance drums, cymbals and other percussion instruments. Often the emphasis is on rhythm, but the xylophone and marimba are examples of melody instruments with a chromatic tuning.
Most acoustical instruments, as found for instance in a symphony orchestra, are in fact members of the second category, *passive mechanical*, and have taken the sensitivity of the interface to an extreme. The basis of most of the instruments, where the tone is excited, is often an object such as a string bowed, hit or plucked, a vibrating reed, the mouthpiece of a brass instrument or flute. The tone is then further manipulated through mechanical constructions of valves, keys, pistons and levers. The interface is extremely well fitted to the human player, and the ergonomics of such an instrument design are quite straightforward and visible. They are highly elaborate, though constrained by the physical processes controlled – for instance to make a low tone sound good and loud enough on a string instrument it needs to be big, like the double bass, or very small if a higher pitch is required, like the violin. These issues manifest themselves in the shape and design of the instrument[7]. Acoustical instruments are controlled using the most dexterous and most sensitive parts of the human body: the mouth and the hands. Their output and feedback addresses the ears of both the player and the audience, and the sense of touch of the player. The requirements of pitch range and volume often result an instrument design that requires big efforts of the player. The carillon is an interesting example of this - 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. These are in the category of *active mechanical*. The pneumatic church organ is an example in this category.


Organs, at the cathedral in Köln, Germany on the left and Mechelen, Belgium on the right

2.2.2 Electric instruments

The electric medium was brought to existing instruments from the beginning of the 20th century, for instance most well known is development of pick-ups which were added to the acoustic guitar. String instruments like the guitar and lute had been around for centuries. The electric pick-up is a coil of metal wire around a permanent magnet, transducing the movement of the magnetised metal string into electricity which can then be further processed. The primary aim if this endeavour was to amplify the sound, for which the body of the guitar had to become solid to avoid feedback, but later new ways of playing and new sounds became possible. The strategy of increasing the volume of instruments by having more people play the same thing together, such as the tutti string players in a symphony orchestra, was less practical for some other kinds of music than classical music, even impossible in music that is improvised rather than composed.
One of the best known inventors of the electric guitar was the American Leo Fender, who developed in 1951 the Telecaster (the name was inspired by the word television, though it was first named Broadcaster), which was the first mass produced solid body electric guitar, specially designed to be manufactured and assembled more easily. This instrument and later the even more innovative Stratocaster (1954) has all six tuning pegs in one row on the top of the head of the guitar, making an ergonomic improvement because all pegs were more easy to reach[8]. It allowed several new playing techniques and sounds to be developed. The Strat with its whammy bar (detuning the strings making it possible to play a glissando) and three pickups, the Gibson Les Paul with its humbucker pick up (double coils, to cancel out the noise signals), and other improvements were introduced such as the Fender Precision Bass – a four string bass guitar (that didn't exist before), solid body and with electric pick ups, and frets (hence the name 'precision'). Ironically, it took decades before players started to actually remove the frets, in order to be able to play glissandi and change the sound. Jaco Pastorius was one such player, in the seventies[9]. Electronic additions were invented to manipulate the sound, such as the Wah-Wah pedal (to be controlled with the foot!) changing the timbre of the sound by changing the centre frequency of a narrow band filter by the movement of the pedal. It took decades before the

instrument, itself mature, with its extensions, was played in a way that its full potential was used. For instance, Jimi Hendrix in the sixties who used the possibilities of feedback and effects machines, Bootsy Collins use of the bass guitar in the late 70's, and today’s stunt guitarists such as Steve Vai, Vernon Reid and Buckethead have taken the electric instrument to new levels.

Earlier in the century the Italian Futurists had used and even specially made electro-mechanical sound machines. After the Futurist Manifesto in 1909 by F. T. Marinetti, Luigi Russolo not only expanded the manifest but actually developed and built many 'noise instruments'. With these *intonarumori* instruments the new sounds of industrial environment could be used, instead of relying on traditional instruments for making their non-traditional Futurist music. None of the instruments have survived, unfortunately[10]. Some have been reproduced recently in order to find out what they would have sounded like, but due to the absence of detailed designs it remains uncertain.

2.2.3 Electronic instruments (analogue)

After the new electrical instruments, soon *electronic* musical instruments came about. These were based on electronics that can change or even generate the waveform. New interfaces and ways of playing were introduced[11].

Theremin

A very interesting example from an ergonomic point of view is the Theremin. 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. The electronics consisted of two valve oscillators tuned at a very high frequency, slightly detuned producing a beating frequency in the audible range[12]. Theremin made several versions of the instrument, including one that looked more like a cello (with a sensitive fingerboard), and a sensitive floor for dancers.

Trautonium

Another example is the Trautonium, conceived by the composer Richard Trautwein in the 1930’s and built and further developed by Oskar Sala, who was an engineer who also studied composition with Paul Hindemith and Trautwein in Germany. The instrument looks a bit as if it has a keyboard, however it is based on a electrically sensitive metal string which controls the pitch of the tone played proportional to the position were it is touched. To facilitate playing in tune there are levers which act as keys by pushing down on the touch-sensitive metal string. But unlike the standard keyboard it is possible to play in between the notes, produce quartertones, and play severely out of tune as can be heard on the recordings that are available. The instrument was further extended by Sala with various electronic effects, most of which could be controlled in real time, in the 1950’s and by then called the Mixtur-Trautonium. The sound of the instrument can be heard on many movie soundtracks, such as Alfred Hitchcocks “Birds”, but Oskar Sala remained the only person in the world who played the instrument until he died in 2002[13].

Ondes Martenot

In France Maurice Martenot started to develop his instrument the Ondes-Martenot in 1928. This instrument has a keyboard but also a large slider and several other elements that influence the sound in new ways. Unlike Sala's instrument, the Ondes-Martenot received more widespread recognition. Many composers wrote pieces for it (most well known is the Turangalîla Sympony by Olivier Messiaen, but also Boulez, Milhaud and Varèse liked it) and of course it did well in film music such as Star Trek. It is played by many people still today[14], and one can study the instrument at the Conservatoire. The pictures below are from an ensemble of Ondes-Martenot players called Ondes de Choc, who I've met in the beginning of 1999. What is also interesting is the way the loudspeakers are part of the instrument – they are combined with resonating elements, drum heads and springs[15]. The existence of such a traditional form, a quartet dedicated to the instruments, underlines the official status of the Ondes Martenot as an accepted instrument form in France[16].



Moog and Buchla

Thanks to the invention of the transistor in the 1950's electronic circuits became smaller and more affordable. Electronic sound sources (synthesizers) and sound manipulation devices became more widespread, for instance the pioneer Robert Moog developed many synthesizers in this category of *analogue electronic*. The trend of adapting existing instrument forms to newer technologies persisted, so most synthesizers are controlled with a keyboard interface. The ergonomically interesting bits are in the extensions, such as the wheels, joysticks and ribbon controllers as developed by Moog, Don Buchla and others. Bob Moog usually insisted on having a keyboard on or at least near his synthesizers, to make clear that it would look like a musical instrument[17]. Don Buchla however rejected the keyboard because he felt that it was inappropriate for new electronic music. In the nineties Buchla brought out several new controllers such as the Thunder (complex touch sensitive surface) and Lightning (gesture tracking system based on infrared light), while Moog kept making ribbon controllers and Theremins (also under the brand name Big Briar).
As stated before, a musical instrument actually consists of two parts; the interface and the sound source. In traditional instruments these two elements are often one part and tightly coupled.
Although in mechanical instruments in some cases the sound source is remote, such as in a church organ, or touched indirectly such as with the bow of a cello, with electronic instruments the interface could in some cases be developed entirely independently. The keyboard or wheels would communicate with the sound

generating electronics through control voltages (CV). These control voltages were specified and standardized, so that with a controller from one manufacturer one could play the electronics of another. The keyboard became the de facto standard for playing, and while it has proven to be a versatile and useable control surface as it can be found traditionally on many instruments, one can argue that having a new sound source developing a new interface would be the most obvious thing to do.

2.2.4 Recording

After the exciting start of new instrument developments in the beginning of the 20th century 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. Music production became a studio-based activity rather than a live performance. Although it produced a lot of interesting music the emphasis was often on the processes inside the machines rather than on how to control them. The actual control surface in an electronic music studio is actually vast, with many dials and sliders, arranged by function. It is impossible to control them all at the same time, which was never the goal as tape recorders are used to record and layer the sounds produced, much like a composer would put together a score[18].
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[19].
Recording based music has had a great impact on the development of music and our thinking about it.
The Musique Concrète of Pierre Scheafer and Pierre Henri was pioneering since the fourties with using everyday sounds as music by using recordings.

2.2.5 Electronic instruments (digital)

Like any other technology, *digital electronics* were used to make music right from the start. Well known is the Illiac suite, 'composed' by one of the first computers in 1957[20].
Later digital circuits were built specifically for creating sounds (or compositions). These circuits would synthesize the sound through algorithmic calculations, or play back previously recorded sounds (sampling) under the control of the performer.
The vast possibilities, due to the separation of the interface from the sound source, were further accelerated by the introduction of the MIDI protocol (Musical Instrument Digital Interface) in 1984. MIDI allows for two-way communication between the elements, bringing new possibilities for interface designers. In the last decades a lot of new instrument forms have been invented, such as gloves and more abstract forms such as webs and control surfaces. Any form is possible. 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. There are a few commercial products such as the Buchla Thunder from the early nineties, a touch sensitive controller, shown in the picture below. Still available is the rather simpler controller, the Kaoss pad of the Japanese synthesizer manufacturer Korg. Although useful, the

Kaoss allows only a few parameters to be controlled simultaneously instead of providing access to the full potential of a sound source.

Other well known inventions, like the several hand controllers such as The Lady's Glove of Laetitia Sonami and The Hands and The Web of Michel Waisvisz, are quite idiosyncratic - that is, fitting these particular composers and therefore have not become widespread. These instruments are described in the sections below.

As stated before, since the invention of the first computers they were used for making music. When computers became smaller and cheaper, the use of the capabilities of the computer to make music became more widespread. The first International Computer Music Conference (ICMC) was held in 1974[21]. Computers are not only used as sound source (calculating a wave form for instance) but also for algorithmic generation and composition. A machine that can be programmed to have its own behaviours is a basis for interaction, that is a two way process of information flows were both sides (human and machine) have changed state afterwards. Using MIDI, the processes inside the computer can be controlled through the human interface.
Ironically the MIDI standard is quite biased towards the Western keyboard, among the parameters that it describes are typical keyboard issues such as velocity and key pressure. At the same time it is a very open standard with many unspecified parameters, so that it indeed became possible to apply it to other and new instrument forms. Other traditional instrument forms were also taken as a model for electronic versions: the guitar, several wind instruments, and drums. The tendency of adding new technologies to existing instruments also persisted, extending instruments such as the guitar or the piano with electronic control elements (sensors) linking it to digital electronics and interactive computers systems, creating hybrid instruments[22]. Hybrid instruments that I've built are described in section 2.3.4. At the MIT Media Lab the group of Tod Machover calls these instruments Hyperinstruments[23].
In the sections below some instruments that I have co-developed are described and further discussed. Most of these instruments are well known in the electronic music world, and because of my involvement in the design processes I am familiar with a number of relevant issues that will be discussed.

2.3 New Electronic Musical Instruments

There have been many developments in specialised interfaces for music making with electronic instruments. Through MIDI and later other protocols it became possible for digital electronics to communicate with each other. Sensor signals are transferred from analogue to digital and then further processed and mapped to sound parameters. The sensors and their application are described in more detail elsewhere.[24] In this section some instruments and composers are described that I've worked with as an instrument developer since 1987.

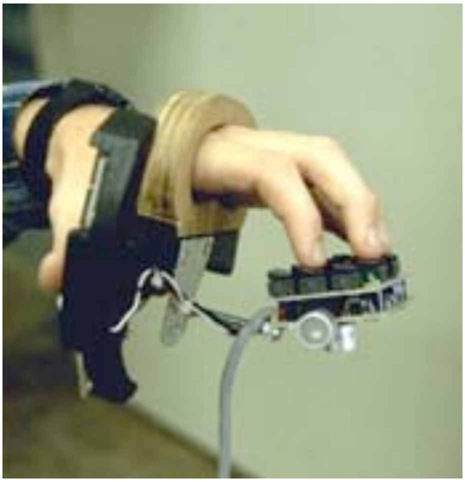
2.3.1 The Hands

In the early eighties Michel Waisvisz, the director of STEIM (Studio for Electro-Instrumental Music) Amsterdam, realised that that the standard piano keyboard interface for performing electronic music was not sufficient. He had by then developed a reputation as the inventor of the Crackle Synthesizer (and a small spin-off the Crackle Box) which was played by touching the electronics of the analogue circuits *directly* with the hands. When digital electronic equipment became available, there was little point in trying to influence the processes directly by touching the electronics. But the MIDI protocol as mentioned above was seen as a way to enter the domain. Together with engineers at STEIM he started to experiment with aluminium plates strapped to the player's hands, mounted with various switches, dials and other sensors. A small microcontroller worn on the back converted the sensor signals into MIDI commands which were sent to the synthesizers. Michel made the first move to free himself from the piles of equipment many other players at that time used to hide behind on the stage. The Hands, as the instrument was called, were not just a set of remote controllers but also very sensitive to gestures on different planes and scales, enabling a more intuitive control of the sounds produced. It was played in a concert first in 1984 at the Concertgebouw in Amsterdam, and presented the next year at the ICMC conference[25]. In the first years several versions were built, experimenting to find the right form and layout of the switches and sensors, and develop the MIDI converter. The difficult problem of how to design a new instrument form and function was approached in a trial and error fashion, experimenting until a satisfying solution was found. Sometimes inventions were made by coincidence, for instance the very good sounding 'scratch mode' (where every movement of the hand would re-trigger a note) was discovered by accident, due to a loose wire and a programming error of one of the engineers. The story goes that the engineer wanted to correct his 'mistake' immediately, but Michel saw its musical potential and insisted on leaving it as a feature (one that can be switched on or off of course). A good example of serendipity.
By the time I got involved at STEIM (then as a engineering student intern) it was 1987. I worked on the first Hands only a bit, adding some more controls elements. This happened in the same way as the other developments were made, from a musical need (compositorial or performative) Michel would express a need for a control element. These were the last additions, as Michel realised that it would be best to stop changing the instrument and focus on the playing. This pair of Hands is now in the vast collection of the Music Department of the Gemeentemuseum in The Hague, and shown in the book about this collection on the picture below.

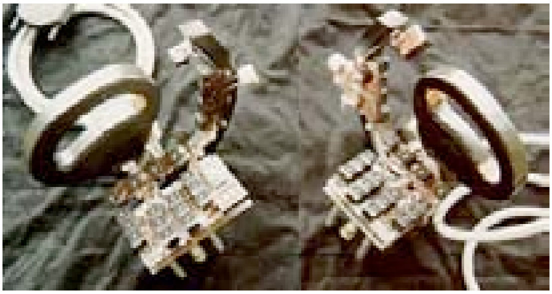


In 1988 at STEIM I developed and built a new set for the Musikhochschule (Music Academy) in Basel. This version was adjustable so that it could be fitted to various hand sizes, by moving the keys and other controls. I painted the aluminium instrument and converter parts mint green.

Since 1989, working as an instrument developer at the Sonology department of the Royal Conservatory of Music in The Hague, Michel and I collaborated in the development of a new instrument called the MIDI-Conductor. This instrument was going to be a simpler version of the Hands, and based on the (obvious) metaphor of a conductor – the right Hand had the shape of a baton. We developed a series of six of these instruments, based on a wooden frame, to be used by students, teachers and others. The pictures below show the left hand part of the instrument, which looks like on the The Hands, and a prototype of the right hand controller, the actual 'baton' (made out of aluminium and brass, the final version was made of wood)[26].



The wooden frames were made by Michel, and he liked these so much that it was decided that the next version of the Hands was based on a similar shape and material. Functionally they were almost entirely the same as the old Hands with their metal frames. I built two sets of these Hands II, Michel always had a spare set backstage in case the instrument would fail. They were prototypes after all... However, they lasted from 1990 to well past the year 2000 and were performed with all over the world[27]. Around 2002 two improved new sets of Hands were built at STEIM by Jorgen Brinkman.



The Hands contain various sensors. There is a small keyboard with twelve keys for each hand, four keys for special functions, four keys to modify the sound, a pressure sensor, four mercury tilt switches, and a sensitive ultrasonic sensor to measure the distance between the hands. It is interesting to note that, while the instrument (the human interface part) remained functionally the same for 20 years, the sounds and processes controlled changed constantly. Indeed, the concerts that I witnessed over the years were radically different in composition, sounds used, and presentation – and always an engaging performance. The first concerts were performed with stacks of various synthesizers (particularly Yamaha FM synthesizers) and later samplers which allowed existing sounds to be reproduced in manipulated form, all controlled by MIDI. In the late eighties a personal computer (first an Atari ST and later an Apple

Macintosh) was added to the set up, with an essential role. A software program called the Lick Machine by Frank Baldé at STEIM, would enable the player to produce a string of notes triggered by pressing a key. The way the sequence of notes[28] was played was influenced by the player through the movements and motions sensed by the instrument. Around the mid nineties personal computers were fast enough to take over the sound producing role of the synthesizers and samplers, which were basically dedicated sound computers in a sense (based on DSP chips rather than the CPU). Also it was found that commercial samplers, being developed for studio use primarily, would not allow the player to sample sounds while playing back sounds at the same time. Frank Baldé at STEIM developed together with Michel 'LiSa', a software program for the Apple Macintosh that would allow Live Sampling. By the end of the nineties most sound producing was done by just one computer, running the LiSa program. This is relevant because it illustrates the implosion of technology as discussed in Chapter 1, starting from stacks of synthesizer units and several computers to only one computer. Unlike many other cases where technology disappears, the interface in the case of the Hands remained the same. The performer has a powerful and sensitive interface[29].

2.3.2 Gloves

Using gloves as input devices for computers became popular in the mid eighties in VR research (Virtual Reality)[30]. This idea was first developed by Tom Zimmerman (then at MIT) and Jaron Lanier, who coined the term Virtual Reality[31] and later founded the company VPL to manufacture the DataGlove. The DataGlove became the de facto input device for VR for many years. It used fibre optic cables to measure the bending and abduction of the fingers, and a Polhemus position and orientation sensing system[32]. Later other companies started to make gloves, like the CyberGlove and the cheap Mattel Power Glove which was developed in 1989 to interface with the Nintendo game controller. The Power Glove used specially developed resistive strips as bend sensors, ultrasonic position and orientation sensors and a built-in Hitachi microcontroller[33]. As a game controller it rather failed to be become a success, but due to its low price it became a popular option for interface researchers as an alternative for the expensive VPL Dataglove[34].

In the US several musicians and artists started to use the Power Glove to control sound generated by or through computers, such as the members of the The Hub in the San Francisco bay area Mark Trayle, Scot Gresham-Lancaster and Tim Perkis[35].

SonoGlove
At the Sonology Institute of the Royal conservatory of Music where I worked at that time various composers started to have an interest in using gloves to make music. For instance the Dutch sonology student Wart Wamsteker I developed a glove based on the Power Glove. We first took the Power Glove as it was, using the sensors and the plastic glove (a gauntlet, rather) and replacing the electronics with the STEIM SensorLab sensor to MIDI converter. This way we were able to read the sensors which a much higher precision[36] and range, the Power Glove electronics read the bend sensors in 4 steps (while the SensorLab has a resolution of 8 bits) and a larger range of movement was necessary for performing. Instead of a synthesizer Wart used filters and feedback, controlling the filter parameters with the bend sensors and movement of the glove. Before developing the glove Wart used to play 'no-input mixer', using the same principle of feeding back an output signal into the input of a mixing desk without further sound source. After a first performance with this no-input mixer we realised that a dedicated interface was needed – the SonoGlove.

Chromasone
English musician and composer Walter Fabeck came from the perspective of a piano player, and we decided to develop a kind of 'air-piano' during his stay at Sonology starting in 1993. To restrict the movement of the fingers less than the thick plastic of the Power Glove did, we used golf gloves (very nice thin blue leather) and sewed the bend sensors (taken out of a Power Glove) on the outside. Later I started using 'winter play' golf gloves, which consist of two layers enabling us to slide the sensor between the layers. The electronics, connector and ultrasound sensors were mounted on the outside. To guide the movements through the air with the gloves, Walter had developed a keyboard 'template' made of see through plastic which swivelled on a stand with three Degrees of Freedom. He has performed with the instrument in several theatre plays and many other performances[37].


The Lady's Glove

Laetitia Sonami from Oakland, CA, first working with Paul Demarinis on a performance for the Ars Electronic in Linz, Austria in 1991, using Power Gloves, started making musical gloves by using rubber kitchen gloves and sticking sensors on them. Later she made a velvet glove, with sensors inside. She became quite well known with her Lady's Glove, and in 1994 STEIM commissioned me to build a new glove for her. I changed the design and the looks, functionally it remained almost unchanged from the earlier one. There were three bend sensors on the main fingers, each with a centre tap in order to read the signal in two areas relating to two different knuckles, a double bend sensor on the wrist in order to read the movement in two directions, little switches on the fingernails, mercury switch for tilt sensing, ultrasound sensor for distance measurement of the glove in relation with the body and a foot, and continuous magnetic sensors on the fingertips activated by a magnet on the thumb to measure the distance between the fingers in the hand. Al these sensors were sewn onto a thin lycra glove, custom built in Paris for Laetitia's hand by a firm that manufactures gloves for theatres. The idea was to then cover the whole thing with an outer glove, of different colours and patterns. The improvements in the mechanical design greatly influenced the looks of the glove, as it turned out. The uncovered glove, with its coloured wires and shrink wrap of the several sensors, had a 'cyber' look that fitted the purpose. As a result, the covering gloves were never used. In 1995 she added an accelerometer, a small circuit that I developed to meet musical needs (high sensitivity)[38].


The reason for describing this glove in so much detail in this chapter is to illustrate the sensitivity of the device, getting so close to the skin of the human body, and how difficult it is to achieve a mechanically reliability. The hand moves a lot, in many degrees of freedom and wires and sensors have to move with it without restricting the movement and without breaking. The solution we found was to enable the electronic parts and the wires to move relatively freely, and find their own way around the motions and postures of the hand. We used very thin and flexible wire, yet very strong with a multi core and Teflon insulation, secured with sewing and glue around the soldering points where the cables are weakest. Another technique I developed for these kind of applications was to bend the circuit boards by heating them (before the parts were put on) to better follow the human body, and
painting them to match the design.
Laetitia did numerous performances over the years with the Lady's Glove, and in 2003 came to Barcelona to have a second glove built by me and Yolande Harris, again the same design but with different colours.
The only way to get closer to the human body would be to connect directly to the (electrical) nervous system and brain. Sensors can be put inside the body or on the skin, measuring the small voltage changes of the nerve signals to the muscles. An example of this approach is the Bio-Muse, as used by the American performer Atau Tanaka[39].

2.3.3 The hand in the Web

Michel Waisvisz had realised that the in addition to the keys on the Hands, more continuous control would be essential for manipulating sound, moulding it like clay[40]. He came up with the concept of a spider's web, flexible and all elements linked[41]. In the early nineties we designed The Web, an aluminium frame in an octagonal shape with a diameter of 1.20 m., and consisting of six radials and two circles made with nylon wire (material from harp strings – the red C string). In 24 of the resulting string parts, the physical tension caused by the player was measured by custom designed sensors[42]. The player thus has continuous, real time and simultaneous control over 24 parameters of the sound, making it a good timbre-controller compared to a standard keyboard which would have in the most optimal case only three parameters (pitch, velocity and aftertouch). As in traditional instruments, these parameters are linked in a fixed configuration, due to the web-structure. In a way, the instrument was difficult to play in a traditional way compared to for instance a keyboard. Hitting the Web with say, one finger in the middle, would lead to a complex set of changes of many of the parameters of the sound. Hitting it again in exactly the same way, would give a slightly different set of changes. It may seem that we had produced the ultimate useless controller if it gives a different output with exactly the same input. However, there is no such thing as exactly the same input. Due to slight variations of the movement of the hand, each time it hits the Web it does so slightly differently which is translated into slight changes in the sound. As a human being it is impossible to make exactly the same gesture multiple times, there will always be variation ('noise' in engineering terms). I think that the beauty of the sound of traditional instruments has partially to do with the sensitivity of these instruments to these very variations of the player.

The Web has been used a lot by Sonology student Erik Stalenhoef, who would take the sound from another instrument playing (for instance a recorder, or at the Sonic Acts festival the sound of Jonathan Impett's trumpet) and mangle the sound using an effects processor (Lexicon) controlled by the strings of the Web. An even clearer effect was demonstrated by another Sonology student who would control the parameters of an FM synthesis program, influencing the individual oscillators with the tensions in the Web.
The Web still exists, it is now part of STEIM's travelling exhibition on Touch, but it has less strings now to make it simpler to play.
Ultimately, we would make tiny webs that fit under the tip of the finger of the player.

2.3.4 Hybrid Instruments

As mentioned before, musicians using traditional instruments often extended the instruments by *mechnanical* means, for instance preparations of the piano. In this section *electronic* additions are described which extend the interaction space of the instrument. Through the electronic parts (sensors and interfaces) added to the instrument, the possibilities of electronic media can be explored whilst the instrumentalist still can apply the proficiency in playing acquired after many years of training.
In 1995 the Israeli musician Gil Wasserman came to Sonology, and I extended his electric guitar with several sensors. Among other things it got an extra neck, with a movable element with an array of switches and pressure sensors. Gil is a very able guitar player, and could cope with the added complexity quite well (although I think he is still working on it).
Another example is the Cello++, extensions built together with Yolande Harris for the American / Dutch cello pioneer Frances-Marie Uitti in 1999. Frances-Marie is a very well known virtuoso, known for inventing and developing a playing technique using two bows simultaneously, and many contemporary composers have written pieces for her[43]. For Frances we made soft pads (it had to be put on her precious ancient cello

without damaging it) with switches, sliders and sensors, controlling processing in the computer.

In 1992 – 93 I worked together with the English trumpet player and researcher Jonathan Impett on developing an electronically extended trumpet, which he called the Meta-Trumpet. Jonathan plays a lot of contemporary music, but is also a well known baroque player regularly working with the Orchestra of the Eighteenth Century and the Amsterdam Baroque Orchestra[44]. Using half-round brass base plates to mount the electronics and sensors on, I achieved that the additions looked very much part of the original instrument[45]. A design consideration was also that the additions should be able to be easily removed so that Jonathan could play baroque or classical music on it. (In practice this never happened.) We added several mode switches on the top of the instrument, pressure sensors on the outside of the piston-tubes, proximity sensing inside the pistons, mercury tilt switches, an accelerometer, and a 2D ultrasound positioning system. Particularly the latter enables Jonathan to play the instrument as a gestural controller. Generally the control parameters of the electronic extensions could be used independently of the original playing techniques. With this instrument Jonathan could play with the compositional system he wrote a computer program for, first for the Atari in C and later on the Silicon Graphics O2 and currently on the Apple PowerMac in Max/MSP. It is this combination of sensitive and rich instrumental input and computer algorithms that is important. In fact, his composition Mirror Rite won the Prix Ars Electronica in 1994[46]. Several papers describe the instrument and compositional issues in more detail[47].
I worked with Jonathan on other projects which will be described in Chapter 7.

2.4 Tactual Feedback – the touch of the instrument

Due to the decoupling of the sound source and control surface, a lot of *feedback* from the process controlled was lost (and later found when explicitly designed in). In electronic musical instruments, the main sense addressed is the auditory through the sounds produced and there is visual feedback in some cases. But the touch feedback from the sound source is hardly used, the feel of a key that plays a synthesised tone will always be the same irrespective of the properties of the sound (the device can even be turned off entirely!). Compare this with the feel of quite similar keyboards on the piano and the harpsichord, or the differences in the touch of an pneumatic organ or an electronic one.

Musicians traditionally rely strongly on their sense of touch when playing acoustic instruments, which helps them to control and articulate the sounds produced. In these cases, there are three sources of information for the player:

- kinaesthetic feedback: the internal sense of the players own movement (proprioception)
- passive tactual feedback, the shape of the instrument and the elements touched (strings, keys)
- active tactual feedback, through the vibrations or other changing properties of the instrument

As with other electronic systems in general, players of electronic musical instruments such as synthesizers lack the information channel of active tactual feedback, unless it is explicitly built into the system. Due to the decoupling between control surface and sound source through the MIDI protocol, players are not inherently in touch with the means of sound production. The third feedback modality of a traditional instrument as mentioned above is missing. However, this decoupling can also be used as an opportunity because of the two-way nature of the link between interface and sound source, by designing and applying the active tactual feedback.

Ever since the Theremin, gestural controllers have been popular in electronic music. However, from the three feedback modalities mentioned above now only one remains, the proprioception. It is therefore more difficult to play accurately.

Research has been carried out about addressing the sense of touch in order to restore the relationship between that which is felt and the sounds produced. It is an important source of information about the sound, and the information is often sensed at the point where the process is being manipulated (at the fingertips or lips). This immediate feedback which supports the articulation can be described as articulatory feedback. I will return to this topic in chapter 5 in more detail.

2.5 From the Intimate to the Spatial

In this chapter I described musical instruments that operate on the intimate scale, close to the human body. The same technology however is easily scalable to much bigger sizes, reaching the architectural scale. In Chapter 7 I will describe a number of projects that work on this scale by using video projections and networks, in this chapter the emphasis is on projects of other people that I've been involved in as an instrument designer. They are good examples of how the *e*-cology can be on this scale.

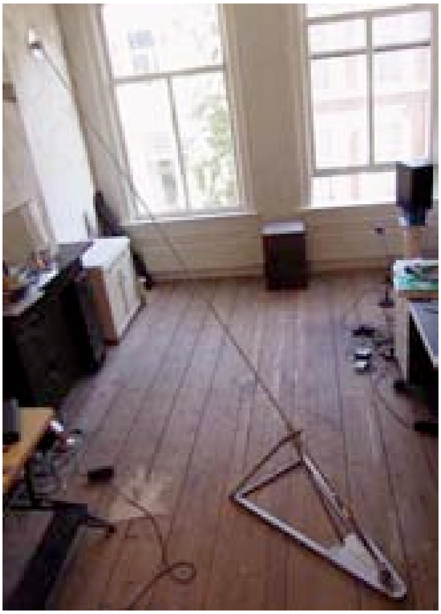
There are of course historical examples of traditional instruments on a larger scale, such as a double bass that is so tall that it occupies two floors and has to be played by two people – one for the bowing and the other one for the fingering[48]. Also church organs can reach massive proportions and be distributed around the building such as in the case of the cathedral of Passau in the south of Germany[49].

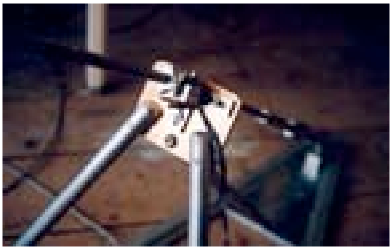
2.5.1 Soundnet

Inspired by The Web, the members of Sensorband[50] approached me in 1995 to help develop a web on a slightly less fiddly scale than the one developed with Michel Waisvisz[51]. Their SoundNet, as it was called, is about ten meters high and six meters wide, to be played by the ensemble by climbing on it. To achieve this, we had to develop string tension sensors to withstand a force of about a 10,000 N, and an adjustable spring tension of 3000 – 5000 N. With the help of a mechanical engineer[52] we developed these sensors, connecting to the sensing system with long wires. The rest of the instrument consisted of rented material (the aluminium frame) and shipping rope acquired to match the right feel and strength. The developing of the instrument and the first performances by Sensorband were commissioned by two French festivals, one in Créteil (see the picture below) near Paris and the other one in Maubeuge near the Belgium border in 1996. As the musicians climb and bounce their way up and around the Soundnet, the sounds would change according to their actions. Another performance was done at the DEAF (Dutch Electronic Art Festival) later that year, in this occasion the Soundnet was tilted at a less steep angle so that the performers were actually over the audience (and wore safety harnesses in case they would fall down).
One problem with this instrument is obviously to find a suitable rehearsal space, so it is difficult to take the artistic potential further. Performances are quite an experience however[53].

2.5.2 Global String

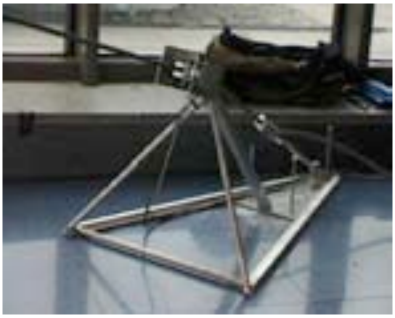
One of the Sensorband members, Atau Tanaka, together with Kasper Toeplitz, a Polish bass player and composer living in Paris and often working at IRCAM, came up with the idea for a 'global string'. Real strings are placed in physical locations in different places in the world, linked by a virtual string across the Internet. In 1998 they won a price by Siemens and the WDR (West Deutsche Rundfunk, a very influencial radio station and studio in Cologne), and we formed a team to develop a prototype of the instrument. The picture below shows the working prototype at my lab in the Piet Heinstraat in The Hague.





With this we were able to demonstrate the principle and Atau secured funding from the Daniel Langlois Foundation in Montréal, Canada, to develop and build the full version. The string is a 10 metre long and 16mm thick stainless steel multicore cable, with fittings all made by a Dutch yachting supplies company. The frame is made of aluminium by a mechanical engineer. At the top the string is attached to the wall at about six meters above the floor, and the base is attached to the floor. In the base we've built the sensors and an actuator. The sensors were a piezo disc which was read into the analogue input of an Apple Macintosh triggering and influencing a physical model of a string – the sound heard was thus of the model rather then of the real string. The sound was further influenced by two proximity sensors mounted next to the string, measuring the bending. All these signals were sent via the Internet to the other part of the instrument, a similar string at the remote location. The path that the data packages took over the Internet was continuously changing, and this influenced parameters of the sound as well. In a way it was as if the network became part of the 'resonating body' of the virtual string. There was haptic feedback for the players as

well. If the string was hit in one location, it could make the string in the other location move by a large electromagnet which would send a pulse through the string. One player could, as it were, touch the other, creating a kind of remote touch or tele-touch. The players could also see and hear each other through a video-conferencing system, and had to work with the latency this introduces.
The installation was first presented at the Dutch Electronic Art Festival (DEAF) in 2000 in Rotterdam, the Netherlands as one location where Atau was playing and with the Ars Electronica Centre in Linz, Austria as the other location with Kasper. A second performance took place in 2001 between Linz and Budapest, as part of a festival organised by C3[54]. There is currently interest from an organisation in India to develop the idea further. It was an interesting experience to develop an instrument on this scale, linking two remote locations using the Internet, potentially expanding the *e*-cology worldwide.
In the next chapter more instruments and installations are described dealing with this scale, from the field of architecture.



2.6 Discussion on musical instruments

In this chapter I have discussed traditional musical instruments as well as new electronic instruments developed in the last decades. They are very sensitive interfaces which enable a rich interaction, using many modalities including the tactual. The development of new instruments often occurs in an incremental, evolutionary way. For instance, Adolphe Sax, who invented the saxophone around 1850 in his workshop in Dinant, Belgium, was a renowned clarinet builder and developer of many wind instruments. His goal was to develop an instrument that would sound more like a string instrument, but then without all the disadvantages present in string instruments at that time. He didn't need to start from scratch, but based his designs on existing knowledge of instruments. At the same time he made an interface which enabled many expression beyond his knowledge. Sax couldn't possibly have the music of Eric Dolphy or John Coltrane in mind when he invented the saxophone.

Likewise, Leo Fender could not predict that Jimi Hendrix would play the Stratocaster, by the end of the 1960s, left handed, using acoustic feedback and other effects to take the instrument to another level. But these inventors created something that enabled new music and ways of playing to be discovered. I think this is relevant to emphasise because at present software tools are often developed with a much more narrowly defined goal or set of tasks in mind, inherently prohibiting other kinds of use than intended by the designers[55]. The goal is to design for possibilities, for inclusion rather than exclusion of tasks and functions – even those unknown. A number of instrument design issues are further discussed in an interview I did with the members of Sensorband, including the issue of how the tool can influence the outcome of the work[56]. Very interesting is also the 'round table' discussion on the electronic book on gestural interfaces by IRCAM. They conducted this via e-mail as a kind of multi-person interview with all the main players in the field, including most people whose work is discussed in this thesis[57].
In the last 20 years the development of new electronic musical instruments has made a lot of progress. After being a regular topic in the computer music conferences (ICMC), the field has its own conference: New

2.6.1 Presentation and testing

Interfaces for Musical Expression (NIME), yearly since 2001[58]. This acts as a platform for developers, researchers and musicians to exchange ideas, present new interfaces, discuss novel instruments and interaction paradigms. Several festivals have taken place presenting new instruments, for instance the first Sonic Acts festival in Paradiso Amsterdam in 1994 with the Sonology participation[59]. These festivals and concerts are essential parts of the design process as they function as the testing ground for the instruments.

In order to bring new audiences in touch with these kind of instruments and generally spreading the ideas I organised and curated a festival in the art gallery Metrònom in Barcelona in January 2002. The theme was *New instruments, new music, new paradigms* and several of the performers described in this chapter played there, in addition to some promising local groups that I invited. Workshops were given during the day, and concerts in the evening. The aim of this festival was also to extend the field of instrument development from music to other art fields such as video and dance. There have been a lot of developments particularly in the last ten years turning video art into a performative medium. The Meta-Orchestra ensemble I founded together with Jonathan Impett (see section 2.3.4) is addressing this by bringing together people from various disciplines in a networked and performative setting. I think this is a very important issue and will return to this in Chapter 7, to discuss the field and my contributions to it in more depth.

2.6.2 Learning curve and enabling virtuosity

Most of the new instruments presented in this chapter were developed for expert players. Often they are composers who wanted a solution for their own idiosyncratic way of music making. I have shown that it is not trivial to generalise these instrument designs to be played by a wider audience. Traditional instruments are difficult to play, and require years of dedicated training before mastered at a level that full expression becomes possible. Instruments differ in their learning curves. However, the highest level of virtuosity that can be reached, such as established by a sometimes centuries long development of musical practice, is the same for every instrument. This has also to do with the fact that the player's musicality has to be developed too, and that does (and always will) require years of training. With the freedom of design in the case of electronic instruments the learning curve does not need to be steep, while at the same

time the instrument should facilitate the development of virtuosic levels[60]. It is also possible to design instruments for different target audiences, such as experts (who are or want to become virtuosic), generalists (with some music skills), and novices.
An interesting example is the design of the first commercially available electric bass guitar in 1951 , the Fender Precision Bass, the name referring to the presence of frets to make it easier to play in tune. As dicussed in Section 2.2.2, it was later realised that the design with the frets also limits the freedom of expression. Players started to modify the instrument as mentioned before, taking the frets out to enable smooth glissandi. Nowadays instruments are made by manufacturers as fretless bass guitars.

2.6.3 Form and function

The difficulty of playing traditional instruments is related to the physical nature of the sound making process, and this process determines to a large extend the design of the instrument. With electronic instruments the form factor is free, so it becomes possible to take the human as a starting point and develop ergonomically more optimal instruments. Total freedom however is difficult to design from, as there is often no concrete function to dictate the form. The functions are abstract (in sound, but also in other interactive systems) so the form has to 'follow the function' in other ways. Metaphors are often used (but they have their own limitations), or translations from one modality to another in an almost synaesthetic way.

2.6.4 Effort

The development of musical instruments in the successive technological stages show clearly how the instrument becomes more invisible, less physical, often 'easier' to play, but harder for the player to express him or herself with. This is because *effort* is actually often a good thing. When playing the instrument, the physical resistance is a source of information about the process of playing and articulating sound. The lack of physicality must be compensated for, by including haptic design, ie. force feedback and vibrotactile feedback.

2.6.5 Conclusion

Musical instruments facilitate a sensitive, multiple Degree-of-Freedom, and multimodal interaction. With most musical instruments it is possible to play multiple parts at the same time. The interaction is traditionally on the intimate scale, but can extend to the spatial scale. Furthermore, instruments allow a high relative precision.
Many of the issues mentioned in this chapter translate to the general field of design for interactive systems. They are essential parts of the *e*-cological approach, where a rich interaction between the entities of the electronic ecology is key, from the intimate to the spatial scale. In the next chapter the spatial scale will be explored further.

[1] By using the term *intimate* I am emphasising the closeness and directness of the interaction. Indeed, as Sid Fels describes it in his papers, an instrument or tool becomes *embodied* when this intimacy is reached. The instrument seemingly becomes part of the player [Fels, 2005]

[2] In fact, it was the thinking about, describing and organising musical instruments in the first place that started the identification of relevant technological categories and functions.

[3] In this thesis I will not describe examples of optical or even chemical instruments, although they exist.

[4] Erich von Hornbostel and Curth Sachs published their classification in 1914 in an article. Curt Sachs published a book in German as a *Handbook for Musical Instruments* in 1919 and a second eddition followed later [Sachs, 1930]. An English translation became available later.

[5] The English electronic musical instrument builder Hugh Davies (1943 – 2005) extends the classical instrument category of *electrophone* in these combinations as well, as published in a book by the Gemeentemuseum in The Hague, Netherlands about the electronic instruments in their renowned collection of musical instruments [Mensink, 1988].

[6] These flutes were already used before *homo sapiens*, by the Neanderthals, as described in *Musical Instruments, a worldwide survey of traditional music making* [Rault, 2000, p33].

[7] And is strongly bound by tradition, as described in an article by Karin Bijsterveld and Marten Schulp [2004] about the evolution of classical musical instruments (which also refers to the Hornbostel and Sachs system).

[8] Although this made the Fender guitars look different from other (semi-)electric guitars at that time, the design of all tuning pegs in one row is not new – for instance J. G. Stauffer made a guitar in 1820 with this design.

[9] And so did I, but that was much later, in the eighties.

[10] Russolo's book is translated into French and later English as *Art of the Noises* [1913], see also the chapter on Futurism by Joshua C. Taylor in Herschel B. Chipp's *Theories of Modern Art* [1968] and *Destroy all Music* by Mark Sinker in the Undercurrents book of the Wire [2002] which was published first in the Wire Magazine in 1999. In *The Soundscape of Modernity* Emily Thompson describes the Futurists and other currents of using environmental sound in music in the context of the rise of the industrial age, which makes the issues much clearer [2002, pp. 134 – 138]

[11] A number of the developments described in these sections are also discussed in Joel Chadabe's book *Electric Sound – the past and promise of electronic music* [1997].

[12] "Sounds from thin air", the newspapers wrote in the twenties. The Theremin 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 on ‘Mysterons’ of Portishead. Transistor versions exist, as well as ones without any sound generating electronics – acting as a controller. There are several recordings available of Theremin players, and a documentary film by Stephen Martin from 1995 shows the diversity of the use of the instrument over the century, and Leon himself as an old men returning to New York (*Theremin, an Electronic Odyssee*). The reason for him suddenly leaving NY in the twenties remains unclear, one popular story is that he was whisked away by the KGB in order to work on spy equipment in total anonymity only to resurface in the eighties [Glinsky, 2005].

[13] Several recordings of the Mixtur Trautonium exist, such as the CD *My Fascinating Instrument* from 1995 with Oskar Sala playing several of his compositions. There is also a book in German and English about him and his instruments, written by Peter Badge [2000].

[14] Including Jonny Greenwood from the pop band Radiohead, who often uses it. This brought the instrument to the attention of a new audience.

[15] The springs are used for a reverb effect, old guitar amplifiers like the Fender Twin Reverb often contain a similar system – the electric guitar sound goes through the spring which makes sound like a reverbrating hall.

[16] An extensive source of information about these and other electronic instruments can be found on-line at www.obsolete.com/120_years, *120 Years of Electronic Music, electronic musical instrument 1870 – 1990*, maintained by Simon Crab, and there are books like André Ruschkowski *Soundscapes* (in German) [1990] and Bart Hopkin's *Gravikords, Whirlies & Pyrophones* book and CD [1998].

[17] As described in an article by Trvor Pinch (who also wrote a book on Moog) and Karin Bijsterveld [Pinch and Bijsterveld, 2003]. Robert Moog passed away in September 2005.

[18] See the article by Peter Manning [2003], *The influence of Recording Technologies on the Early Development of Electroacoustic Music* in the Leonardo Music Journal. In the article also optical recording technologies are discussed.

[19] For instance Kid Koala's reworkings of old jazz records into new collages of sound on the CD *Carpal Tunnel Syndrome*, Ninja Tune, 2000. David Toop has written articles and books on the history of 'Turntabelism', and the chapter *Deck Wreckers* in the Undercurrents book of the Wire [Shapiro, 2002] gives a good insight in the history and techniques used. Kjetil Falkenberg Hansen and Roberto Bresin of the KTH in Stockholm have analysed several gestural techniques by DJ's while scratching [2003].

[20] The program for the Illiac computer was created by composer Lejaren Hiller, working with Leonard Isaacson at the University of Illinois at Urbana-Champaign in the US. See ems.music.uiuc.edu/history/illiac.html.

[21] See the web site of the ICMA, the computer music association that is responsible for the conferences: www.computermusic.org/icmc/icmc_main_frameset.html. The ICMC started as a US conference and is since 1982 held every other year in a different place in Europe or elsewhere in the world.

[22] Musicians can (and do) extend acoustic instruments also with all sorts of mechanical means, so called prepared instruments. There are many pieces written for prepared piano for instance, since the sixties (by composers such as John Cage), specifying in the score the preparations to be made and the materials to be used. The result is a changed sound, with rattles, different resonance frequencies, percussive sounds, playing harmonics etc. by placing objects on the strings.

[23] Joe Paradiso, the engineer at the Media Lab responsible for most of the technology behind the Hyperinstruments, wrote a good overview for the IEEE Spectrum [Paradiso,1997] about the Media Lab projects but also other instruments including the ones described in this chapter. A longer version of this article can be found at web.media.mit.edu/~joep/ieee.html

[24] In a chapter for the IRCAM electronic book on new instruments [Bongers, 2000].

[25] The article is written by Waisvisz [1985] about the first version of the instrument. The later versions are described for instance in Het Boek voor de Elektronische Kunst (also in English) [Mulder and Post, 2000], pp. 166-167.

[26] The photograph of the prototype is made by Ernst Bos.

[27] I built another set of the Hands II for STEIM for a Swiss musician, but this set is now back at STEIM – it shows again how difficult it is to create a new *generic* musical instrument.

[28] A 'Lick' in rock music terms, or Riff in jazz music terms, or something like an arpeggio in classical music.

[29] More information about The Hands and Michel Waisvisz can be found on his web site: www.crackle.org, his recent keynote speech (closing plenary at the CHI2005 in Portland, OR).

[30] See for a historical overview of VR for instance the book by Howard Rheingold [1991], and for a more detailed technical and scientific description other books [Aukstakalnis & Blatner, 1992] [Kalawsky, 1993].

[31] The term Virtual Reality subsequently put the whole research effort on the wrong foot, later restored by speaking of Virtual Environments instead of emulating what's already there, or Augmented Reality in the case of a mix or real and virtual environments.

[32] See the article by Tom Zimmerman, Jaron Lanier and others [1987], and also an article by Jim Foley in a Scientific American special issue [1987].

[33] See the article by Rich Gold in Cyberarts book [1992]. Rich was the team leader at Mattel and also known for his work in the electronic music world, later worked at Xerox Parc to set up a program to pair artists and scientists. He died in January 2003.

[34] The Power Glove was often sold off in surplus stores for $50, whereas the DataGlove system was around $6000. One of the main reasons it had not become a commercial success as a game controller was the lack of games particularly made to be played with this controller [Gold, 1992].

[35] See for more information about The Hub: emfinstitute.emf.org/exhibits/hub.html

[36] It was also possible to connect the whole Power Glove to a computer through a specially developed box, the Gold Brick by Transfinite Systems Co., interfacing the Nintendo plug and protocol to the serial port of a computer. There was even a Max object to read it, which eventually disappeared when OSX version of Max came out.

[37] See for an overview his web site www.walterfabeck.com. There have been several articles about his work in the English new music magazine The Wire, and was interviewed in the BBC television program Tomorrow's World, demonstrating the instrument.

[38] More information about the Lady's Glove and Laetitia's work can be found on her web site, www.sonami.net. The Lady's Glove also appeared in several articles in magazines such as the Electronic Musician (an article written by 'Bean' [Blaine, 1998]), Wire, and Joel Chadabe's book on the history of electronic music [1997, p.230].

[39] Tanaka's experiences are described in his paper for the ICMC [1993] and discussed in the interview in the Computer Music Journal [Bongers, 1998]. The Bio-Muse and a general overview of technologies for reading bio-electrical signals from the body can be found in an article by Hugh Lusted and Benjamin Knapp in the Scientific American [1996] and in the CMJ [Knapp and Lusted, 1990]. This topic is further described in Chapter 4.

[40] I called it SonoPutty once, in a ICMC paper at that time [Bongers, 1994].

[41] Many of the ideas behind the web are described in an interview with Michel Waisvisz in the Computer Music Journal [Krefeld, 1990].

[42] The tension sensor was based on a moving encapsulated magnet and a sensor in a small unit I designed with a mechanical engineer. It is described in more detail in the IRCAM paper [Bongers 2000].

[43] I think it is important to mention this, people could also start to add electronic elements to their music to cover up for a lack of instrumental proficiency, or worse – musicality. See for more information www.uitti.org

[44] Often I notice that baroque musicians are very keen on trying out electronic technological advancements, which at first I thought was strange but then realised that it can be explained by looking at the original spirit of music in the baroque period which was very forward thinking and explorative.

[45] Though Jonathan described the instrument in the notes of his CD (see below) as "a trumpet in intensive care".

[46] The report of the jury is on line available at: www.aec.at/en/archives/prix_archive /prix_projekt.asp?iProjectID=2514

[47] See the paper for the ICMC in Århus, Denmark [Impett, 1994] and a paper for the journal of Organised Sound [Impett, 1996]. The piece is on Jonathan's solo CD Mirror Rite, Ladder of Escape nr. 7 CD, Attacca Records, Amsterdam, 1994.

[48] ....and a third one to read the notes, according to Gerrit van der Veer who told me this anecdote. The instrument is in the Victoria and Albert museum in London.

[49] This church has five organs, which can be played from one general console, and was until recently known as the biggest organ in the world. One organ resides in the roof and is called the 'echo-organ'. See http://infopuq.uquebec.ca/~uss1010/orgues/allemagne/passau.html.

[50] An ensemble of players of new electronic musical instruments founded in 1993. Following the model of a seventies 'power trio', it consisted of Zbigniev Karkovsky as a kind of drummer (using photocells as gesture triggers), Atau Tanaka as the guitar player (using the Biomuse) and Edwin van der Heide as the voice (playing the MIDI-Conductor as described earlier, and DSP voice synthesis). See www.sensorband.com, and the interview for the Computer

Music Journal I had with them in late 1996 [Bongers, 1998], available on line as a sample article at www.mitpress.mit.edu/journals/COMJ/sample-article.html.

[51] This use of a web was indeed predicted by Waisvisz in the CMJ interview [Krefeld, 1990], and in the meantime I had made already slightly bigger string tension sensors for him to use on stage.

[52] Theo Borsboom, actually a Harley Davidson mechanic who developed belt drives and rear-gears (for Harley's with a sidecar), has done the mechanical part of most of the instruments of that period.

[53] The instrument and players featured in an article with several photos in the Wired magazine (the UK version which existed around that time). See also www.sensorband.com /soundnet

[54] The technical as well as aesthetical issues are further described in a paper for a conference on Mixed Realities [Tanaka & Bongers, 2001].

[55] This issue is discussed in the *The Art of Programming* [Evers et al, 2002], the proceedings book and DVD of the Sonic Acts conference on 'Digital art, music and education' and festival in Paradiso, Amsterdam in 2001.

[56] The interview for the CMJ [Bongers 1997].

[57] The round table was called *Electronic Controllers in Music Performance and Composition*. Participants were (in alphabetic order) Bill Buxton, Don Buchla, Chris Chafe, Tod Machover, Max Mathews, Bob Moog, Jean-Claude Risset, Laetitia Sonami and Michel Waisvisz. [Wanderley and Battier, 2000].

[58] The first NIME was a workshop at the CHI conference in Seattle in 2001, and since 2002 it is a yearly conference of which I am committee member.

[59] Bringing all these new instruments on stage together was quite a challenge, and some new problems occurred such as the ultrasound systems of different performers influencing each other.

[60] This issue is discussed in a paper by researchers from CNMAT at the University of Berkeley David Wessel and Matt Wright *Problems and Prospects for Intimate Musical Control of Computers* presented at the first NIME workshop [Wessel and Wright, 2001] and later as a paper in the Computer Music Journal. They put it as follows: "low entry fee with no ceiling on virtuosity".

3.
Dynamic Architecture
the spatial interface

Architecture can be another source of knowledge and inspiration for creating interfaces and developing new interaction paradigms for ubiquitous computing, and is an essential part of the *e*-cological approach.

Historically, the field of architecture has always been involved in the development of spatial interfaces for people, making the building suitable for human use. However, architecture is undergoing dramatic changes over the last decades due to the increased use of computer technologies. With the merging of buildings of ‘brick and mortar’ with electronic computer systems and other technologies, and the dominant role of the computer in the design and manufacturing process, architecture is increasingly described as dynamic, ‘liquid’, even *interactive*.

In this chapter a concise historical perspective is given in section 3.1, focussing on the ‘hybrid architecture’ of the second half of the 20^{th} century which brings together real and virtual architecture, and particularly the developments in interactive architecture. The distinction and relationship between energy or *power* and *information* is discussed in section 3.1.2.

The notion of interactive architecture is illustrated by projects of some of the main players in the field of hybrid architecture, the Dutch architects Kas Oosterhuis and Lars Spuybroek, with whom I have worked as developer of sensor systems and interaction styles in section 3.2. Their aim is to create dynamic and interactive buildings, that can evolve in real time by applying not only the dynamic ‘materials’ such as sound, light and water, but by actually physically moving and changing the shape of the construction using mechanical actuators. Through the sensing systems the inhabitants or players in such a space can interact in real time with their dynamic environment. In this section our approaches and results achieved so far are described, which enable the interactions to take place in the real and physical world instead of inside the computer world.

The approach from the field of architecture is contrasted with the approach from the field of HCI research in section 3.3. A project is described in which I have been involved, at the Dutch electronics company Philips, which investigated interfaces for networked multimedia home systems. The design approach, and the interaction styles that were developed and tested, are described in this section.

In section 3.4 experiences are described of being involved in the Media House project with the Metapolis group of architects in Barcelona, in collaboration with the Things That Think consortium of the MIT MediaLab. This project could be seen as an attempt to bring the approaches of HCI and architecture together. Particularly relevant is the distributed sensing and actuating technology developed by the MediaLab.

The last section, 3.5, is a discussion of the issues introduced in this chapter.

3.1 Introduction

Architecture is becoming increasingly dynamic. After decades of developments, partly enabled by the use of computers in the design process, buildings have appeared with free form curves, suggesting motion, as a frozen movement. This is often called BLOB architecture, Binary Large Object or just (critically) referring to the blob-like shapes of the proposals of architects. In the last years some of the proposals are actually being build, particularly by the pioneers in this field: offices and architects such as Mark Goulthorpe (dECOi), Ben van Berkel (UN Studio), Lars Spuybroek (NOX), Kas Oosterhuis (ONL), Zaha Hadid, Greg Lynn and Marcos Novak[1]. Why so many Dutch architects are active in this field we don't know, although it might have to do with our relationship with water[2]. There is a vision of ‘liquid architecture’, ranging from an “architecture that is more of time than of space” as Ignasi de Sola Morales has put it[3], the combination of water and dynamics in the vision of Kas Oosterhuis[4], to the inclusion of the “fourth dimension” in the Trans-architecture from the digital to the real world of Markos Novak[5].

Many architects seem satisfied with the frozen movement, the shape of the buildings *suggesting* motion as can be seen clearly in the architecture of Zaha Hadid or Greg Lynn[6]. Others, like Kas Oosterhuis, are striving for really physically moving structures, in touch with their environment and inhabitants, interacting through sensors and displays[7]. Kas Oosterhuis runs a 'multidisciplinary design office' called ONL in Rotterdam, the Netherlands together with his partner, the visual artist Ilona Lénárd. Kas and Ilona have been working on bringing together architecture and visual art in most of their projects for many years, one of the first manifestations was the project 'Sculpture City' in 1995[8].

Kas is also leading the Hyperbody Research Group at the Department of Architecture at the Technical University of Delft. Here I work on the development of the interactive collaborative design environment called Protospace, which is described in more detail in this chapter and in Chapter 8.

A real time moving architecture is emerging. Architecture was never meant to be static.

3.1.1 History

One of the earlier attempts to create a connection between architecture and media is the well-known Philips Pavilion, developed for the World Fair in Brussels in 1958. The building was designed by Le Corbusier with a strong influence of Yannis Xenakis, the composer and architect working in Corbusier's office at that time. Together with the engineers and scientists of the Philips NatLab[9] Edgar Varese composed a piece of music called *Poème Electronique* for the hundreds of loudspeakers distributed throughout the building[10].

The Philips pavilion building, and the entrance sculpture
(now at the campus of the Eindhoven University of Technology)

A film was projected as well, which had quite abstract images in it and looks surprisingly contemporary even when viewed today. The building did not survive, only the sculpture that Le Corbusier designed to be put near the entrance remains[11], but currently there are plans in Eindhoven to rebuild the pavilion.

Another important building was the IBM Pavilion at the 1964 World Fair in New York, designed by Charles and Ray Eames. It involved multiple screen projections and sound[12].

The first 'interactive' building I heard of was designed by the German architect Christian Möller in 1992, *Kinetic Light* for a gallery in Frankfurt. The facade of the building contains lights, moving panels and loudspeakers, all these displays react to the environment and the weather[13].

But the oldest examples of the relation between architecture and media are ancient caves as inhabited by prehistoric man. Research has been carried out on the acoustics of caves and there seems to be a relation between the locations of cave paintings and the particular acoustics. At the locations the acoustics are influencing the sound made by the inhabitants by voice or musical instruments in a particular way[14].

3.1.2 Power and information

A useful distinction to make when analysing the interaction within the electronic ecology is between supplies of *power* and *information*, as described in chapter 1.2. 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 or *power*, such as the 'mains' electricity, water, light and gas, and flows of *information* such as the Internet connection, telephone, and television. The flows of power and information can have two directions, for instance fresh water in, sewage out. There is a two directional information exchange over the telephone. The power or information flows can also have just one direction, for instance electrical power in, or the reception of television information.
The delivery of energy and information 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[15].
As computer systems increasingly merge into the house, new possibilities for control become possible as shown in domotics applications in the home and office automation systems.

3.1.3 The Nervous System of Architecture

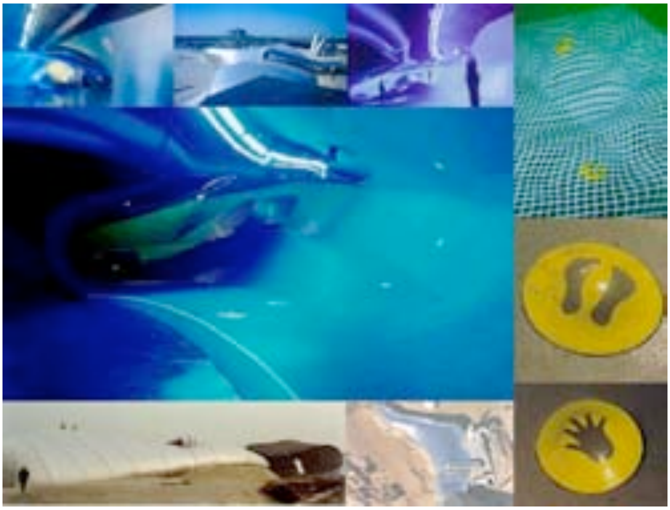
Electronic systems, communication technologies, computers and networks form the nervous system of the architectural body. By giving this nervous system sense organs (sensors) and hands and feet (actuators) and a brain (computer) it becomes possible to ‘interactivate’ a space[16]. An Interactivated Space is an environment which interacts with the people that are in it. Interactivated Spaces sense the activity of people, and (re)act through a variety of displays: auditory, visual, kinetic, haptic.
Already there are many dynamic elements and materials in buildings such as elevators, doors, windows, air flow, heating, sound and light[17]. Technologies are now becoming available to enable dynamic structures. To give meaning to these dynamics, to control it and to interact with it, sensing and actuating systems are needed that facilitate the connection between people and their technological environment. In the next sections developments and projects in the field of architecture are described. These are projects I have been involved in since 1997.

3.2 Architectural projects

In this section several architectural projects are described involving dynamic elements and interaction. In these projects I developed sensor systems and the interaction engineering.
A merging of disciplines is taking place. It is crossing the traditional organisation along sensory modalities, bringing in knowledge from the fields of music (the ear, performative, time based, intimate), video (the eye, time based, screen size), architecture, and new technological developments[18].

3.2.1 Water Pavilion

The first project I was involved in was the Water Pavilion, built between 1993 and 1997 as part of the Delta Works in The Netherlands. The Delta Works started after the disastrous flooding of the South-West part of the Netherlands in 1953, aiming to bring all dykes and waterworks to a safe level. It involved many big engineering works and in the finishing stage in the nineties it was decided to celebrate the works by putting up a special exhibition space, the Water Pavilion.
The Dutch architects Lars Spuybroek and Kas Oosterhuis were commissioned around 1993 to design the building in a 'Fresh Water' part and a 'Salt Water' part respectively. In the very last stage of building, at the beginning of 1997 only three months before the opening, the plans were changed and it was decided to commission both architectural firms also with the making of the exhibition. The architects then decided to make the space interactive, and approached the theme of 'water' in a more abstract way bringing together a team of other experts from music, visual art, and technology. This interactive building is very well known and documented extensively[19].

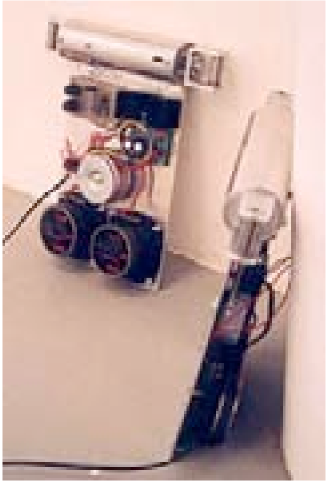


The Water Pavilion – sensors and projections in the Fresh Water part

The sensors used were photocells, detecting the presence and motion of the audience in a certain area, and several sensors that I specially developed for this project: touch sensors to be pushed by the hands or to be stepped on by the feet by the audience, pulling sensors, and the 'Surfboard' which was essentially a large joystick (custom developed based on infrared proximity sensors that translated the three Degrees-of-Freedom (DoF's) into electrical signals). These sensors would influence the computer generated projections of virtual worlds and surfaces, sound spatialisation and light movements. Water flows and environmental light were modulated as well, making use of all the traditionally dynamic materials. In addition to the sensors mentioned, an electronic weather station captured and relayed environmental conditions such as wind speed and direction to the system, influencing the behaviour of the space.

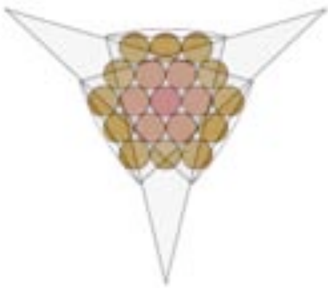
3.2.2 Deep Surface

For an architectural exhibition on the work of Lars Spuybroek in Hilversum, The Netherlands in 1999, a lightweight curved projection surface was designed by the architect. This surface floated in space suspended by connections to the columns of the actual building[20]. The aim was to make a *sonification* of the structural tension between the floating structure and the resident architecture and the minimal changes in it. I acheived this by developing two oscillator units with built in tension sensor, apmplifier and speakers.
The oscillators produced a pure sine wave with a base frequency 800 Hertz and a constant volume. The frequency was influenced by the structural tensions, measured by two custom built tension sensors. The sensors consist of a moving part (which is connected to the ropes of the structure) inside a spring, fitted in an aluminium tube. The moving part, the piston, is connected to a slide potentiometer. The sensors are sensitive around 400 kg (mechanically adjustable by changing the spring compression)[21]. The frequencies of the two oscillators were voltage controlled through the movement of the potentiometer of the sensor. The combined sound resulted in a beating frequency due to the de-tunings[22].



3.2.3 Trans-ports

Behind the ongoing project 'Trans-ports' of Kas Oosterhuis lies the vision of a moving, interactive architecture, which displays information surrounding the inhabitants, and is connected to other systems through networks.
In 2000 a version was developed for the Architecture Biennale of Venice. It was about the only interactive installation in the whole architecture exhibition[23].
Three curved screens were hung in the space, enclosing a space where images were projected. These images were influenced by the audience through sensors. A system of three networked computers, one for each video projector, generated virtual worlds by a program called Virtools[24]. The Virtools program was partially controlled by the information from the sensors. The sensors were PIR (passive infrared) motion detectors, which I hung from the ceiling above the audience, with the lenses partly covered with tape in order to limit the field of detection in the horizontal plane. The result is a detection grid which somewhat looks like the picture below (on the left) and the picture on the right shows the location of the installation in the building of the Italian Pavilion.

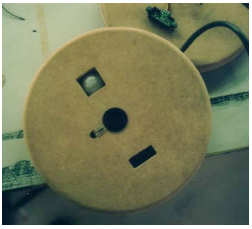


some of the developers inside the Trans-ports area

Of course, the sensitive areas are not perfect circles due to the way the PIR sensors work. This is not really a problem, although it is not immediately clear to the participants how their actions translate in system responses. In the original proposal there were sensors mounted on the floor, which would have given a more precise reading but it was decided that it would be in the way and too fragile for this situation[25].

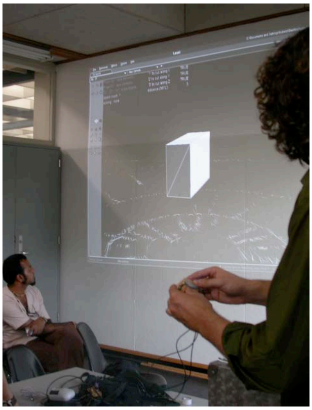
3.2.4 Muscle

For the 'Non-Standard Architecture' exhibition in the Centre Pompidou in Paris (November 2003 – February 2004) the architectural office ONL of Kas Oosterhuis and Ilona Lénárd devised a new structure called 'Muscle'. It is a structure balanced by the pressure of a big air balloon which is spanned by pneumatic 'muscles'. The pressure of the balloon volume is constant, while the tension of the muscles can be varied in real time under computer control by changing the air pressure of each individual muscle, resulting in a dynamic system of pushing and pulling forces. These muscles can produce a force of several thousand Newton[26]. The structure is about ten meters long, four meters wide and two meters high. The controlling computer system and the valves that regulate the muscles are placed inside the balloon, which one could enter through a narrow entrance. The computer system runs Virtools, controlling the parameters of the virtual model inside the computer. The computer model now becomes present in real space not by a visual display or video projector, but by the actual movements of the muscles of the real structure.
On the cross points of the pneumatic muscles eight sensor discs are mounted. Each sensor disc contains a proximity sensor, a motion detector, and a touch sensor. Through these sensor discs the audience is able to, explicitly or unconsciously, interact with and influence the behaviour of the Muscle 'body'.
The discs and their fixations were fairly robust, but the audience in Paris managed to wreck many of them – for some reason people liked to try them as steering wheels, perhaps due to the perceived affordance of the round shape resembling a car steering wheel. After the first week they were removed. We also found that it was difficult to reliably read the motion detector, a PIR sensor which should be only sensitive to moving human bodies, but responded to other motions as well. Because the Muscle has no separate sensors to register its *own* movements as the human body does (proprioception, see chapter 4), it cannot discriminate between a human moving in relation to a stationary Muscle or the combination of a stationary human and a moving Muscle[27].
Several structures with different shapes were developed later by students in the Hyperbody research group at the TU Delft, such as the Muscle Tower.



3.2.5 Protospace

At the architecture department of the Technical University of Delft an interactive space has been developed since 2003 called Protospace, by the Hyperbody research group of Professor Kas Oosterhuis. The aim of this space is that through multiple, full field of view and eventually 3D projections, teams of designers can work collaboratively on the creation of structures and environments. The parametric nature of these kind of architectural designs is particularly well suited for interactivating, that is, actively being interacted with by the users through sensor systems. For Protospace we developed a system consisting of a combination of on-body and in-space sensing techniques, to control the virtual worlds and elements.
The in-space elements are photocells, creating sensing paths across the room, PIR motion detectors, infrared proximity sensors, and a grid of switch mats on the floor. The on-body sensors, to be held by the participants, are pressure sensors and tilt switches fixed on a little wooden cube and wireless game controllers with several DoF's sensed.
Further extensions of the interaction in Protospace were developed in a structured design effort, described in more detail in Chapter 8 were the project is discussed in more detail.



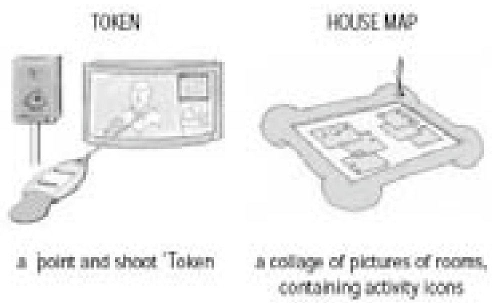
3.3 Home of the Future

There are many projects that look into the future of the home, such as the Living Tomorrow house or the House of the Future in the Netherlands[28]. All large technology companies have research labs of a variety of scale and relevance to investigate the role of future technology in people's everyday lives, ie. in the home. This involves issues such as new interaction styles, networked multimedia content and ubiquitous computing. The Philips corporation in the Netherlands opened their HomeLab in April 2002, as a joint effort of the research and design departments[29]. One of the aims is to investigate what is called Ambient Intelligence, a combination of rich interaction and intelligence in a ubicomp environment[30]. In this section I will illustrate this with an example from some of the first projects and early experiments I was involved in as an interaction researcher. This was in 1996 and 1997 when the project started at the Institute for Perception Research (IPO), a then joint institute of Philips and the Technical University of Eindhoven. This research, carried out by a group of scientists, technologists and designers, looked at interaction issues with networked home entertainment systems[31].

The project consisted of several phases[32]. First, a framework of Use Cases was developed to get an overview of the possible functionality of such a system. As a group we then analysed the scenarios of use that were developed by the designers. In every part of the scenarios *interaction issues* were identified. These were issues that seemed to us often potentially problematic, interesting, or unresolved. We identified fourteen of such interaction issues, such as *content awareness* (how does one know where or what the media content is in a ubicomp environment), *activity handling* (how can a user switch between tasks and activities) and *freedom of movement* (how can one take media content around the house). This last one, freedom of movement, we found particularly interesting as it was about new functionality. At that time the easiest way to take for instance music with you around the house was by carrying the content, carrier and player, for instance a walkman. It was anticipated that in a networked multimedia system this functionality would appear in the next few years[33], and how to interact with it needed to be investigated before it was going to be built.

Following the QOC (*questions*, *options* and *criteria*) method[34], to answer the *question* of "how to take content around the house" we devised nine different interaction styles as *options*, which were all compared using *criteria* such as efficiency, pleasure, learnability and feasibility. Two of such options were chosen to be developed further to a functional prototype stage and tested in the IPO usability lab (the 'huiskamer', or living room).

Together with a colleague I carried out user trials to test out new interaction styles for taking multimedia content (music or a television program) through the house. In order to test this, we set up a two room situation in the usability lab. The subjects were asked to bring their own music on a CD, which they could put into the system, and then the subjects had to move around making the music following them. The networked system had to be simulated as the real system was still under development, but the interaction with the functionality was present. The two interaction styles developed were called House Map and Physical Token.



House Map was a visual representation of the rooms in the house and content objects that one could interact with in a drag and drop style, built in Visual Basic[35]. The Physical Token[36] contained an infrared[37] remote control, and served as a token that could be programmed to take the music or TV program in it by pointing at the loudspeaker or TV screen respectively[38]. The user would get the experience that the content was put into the token (the content display would disappear) and then when taken to the other location made to reappear by pointing at the loudspeakers or TV screen in this location. Having the participants carrying out the set tasks with their own content (CD) or live television helped to make the interaction more familiar and the system more believable. In total 24 subjects participated in the trials, carrying out tasks of relocating media with them, and being interviewed in a structured way. The results indicated that the participants generally appreciated the functionality of relocating media. The pointing token, as an innovative interaction style, was certainly appreciated for its clarity and tangibility, but obvious drawbacks were indicated such as the risk of losing the token (and thus losing the ability to control), by some it was interpreted as "just another remote control", and some had difficulties with the aiming at the displays.

3.4 The Media House

In 2001 in Barcelona I got involved in the Media House project, a collaboration of the initiators Metapolis, the MIT MediaLab, the Polytechnic University of Catalunya (UPC), and the Elisava design school.
Metapolis is a group of mainly Catalan architects, at that time Vicente Guallart (also involved in new media productions), Enric Ruiz-Geli (theatre productions), Manuel Gausa (publisher), Xavier Costa (writer) and Willy Müller. They set up a 'postgraduate program' called *Advanced Architecture for Digital Cities*, partially to create a workforce for the Media House project. I taught in the program and helped setting up the studio. Students and teachers from the Elisava design school participated, and from the UPC university researchers participated involved in the development of Internet-2 applications. Internet-2 enables network connections between scientific and educational institutes, similar to how the Internet started but at a much higher bandwidth. In contrast to the current situation of 'Internet-1', the Internet-2 is not to be used for commercial applications. From the MIT Media Lab Neil Gershenfeld and others from the Thinks That Think consortium were involved, bringing in the idea of a distributed sensor and actuator network[39].

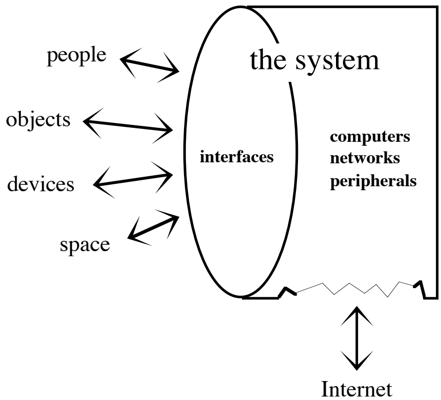
Sensor workshop at the Advanced Architecture course

3.4.1 Distributed computing

The basic idea of Gershenfeld's group was to give every element and device in the house a unique network address and embedded processing, so that they could work out relationships between themselves rather than being centrally organised. For example, a light bulb could be associated with a particular switch, the relationship being established between the bulb and the switch without involvement of a central intelligence. They had already developed a tiny web server, basically just one small PIC[40] chip with its own IP (Internet Protocol) stack including the IP address. However, giving all the devices in the house their own IP address would be too expensive, so they developed a kind of 'Internet light' for the purpose, were one element on the Ethernet network with its own IP address would relay information to and from the devices connected with a RS-485 serial bus. This idea was at that time called 'Filament', comparable to the 'Smart Dust' project at Stanford University. In the later years the idea was worked out further, resulting the development of what they now call Internet-0[41]. All devices and elements in the house can be connected using this Internet-0. The essential advantage of this approach is that devices and elements can be added to the system on the fly. The configuration takes place in a distributed way rather than relying on a central server.

3.4.2 Structure

The result was going to be a 1:1 prototype of such a Media House, including a kitchen, work room, bed room etc. presented in a performative setting in a large theatre the Mercat de les Flors in Barcelona.

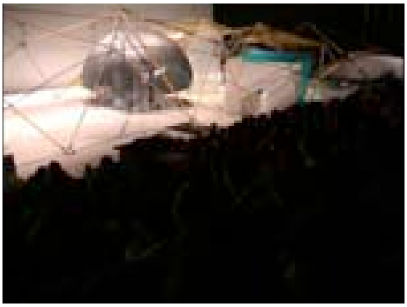


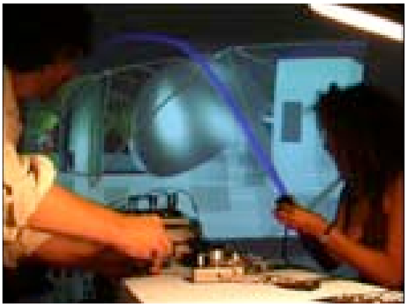
In a way the project was unique as it aimed to bring together an architects way of thinking of Metapolis (as an environment of "people, space, objects, limits, networks and contents") and the extreme ubicomp way of thinking of Gershenfeld's group. The slogan which unifies the approaches of the Media House was "The house is the computer, the structure is the network".

For the structure to be the network, a grid had to be developed to bring power and data (energy and information, see section 3.1.2) throughout the house. Standard lighting rails was used, adapted for the purpose with different electrical connections and reinforced with a wooden beam. This lighting rails, made by the company Erco, is quite common on ceilings of offices, shops and museums, for instance to place lamps or power supplies along the rails at any point[42]. The fittings slide in the rails, which contains six electrical conductors. This redundancy was taken advantage of by assigning only two conductors for the mains supply (220 V AC), and using two other conductors for the data of the RS485 network[43]. I had proposed to power the logic circuitry of each node with the mains supply, converting it into 5V DC with a tiny transformer (power requirements are very low), rectifier and stabiliser, but instead it was decided to include a 5V DC power supply (two lines) in the structure. It is a trade-off between the simplicity of the network structure and circuitry.
Small PIC-based boards were developed by an engineer at the Media Lab, containing all the circuitry for the communication between devices and sensor inputs and actuator outputs[44].

3.4.3 Performance

The final presentation consisted of a series of concerts, with the participation of a variety of artists such as performers, technologists, a dancer and cooks (!)[45]. The audience watched the house, which was transparent, and its 'inhabitants' (the performers) in a "Digital Day @ Media House", fast forwarding one full day in one hour (24 horas en una hora)[46]. Various video and image projections were made on a huge screen behind the house, with three coupled computers. Yolande Harris and I were asked to deliver a Video-Organ performance (see Chapter 7) as part of the concert, which we did in a small bubble with a projection and ourselves inside. The video material we used was, among other things, 3D CAD models of the house that we moved and transformed using our instrument. The audio material included sounds of the instrument building, to emphasise the process. During the whole performance, the audience could walk around and explore, and follow the locus of action, much like what we were already doing with the Meta-Orchestra performances (see Chapter 7).





3.4.4 Conclusion

The ambitions of the Metapolis people were very high, and kept high until the very end which unfortunately led to a sub-optimal result. The gap in technological understanding between the Media Lab approach and the Metapolis group proved to be far too big and ignored for too long. This was frustrating at the time, and I decided to concentrate together with Yolande on making a good Video-Organ performance. In the final presentations, the filament principle was demonstrated by linking one light bulb and one switch, which was convincingly showing the potential but all the piles of other nodes that were developed by the Media Lab engineers and students of the course were not used. If the aims would have been adjusted during the project to more realistic levels, an interactive environment could have been presented at the end of the project.
The performance of the group and the whole presentation in the theatre was however quite convincing. The political hooplah around it also helped covering up the failures, the house was opened by the mayor of Barcelona Joan Clos and the Catalan minister of ICT Andreu Mas-Colell among other people and there was extensive attention by the press. A book has been published (finally) in 2005, which gives a good overview of the project, the ideas behind it, the process and the results[47].

3.5 Discussion

It takes time and effort to make a transition from the traditionally static media, such as graphic design, to dynamic media such as music and video, to the new interactive media forms. This can be seen in the developments in architecture too, from static, to time based, to interactive. One of the developments that accelerates this process is the thoroughly parametric nature of the architectural models made with the computer. These parametric models are particularly well suited for real time control from the outside world. And once the gap is crossed by the sensors from real world actions into the computer systems, usually the most difficult step is the *mapping*. Mapping is

giving meaning to the signals sensed and put out, in relation to the parameters of the system. In contrast to the musical disciplines, where there is more of a tradition of real-time and performative aspects of the whole trajectory including mapping, a lot more needs to be invented and explored in the realm of interactive architecture. The scale is very different, or at least extended from the primarily intimate scale of the musical instrument to the larger scale of architecture[48]. The projects discussed in this chapter attempted to deal with this, particularly the Protospace project which is set up as a longer term research project and is further discussed in Chapter 8.
Another issue to deal with is that in these situations, as opposed to most electronic musical instruments, is the multi-user (or multi-player) nature of the architectural situation. This is one of the main research issues addressed in the Protospace project. There are limitations of the current technologies, and future improvements have been identified. These include both the application of more advanced technologies from the real time disciplines such as music, as well as technologies from other research fields such as ubiquitous computing and HCI. It was interesting to experience in the projects described in this chapter how different disciplines with their approaches, dogmas, knowledge and attitudes got together in these architectural and ubicomp projects. Sometimes there was friction but the issues are so broad and so important (it is about how we might live and work in the future) that it is essential to have all disciplines involved.
In the Protospace project in particular a tension was experienced between the extreme malleability of the virtual models and the limitations of the physical control elements. An early attempt to interact with a model in Virtools, a virtual cube of which the dimensions and orientations were changed by manipulating a real world object that consisted of a wooden cube with pressure and tilt sensors, showed the strength and at the same time the limitation of such an approach. The strength is the direct connection between the real world object through which the virtual object is manipulated, which turns into a weakness when one realises that the real world object can't change as much as the virtual object, thus limiting the malleability[49]. On the other hand however is the more traditional way of manipulating the virtual objects and movement of a character or viewpoint ('camera') in virtual space, by pressing the arrow keys, and this is not very satisfactory either. Somewhere on the line between these two extremes may be an optimum, but perhaps it can only be found on a line in a completely different plane. This is what we search for, which is fascinating and hopefully it will drive us towards solutions.

In this chapter I have given an overview of a number of projects that helped me to develop an ecological way of thinking about interaction on the spatial scale. The inspiration came from architectural projects and HCI research projects, and the combination of these two approaches. In an *e*-cology people are interacting with each other and their environment on a scale from the intimate (such as with musical instruments as discussed in Chapter 2) to the architectural scale of buildings.

[1] A good overview is given in the book by Peter Zellner [1999], *Hybrid Space, new forms in digital* architecture. It contains an clear introductionary essay by Zellner on *Emergent Dimensions, Information Technologies and Evolutionary Architectures*, and descriptions of the offices and projects pioneering this field. Another good overview is an issue of the Architectural Design magazine, guest-edited by Stephen Perrella [1999].

[2] As Kari Jormakka does in his book *Flying Dutchmen, Motion in Architecture* [Jormakka, 2002]

[3] In the article *Liquid Architecture*, in the Proceedings of the Anyhow conference [Solà-Morales, 1998]

[4] There are several articles and books by Kas Oosterhuis, particularly relevant is the article called *Liquid Architecture* which appeared in Archis Magazine, 11, 1995 and is reprinted in his book *Architecture Goes Wild* [2002]

[5] Probably the first one to use the term *Liquid Architecture* [Novak, 1991]

[6] I remember the artist Perry Hoberman gently asking Greg Lynn at a symposium on the topic in 1998 if he really was satisfied with this apparent or simulated motion, which he confirmed. This symposium took place on 20 and 21 November 1998, in Rotterdam as part of the Dutch Electronic Art Festival (DEAF) with the theme *The Art of the Accident* [Brouwer, 1998].

[7] Kas Oosterhuis has written several books about his ideas and projects. *Programmable Architecture* [2002] is a A4+ size quite glossy book published by the Italian l'Arca Edizione, *Architecture Goes Wild* bundles a number of significant essays and other writings from 1988 to the date of publishing [2002] and the most recent book is *Hyperbodies*, in the series of little books edited by Antonio Saggio: *The IT Revolution in Architecture* published by Birkhäuser [2003].

[8] A book and CDROM was published about this Sculpture City project [Meeuwissen, 1995]. Another publication juxtaposes their individual work and at the same time fuses art and architecture, each starting 'upside down' from either end of the book [Oosterhuis et al, 1998].

[9] NatLab stands for Natuurkundig Laboratorium, ie. the physics research labs of Philips. Dick Raaijmakers was one of them, in a documentary made by VPRO television in the Netherlands in 1998 he looks back on it.

[10] See the book by Mark Treib *Space Calculated in Seconds: The Philips Pavilion, Le Corbusier, Edgar Varèse* [1996]. The picture of the building is from this book, from Philips.

[11] Corbusier realised that from the shape of the building it was not apparent what the entrance and what the exit was, the purpose of putting the sculpture at the entrance was to make it clear. The sculpture is now at the campus of the Eindhoven University of Technology.

[12] See for instance the book *Eames Design, The Work of the Office of Charles and Ray Eames* [Neuhart et al. 1989]. The pictures are from this book.

[13] The work was presented during Möller's talk *Interactive Architecture* at the first Doors of Perception conference in 1993 [Möller, 1994]. See also his web site www.christian-moeller.com, and a recent book describing his work [Möller, 2004], where the *Kinetic Light* work is now described as a "reactive facade". The picture is from the web site. I have visited the site in 1994.

[14] As described by Lucie Rault in the book *Musical Instruments* [2000, pp. 14 – 25], referring to the research of Iégor Reznikoff at the caves of Niaux, France, and others.

[15] The Home Radio project at Philips [Eggen, Rozendaal and Schimmel, 2003] also emphasises the dynamic elements of a building, "the house as a medium". They describe the use of information about flows of water, gas and electricity supplies of the house and relay this information as ambient display in a remote location.

[16] I wrote an article on "Interactivating Spaces" in 2002 for a conference in Baden Baden, Germany, about interactive architecture and later made a more concise version of this for the influential Italian architecture magazine l'Arca Edizione in combination with the images of Sonia Cillari's work [Bongers, 2002, 2003].

[17] See for instance the book by Valerio Travi [2001] about the relationship between buildings and infrastructures, or the book *Smart Architectures* by Ed van Hinte et al [2003].

[18] The sensing technologies are described in more detail in a conference paper [Bongers, 2004].

[19] See for instance the yearbook of the Netherlands Architectural Institute [Ibelings et al, 1998], the books by Peter Zellner [1999] and Kari Jormakka [2002], and an article in Archis magazine which calls it "a testing ground for interactivity" by Ineke Schwartz [1997].

[20] The installation and the ideas behind the work are described in a small book published for the exhibition [Spuybroek, 1999]. See also www.noxarch.com.

[21] These sensors were are variation on the Soundnet sensors described in one of the last sections in Chapter 2.

[22] After this project Lars seemed to turn away for a while from interactivity, and even giving up the idea of physically moving buildings unlike Kas Oosterhuis. In his book *NOX: Machining Architecture* Lars writes "There is a persistent misunderstanding of the architecture-movement relationship. Through topological vagueness [sic] architecture can acquire a language of movement, i. e. 'splitting', 'merging', 'bending', 'twisting', which enables the architecture to move without the actual moving of the building" [Spuybroek 2004, p. 39]. However, his D-Tower is a architectural sculpture in the town of Doetinchem in the Netherlands which visual appearance can be influenced by the audience filling in a questionnaire on the Internet, and the Son-o-House Edwin van der Heide made a sound scape that is influenced by the moves of the audience in the space over time.

[23] The exhibition was curated by Massimiliano Fuksas, presenting 97 architectural offices of around the world. An extensive catalogue of the exhibition has been published, edited by Doriana Mandrelli [2000].

[24] Virtools is a programming environment used for the development of games and vritual worlds, and is often used in the projects of Kas Oosterhuis. It allows the 3D parametric architectural models to be manipulated in real-time.

[25] In a later version at an exhibition in Nancy, France, in 2005 (that I wasn't directly involved in) however a sensitive floor was created with switch mats.

[26] The air muscles and valves were made available by the manufacturer, Festo.

[27] Although the Muscle system *could* now which signals it has sent to the muscles, which in the human proprioception is called *efference copy* (see Chapter 4), which gives some information about the potential movements.

[28] The Living Tomorrow project is a Flemish initiative by Peter Bongers (not related) and Frank Beliën, and the most recent building (by Ben van Berkel / UNStudio) in Amsterdam is rather a showcase of current technologies of the participating companies than a view of the future. The systems are often not linked, so it is not very ubicomp, but it does a good job though communicating it to the general public. A small book has been published about it [Verrips et al, 2004]. The ambition is indeed *tomorrow*, which is just the near future. It is also interesting to look at past visions of the future, for instance the in Holland well known Kantoor van de Toekomst' (Office of the Future) initiated by Chriet Titulaer is slightly hilarious to look at fifteen years later but it *does* have the vision of ubicomp in it [Titulaer and de Kort, 1991].

[29] Two small books have been published about the research projects in the HomeLab [Eggen, 2002], [de Ruyter, 2003]. The book *The New Everyday* edited by Emile Aarts (scientific program director at Philips research) and Stefano Marzano (CEO of Philips Design) describes many projects and ideas of researchers and designers from within or around Philips [Aarts and Marzanom, 2003].

[30] See for instance the chapter *Ambient Intelligence* by scientists and (then) managers of Philips Research Emile Aarts, Rick Harwig and Martin Schuurmans in the book *Invisible Future* edited by Peter Denning [2002, pp. 235-250], and the proceedings of the conferences on Ambient Intelligence [Aarts et al, 2003], [Markopoulos et al, 2004].

[31] As part of the project called WWICE, Windows to the World of Information, Communication and Entertainment. This project was already running for several years at the NatLab of Philips.

[32] The whole project is described in an internal Philips report, a company restricted Technical Note, written by the team members Berry Eggen (project leader), Steffen Pauws,

Richard van de Sluis and myself (Philips IPO), Huib Eggenhuisen (Philips NatLab) and John Jansen and Han Kohar (Philips Design) [van de Sluis et al, 1997]. A paper has been published about this work and a subsequent phase that took place in the HomeLab, presented at the Interact conference [van de Sluis et al, 2001].

33 Of course, now in 2005 many household have a network, even wirelessly, which potentially would offer this functionality. Apple's Airport Express in fact has a stereo analogue output for streaming music for instance from one's iTunes library around the house – *not* the interaction though. The interaction style is also missing in the Philips Streamium system for delivering media content through the house, see www.streamium.com.

34 The QOC method is described in an article in the HCI journal [MacLean et al, 1991].

35 Programming the interface in Visual Basic was done by Richard van de Sluis.

36 The token was built by Han Kohar.

37 In a later version (that I was not involved in) this physical token was further developed using transponder technology, relationships could be built by the user between their tokens and multimedia content.

38 This idea of the token is also present in the work on Graspable or Tangible User Interfaces [Fitzmaurice et al, 1995], [Ishii and Ullmer, 1997].

39 As already described by Gershenfeld in his book *When Things Start to Think* [1999].

40 A PIC is a microcontroller, a one-chip computer with all connections for communication and input and output. The manufacturer Microchip has many different types, depending on the application. PIC could stand for Peripheral Interface Controller, and they are very popular on all sorts of sensor and actuator interfaces.

41 A very good description of the technology and the ideas behind Internet-0 can be found in the article *The Internet of Things* in the Scientific American [Gershenfeld et al, 2004].

42 iGuzzini is a large company that makes these lamps and fittings, and was a sponsor in the project.

43 RS485 is a standard of the Electronics Industry Association (EIA). It is a two-wire bus system that allows up to 32 drivers and 32 receivers, which can communicate over distances up to about 1200 meters due to the differential voltage of the two wires, and a speed of up to 250 kb/s.

44 The circuit used SMD (Surface Mount Device) technology and was developed by Master student Matt Hancher.

45 Paco Guzman and his staff from the restaurant Santa Maria in the Born area in Barcelona, where they serve the most wonderful food as a sort of high-end tapas, proved to be a natural performer. He insisted that a good cook has to be a good performer, creating not only food for his audience but also a whole atmosphere. In Santa Maria, the cooks are very prominently visible through a big window into the kitchen, quite a spectacle indeed.

46 The performances took place in the Mercat de les Flors theatre in Barcelona, at the end of September 2001.

47 The Media House book is edited by Vicente Guallart [2005].

48 This issue is discussed in more detail in a paper for the Organised Sound Journal I co-authored with Yolande Harris [2002].

49 Other 3D interaction systems developed such as the Visual Interaction Platform at the Eindhoven University of Technology seem less concerned by this issue. Perhaps this is due to the scale of the interaction (desktop rather than whole space), but it indeed does show the strength of having physical manipulation objects and 'props' as they call it [Martens et al, 2004], [Aliakseyeu et al. 2003].

Part III

Foothills

This Part describes frameworks and experiments in multimodal HCI, partially informed and inspired by the projects and developments described in Part II.
It consists of three chapters. The first chapter introduces the research field of HCI, describes all the elements of the interaction loop between humans and technology, and develops a framework for multimodal interaction. The next chapter further explores the human sense of touch, the haptic modality. It reports investigations using vibrotactile actuators that give feedback on actions performed with devices, through which virtual textures can be displayed by what I call ‘Palpable Pixels’. In the last chapter in Part III, a design space or taxonomy is described for physical interfaces. This Physical Interface Design Space (PIDS) is illustrated by several examples of projects and instruments as mentioned elsewhere in this thesis.
All chapters contain indications for future research. The title ‘Foothills’ of this part was chosen to emphasise its double nature, of reporting results and frameworks developed while at the same time informing my future research agenda.


WaM
We are Multimodal

4.
Multimodal Human-Computer Interaction
Interfacing with the e-cology

This chapter gives an overview of HCI knowledge in a different way than most of the standard literature, with a particular emphasis on the *physical* interaction layer acting as a firm base for other layers of the interaction. The structure of the chapter is described below.

In section 4.1 the HCI discipline is described as an inherently multidisciplinary research field. It is increasingly becoming an independent field, although three different approaches can be identified: from psychology, from computer science, and from the design disciplines.

From the fields of communication science and semiotics, knowledge is drawn and applied about information, and a distinction is made between *representation* and *feedback* in section 4.2

In order to investigate the interaction between people and their technological environment in more detail, all relevant elements of the interaction loop are discussed in section 4.3. The human is described in this context of interaction, analysing the senses, perception, memory & cognition, action and body. The multiple *levels* in the interaction are described, which take a human action from its conception in the human mind, through physical utterance and articulation, and back again. In order to fulfil the urgent need to increase the bandwidth of the human-computer interaction, multiple modalities or communication channels can be applied simultaneously. This *multimodal interaction* can consist of several *modes* of interaction, such as text based or image based, and several *sensory modalities* such as sight, hearing and touch.

To bring together these modalities and interaction layers I have developed a framework, a design space which consists of the dimensions of *modes*, *senses*, and *levels of interaction* - The Multimodal Interaction Space (MIS) as described in section 4.4.

The technological side of the interaction is described in more detail in Chapter 6, particularly the interface, sensors and displays of the computer. It is important to emphasise that when I mention 'the computer' it is regarded in the broadest possible way, ie. distributed, networked, and embedded. The aim is to describe an approach to HCI that is relevant in the context of the electronic ecology.

The ecological approach to perception, as developed by J. J. Gibson, is a source of inspiration throughout this chapter, for instance the notion of *affordances* gains relevance in the interaction with our technological environment.

4.1 the interaction between people and technology

Human-Computer Interaction (HCI) can be defined as the research field that studies the relationship between humans and the technological environment. It develops interfaces that enable the interaction.

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, which gives an overview of most of the disciplines involved. The disciplines are grouped in the human sciences (left), engineering sciences (right) and design (top). They all meet in the middle, in the research field of HCI, the interaction between people and technology.

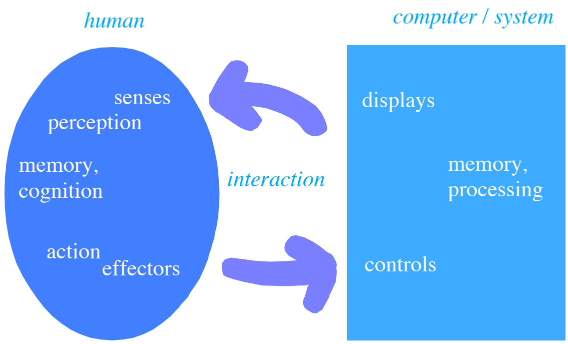
The diagram is built up as follows:

The interaction is studied by the human science disciplines, the engineering disciplines, and the design disciplines.

There are three main approaches in HCI. One approach is from computer science, another one is from cognitive psychology, and there is the design approach. Each of these disciplines has 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 traditionally 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[1]. 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.
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 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 person 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[2].
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.

4.2 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. The notion of affordances is originally thought out by J.J. Gibson in the sixties[3]. Later it has been applied and made popular in the context of HCI by Donald Norman[4]. It was further developed for instance by Bill Gaver, who extended it to include other senses *and* the notion of time[5].

4.2.1 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 provide. 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 they signify are called *symbols*, such as in written or spoken language or a musical score. Humans are the only animals that create and use symbols. Symbols can be organised in language, such as our speech, which developed first, and later was written down. The first written languages were very iconic, such as hieroglyphs, and later the phonetic alphabet was invented[6]. A language can be verbal as well as non-verbal (such as gestures), or a combination. Non-verbal signs are sometimes uttered unconsciously.

<u>information signs:</u>

- 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

4.2.2 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 there are philosophical implications of this, which are beyond the scope of this thesis. 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[7]. 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 and what affordances they have. 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, in different temporal scales. Information that is presentation in one case, can be feedback in another situation or even at the same time, depending on the context of control.

The information can have the form of messages (symbolic) or signals. If the feedback is presented in order to guide the users actions, to support them in articulating their intentions, it is called *articulatory feedback*[8] or synchronous feedback[9]. Articulatory feedback is particularly relevant in gestural interfaces, often using tactual modalities as shown in musical instruments[10].

When the system is generating information that actively draws the user to something, it is generally referred to as *feed-forward*. The strongest examples of this can be found in haptic systems, that actively 'pull' the user towards some location.

Feedback can come from elements specially designed for that purpose, such as message boxes and widgets that allow manipulation, or from the content itself (this is sometimes called functional feedback[11]).

Most feedback is actively generated by the system, which I call *active feedback*[12]. But some feedback can come from passive elements of the system, *passive feedback*, sometimes also called inherent feedback[13]. An example is the mouse click felt when the button is pressed - it is useful information but not generated by the system, it is passive feedback. 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 machine has crashed, or is not even on. In fact this is a bit of real world information, blending in an often useful way with the virtual world information. Mixing real and virtual phenomena is a good thing as long as one is aware of it, and it is designed as a whole. In the example of the mouse click it can be said that it is estimated information - usually true, but not always.

Presentation and feedback information can be displayed in various ways, addressing various human senses. In each case, particularly as part of parallel and multitasking situations, the most appropriate modality has to be chosen to convey the information.

4.3 Multimodal Interaction

A modality is a communication channel, for instance related to the human senses or the form of expression. In HCI, a considerable amount of research has been done on combining multiple modalities in order to achieve a higher bandwidth of interaction between people and their technologies. The goal is not only to make the interaction more efficient or effective, but there can be other objectives such as making the interaction more pleasurable or fun, or more natural.

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.

Multimodal interaction refers to the situation where the interaction takes place using several modalities often at the same time. For instance, a combination of visual, auditory and haptic feedback addressing the human senses, 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)[14]. In a paper about multimodal interaction by Laurence Nigay and Joëlle Coutaz a useful distinction in simultaneous use of modalities is made between *concurrent* (actions unrelated) and *synergistic* (actions combined), and taking into account the semantics and both input and output[15]. Most interactions with our natural environment are in fact multimodal.

A number of research projects have been carried out in order to investigate multimodal interaction between humans and technology[16]. In the final report of the MIAMI European project in the mid 90's, a good overview is given of all issues and work involved organised in a categorisation[17]. Other work looks at how, through these media, communication takes place between people[18]. The World Wide Web Consortium works on a Multimodal Interaction Framework, the emphasis however is on the interpretation and semantic layer *inside* the system[19].

My focus is on the *real space* where the interaction takes place, closer to the human, and I am developing a descriptive framework for interaction styles. This *Multimodal Interaction Space* (MIS) is described in:

- levels (physical, syntactic, semantic, task, goal etc.)
- modes (textual, continuous, non-verbal, subconscious, intentional, etc.)
- senses / modalities

In the next sections the dimensions of the Multimodal Interaction Space will be described in more detail.

4.3.1 Levels of interaction

Any interaction can be described in several layers, taking the user from a goal and intention, formulating a task and subtasks, carrying out these actions whilst receiving feedback on the physical level, and evaluating the result.

An action is usually initiated in order to achieve some higher order goal or intention, which has to be prepared and verbalised, and finally presented and articulated through physical actions and utterances. The presentation and feedback by the computer passes through several stages as well, before it can be 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 levels are discerned: semantic, syntactic, and lexical[20], but for most cases more levels can be described. Jakob Nielsen's virtual protocol model is an example of this, specifying a task and a goal level above the semantic level, and an alphabetical and physical level below the lexical level[21]. It is interesting to note that a Hierarchical Task Analysis (HTA) often reflects these levels. The levels particularly describe well the spoken or written language, but can also be applied on direct manipulation interface paradigms[22].
Donald Norman makes a useful explicit discrimination between input and output flows of information in *stages* in his Theory of Action[23]. 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 which emphasises the asymmetry in the interaction.
The Layered Protocol is an example of a more complex model[24], particularly to describe the dialogue using the speech modality, but also applied to general user interface issues[25].
When more sensory modalities are included in the interaction, models often have to be refined. Applying the Layered Protocol on the interaction which includes active haptic feedback, introduces the idea of (higher level) E-Feedback which has to do with *expectations* the user has of the system, and the I-Feedback which communicates the lower level *interpretations* of the user's actions by the system[26].
It can be said that virtual messages are exchanged between higher levels between user and system (still through translations to the physical level though), and that various messages are multiplexed into others and vice versa[27].
Garett's Elements of User Experience is an example of a more recent model, developed to include approaches from design and engineering particularly of web site architectures[28].
The articulatory feedback (or interpretation feedback) on gestural control which is studied in the research described elsewhere in this thesis, takes place at the physical level but can be extended to include the semantic levels.
Summary of levels: <u>goal</u>, <u>task</u>, <u>semantic</u>, <u>syntactic</u>, <u>lexical</u>, <u>alphabetical</u>, <u>physical</u>

4.3.2 Articulation

In the final phase of the process of making an utterance or a gesture we rely on feedback in order to shape our actions. Any action is a continuous process of acting, processing feedback, and adjusting. When speaking, we rely on the auditory feedback of our utterances and continuously adjust our articulation. When manipulating objects or tools, we rely on the information conveyed to our senses of vision, touch, sound, smells, including our self-perception, in order to articulate. The mainstream computer interface paradigm relies almost entirely on the visio-motor loop, sometimes with an added layer of auditory feedback such as sound-sets built into the operating system.

However, in a real world 'direct manipulation' action the closest sense involved in that act is usually the sense of touch. Musicians know how important the touch feedback on articulation is, and so does the craftsman. Computers seem to have been conceived as a tool for intellectual processes such as mathematics rather than as a 'tool' for manual workers, and have inherited a strong tendency of anti-crafts, and therefore anti-touch[29].
Anticipating a further development and emphasis on gestural control of computers, including the fine movements and issues of dexterity, there will be a need for the feedback to be generated properly in order to be adequate. That is, we need feedback that supports the articulation of the gesture, enabling us to refine the action during the process.

4.3.3 Senses (human input modalities)

An interaction can be based on involving multiple sensory modalities such as the visual and the auditory. The traditional organisation into five senses (seeing, hearing, smelling, tasting and feeling) is too limited to properly describe multimodal interaction. For instance, lumped together under the fifth sense of feeling (or the bodily senses) are in fact a number of senses. One can feel pain (nociception), motion, gravity, acceleration, equilibrium, pressure and so on, which are all very relevant in the context of the physical interface.
At the level of actual receptors we can discriminate between mechanoreceptors, chemoreceptors, and optical receptors.
Our sense of touch, the tactual sense, has three sources[30]: 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.
Furthermore, there is the issue of self-perception or *proprioception*. When interacting an individual is inherently active, and therefore aware of it. There are internal feedback loops that guide 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.

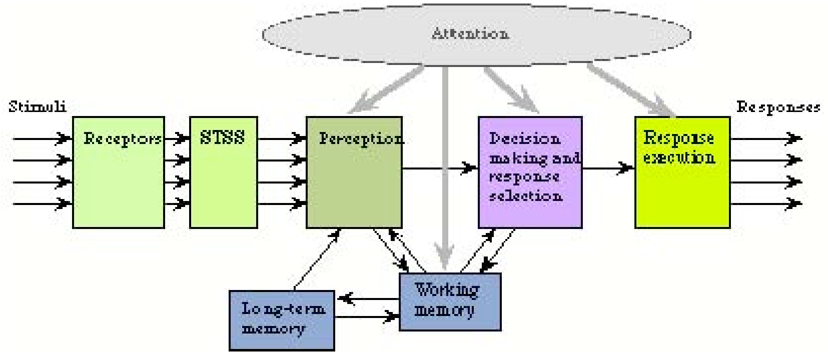
In summary: <u>visual</u>, <u>auditory</u>, <u>tactual</u>, <u>olfactory</u>, <u>gustatory</u>, <u>tactual</u>, <u>temperature</u>, <u>nociception</u>, <u>vestibulary</u> (almost all of these senses have an outside as well as an inside – proprioceptive – element)

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, the majority of this research is based on stimulus-response paradigms in fixed laboratory conditions. 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. I think therefore that the work of J. J. Gibson is useful in the study of human – technology interaction, because of his emphasis on active perception and the role of the context or ecology that the interaction is part of, as described in his third book[31]. In Gibson's second book he already proposes to "consider the senses as perceptual systems", in five categories (leaving the proverbial sixth sense intact) or *systems*: Basic Orientation, Auditory, Haptic, Taste - Smell, and Visual. He emphasises the *activity* in each system, eg. looking, listening, touching / feeling rather than seeing, hearing etc. [32].
The taste – smell system is not much used in the interaction with computers, but it is in other technologies. One could say that preparing a meal, with a good glass of wine, is a communication from the designer (the cook) to the one who enjoys it and interacts with the food and drink. Eating is a thoroughly multimodal experience, it involves at least the senses of taste and smell but it is also haptic[33] - for instance the texture of the food.

4.3.4 Memory and Cognition (human information processing)

Human information processing can be described in more detail, as shown in the diagram below. This diagram is based on existing models in the literature[34]. The functions of perception, processing and action are also called encoding, processing and responding, respectively.



The first stage describes the perception, where sensations from the sense organs (or from their STSS) are perceived and recognised. The STSS (Short Term Sensory Store) is different for each modality. The STVS (Short Term Visual Store or iconic memory) can hold an image for up to a second, and the STAS (Short Term Auditory Store or echoic memory) can hold a sound (or parts of a spoken sentence) from two to eight seconds. There is some knowledge about a short term kinaesthetic store which can hold an equal amount of information, but it may be important to know more about this in order to design interfaces that actively use the sense of touch.
The perception stage is connected with both the working memory and the long-term memory. Memory plays an important role in the decision and response selection stage,

and the final stage is the response execution by the motor system. Attention in this diagram is divided over almost all the stages mentioned and plays an important role in multitasking.

4.3.5 Action (human output modalities)

At the physical interaction level we can influence our surroundings. The progression of technological stages as introduced in Chapter 1 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 has only two knuckles but its abduction has two degrees of freedom. 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)[35]. 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.

Classifying human output modalities is not as straightforward as the input modalities. One way of looking at it is that every output modality has the goal to establish communication, and therefore aims to be perceived. Whether it is a human output modality or computer system output (display), a way of describing often found in the literature is by sensory modality (potentially) receiving the information. However in some cases an utterance, for instance a gesture which is intended to be perceived visually (by another person or an electronic system) can also be perceived haptically if the other person is touched. This influences the action, because it becomes an interaction. An interesting case is the Tadoma method, where a deaf and blind perceiver puts the hand against the face (on the cheek) of the speaker, perceiving the spoken utterances through a combination of the vibrotactile and haptic senses.

The same is true for the meaning of the action (at the semantic level, see above). A gesture in free space may mean nothing, until it encounters for instance the light switch. This means in the case of a more complex interactive system that the person making the gesture must be aware of whether the motion is tracked for instance with a camera system, and what results the actions (might) have[36].

Human output modalities are usually involving our muscles, such as for manipulating things, for locomotion, and for the fine motor control involved in producing speech. Not only are our perceptions often multimodal, most utterances or actions are too. For instance, when speaking not only information is conveyed through the meaning of the

words, but also the tone of the voice (pitch, prosody) and the accompanying gestures and body language.
There are many other human output modalities not involving muscles. There are several somatic (bodily) modalities such as blood pressure, temperature (blushing), excretion (sweating, crying), and heart beat. Some of these are not under conscious control and may be unintentional. It therefore makes a difference whether the actor cries in a movie, or a person cries for a genuine reason.
People still communicate through smells (not as much as animals do, or our ancestors did), either involuntary by body odours or intentionally by putting on perfumes[37]. Some output modalities can only be applied by involving an interface, in the case of some of the somatic modalities as described above, and particularly in the case of bio-electricity.
Communications can be asynchronous, for instance sending a letter by pigeon or e-mail, or preparing a meal through which the cook will address the taste-smell system of the perceiver.

4.3.6 Modes

Interactions can take place in several *modes*, for instance a text mode or a manipulation mode (here called 'continuous', described as 'analog' in Niels Ole Bernsen's Modality Theory[38]).
The description of modes reflects primarily the human output modalities with which a person influences its environment and communicates with other people (possibly mediated through technology). The modes are: <u>symbolic</u> (eg. text[39], speech, Braille), <u>iconic</u> (mimicking), <u>expressive</u> (para-linguistic, or non-verbal, eg. accompanying symbolic mode). Most human communication involves these modes all at the same time. The manipulative or continuous output or action comes under <u>expressive</u>.
Note that these modes often depend on the context. For instance, when typing on a keyboard the movements of the fingers (gestures) have a different meaning than when playing the piano, or when tapping on the table.
Furthermore, as described in the previous section, human utterances can be unconscious, and in some cases also involuntary. There are measuring devices that pick up signals from the body for health monitoring purposes. Interfaces can be (and are being) developed which enable humans to use these 'modes' as ways to expressing themselves through the system, for instance in the case of disabled people.

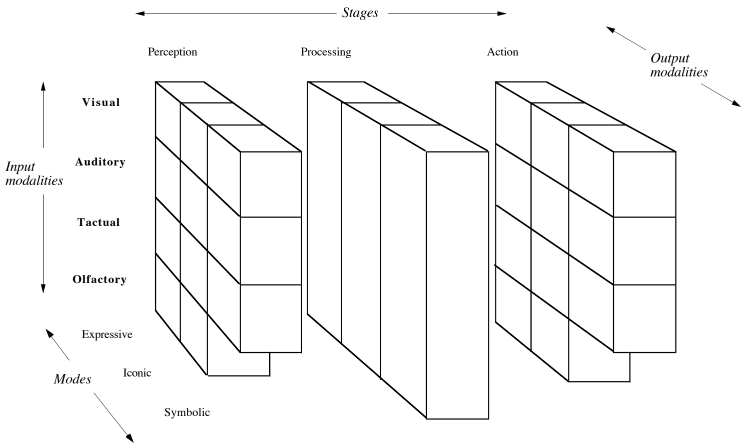
In summary:
Symbolicthis involves language, made up of words. This can be spoken or written text, using the alphabet or other characters like Kanji[40], Cyrillic, or the notation system used in music.
Iconic semantic communication by icons, gestures, etc. For instance, pictograms, hieroglyphs[41].
Expressive often subtle and non-verbal communication which we are often unaware of, usually in combination with another level of communication, also called paralinguistic communication

The table below gives an overview of these levels for several sensory modalities. It gives examples of how common communications can be distinguished in the separate levels.

Modalities	*Symbolic*	*Iconic*	*Expressive*
Visual	written language sign language lip reading	icons, drawing gestures	font size, colour spread of arms indicating volume facial expression, posture
Auditory	verbal (speech)	non-speech	non verbal (tone of voice, etc.)
Tactual	Braille Tadoma	touch (gesture)	touch (handshake)
Olfactory	-	scents (perfumes)	smells
Gustatory	-	-	-

People interact with their computers mostly in a combination of symbolic and iconic in the direct manipulation (DM) paradigm, or only in the symbolic way with the command line interface.

Various stages of information processing can be distinguished as shown before, in the crudest form they are *perception - processing - action*. These stages as well as the levels of communication or interaction are summarised in the diagram below. It suggests that some processes can take place at the same time, but many limitations have to be taken into account. For instance, limitations of the human central processing channel in the middle block in the diagram.
The diagram is part of earlier work and still in progress, in an effort to find a way to depict the elements of a multimodal interaction[42].



modalities, modes and processing stages from input to output

4.4 The Multimodal Interaction Space

The point of this section is to illustrate how many more possibilities there are to increase the bandwidth of the interaction between humans and their technological environment. Through the use of technology, from a pen or paint brush, a musical instrument, to new media, humans can express and act in a far bigger scale and with more variety than ever before, and this is still increasing. This has implications for the way the interactions are organised. The framework is not just a classification of existing interaction styles but is intented to leave room for what *would be* possible.

In this chapter the interaction between humans and technological environment has been analysed in its parts and brought together in the descriptive model of the *Multimodal Interaction Space*. The dimensions of this design space are:

- levels (physical, syntactic, semantic, task, goal etc.)
- modes (textual, continuous, non-verbal, subconscious, intentional, etc.)
- senses / modalities

Any *interaction style* can be placed in this space. Interaction usually (ideally!) takes places using many possible combinations of modalities, sequentially and / or in parallel. An interaction style is therefore not a place in the Interaction Space but a trajectory through it, particularly described in the levels (getting from the goal to the action, and back again analysing the results of the action).
In an *e*-cology many interactions can take place using multiple modalities and modes, simultaneously or sequentially, on many different levels. In order to describe these interactions a framework is needed that covers all possible interactions. The aim of the Multimodal Interaction Space is to describe the complex interactions which take place in an *e*-cology.
In Chapter 8 several projects are described in the terms of the Multimodal Interaction Space[43].
The framework is human centred, ie. it is not concerned with machine input and output modalities. This physical level of human interfaces with technology is described in the Physical Interface Design Space in Chapter 6.
In the next chapter, the physical layer of the interaction is further investigated by several projects involving the tactual sense.

[1] 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.

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

[3] The concept of affordances was mentioned in *The Senses Considered as Perceptual Systems* [Gibson, 1966], and further worked out in *The Ecological Approach to Visual Perception*, where a whole chapter is dedicated to the topic [Gibson, 1979, chapter 8] which refers to the ideas of the Gestalt psychologists in the beginning of the 20th Century. See also the book by Edward Reed *James J. Gibson and the Psychology of Perception* [1988, pp. 231]

[4] In the book *The Psychology of Everyday Things* in 1988, which was reissued and since has become a best seller book *The Design of Everyday Things* [1989].

[5] For instance in the paper at CHI 1991, *Technology Affordances* [Gaver, 1991].

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

[7] Daniel Dennet refers to "the brain in the vat" in a thought experiment in *Consciousness Explained* [1991].

[8] As it is called in the HCI book by Deborah Hix and Rex Hartson [1993], p 40.

[9] This is the term Tom Erickson uses [1995].

[10] Some work on this topic has been done at the Center for Computer Research in Music and Acoustics (CCRMA, pronounced as *Karma*) at Stanford University by Chris Chafe [1993] and /or Sile O'Modrain [1996]. My own work at Sonology has been described in a journal article [Bongers, 1998].

[11] The term is used by Stephan Wensveen [2005, Chapter 6], [Wensveen et al, 2004], who was at the Delft University of Technology and now at the Industrial Design department at the Eindhoven University of Technology.

[12] Or augmented feedback as Stephan Wensveen calls it [2005]. In his framework it seems that what I call presentation is always called feed-forward, indicating that the presence of a human interactor is essential.

[13] In Stephan Wensveen's writings. Also in the MIAMI report (see below) this term is used [Schomaker et al, 1995]. The point is whether it is *designed* or not, ie. on purpose or not, perhaps it should be called inherent and *explicit* (instead of active or augmented).

[14] More information about the parallel use of modalities can be found in my Master's thesis for UCL London, *Investigating the Parallel Use of the Sense of Touch in Multimodal HCI* [Bongers, 1999].

[15] The paper is called *The Design Space for Multimodal Systems* [Nigay and Coutaz, 1993]

[16] See for instance the work of the group of Antonio Camurri at the University of Genova, Italy [Camurri et al., 2003] and some other recent papers [Dragicevic et al., 2004], [Schaefer et al., 2004]. Our own work at Philips on multimodal interaction styles is described in a conference paper and journal paper [Bongers et al., 1998], and in the report *Key Concepts of Multimodal Interaction* [Eggen et al, 1996].

[17] The MIAMI reports can be found on-line at http://hwr.nici.kun.nl/~miami /reports/reports.html, including the final report [Schomaker et al., 1995].

[18] For instance the book on *Multimodal Discourse* [Kress and van Leeuwen, 2001].

[19] This report is available on line at www.w3.org/TR/mmi-framework [Larson et al, 2003].

[20] At the beginning of the chapter on Dialogue Notations and Design in *Human-Computer Interaction* by Alan Dix, Janet Finlay, Gregory Abowd and Russell Beale [1993], this is Chapter 8 in the first and second edition of 1993 and 1997, and Chapter 16 in the third edition of 2003.

[21] Nielsen's paper in the *International Journal of Man-Machine Studies* gives a good overview also comparing different models [1986].

[22] The article *A Layered Interaction Analysis of Direct Manipulation*. is available on line at www.useit.com/papers/direct_manipulation.html [Nielsen, 1992]

[23] In his chapter *Cognitive Engineering* in the book edited by Norman and Draper, *User Centered System Design* [1986].

[24] Developed by Martin Taylor and published in two papers in the International Journal of Man-Machine Studies (now Human Computer Studies) [1988].

[25] Research done by Berry Eggen, Reinder Haakma and Joyce Westerink at the Institute for Perception Research [Eggen et al, 1996].

[26] See the journal paper *Improved efficiency through I- and E-feedback: a trackball with contextual force feedback* [Engel et al, 1994].

[27] This idea is worked out in *Multiplexing, diviplexing, and the control of Multimodal Dialogue* [Taylor and Waugh, 1991].

[28] This can be found in Jesse James Garrett's book *The elements of user experience* [2002] and is summarised in a one page diagram at www.jjg.net/ia/elements.pdf

[29] As Malcolm McCullough describes in his book *Abstracting Craft, The practised digital hand* [1996] and also Neil Postman has discussed this issue in his book *Technopoly* [1992].

[30] See the chapter on Tactual Perception by Loomis and Leederman in the *Handbook of Perception and Human Performance* [1986], and Chapter 5 of this thesis.

[31] *The Ecological Approach to Visual Perception* [Gibson, 1979].

[32] *The Senses Considered as Perceptual Systems* [Gibson 1966].

[33] The sense of touch involved in eating is also called trigeminal or mouthfeel, as described by Peter Klosse who is the *chef* at the restaurant Echoput (discovered by Gerrit van der Veer). He developed a framework for describing flavours [Klosse, 2004].

[34] For instance in the (engineering) psychology books of Christopher Wickens [1992, p. 17] and Paul Barber [1988, p. 30].

[35] As described by Stephen Pheasant in his book *Bodyspace* [1996].

[36] This is getting frightfully close to the philosophical question about the sound that a tree makes when falling in the middle of the woods where no one can hear it.

[37] See for instance the chapter on smell in the book *A Natural History of the Senses* by Diane Ackerman [1990].

[38] The web site of the project is www.nis.sdu.dk/~nob/modalitytheory.html, and an overview can be found in a paper for an ERCIM Workshop [Bernsen, 1993].

[39] Text can be hand written or typed.

[40] In the Chinese and Japanese ideographs or characters, one symbol usually means one word referring to a thing, action of concept. In some cases the iconic nature can still be seen.

[41] Although hieroglyphs already contained a lot of symbolic information.

[42] Part of my MSc. thesis work at UCL London [Bongers, 1999]. The diagram is an extension of the well known "structure of processing resources" of Christopher Wickens [1992], replacing his "encoding" and "responding" with *perception* and *action*, respectively, adding more sensory modalities than two (!), replacing the "codes" (spatial and verbal) with *modes*, and correcting the perspective (the original diagram was isometric which hurts the eyes a bit).

[43] The Design Space has been presented at the Gesture Workshop in Vannes, France in May 2005. A full paper describing MIS based on this chapter illustrated by the projects in Chapter 8 has been submitted as a journal article [Bongers and Van der Veer, 2006].

5.
Haptic Display of Information and Feedback
giving meaning to what is felt

In this chapter the human sense of touch, or tactual perception, is described in all its complexity in section 5.1. This is placed in relation to haptic displays, through which technology can present information and generate feedback to be felt. From application fields such as musical instruments and interfaces for motion-impaired users, projects and experiments are described. This work was carried out in order to further investigate the role of the sense of touch in HCI, and measure the effectiveness of vibrotactile feedback.

Various vibrotactile feedback techniques that I have developed are described here for the display of tangible virtual textures or Palpable Pixels in section 5.2. This is illustrated with several demonstrators including a Haptic Finder.

A range of experiments measuring the effect of tactual feedback on the articulation of gestures are described, and the results presented, in section 5.3.

5.1 Haptic Feedback

Many interactions in our direct environment are guided by touch, such as picking up a cup of coffee, typing on a keyboard, or more complex tasks like creating a sculpture from clay. Yet in the interaction with the computer, the current GUI paradigm does not allow the user to feel the icons or windows that are 'directly manipulated'. This lack of *articulatory feedback* as described in Chapter 4 makes the interaction more difficult, and the 'direct manipulation' is therefore necessarily crude compared to real world interaction. Gestural input, although yielding some short term successes such as flying around by pointing in Virtual Reality (VR) or gestural control of music by actors on stage, actually introduces a number of usability problems such as fatigue and lack of feedback. The lack of touch feedback makes articulation of certain gestures difficult, as has been found in research in gestural control of music as mentioned in Chapter 2 and further described below.

Although lessons can be learned from interaction in the real world, attempts to literally recreate reality as aimed for by the field of Virtual Reality is a less suitable approach for HCI. This is especially true for motion-impaired users, for whom interacting with the real world can be difficult enough. It should therefore be strived for to *enhance* the interaction with their world, both real and virtual. Some developments for motion-impaired users are described in this chapter.

This approach is different from the research into TUI's, Tangible User Interfaces. TUI's are more about representing information and control of system parameters by physical elements[1]. The projects described in this chapter however are about *active* feedback, that is, generated by the system and therefore programmable. We are developing and applying haptic display techniques to actively address the sense of touch of the users.

In this chapter several developments and experiments are described that investigate virtual textures and other tactual feedback. First the human sense of touch is described in detail, how it can be addressed by tactual presentation or feedback, and an overview of existing feedback devices is given. Then there are some short sections on the use of touch feedback in musical instruments, the research done with the force-feedback trackball, and a description of the specific user group of the motion-impaired. Section 5.2 describes an experiment and demonstrators of Palpable Pixels. Section 5.3 describes more thorough research including quantitative measurements and statistical analysis of articulatory feedback on a 1-DOF gesture.

5.1.1 Tactual Perception

Our sense of touch has been explored for a long time, most systematically starting by Hermann von Helmholtz and later E. H. Weber[2] in the 19th century, Katz[3] in the early 20th century and J. J. Gibson[4] in the sixties.

The human sense of touch gathers its information through various interrelated channels, together called *tactual perception*[5]. These channels and their sub-channels can be functionally distinguished, in practice however they often interrelate.

The tactile perception receives its information through the *cutaneous* sense, from the different mechanoreceptors in the skin[6]. Proprioceptors (mechanoreceptors in the muscles, tendons and joints) are the main input for our *kinaesthetic* sense, which is the awareness of movement, position and orientation of limbs and parts of the human body[7]. A third source of information is 'efference copy', reflecting the state of the nerves that control the human motor system. In other words, we know that we are moving and this is a source of input as well. This is called active touch as opposed to passive touch[8]. *Haptic* perception uses information from both the tactile and kinaesthetic senses when actively gathering information about objects outside of the body. Most of the interactions in the real world involve haptic perception, and it is the main tactual modality for applying in HCI.

The feedback discussed in this chapter mainly involves the tactile sense.

There are four sense systems involved relating to four types of mechanoreceptors in the skin, making up all four combinations of the parameters *adaptivity* (slow and fast, having to do with frequency) and *spatial sensitivity* (diffuse and punctuate). The two of those mechanoreceptors that have punctuate sensitivity are the fast adapting Meissner corpuscles (RA) and the slower adapting Merkel disks (SAI), the other two have diffuse sensitivity: the rapidly adapting Pacinian corpuscles (PC) and the slow adapting Ruffini endings (SAII)[9]. Furthermore, movement of hair is sensed by hair root plexuses, and the skin is sensitive to temperature and pain. The tactile sensitivity is highest in the skin on the fingertips and the lips, where the highest density of mechanoreceptors can be found.

The experiments described in this chapter are particularly addressing the fast adapting diffuse system. This Pacinian system is important for perceiving textures but also vibrations – its sensitivity overlaps with the audible range.

5.1.2 Tactual Feedback Devices

Several devices have been developed to actively address the human sense of touch, and many studies have shown the improvement in speed or accuracy in the interaction. Existing input devices such as the mouse were retrofitted with solenoids for tactile feedback on the index finger and electromagnets acting as brakes on an iron mouse pad for force-feedback[10]. The now discontinued Logitech force-feedback mouse, and its predecessor the Immersion FEELit mouse, have two motors influencing the mouse movement through a pantograph mechanism. These have been used in several studies[11] and in a continuation of the studies with the vibrotactile device as described in this chapter in section 5.2, using force-feedback[12], all showing performance improvements by applying various forms of feedback as described above. The Immersion TouchSense protocol, defining tangible display elements, is used in many of the commercial force feedback devices[13]. The Logitech iFeel mouse uses this protocol, generating vibrations with a little motor device. This mouse device is now discontinued, perhaps due to the fact that the feedback was applied in the palm of the hand which is perceived as rather irritating. Ironically, a recently introduced anti-RSI mouse device called Hoverstop uses a vibrating element to warn the user when it is not used but still held ('hovering'), triggering the user to let go of the mouse whenever possible[14].

Another mouse with built-in vibrotactile feedback is the Vmouse from AVBtech, which has a motor with an eccentric weight inside (a large version of the vibration device found in mobile phones and pagers), driven by the audio output of the computer[15].

The AVB Tech mouse with eccentric weight (left)
and a Logitech force-feedback joystick with motors (right)

Several motor-based force-feedback joysticks have been used for generating virtual textures[16], and other experiences[17], and became cheaply available for gaming applications, such as the devices from Microsoft and Logitech using the TouchSense protocol.
The Phantom[18] is a well known device, it is a multiple degree-of-freedom mechanical linkage that uses motors to generate force-feedback and feed-forward on the movements. It has been used in many studies that investigate the advantages of tactual feedback[19]. Several different sizes are available.

5.1.3 Tactual feedback for musical articulation

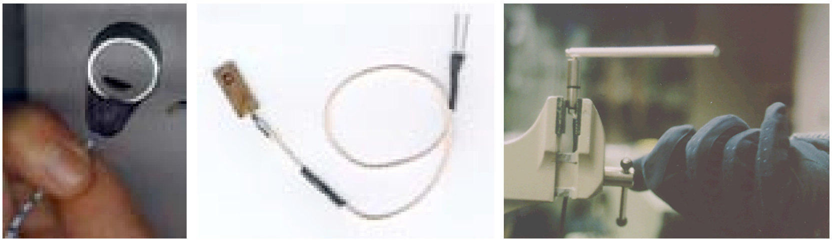
Musicians rely strongly on their sense of touch when playing a musical instrument. Many traditional musical instruments are inherently designed to display vibrotactile information, in addition to the display of auditory information. For example, the vibration of a string on a violin or the reed of a clarinet can be felt. This non-auditory information is used by the player to improve articulation in producing the sound.

Musical touch
Unlike acoustical instruments, electronic musical instruments display a synthetic sound source which in most cases only can be heard and not felt. It is known that the tactually display of attributes of the sound (e.g., pitch, amplitude envelope, timbre) enables the performer to improve muscular control. This comparison led to the realisation that the link between the (electronic) sound source and its "feel" was missing. For instance, a sharp sound should have a clearly tangible threshold, and a dull sound a more soft feel. Yet any sound played on a conventional electronic keyboard has the same feel...
Acoustical instruments can generate sound by being plucked, hit, blown, or bowed and often are amplified by a resonating body. With most instruments, the player is in direct contact with the vibrating parts. It is known that the vibration amplitudes at the

left hand of a violin or cello player are well above threshold levels of tactile perception[20].
Of the different types of mechanoreceptors in the skin, the Pacinian corpuscles play the biggest role in our vibrotactile perception because of their sensitivity in the audible range. At the fingertips, the lowest frequency that can be detected is 40 Hz, this sensitivity increases for frequencies up to 250 Hz where the highest sensitivity is reached. The sensitivity then decreases for higher frequencies, up to 1000 Hz[21]. Pitch discrimination through vibrotactile perception is poor compared to the ear, but vibrotactile feedback does play a role in the determination of the amplitude envelope.
Electronic sound sources are able to produce many different sounds, but each sound has the same "feel" because nothing physically changes in the control device. This is not intuitive. In the real world for example a thicker string will produce a lower, heavier sound and gives more force feedback.

Other research
Researchers at ACROE in Grenoble have built a motor controlled keyboard, which can give the player synthetic force feedback[22]. Brent Gillespie, then at the Center for Computer Research in Music and Acoustics (CCRMA) of Stanford University, modelled various types of piano action and developed the "Touchback Keyboard" which could emulate the feel of different pianos[23]. At IRCAM in Paris two guest researchers worked on vibrotactile feedback, developing a system for virtual textures. They applied feedback on a ring on the finger (not on the tip though) and on foot pedals[24].

Sonology
At the Institute for Sonology at the Royal Conservatory of Music in The Hague in the early nineties I started researching the use of vibrotactile feedback on gestural control. My aim was to make sound tangible, and developed the Tactile Ring using a miniature electromagnet to generate tactile cues, somewhat similar to a solenoid.



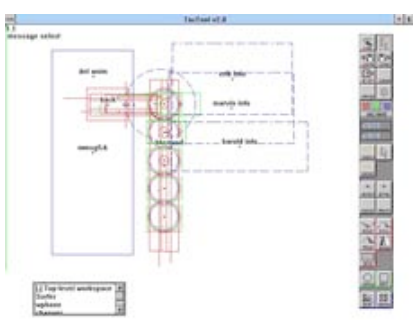
The Tactile Ring, a Tactor, and a mini motor controlled by SonoGlove

The Tactile Ring consists of a small aluminium ring, which can be worn around the tip of the finger, fitted with a miniature electromagnet actuator. This actuator is made from a small relay coil, which drives a pin with a diameter of 1 mm against the skin of the fingertip. The mechanical part of the actuator is covered with a bit of cloth, to muffle the clicking sound in order to avoid interference when used in combination with an ultrasound tracking system. In that time I also experimented with Shape Memory Alloy (SMA), like muscle wire and Tactors, and miniature motors[25].

One particular instrument was thought to benefit of this feedback, the Laser Bass. This is an instrument devised with Florentijn Boddendijk at Sonology, who performed with it ever since particularly in music theatre productions[26]. The idea of the Laser Bass instrument is quite simple, it consists of a vertical visible red laser beam, which can be 'played' by intercepting the beam (sensed by a light sensor) which triggers a note corresponding with the height above the floor. The expectation is that making the beam tangible, would improve the accuracy both temporally and spatially of playing the virtual string. However, as often the human is very good at adapting so Florentijn learned to play the instrument rather well without the added feedback. Recently I have picked up on this idea again and at the Vrije Universiteit we are working on developing a version that can be tested[27]. The aim is to measure whether a musician can play a gestural controller more accurately when provided with tactual feedback.

5.1.4 The Force Feedback Trackball

In 1997 I worked in a team of researchers and designers at Philips and the Institute for Perception Research (IPO) in Eindhoven, the Netherlands, on the development of multimodal interaction styles for multimedia home systems. I was particularly interested in the force-feedback trackball they had developed, which was used in the project.
The force-feedback trackball was developed by Philips and IPO originally to investigate the notion of E- and I-Feedback as described in Section 4.3.1. Using computer controlled motors it was possible to influence the movement of the ball, enabling the system to generate feedback and feed-forward[28]. This device was further used for studies in tactual perception[29], and the development of multimodal interfaces as described below.
To make these tactual feedback 'feels', a program was developed called TacTool, which at that stage could be used as an authoring tool to design touch, sound and image[30]. With this software force fields such as holes, hills, textures, conveyer belts and edges can be designed. Events can be assigned as well, to create more complex behaviour.

The IPO force-feedback trackball (left) and a screen shot of the TacTool program in edit mode.

Around the Force Feedback Trackball we developed an number of multimodal interactions styles, as part of the development of complex multimedia home entertainment systems. Such systems would combine functionalities such as television, music, phone and messaging.
At that time I was part of a team of interaction researchers from IPO and the Philips NatLab (physics lab) and designers from the Philips Design department[31]. Four interaction styles where developed and implemented for four scenarios of use. The result was used as a demo within Philips, and served also as a basis for an Expert Appraisal conducted in the IPO usability lab (living room) with a number of user interface experts from within the company[32]. The reactions on the multimodal interaction styles were positive in the Expert Appraisal, and a number of useful suggestions were made. Several other application domains were mentioned where multimodal interaction could be useful.

Two screen images of a multimodal interaction style. The disks are made tangible using force feedback.

A preliminary user test was done in the usability lab with 24 (paid) subjects from outside IPO, to obtain an opinion of target users. A randomised experimental design was employed, in which the participants were presented with all four scenarios (interaction styles) in both a multimodal and a mono-modal version. The pictures above show one of these styles, for a scenario of combined television watching and message browsing. The little disks visible on the right hand side are icons representing the various messages (text or voice), controlled with the movement of the ball with feedback which made a realistic experience of flipping a disc. The other scenarios were a channel changer for basic TV zapping, answering a phone call, and selection of TV channels based on categorised content.
The users were not informed beforehand about the special kind of feedback they might experience, and all technology was hidden. Indeed the sounds and forces were not commonly mentioned in the questionnaire, which may indicate that the cues were subtle. Subjective usability was measured by 5-point scales of perceived practicality of the interface, task completion time, error rating, learnability and pleasure.
The results of the questionnaires and usability scales of the User Test indicated a general preference for the multimodal versions of the scenarios over the visual-only versions. Factors such as computer and mouse experience, and having a technical background were shown to influence results, but the factor age was of no influence. We have concluded that users accept the concept of multimodal interaction styles[33].

The Force-Feedback Trackball was a research tool rather than a commercial product. Eventually a new device was designed and developed together with a researcher at the Philips NatLab, with only one rotational degree of freedom[34]. This simplification was a logical step in the development phase towards a commercial product.

5.1.5 Haptic feedback and special needs

For the development of interactions for the complexity of an *e*-cology it is important to look at several extreme cases of usage, such as I have done in the previous chapters (musicians, architects). More examples will follow, and it this point I will describe some research work I have carried out with computer users who are physically handicapped or more specifically Motion-Impaired Users. The research question was whether haptic feedback could enhance the interaction in the case of these users.
One of the goals of HCI research has always been to increase the bandwidth of communication between humans and computer. However, the current matching of human capabilities and machine modalities is still far from optimal. When one considers the interaction of people in everyday life with their environment or with other people, the current level of interaction with computers seems to handicap *everyone*.
When the graphical user interface was introduced it took users away from the dark world of the command line interface. Visually impaired people however were left behind, and only started to catch up by using tools later introduced to make the GUI accessible for them, often by using sounds[35]. Now that the findings from VR research and enabling technologies, such as multimodality and enhanced feedback, are about to be introduced into the desktop computer paradigm, there is a risk that *again* functionally impaired users are going to be left behind. Instead, we can take it as an opportunity to actually make computers more accessible for everyone, including the elderly and the motion-impaired because modalities can be used that were not available for interaction before. However, to do this we need to understand how to make the best use of the available input and output modalities to ensure usability. There are many research efforts and several conferences yearly organised on topics such as Design for All and Inclusive Design.

Motion-impaired computer users often exhibit tremors, spasms, reduced muscle strength and decreased co-ordination. This may then lead to problems when accessing computers using standard mouse and keyboard input devices. Gestural input and multimodal systems are often seen as potential enhancements of the Graphical User Interface (GUI) paradigm, however recent findings suggest that for the motion-impaired, gestural and multimodal interaction have been shown to significantly *increase* the physical and cognitive workload when it is designed badly[36].
Motion-impaired users may have decreased motor control and muscle strength, but there is not necessarily a decreased sensitivity of touch. It is therefore expected that this group of users can benefit from enhanced articulatory feedback using haptic output. Mapping sensitive, multi-degree of freedom input to haptic feedback can also enable users to augment their strength. This has implications for the tailorability of the interface. For instance a system can adjust its friction to restrain movement for a user with severe tremor, or create feed forward to give users suffering from decreased muscle strength guidance in reaching goals. The interface should be tailored, either

manually and / or automatically, to both the users' output space and their sensory idiosyncrasies. The experimental set-up described in section 5.2 was developed in order to carry out research in this direction. This research I carried out at the Engineering Design Centre at Cambridge University, in 1999 and 2000[37].

5.1.6 The experimental set up

Most of the experiments described in the next sections of this chapter use the Max/MSP graphical programming environment on the Apple Macintosh for the generation of vibrotactile feedback. This environment was originally developed for electronic music and multimedia applications, and as a result has suitable real time capabilities. It has been successfully applied for the acquisition and processing of interaction data for psychometric experiments[38]. Using the signal processing capabilities of Max/MSP, low frequency audio signals can be generated relating to cursor movement and position. These are transmitted to the user via the control surface through the use of electro-mechanical drivers. The aim is to translate pixel values into tactile stimuli, thus making the pixels *tangible*. Black and white can be translated to on/off events; brightness to intensity of the stimulus; and colour, for instance, to the frequency of the stimulus. Using this environment, a number of textures have been generated and tested with different users, including motion impaired users.

5.2 Palpable Pixels: a method for the development of virtual textures

I have developed an experimental set up to display virtual textures to a computer user. The focus of the work is on the vibrotactile sensations, alone or in combination with visual and auditory textures.

In order to simulate the feel of textures, computer generated vibrations are presented to the user who is actively exploring an area using a computer mouse. A pixel value can be translated into vibrations generated by a small loudspeaker, which can be felt on the user's fingertip. The sensation is somewhat like stroking sandpaper. Some key parameters of virtual textures have been identified, and a set up has been implemented which is using low frequency sounds and is based on knowledge and tools from computer music research.

The advantage of using a miniature loudspeaker however is that many more pressure levels and frequencies can be generated. This is the rationale behind the developments described in this section and earlier research.

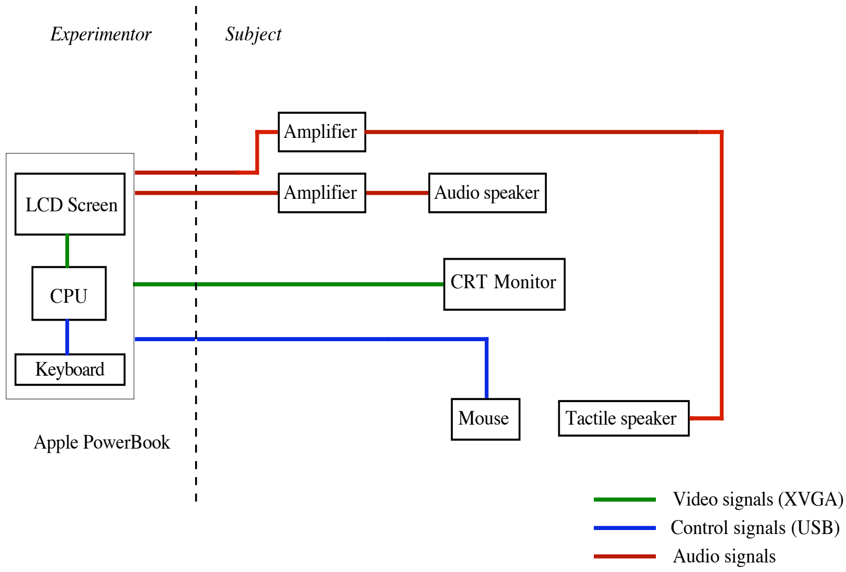
The goal of the research is to determine the minimum threshold levels of sensitivity, and to determine how many different textures can be discriminated by touch. The result can be a *palette* of textures that can be used to design with. This can be applied in any combination of modalities, for instance a purely haptic interface for blind users (monomodal), or combined with sound (duomodal), or in a truly multimodal interface addressing several senses.

5.2.1 The Development of virtual textures

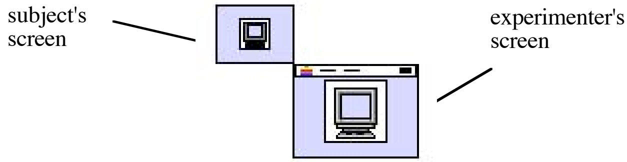
Using vibrotactile and force feedback can lead to a further understanding of the application of haptic sensations in user interfaces. User trials have been carried out with motion-impaired users and demonstrators have been developed in order to create a library of computer generated signals that create haptic sensations based upon the textures and forces which can be discerned and applied in the user interface.

5.2.2 The test and demonstrator set-up

An Apple Macintosh PowerBook G3 is used, running a Max program ('patch') for generating the stimuli. The subject has a separate monitor (VGA 640x480 pixels) and mouse, both connected to the same computer as the experimenter. The experimenter uses the (internal) keyboard, trackpad and screen of the PowerBook to control the experiment. The diagram below shows the set up.



A standard Logitech mouse is used (MouseMan or Pilot Wheel USB), button functions are disabled, subjects use their preferred hand. Because both the experimenter and the subject use the same cursor, the Max patch provides a way of positioning the cursor on either of the screens with a keyboard shortcut.
The Mac is set up in dual-monitor mode, with the external monitor (for the subject) beyond the top left hand corner of the main screen. To avoid subjects accidentally loosing the cursor off their screen onto the main screen (the screens are connected through the two adjacent pixels only) this configuration was chosen, because for right handed mouse use the bottom right hand corner is hardest to reach.



5.2.3 Threshold levels of tactile sensitivity of motion-impaired people

An experiment has been designed and carried out to investigate the general response of Motion-Impaired computer users to haptic feedback, and to measure the threshold levels of their vibrotactile sensitivity.
The particpants were four motion-impaired users from the Papworth Trust near Cambridge, who have been participating in user trials for the research group for a longer time.

1. Participant PH1 is right handed, has degenerative Cerebral Palsy, decreased manual dexterity, spasms, and uses a wheelchair.
2. Participant PH2 is right handed, exhibits a tremor, has decreased manual dexterity and quite clenched fingers, and uses a wheelchair.
3. Participant PH3 is right handed, has Cerebral Palsy, walks with sticks.
4. Participant PH4 is left handed, has Cerebral Palsy, has decreased manual dexterity, is deaf, and walks with sticks.

Some exploratory studies were conducted with the Logitech force-feedback mouse which will not be described in this section. Here the emphasis is on the experimental set-up for the vibrotactile stimuli. The experiments are described and some results discussed.

Task
The participants had to move the cursor with the mouse on the screen with a virtual pattern. Visual feedback consisted of a pattern of vertical lines. Each time the properties of the virtual pattern of stimuli changes, the participant had to report whether something was felt. This was done orally by a "yes" or "no", or by nodding the head. Then a new stimulus would be set.
The subject's screen had a small window programmed for displaying visual messages to the subject, in addition to the oral discourse.

Stimuli
The tactual stimuli generated by the computer are variable in a number of ways. The amplitude of the stimulus can be varied as well as the choice of different actuators as described below. Also the wavelength (and thus the frequency) of the basic stimulus as well as the waveform can be varied, and finally the spatial distribution of the virtual pattern. Only one waveform was used in this experiment, a triangular waveform was chosen to approximate a delta-function to have a short and intense stimulus. The base

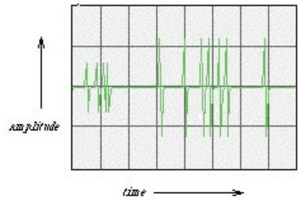
frequency of the stimuli was either 25 Hz or 83.33 Hz. These frequencies were chosen to avoid as much as possible the sensitivity range of auditory perception.
Three actuators were used: a small loudspeaker vibrotactile stimulator (Ø 20 mm)[39] stuck on the mouse felt with one of the subject's index fingers or thumb, a medium sized loudspeaker (Ø 65 mm)[40] held under the fingers of the left hand, and a low-frequency driver mounted on a wooden plate below the mousepad vibrating the whole mouse[41]. This vibrotactile mousepad, as shown in the picture below, I developed specially for this range of experiments.

the vibrotactile mousepad

External amplifiers were used to drive the actuators on one channel of the stereo output, while the other channel in some cases was used to drive an audio loudspeaker to mask the sound simultaneously generated by some of the vibrotactile actuators.
The table below describes the parameters and the possible variations used in the experiment.

parameter	*variation*	*values*
amplitude of stimulus	four levels	0, 30, 60, 100 %
actuator choice	three levels	
frequency of stimulus	two frequencies	25, 83.33 Hz
waveform	one form	triangular
spatial distribution of lines	three distances between the lines	1, 2 and 4 pixels

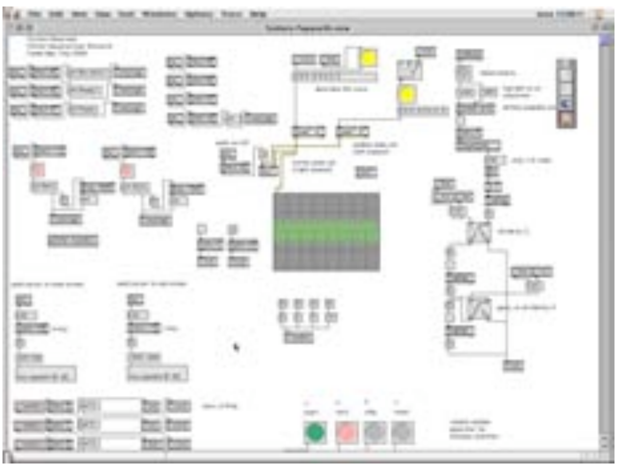
The three levels of actuator choice are the three different actuators, and the low-frequency driver was used on two volume levels of the external amplifier.
The picture below shows the waveform in an oscilloscope window as a result of a cursor move, with amplitude levels 30% (on the left hand side) and 60% (on the right hand side).



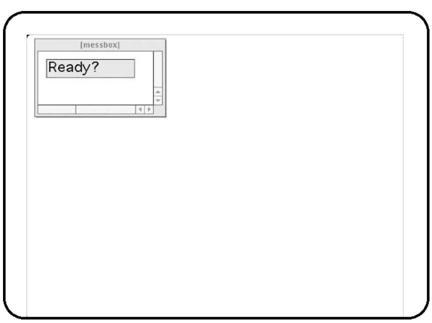
Under normal conditions - finger(s)on actuator - the vibrotactile cue is not audible. Only with the highest level of stimulus, the low frequency driver with its amplifier set to a higher level, the stimulus becomes audible.

Method

The picture below shows the experimenter's screen with part of the Max program visible and the controls. The screen shows the waveforms generated, a variety of settings of the vibrotactile textures, controls for of the progression of the experiment, and it could send messages to the screen of the particpant.



The picture below shows the participant's screen, with a message from the experimenter on it.



An exploratory session with three participants PH1, PH2 and PH3 was performed, to explore the tactual sensitivity of the participants and response to the various tactual displays.
For the final test a full random design was employed, all 24 combinations resulting from varying the parameters amplitude, frequency, and spatial distribution as shown in the table below. This test was carried out with participants PH2, PH3 and PH4.

condition	*distance number of pixels*	*amplitude %*	*frequency Hz*
1	1	0	83
2	2	0	83
3	3	0	83
4	1	30	83
5	2	30	83
6	3	30	83
7	1	60	83
8	2	60	83
9	3	60	83
10	1	100	83
11	2	100	83
12	3	100	83
13	1	0	25
14	2	0	25
15	3	0	25
16	1	30	25
17	2	30	25
18	3	30	25
19	1	60	25
20	2	60	25
21	3	60	25
22	1	100	25
23	2	100	25
24	3	100	25

table of texture parameter combinations

In the **results** section the graphs refer to this table.

For each actuator, the participants went through the trials at their own speed, the program generating the stimuli in random order with the right settings automatically. Results were logged by hand, and some of the trials were recorded on video. The picture below shows a typical test set-up.

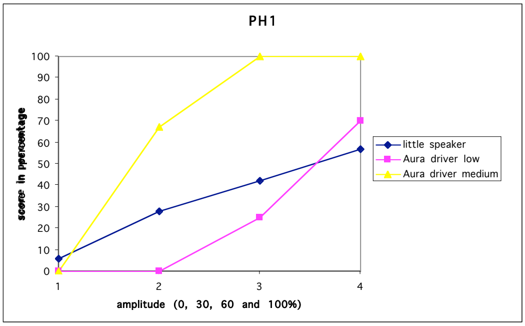
Results

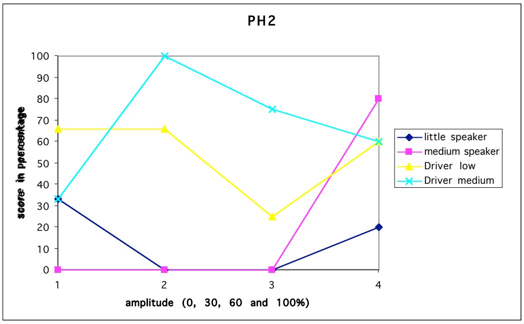
First I describe some general observations about some of the prarticipants. Then the results of the exploratory study are presented, and finally the results of the actual test.
One of the participants (PH2) had difficulty feeling anything at all at the low levels of stimulus. It was not clear whether this was due to the reduced manual dexterity which results in clenched fingers and tendency to press too hard on the loudspeakers which can dampen the vibration entirely, or an actual reduced cutaneous sensitivity. The participant himself thought the latter is indeed the case, so it might be at least a combination of the two factors. The positive results with the low frequency driver, which can't be damped by the hand's pressure, may suggest this but this may be misleading because of the auditory pollution.
Another participant (PH3) showed a very high sensitivity in all situations, his cutaneous sensitivity is the same or perhaps even better than average. Unfortunately at this point no data is available for able-bodied people. This data should be gathered to compare.
The deaf participant (PH4) didn't have very good results with the little speaker. Observations during the trials indicate that this was mainly due to the pressure he applied to the actuator. He clearly perceived the stimuli of the low frequency driver, which was set to the highest setting and because of his deafness there was no auditory interaction.

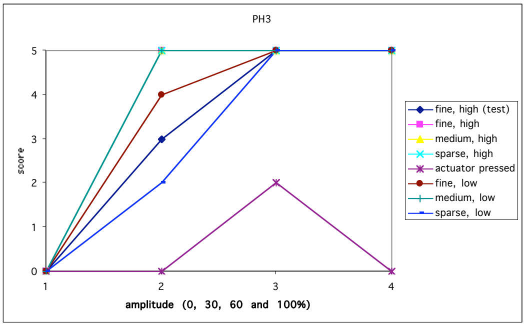
In the graphs below the results of the exploratory studies are summarised for the three participants PH1, PH2 and PH3. Because of the uneven distribution of amplitude levels, the score is presented on the Y-axis in percentages. With PH1 there were six runs each of 15 stimuli done with the little speaker (Ø 20mm). The graph shows the combined result. It must be remarked that the results improved over time, because the touch feedback was an entirely new experience for the subject. Also shown are the results of two runs of 15 stimuli each with the vibrotactile mousepad (the Aura driver) at the low setting. Again the results got better over time but the graph shows the summarised data. The third graph shows one run of 15 trials with the driver on a medium setting, the results are fairly good but there is auditory pollution.
Note that all scores above zero on the 0% amplitude level are errors.
With PH2 in the first session I used the little transducer (Ø 20mm), the medium one (Ø 65mm) and the Aura driver. The hand of this subject was quite clenched, the natural position of his fingers is bent entirely around the middle joints. He stretches

them to touch the actuators and to hold the mouse, but this is clearly not optimal. The graph below shows the results of the various actuators. The results seem very random and not above chance level.

With PH3 I mainly tried the little speaker (Ø 20mm) with different levels (shown on the x-axis), frequencies (low and high) and spatial distributions (fine, medium and sparse). The graph below summarises the results for all conditions. The levels of the stimuli were equally distributed, each run consisted of 20 trials, each condition had one run. The diagram is a bit crowded with lots of data points on the same position. There was one condition where the responses were measured with the subject's finger pressed fairly hard on the actuator, by having him pressing down the mouse button. This gave negative results. The first run was a trial run and the results were a bit less. With a low base frequency of the stimulus the results start to get less good, and the spatial distribution plays a role as well.

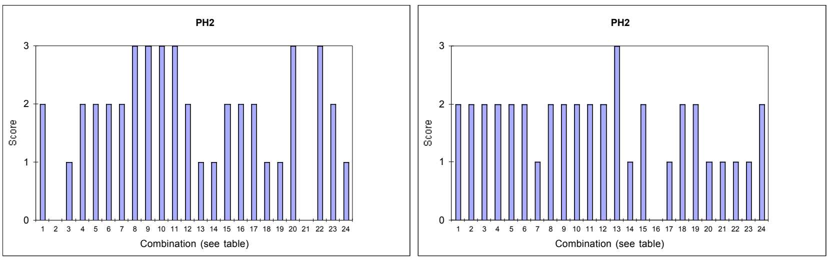






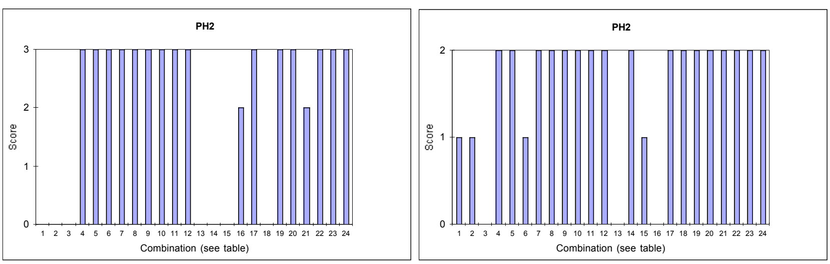
In the graphs below the results of the study with the randomised design with all 24 combinations of the varying levels of density, amplitude and frequency (see the table of texture parameters above) for different actuators are shown. The number of runs varies. When results were obvious after two runs the trial finished to avoid boredom or annoyance of the subject.

With participant PH2 I tried addressing both the left and the right hand, and with the little speaker on the thumb as suggested by the participant. With the small speaker the results are quite random, as clearly shown by conditions 1,2,3 and 13,14,15 which have all an amplitude of zero and should therefore be interpreted as no stimulus.



results of three runs with the little speaker on the thumb of the participant PH2's right hand right) and left hand (left)

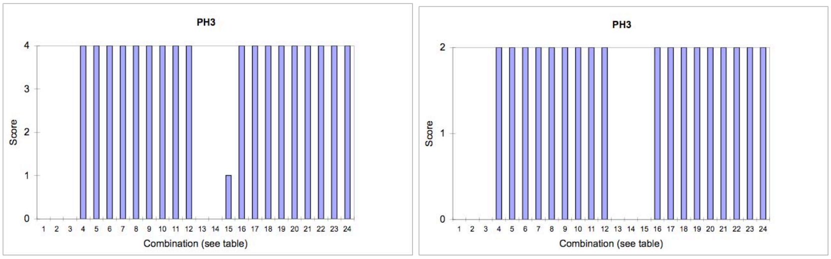
The results for the vibrotactile pad are shown below. These cues are clearly perceived by the subject, although it is not certain to what extend this is due to the auditory modality.



results with the vibrotactile mousepad from two runs on the right hand (right) and three runs on the left hand (left) for subject PH2

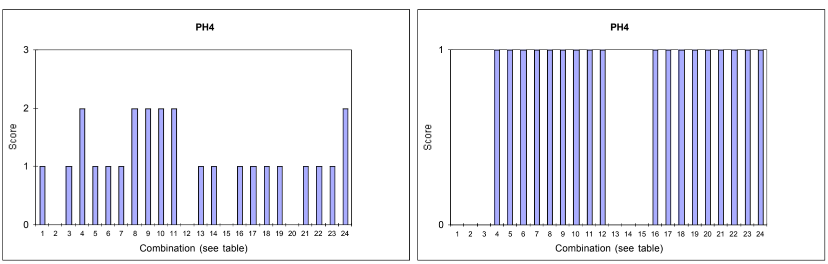
With participant PH3, who showed very good tactual sensitivity in the exploratory study, the results were very positive. Four runs were performed in this trial, with the little speaker under the right hand index finger on top of the mouse. The results are shown in the graph below on the left. The maximum score (4) was reached on all conditions. One error was made, condition 15 has an amplitude of 0 while a sensation was reported.

Then two runs with the medium speaker under the left hand were performed, with a masking sound. The graph below on the right shows the results. The maximum score (2) was reached on all conditions were a stimulus was present, and zero when the amplitude was 0.



the results of PH3, with the little speaker (left) and the medium speaker (right)

With participant PH4 (who is deaf) there were time constraints, and had to spend extra time on explaining the procedure of the test because everything had to be written out. The advantage however is that in addition to the video coverage, I had now a written record of the conversation also with notes of the subject which contains some interesting and more qualitative data.
The first trial consisted of three runs of all conditions, with the little speaker fitted under the left hand holding the mouse. The graph below on the left shows the results. The highest score of 3 was never reached, and overall it is fairly random. The force exerted on the speaker was too high which stopped the vibration.
The graph below on the right shows the results of one run[42] with the vibrotactile mousepad, no masking noise needed this time. The score is 100%, and the subject reported very clearly his excitement.



the rsults of PH4, with the little speaker (left) and the vibrotactile mousepad (right)

5.2.4 Conclusion and discussion of the threshold experiments

The results so far clearly showed that at least some of the motion-impaired users can perceive tactile stimuli, in certain cases at least as good as average people[43]. If for all subjects an appropriate solution can be found, it can be applied in the further tests to

investigate the possible benefit of the haptic modality in the interaction with the computer.
For the subjects who exhibit difficulty perceiving the tactile stimuli several options are considered and further tested. One option is to improve the actuator (by partially covering it the muffling of the fingertip which stops the vibration can be avoided, see section 5.3), and another option is to experiment with different frequencies. The base frequencies chosen for this experiment, 25 Hz and 83.33 Hz, are certainly not optimal for addressing the cutaneous sensitivity. Addressing the Pacinian system, which has its highest sensitivity at 250 Hz and is still sensitive at higher frequencies, possibly in burst of several periods of these short wavelengths may be the best option. This has to be tested.
When the cursor is moving fast, not all pixels generate a stimulus due to constraints to the cursor update frequency in the Macintosh operating system. It was found that the resulting frequency at a fast mouse movement, which is a cascade of individual waves of the base frequency, never exceeded 83.33 Hz.
For future experiments it may also be interesting to vary the waveform. The triangular waveform was chosen to resemble a delta-function as closely as possible but at this wavelength it may introduce higher harmonic frequencies which may become audible. A pure sine wave shape may be preferred therefore, but the main interest is to determine whether a difference in waveform can be tactually perceived.
Further improvement of the auditory masking signal can be done as well, currently the medium speaker when used as a tactile actuator will be auditorily masked very well by the loudspeaker used because they are exactly the same type. The frequency range overlaps the range of the little loudspeaker as well, so this can be masked as well although that is not necessary. The big driver however produces so many low frequency sounds, which it is made for, so this is not properly masked by the medium speaker. A bigger sound system, perhaps including a sub woofer, may be used for this and instead of using the same frequencies as produced for the tactile stimuli masking may also be done with more general sounds such as music. However, while masking may be interesting for experimental purposes, in real world applications it defeats the point of having a separate modality.

5.2.5 Demonstrators

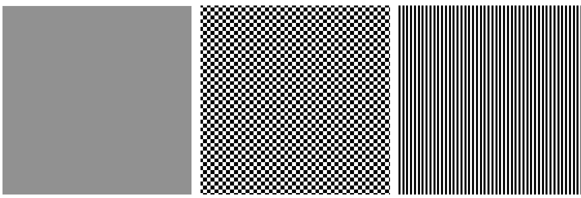
Experiments such as described in this chapter are strongly based on the notion of *active* perception. This notion was pioneered by J.J. Gibson in order to open a way for psychological experiments that have more relevance to realistic situations, instead of the often hard to apply results from classical stimulus-response psychometric experiments. What is true for objects in the real world can also be considered true for the virtual 'objects' generated by the computer, in the approach of applying people's manual skills and perception in the development of user interfaces.
The tactile 'stimuli' can only be perceived by a user who is actively exploring the virtual objects. In order to quickly asses various virtual textures I developed some Max patches, that can display a variety of patterns visually, tactually and, if needed, auditory[44]. These patches are intended to demonstrate the idea of Palpable Pixels[45].

Tactile explorer on the mouse

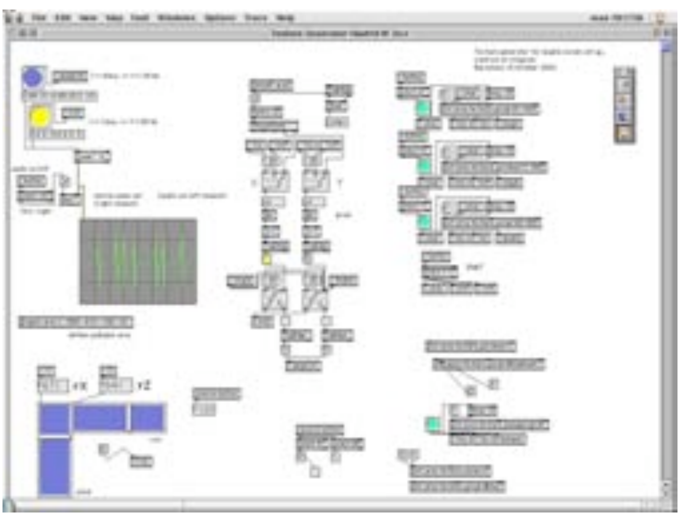
To demonstrate the notion of 'palpable pixels', I programmed a Max patch that can display various visual patterns on the computer screen and generates tactile stimuli when this area is explored with the mouse. The tactile sensations correspond with the visual patterns.

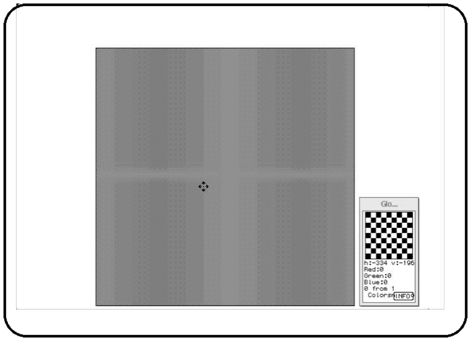
An improved version of the tactile actuator described in the first section is used, the little loudspeaker is now covered with a flat ring (also Ø 20 mm). The ring protects the loudspeaker and prevents the user from dampening the vibration by pressing on the actuator, while being able to feel the vibrations through the hole (Ø 10 mm).

Again there is an experimenter's environment and a subject's environment, sharing the same computer. The experimenter can switch between the multimodal textures to be displayed to the subject, using a device with several buttons, for several settings through its buttons. One of the buttons is used to toggle the cursor position between the field of the user and the field of the experimenter, and the tactile channel can be switched on/off. Below some textures are shown that are used. The experimenter can switch between these with the buttons on the device[46]. There is also a blank texture. The tactile cues are triangular impulses with a base frequency of 25 Hz or 83.33 Hz.



These textures are displayed on the users monitor in blocks of 400 x 400 pixels. A smaller window shows a 'magnification' of the area explored by the pointer, using an existing program called Color Locator, visualising the individual pixels[47].





Articulatory feedback of gestural control

Gestural control is often used in novel computer user interfaces. When making an unguided gesture, ie. in mid air, we only perceive feedback from our visual system and our (internal) proprioception. It is expected that simulating the feel of touching an object or shape can guide such a movement resulting in a higher precision. This effect can be demonstrated and researched by attaching a tactile actuator to a gesture or motion tracker. In the demonstrator the motion sensing capabilities of the Logitech Wingman game controller are used. The motion sensing of the Wingman is based on an Analog Devices ADXL202 dual-axis accelerometer, which has a sensitivity of ± 2 g and can be used to measure inclination in relation to the earth's gravitational field. The device limits the range of tilt measured to less than 180°, it has a good resolution (10 bits) but the sample rate is a bit low for certain applications.

Every change in angle is then displayed tactually by a cue generated by the Max patch, allowing the user to feel a texture while rotating the device in mid-air. To test whether this leads to improved gestural control, an experiment could be set up using Max to measure human movement under the varying conditions.

Haptic Finder

Instead of using sounds to add information to the Graphical User Interfaces, such as demonstrated in the Sonic Finder[48], tactual cues can be used. This is done by replacing sounds in the Sound Set that can be selected in the Macintosh Finder since System 8.5 by the pulses as described in the previous experiments. For instance, when scrolling through a (pull down) menu, every item can be felt in addition to the traditional visual feedback. Opening a menu gives a different feel. There are events defined in the Sound Sets for every possible action in the Macintosh Finder, not only for articulatory feedback but also for process and other feedback. All these events could be linked to haptic cues.

To test the effects I set up an experiment using Max, measuring user response speeds with the conditions varied between visual only and visual + tactual feedback, reported in section 5.3.

In practice, most people disable the function of sound sets on personal computers, not only because of their perhaps not optimally designed sounds[49] but mainly because it is considered obtrusive for the environment. Haptic feedback, inherently operating in the intimate range of human perception, can overcome this problem.

5.2.6 Discussion of the demonstrators

The presented experimental set-up based on Max/MSP proved to be useful for quickly assembling a variety of experiments and demonstrators. The experiment with the motion-impaired users showed that this group in many cases can perceive vibrotactile stimuli. The demonstrators are useful as a proof of concept of the idea of enhanced feedback in the user interface. They suggest many experiments which need to be carried out in order to investigate whether there is a measurable positive effect in speed, accuracy or quality of the human-computer interaction when applying haptic feedback.

The 'tactile explorer' actuator on the mouse seems to work well for a range of users accommodating for different finger shapes, thanks to the improved design of the protecting ring. The most naturally intuitive position for the actuator is under the tip of the index finger of the mouse moving hand. However, as this finger is also used for clicking, the improvement of the ring enables the user to feel the vibrations even when pressing down. It is a small device that can be added to any mouse and some other input devices.

The vibrotactile mousepad can be used to convey palpable pixels to the user through a wider range of input devices, such as the mouse or a drawing tablet. It is important however to design different 'sounds' to be felt specifically for the physical characteristics of the vibrotactile mousepad. Also sounds become audible with the pad which is often unwanted.

Other actuators may be investigated to apply for haptic feedback, alone or in combination. For instance, the vibrating effect caused by a small motor spinning an eccentric weight (such as used for the buzzing effect in some mobile phones) can be applied. The AVBTech Vmouse is using this principle, driven by the sound output of the computer as described before. Designing signals for this device is very different than those for the vibrotactile actuators however, because the effect is very different. Due to its construction it is less suited for short and clear signals but can be used for other effects.

The Immersion TouchSense protocol is promising for mainstream computer control devices, and implemented by many manufacturers such as Microsoft, Logitech and HP. However, at the moment it seems that only in game devices such as joysticks and steering wheels actual force feedback (addressing the human kinaesthetic sense of touch) is used. After the discontinuation of the Logitech force feedback mouse, the devices available for desktop applications are mainly buzzing against the palm of the hand (Logitech iFeel mouse). This is a kind of vibrotactile feedback with a limited use. However, it is envisioned that the TouchSense force-feedback library can be used in combination with the sound-based vibrotactile feedback as described in this chapter.

The aim of further research is to establish a *palette* of textures and other vibrotactile stimulations, consisting of variations in base frequency, waveform, amplitude, and change over time such as the volume envelope and frequency pattern. Only when designing an interface with such a palette, established by thorough research, will it be possible to achieve optimal results. Virtual textures can enrich the interaction between human and computer, providing a method of conveying useful information through different kinds of feedback.

5.3 Tactual articulatory feedback and gestural input

In this section several experiments are described that investigate the use of (redundant) tactual articulatory feedback. The results presented show that a significant improvement of effectiveness only occurs when the task is sufficiently difficult, while in other cases the added feedback can actually lower the effectiveness. The qualitative data show a positive appreciation for added tactual feedback. The discussion includes suggestions for further research, particularly investigating the effect in free moving gestures[50].

5.3.1 Investigating tactual articulatory feedback

We have been investigating if there is an advantage in using tactual feedback as secondary notation or added feedback to the user who is manipulating the virtual objects in the computer, such as widgets, icons and menus. The research is particularly concerned with feedback that supports the *articulation* of a gesture. A standard mouse input device is used with an added vibrotactile feedback element based on a small loudspeaker placed under the tip of the index finger of the preferred hand.

As stated before, in the current computer interaction paradigm articulatory feedback is given visually, while it is known from everyday experience that many movements (particularly manipulative action upon objects) are guided by touch, vision and audition. The rationale behind the work as described in this section is that it is expected that adding auditory and vibrotactile feedback to the visual articulatory feedback improves the articulation, either in speed or accuracy, and that of these two the vibrotactile will give the greatest benefit as it is the most natural form of feedback in this case.

The research reported in this section focuses on the physical level of the layered interaction as described before, where the articulation of the gesture takes place. It is at this stage limited to a one degree-of-freedom movement, of a mouse on a flat surface. An essential part of our approach is to leave some freedom for the participants in our experiments to *explore*.

5.3.2 Method

In the experiments the participants are given a simple task, and by measuring the response times and error rates in a controlled situation differences can be detected. It must be noted that, in the current desktop metaphor paradigm, a translation takes place between hand movement with the mouse (input) and the visual feedback of the pointer (output) on the screen. This translation is convincing due to the way our perceptual systems work. The tactual feedback in the experiments is presented there were the input takes place, on the hand, using a custom built vibrotactile element. In some of the experiments auditory articulatory feedback was generated as well, firstly because this often happens in the real world, and secondly to investigate if sound can substitute for tactual feedback. Mobile phones often have such an audible key click, although in that case it is more about confirmative feedback.

A gesture can be defined as a multiple degree-of-freedom meaningful movement. In order to investigate the effect of the feedback a restricted gesture was chosen. In its simplest form, the gesture has one degree-of-freedom and a certain development over time. As mentioned earlier, there are in fact several forms of tactual feedback that can occur through the tactual modes as described above, discriminating between cutaneous and proprioceptive, active and passive. When interacting with a computer, cues can be generated by the system (active feedback) while other cues can be the result of real world elements (passive feedback). When moving the mouse with the vibrotactile element, all tactual modes are addressed, actively or passively; it is a haptic experience drawing information from the cutaneous, proprioceptive, and efference copy (because the subject moves actively), while the system only actively addresses the cutaneous sense. All other feedback is passive, ie. not generated by the system, but it can play some role as articulatory information.

It was a conscious decision not to incorporate additional feedback on the reaching of the goal. This kind of 'confirmation feedback' has often been researched in haptic feedback systems, and has proven to be an effective demonstration of positive effects as discussed in section 5.1.2. However, we are interested in situations were the system does not know where the user is aiming for. We are primarily interested in the feedback that supports the articulation of the gesture rather than the goal to be reached, as the goal is not known by the system. For the same reason we chose not to guide (pull) the users towards the goal. Such feed-forward would be beneficiary as shown in several other studies, and as predicted by Fitts' Law because what is actually happening in such cases is that the target size gets increased[51].

5.3.3 Experimental set-up

The set-up for the experiments is quite similar to the earlier ones as described in section 5.2.2 of this chapter. The visual, object based programming language Max/MSP was used. Max/MSP is a program originally developed for musical purposes and has therefore a suitable real time precision (the internal scheduler is set to 1 ms.) and it has many built-in features for the generation of sound, images, video clips, and interface widgets. It has been used and proved useful and valid as a tool in several psychometric and HCI related experiments. Experiments can be set up and modified very quickly. The software for this experiment run on an Apple PowerBook G3, used in dual-screen mode; the experimenter uses the internal screen for monitoring the experiment and the subject uses an external screen. The participant carries out the tasks using a standard Logitech mouse, with the vibrotactile element positioned under the index finger of the subject where the feedback would be expected. For the right handed users this was on the left mouse button, for the left handed users the element could be attached to the right mouse button. The vibrotactile element is the same as before, a small loudspeaker (Ø 20 mm) covered and protected by a ring as shown in the figure. The ring avoids the user to press on the loudspeaker cone which would make the stimulus dissapear. The vibrotactile element is covered by the user's finger so that frequencies in the auditory domain are further dampened. Generally the tactual stimuli, addressing the Pacinian system which is sensitive between 40 and 1000 Hz, are chosen with a low frequency to avoid interference with the audio range. The wavelengths of the (triangular) tactual pulses were 40 and 12 milliseconds resulting in a base frequency of 25 and 83.3 Hz respectively. The repeat frequency of the pulses would be depending on the speed of the movement made with the mouse, and in practice is limited by the tracking speed. To investigate whether the tactual display really would be inaudible, measurements were performed with a Brüel & Kjear 2203 Sound Level Meter. The base frequency of the tactual display was set to 83.3 Hz and the amplitude levels at 100 % and at 60% as used in the experiment. At a distance of 50 cm and an angle of 45 degrees, the level was 36 dB(A) (decibel adjusted for the human ear) when the device was not covered, and 35 dB(A) when the device was covered by the human finger as in the case of the experiments. At an amplitude of 60% these values were 35 dB(A) and 33 dB(A) respectively. So in the most realistic situation, ie. not the highest amplitude and covered by the finger, the level is 33 dB(A), which is close to the general background noise level in the test environment (30 dB(A)) and furthermore covered by the sound of the mouse moving on the table top surface (38 dB(A))[52].


Auditory feedback is presented through a small loudspeaker next to the subject's screen. The signals sent to the vibrotactile elements are low frequency sounds, making use of the sound generating capabilities of Max/MSP.

In total 35 subjects participated in the trials and pilot studies, mainly first year students of Computer Science. They carried out a combination of experiments, as described below, using their preferred hand to move the mouse and explore or carry out tasks, and were given a form with open questions for qualitative feedback. In all phases of the experiment the subjects could work in their own pace, self-timing when to click the "next" button to generate the next cue.

Not all subjects participated in all experiments. Four out of 35 were pilot studies to adjust levels and establish the test set-up timing, the 31 main ones all participated in the most important phases of the experiment (2, 3 and 5) and 11 of them participated in the 4th phase which was an extension.

Special attention was given to the user's posture and movements, as the experiment involved lots of repetitive movements which is a recipe for RSI, ironically enough because the overall goal of the research is to come up with paradigms and interaction styles that are more varied precisely to avoid such complaints. At the beginning of each session therefore participants were instructed and advised on strategies to avoid such problems, and monitored throughout the experiment.

Phase 1: Threshold levels

The first phase of the experiment was designed to investigate the threshold levels of tactile sensitivity of the participants, in relationship to the vibrotactile element under the circumstances of the test set-up. The program generated in random order a virtual texture, varying the parameters base frequency of the stimulus (25 or 83.3 Hertz), amplitude (30%, 60% and 100%) and spatial distribution (1, 2 or 4 pixels between stimuli) resulting in 18 different combinations. Also a case was included with an amplitude of 0, eg. no stimulus, for control purposes. In total therefore there were 24 combinations.

The participant had to actively explore an area on the screen, a white square of 400 x 400 pixels, and report if anything could be felt. This could be done by selecting the appropriate button on the screen, upon which the next texture was set. The participants responses, together with a code corresponding with the specific combination of values of the parameters of the stimuli, were logged by the program into a file for later analysis. In this phase of the experiment 26 subjects participated.

This phase also helped making the subjects more familiar with the use of tactual feedback.

Phase 2: Menu selection

In this part of the experiment, a random number was generated, visually presented and the participants had to select the matching item from a list of numbers (a familiar pop-up menu). There were two conditions, one visual only and the other supported by tactual feedback where every transition between menu items generated a tangible 'bump' in addition to the normal visual feedback. Response times and error rates were logged into a file for further analysis.

The menu contained 20 items, a list of numbers from 100 to 119 as shown in the figure below. All 20 values (the cues) would occur twice, from a randomly generated table in a fixed order so that the data across conditions could be easily compared - all distances travelled with the mouse were the same in each condition.

Response times and error rates were logged into a file for further analysis. In total 30 subjects participated in this phase of the experiment, balanced in order (15 -1 5) for both conditions.

Phase 3: Slider manipulation

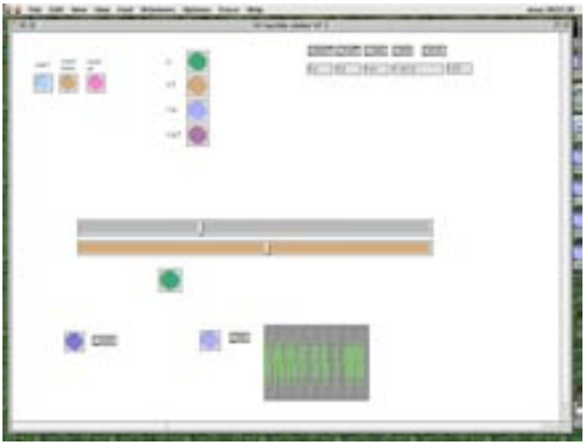
In this experiment a visual cue was generated by the system, moving the horizontal system slider on screen to a certain position. The participants were instructed to place their slider to the same position, as fast and as accurate as they could. Feedback was given in four combinations of three modalities: visual only (V), visual + tactual (VT), visual + auditory (VA), and visual + auditory + tactual (VAT). The tactual feedback consisted of a pulse for every step of the slider, a triangular wave form with a base frequency of 83.3 Hz. The auditory feedback was generated with the same frequency, making a clicking sound due to the overtones of the triangular wave shape.

These combinations could be presented in 24 different orders, but given the nature of the work (the context of user interface applications) it was decided to choose only two, which would reveal enough about potential order effects: V-VT-VA-VAT and VAT-VA-VT-V.

All 40 cues were presented from a randomly generated, fixed order table of 20 values, every value occurring twice. Values near or at the extreme ends of the slider were avoided, as it was noted during pilot studies that participants developed a strategy of moving to the particular end very fast knowing the system would ignore overshoot. The sliders were 600 pixels wide, mouse ratio was set to slow in order to make the participants really move. Through the use of the fixed values in the table across conditions, it was ensured that in all conditions the same distance would be travelled in the same order, compensating for the differences in relationship between target distance and task completion time (as described in Fitts' law), and the mouse-pointer ratio[53].

The cues were presented in blocks for each condition, if the conditions would have been mixed subjects would have developed a visual only strategy in order to be independent on the secondary (and tertiary) feedback. Their slider was also colour coded, each condition had its own colour. 31 subjects participated in this phase, and the orders were balanced as well as possible: in 15 times the V – VAT order and 16 times the VAT – V order.

The figure below shows the experimenter's screen of phase 3, the Slider experiment, with the controls and monitoring of the experiment and the participant's actions.



Phase 4: Step counting
In this experiment the participants were prompted with a certain number of steps to be taken with a horizontal slider, similar to the one in the previous experiment. The range was set to 20 rather then 120 in this case, to keep it manageable. Conditions were visual only (V) and visual combined with touch (VT). No confirmative feedback was given, the subject would press a button when he or she thought that the goal was reached and the next cue was generated.
In this phase of the experiment 11 subjects participated balanced between the orders in 5 V – VT and 6 VT- V order.

Phase 5: Questionnaire
The last part of the session consisted of a form with questions to obtain qualitative feedback on the chosen modalities, and some personal data such as gender, handiness and experience with computers and the mouse. This data was acquired for 31 of the subjects.

5.3.4 Results and analysis

The data from the files compiled by the Max patch was assembled in an MS Excel spreadsheet. The data was then analysed in SPSS.
All phases of the experiment showed a learning effect. This was expected, so the trials were balanced in order (as well as possible) to compensate for this effect.
The errors logged were distinguished in two types: misalignments and mistakes. A mistake is a miss-hit, for instance when the subject 'drops' the slider too early. A mistake can also appear in the measured response times, some values appeared that were below the physically possible minimum response time, as a result of the subject moving the slider by just clicking briefly in the desired position so that the slider jumps to that position. They were instructed not to use this 'cheating' but accidentally it occurred. Some values were unrealistically high, probably due to some distraction or

other error. All these cases contain no real information, and were therefore omitted from the data as mistakes. The misalignment errors were hoped to be analysed as they might reveal information about the level of performance. In the sections below the results of each phase are summarised, and the significant results of the analysis are reported.

Phase 1: Threshold levels

Of the 19 presented textures (averaged over two runs) twelve were recognised correctly (including four of the six non-textures) by all the subjects, and a further ten with more than 90% accuracy (including two non-textures). There were two lower scores (88% and 75%) which corresponded with the two most difficult to perceive conditions, the combination of the lowest amplitude (30%), low frequency (25 Hz) and the lowest spatial distributions of two respectively four pixels.

Phase 2: Menu selection

Table 1 shows the total mean response times. All trials were balanced to compensate for learning effects, and the number of trials was such that individual differences were spread out, so that that all trials and subjects (N in the table) could be grouped. The response times Visual+Tactual condition were slightly higher than for the Visual Only condition, statistical analysis showed that this was not significant. The error rates were not statistically analysed, in both conditions they were too low to draw any conclusions from.

Mean response times and standard deviations for the Menu Selection

Condition	N	Mean response time (ms)	Standard deviation (ms)
V	1120	1806	624
VT	1120	1842	531

Phase 3: Slider manipulation

The table below gives an overview of the means of all response times (for all distances) per condition.

Mean response times and standard deviations for the Slider.

Condition	N	Mean response time (ms)	Standard deviation (ms)
V	1239	1436	530
VT	1240	1512	572
VA	1240	1468	595
VAT	1240	1547	593

The response times were normally distributed, and not symmetrical in the extremes, so two-tailed t-tests were carried out in order to investigate whether these differences are significant. Of the three possible degrees-of-freedom the interaction between V and VT as well as VA and VAT was analysed, in order to test the hypothesis of the influence of T (tactual feedback added) on the performance.

The results of the t-tests

Condition	t	Significance
V-VT	-3.435	0.001
VA-VAT	-3.307	0.001

This shows that response times for the Visual only condition were significantly faster than the Visual + Tactual condition, and that the Visual + Auditory condition was significantly faster than the similar condition with tactual feedback added.
The differences in response times between conditions were further analysed for each of the 20 distances, but no strong effects were found. The differences in error rates were not significant.

Phase 4: Step counting
It was observed that this phase of the experiment was the most challenging for the subjects. It relies a bit more on the participants' cognitive skill than on the sensori-motor loop alone. The total processing time and the standard deviation are reported in the table below:

Mean response times and standard deviations for the Counter

Condition	N	Mean response time (ms)	Standard deviation (ms)
V	200	3569	2281
VT	200	3078	1868

In order to find out if the difference is significant an analysis of variance (ANOVA) was performed, to discriminate between the learning effect and a possible order effect in the data. The ANOVA systematically controlled for the following variables:

- between subject variable: sequence of conditions (V - VT vs. VT - V);
- within subject variables: 20 different distances.

The results of this analysis are summarised in the table below.

The results of the comparison for the two conditions of the Counter phase

Condition	df	error df	F	Significance
V / VT	1	8	12.432	0.008

From this analysis follows that the mean response times for the Visual + Tactile condition are significantly faster than for the Visual Only condition.
Phase 5: Questionnaire

The average age of the 31 subjects who filled in the questionnaire was 20 years, the majority was male (26 out of 31) and right handed (27 out of 31). The left handed people used the right hand to operate the mouse, which was their own preference (the set-up was ready to be modified for left hand use). They answered a question about their computer and mouse experience with a Likert scale from 0 (no experience) to 5 (lot of experience). The average from this question was 4.4 on this scale, meaning their computer and mousing skills were high. The qualitative information obtained by the open questions is categorised as shown in the table below.

Categorised answers on open questions, out of 31 subjects

	tactual	auditory
effective	22	17
effective but potentially annoying	7	3
annoying / irritating	1	5
not effective	1	6

There was a question about whether it was thought that the added feedback was useful. For added sound 16 (out of 31) people answered "yes", 4 answered "no" and 11 thought it would depend on the context (issues were mentioned such as privacy, blind people, precision). For the added touch feedback 27 people thought it was useful, and 4 thought it would depend on the context. The table below summarises the results, in percentages.

Categorised answers on question about usefulness

Added feedback	auditory	tactual
Useful	52%	87%
Not useful	13%	0%
Depending on context	35%	13%

When asked which combination they preferred in general, 3 (out of 31) answered Visual Only, 13 answered Visual+Tactual, 3 answered Visual+Auditory, 7 Visual+Auditory+Tactual, and 4 thought it would depend on the context. One subject did not answer. The results are shown in percentages in the table below.

Preferred combination of articulatory feedback

Preferred combination	V	VT	VA	VAT	depending on context
	10%	42%	10%	23%	13%

5.3.5 Discussion of the results of the articulatory feedback experiments

The results from the Threshold test (Phase 1) show that our subjects had no difficulty recognising the stimuli generated, apart from the cases of the really low levels. For the experiments (Phases 2 – 4) combinations of the stimuli were chosen that were far above these thresholds.
The results from the menu selection (Phase 2) show no significant difference. This task was easy and familiar for the participants.
The results from the slider experiment (Phase 3) show that people tend to slow down when the tactual feedback is added. This can be due to the novelty effect of it, as people are not used having their sense of touch actively addressed by their computer. This slowing down effect may be explained by the factor of perceived physical resistance, as has been found in other research[54].
When the task reaches a sufficient level of difficulty, the advantage of the added tactual feedback can be shown. This has been proved by the step counter (Phase 4 of the experiment), where task completion times were significantly shorter with the added feedback.
The questionnaires show that people generally appreciate the added feedback, and favour the tactual over the auditory. From auditory feedback it is known that it can be perceived as irritating, particularly in some contexts. Note however, that computer generated tactual feedback can be unpleasant as well. Not much research has been carried out investigating this rather qualitative aspect and its relationship to the choice of actuator (eg. a motor or a speaker).

Discussion
The participants carried out the experiments as part of their lecture series on Information Representation at the department. They were therefore easily tempted to be thoroughly involved in the experiments. It can be argued that this would bias their responses, particularly in the quantitative parts of the session, but it must be stressed that the work here is carried out in the context of human-computer interaction research and not as pure psychometric experiments. It is more an expert-appraisal.
The response times between subjects vary largely, which is quite fascinating and a potential subject for further investigation. Clearly, people all have their own individual way of moving (what we call the 'movement fingerprint') and these results show that even in the simplest gesture this idiosyncrasy can manifest itself.
The observation that in some cases some subjects actually seem to slow down when given the added tactual feedback has a lot to do with the tasks, which were primarily visual. The tactual feedback can be perceived by the user as resistance. This is interesting, as we know from everyday experience (particularly with musical instruments) that indeed *effort* is an important factor in information gathering of our environment, and for articulation. Dancers can control their precise movements while relying more on vision and internal kinaesthetic feedback, but only after many years of training. It is still expected that the greatest benefit of adding tactual feedback to a gesture will be found in a free moving gesture, without any passive feedback as is the case when moving the mouse. This has to be further investigated, some preliminary experiments carried out both with lateral movements as well as with rotational movement in free space show promise. The potential benefit of this has already been

shown elsewhere, for instance at Sony Labs where a tilting movement of a handheld device did benefit of the added or secondary feedback[55].

The set-up as described in this paper mainly addresses the Pacinian system, the one out of the four tactual systems of cutaneous sensitivity that has the rapidly adapting and diffuse sensitivity), and that can pick up frequencies from 40 Hz to 1000 Hz. Other feedback can be applied as well, conveying different kinds of information.

In the current situation only pure articulatory feedback was considered, other extensions can be added later. This would also include the results from the ongoing research on virtual textures, resulting in a palette of textures, feels and other tangible information to design with. A logical extension of the set-up is to generate feedback upon reaching the goal, a 'confirmative feedback' which has been proven to produce a strong effect. This could greatly improve performance as it is known that the gesture can be described by dichotomous models of human movement in a pointing task, which imply an initial ballistic movement towards a target followed by finer movements controlled by finer feedback[56]. This was observed in some cases in our user trials.

Other improvements that are thought of are: to have multiple points of feedback addressing more fingers or parts of fingers (Max/MSP works with external hardware to address multiple output channels) and to make the vibrotactile element smaller, so that more can be put on one finger. This can be used to simulate direction, such as in the effect of stroking velvet. The palette eventually should also incorporate force-feedback, addressing the kinaesthetic sense.

Conclusion

In the research described in this section we have investigated the influence of added tactile feedback in the interaction with the computer.

In Phase 1 it was found that the participants were very sensitive and were able to perceive fine tactile 'virtual textures' generated with the tactile display. In Phase 2 it was found that selecting items from a menu list did not show any significant difference in performance when tactile feedback was added. Manipulating a slider under various feedback conditions, in Phase 3, showed a significant difference. Performance was influenced by the added tactile feedback also in the case of added auditory feedback: Task completion speed decreased. When the task was made more difficult, as in the Step Counter experiment Phase 4, a positive effect in the tactile feedback condition was shown. The vibrotactile element, based on a miniature loudspeaker and low-frequency 'sounds', proved to be a cost-effective and flexible solution allowing a wide variety of tactile experiences to be generated using sound synthesis techniques.

In the experiments the added feedback was redundant. In all these cases the various feedback modalities were used to convey the same information, following the recommendations of the Proximity Compatibility Principle (PCP)[57]. In a multitasking situation the feedback would perhaps be divided differently according to PCP, but in our experiment they are tightly coupled. We are not trying to replace visual feedback by tactual feedback, but add this feedback to make the interaction more natural. It is expected that in some cases this leads to a performance benefit. The widget manipulations we chose to investigate are standard user interactions, the subjects were very familiar with it, and they could devote all their attention to fulfilling the tasks. Only when the task is made less mundane, such as in the last phase were the subjects had to count steps of the slider widget, adding tactile feedback helps to improve the interaction. This may seem irrelevant in the current computer interaction paradigm, which is entirely based on the visio-motor loop, but our research has a longer term goal of developing new interaction paradigms based on natural interaction.

Multitasking is an element of such paradigms, and a future experiment can be developed where the participants have to divide their attention between the task (ie. placing the slider under various feedback conditions) and a distracting task.

Multiple degree-of-freedom input is another expected element of new interaction paradigms, and we are interested to see the effects of added tactual feedback on a *free-moving gesture*. In such a case the passive feedback (kinaesthetic guidance from the table top surface in the 2D case) is absent and it is expected that adding active feedback can compensate for this. Such an experiment has been developed and is currently tested.

5.4 Conclusion

This chapter described a number of experiments and developments focussing on the application of active addressing of the sense of touch of the user. In the broad research field my focus is on presenting textures and articulatory feedback to the interaction, and the results so far are promising. The test set-up based on the Max programming environment, using low frequency sound as tangible feedback appears to be flexible and quickly adoptable to a wide range of circumstances.

Touch is an important modality in the context of articulation of gesture, shaping the expression through human motion. It is an essential element of the physical interaction, which is further described in the next chapter.

[1] This is based on the idea of using physical interaction with objects representing virtual elements, such as described in Chapter 3, section 3, where *tokens* were used which were linked to multimedia content. MIT Media Lab researchers Hiroshi Ishii and Brygg Ullmer have described this notion of TUI's [Ishii and Ulmer, 1997], which is based on the work of George Fitzmaurice and Bill Buxton on Graspable interface elements [Fitzmaurice et al, 1995]. A good overview of graspable, tangible and active haptic systems is developed by Elise van den Hoven and published in the PhD thesis [van den Hoven, 2004, pp. 87 – 97] and a conference paper [van den Hoven and Eggen, 2004].

[2] Ernst Heinrich Weber has done a number of observations and descriptions, often as a result of the many (sometimes bizarre) experiments he carried out together with his brother Eduard. His relevant writings are translated from Latin and German and edited in *E. H. Weber on the Tactile Senses* [Ross & Murray, 1995].

[3] The Gestalt psychologist David Katz wrote in German and is only partially translated into English. He is particularly well known for the article *Der Aufbau der Tastwelt*, in the Zeitschrift für Psychologie in 1925.

[4] Gibson based his work very much on the work of Katz. The interesting thing is, that when I started investigating the sense of touch in the context of electronic musical instruments I quite soon encountered the work of Gibson but later found out that in a way for him it was only a sidestep. In the sixties Gibson started his now well known approach to perception as *an activity,* and the clearest demonstration of that is the sense of touch, as can be read in his biography [Reed, 1988, p.197].

[5] A thorough and authoritative source is the chapter on Tactual Perception by Jack Loomis and Susan Leederman in the *Handbook of Perception and Human Performance* [1986].

[6] Another chapter in the *Handbook* describes the cutaneous sensitivity [Sherrick and Cholewiak, 1986].

[7] Kinaesthesia is described in a chapter of the *Handbook* by Clark & Horch [1986]. Note that although the name refers to *motion*, the static position and orientation (formerly known as statestesia) is now also included in kinaesthesia.

[8] As described by Gibson in *Observations on Active Touch* [1962] and in *The Senses Considered as Perceptual Systems* [1966]. However at that time it was not known what the source was, whether the brain stored a copy of the signal (which proved to be the case, the efference copy signal), or whether the signal received from the receptors would be essentially different in both cases. Gibson favoured the latter hypothesis [1966, pp. 38-39].

[9] This is described in more detail in the chapter in the *Handbook* about the cutaneous sensitivity [Sherrick and Cholewiak, 1986], and in another paper it has been described that in fact the whole system is separated in four channels [Bolanowski et al, 1988]. But the elements are also described in a more picturesque way as 'the code senders' in *A Natural History of the Senses* [Ackerman, 1990, p83].

[10] Particularly well known is the research by Akamatsu and Sato [1992, 1994, 1996] with such a mouse. Münch and Dillmann [1997] have developed a similar device, and another article reports a device where solenoids were placed on the side of the mouse for vibrotactile feedback [Göbel et al, 1995]. The principle of electromagnetic braking mouse was also applied in an art interface, an interesting application where the emphasis was not on improving efficiency, and nominated for the Ars Electronica price in 2000 [Kruglanski, 2000].

[11] For instance as reported at the CHI 2000 conference by Dennerlein et al [2000].

[12] Carried out by Faustina Hwang and colleagues at the Engineering Design Centre at Cambridge University [Hwang et al, 2003].

[13] TouchSense was formerly known as Touchware and before that I-Force protocol, and it describes a library of haptic sensations usable for games such as explosions, frictions, blows and shudders, as an extension of DirectX under MS Windows. It works also on the Mac in OSX, and it is possible to make haptically enhanced web pages.

[14] The 'active ergonomic mouse' has been developed by former researchers of the Movement Sciences department at the Vrije Universiteit in Amsterdam, see www.hoverstop.com

[15] The company kindly supplied me in 2001 with two of these mouses to use them in the research. See www.avbtech.com.

[16] Research carried out at British Telecom Labs in Ipswich, UK, by Andrew Hardwick and Stephen Furner [1996, 1998].

[17] Margereth Minsky is well known for her research in using a force-feedback joystick for generating various kinds of tactual feedback [Minsky et al, 1990].

[18] The Phantom range of devices are made by Sensable, a spin off of the MIT. See www.sensable.com.

[19] Stephen Brewster and Ian Oakley and others at Glasgow University started investigating haptic devices in 2000 and have reported several studies [Oakley et al, 2000, 2001, 2002].

[20] Anders Askenfeld and Erik Jansson of the KTH in Stockholm reported their work in a paper *On Vibration Sensation and Finger Touch in Stringed Instrument Playing*, in a special issue of the Journal of Music Perception [Askenfeld & Jansson, 1992]. Chris Chafe of the 'Center for Computer Research in Music and Acoustics' (CCRMA) at Stanford University has done work on this with a cello [Chafe, 1993].

[21] A good description of the frequency response of the Pacinian system is given by Ronald Verrillio of Syracuse University, NY, in the special issue of Music Perception in an article *Vibration Sensation in Humans* [Verrillo,1992].

[22] As reported by Claude Cadoz et al, [1990].

[23] Brent Gillespie, who studied mechanical engineering as well as piano, used the special type of linear motor that normally moves the heads around on a large harddisk [Gillespie, 1992, 1994]. He was also involved in the development of the Moose device, with which Sile O'Modhrain did a lot of research reported in her PhD thesis [O'Modhrain, 2000] and other work at CCRMA [Chafe and O'Modhrain, 1996], [O'Modrain, 1997].

[24] Researcher and musician Butch Rovan from the US worked together with the scientist Vincent Hayward from McGill University in Montreal, both on sabbatical leave at IRCAM [Rovan and Hayward, 2000]. Vincent Hayward has done a lot of research on tactual perception, developed many technologies and even founded a company for haptic displays.

[25] This work is reported in a paper for the ICMC [Bongers, 1994] and a IEE Colloquium in London in 1997, which was then rewritten as a journal article [Bongers, 1998].

[26] Florentijn worked for many years with the Theatergroep Hollandia and other groups.

[27] The ideas behind this new tactual laser instrument are described in a paper for a symposium on Gesture Interfaces for Multimedia Systems in Leeds [Bongers et al, 2004].

[28] The Force-Feedback Trackball was devised by interaction researchers Frits Engel and Reinder Haakma, and the engineer Jos van Itegem [1990].

[29] David Keyson did a lot of research, with professor Ad Houtsma, at IPO in the mid nineties [Keyson and Houtsma, 1995], [Keyson, 1996].

[30] TacTool was developed by David Keyson together with software engineers, as a programming environment for designing tactual feedback, first with Hok Kong Tang [Keyson & Tang, 1995] for DOS and later with Leon van Stuivenberg [Keyson & Stuivenberg, 1997] a version for Windows. Achieving reliable real time feedback under Windows 95 was quite a disaster of course, but this v2.0 was extended with other modalities which made it very useful. Later, at Philips Leon made a version of TacTool incorporated in Visual Basic.

[31] At IPO, the team consisted of Berry Eggen, David Keyson and others, and from Philips Design involved were Pete Matthews and Guy Roberts (graphics), Paul Thursfield (3D design) and Rolf den Otter (sound)

[32] The Expert Appraisal was done with Pete Dixon from Philips Design. We wrote an (internal) report *Ease of use programme, phase two multimodal interaction styles: Expert appraisal report* in December 1996.

[33] The user tests I developed with David Keyson, and carried out with student intern from Biomechanical engineering from the University Bibian Derikx. Bibian wrote a report (in Dutch and 'company restricted') *Gebruikers-waarderingstest van multimodale interactiestijlen* in

May 1997. Part of this work is reported in a paper for the HCI conference in Bristol in 1997 and a journal paper [Bongers et al, 1998].

[34] With Jan Aarts, a mechanical engineer and researcher at the Philips NatLab.

[35] At IPO, Leo Poll had done extensive research and development of a sound based translation of the GUI using a tablet [Poll, 1996].

[36] See [Keates and Robinson, 1999].

[37] This phase of the research was mainly based on vibrotactile feedback, with the set up I developed. The internal report about the research [Bongers, 2000] was later published at a conference [Langdon et al, 2000]. The group carried on working on haptic research with solid results [Hwang et al, 2003].

[38] For instance the research of Roel Vertegaal often uses Max [1998]. I used it for experiments to investigate a cognitive processing bottleneck when multitasking using touch, for my MSc thesis project. By first reproducing a classic experiment and obtaining the same results I proved the viability of this approach [Bongers, 1999]. There is a short paper *Using Electronic Musical Instrument Design Techniques for Measuring Behaviour* [Bongers, 2002].

[39] KDS-2008, 0.1W 8Ω, Ø19.8mm, edge filed of to reduce the height of the transducer from 4.0mm to 3.0mm, mylar cone. CPC Ltd. order code: LS00249.

[40] Sony speaker from the SRS-28 active mini loudspeakers, 0.4W, 8Ω, Ø65.5mm, height 14.3mm.

[41] A loudspeaker without a cone, Aura, Ø87.1mm, attached to the bottom of a wooden plate resting on rubber silent blocs. This actuator came out of an "Interactor Cushion" from Aura, originally intended to give tactual feedback in games.

[42] After one run it was evident that the participant perceived all textures. As this was an exploratory study, one run was enough in this case.

[43] To be certain of this however, data needs to be gathered with this test set-up with non-impaired participants.

[44] This was done to demonstrate the Palpable Pixels at the International Conference on Touch, Blindness and Neuroscience, in Madrid, Spain in October 2002, and described in a chapter in the book that was published after the conference [Bongers, 2004].

[45] I developed these in Barcelona, particularly for the Touch conference in Madrid.

[46] The device at that time was a game controller (a Logitech Wingman), there was a problem in OS8.6 that the response of Max was best when the Finder was in the foreground instead of Max. The game controller was a workaround to switch the functions, which wouldn't work via the keyboard which was only read by Max if the Finder was in the background. In OSX this problem is solved, so it is not relevant anymore.

[47] Color Locator doesn't work in OSX, but we have found the DigitalColor Meter as a useful replacement, a standard utility in OSX. Also there are ways to enlarge pixels in Max, using the Jitter object jit.suckah (sic) and jit.desktop, as explored by student interns Sylvain Vriens and Bart Gloudemans at the Vrije Universiteit Amsterdam in 2004.

[48] By Bill Gaver [1989], unfortunately the Sonic Finder only runs on Mac OS up until OS5 so I have only seen a video of it. The name Haptic Finder was of course inspired by Bill's work.

[49] According to Bill Gaver who doesn't appreciate the OS9 sounds (as we discussed the issue on a visit to Cambridge where I invited him for a talk at the Computer Lab in March 2002).

[50] This research was carrried out at the Vrije Universiteit in Amsterdam, with Gerrit van der Veer, mainly during March 2003 when I was a guest researcher. The experiments and the statistical analysis were carried out with further assistance of Ioana Codoban and Iulia Istrate, student interns from Romania.

[51] As discussed by Motoyuki Akamatsu and Scot MacKenzie in their paper *Movement Characteristics Using a Mouse with Tactile and Force Feedback* [1996].

[52] Thanks to sound engineer Jos Mulder, who helped with the sound level measurements.

[53] The mouse-pointer ratio is proportional to the movement speed, a feature which cannot be turned off in the Macintosh operating system.

[54] As reported by Ian Oakley and Stephen Brewster [Oakley et al, 2001]

[55] Here somewhat confusingly labelled as 'ambient touch' [Poupyrev et al, 2002].

[56] This dichotomous nature of the movement has been reported in several papers [Mithal, 1995], [Philips and Triggs, 2001].

[57] For PCP see the *Engineering Psychology* book by Christopher Wickens [1992], pp. 98-101.

6.
The Physical Interface Design Space (PIDS)
Describing Physical Interaction

In this chapter a framework for the physical layer of interfaces is described and illustrated, based on the experience with musical instruments (chapter 1), interactive spaces (chapter 2) and general interfaces I will propose that for each meaningful human physical action (gesture) it is relevant to describe the *range* of the movement, the *precision* with which it is sensed by the computer system, and how it *feels* – the haptic feedback perceived (computer generated or originating from the real world).
In this chapter first the interface is described in more detail, introducing and defining a number of relevant terms in section 6.1. The issue of mapping is discussed in this section as well. In order to describe interfaces further, the approach discussed in section 6.2 is to decompose or 'parse' an existing interface, analyse its elements such as sensors and actuators, and describe the interface by placing the elements in a design space. For each degree-of-freedom the design space describes the movement by the dimensions *range, precision,* and *haptic feedback*. Related work on the classification of interfaces is discussed in this section.
Section 6.3 consists of Illustrations to further explain the dimensions of the design space, with examples derived from projects that I've been involved in as introduced elsewhere in this thesis. The final section 6.4 discusses further developments of the framework such as the inclusion of the visual and auditory modalities, and contains concluding remarks about the placement and role of physical interfaces in the electronic ecology.

6.1 Introduction

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 input and output. The design space has been briefly described in other articles dealing with design of new instruments or interfaces[1] and will be described in this chapter in more detail.

Device Parsing is an essential element in the analysis[2]. This involves an analysis of functions, by literally taking interface devices apart in order to investigate its inner workings which supports the understanding of its (potential) functional applications. Each sensor or function of the interface device is then further analysed or measured, and together they are to be placed in the design space.

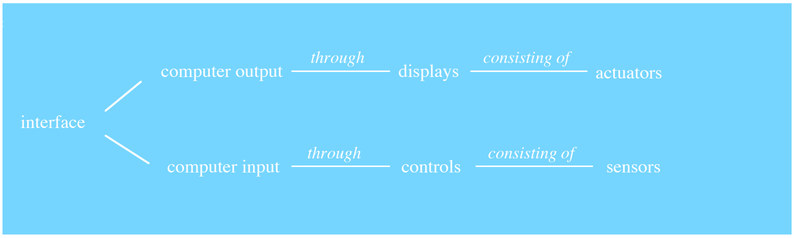
The approach is, as it were, to *decompose* a complicated device into its functional elements, and then to build it up again in Human Factors terms. This way we can compare apples and oranges by defining and describing them as fruit. Currently a uniform way of comparing the quality and possibilities of interfaces is lacking. The aim of the PIDS framework is to be able to compare interfaces by measuring the parameters and placing them in the design space. It can also be a tool for designing new interfaces, for instance for the choice of the functional elements. In Chapter 7.2 I will show this in the structured design approach of the Video-Organ instrument.

The PIDS framework may help identifying opportunities for new devices not yet existing in the design space.

6.1.1 The interface

It is the *interface* that facilitates the interaction loop. Generally an interface is a two-way device (or group of devices) which facilitates the two-way process of interaction. The number of interfaces is increasing in interactive environments nowadays, and particularly in an *e*-cology the interfaces are distributed and interconnected.

The interface 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. The diagram below summarises the composition of an interface.



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 analogue electrical signals from the sensors into digital signals and various levels of software drivers.
The most accurate level of description of human interfaces is the level of individual sensors, which measure (transduce into electrical signals) physical quantities such as light, magnetic field, sound, force, etc. Literature on sensor engineering[3] categorises sensors according to the physical quantity sensed, however these are not always the most meaningful parameters from a Human Factors point of view. In the context of the Design Space therefore, the working principle of the sensor is not the primary way to organise. Instead, a translation is made into the dimensions of the design space: range, precision and feel.

6.1.2 Standard interfaces

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[4] and the current desktop metaphor paradigm was invented in the seventies[5]. 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 as described in Chapter 4 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 time consuming but is also 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’[6].
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 (see section 6.2.1). In ergonomic terminology the pen allows for a 'precision grip' hand position rather than the 'power grip' of the mouse grasp. For developing PIDS I took such expert interfaces as starting point, and applied the experience and knowledge that I gained from developing musical instruments and interactive architecture.

6.1.3 Mapping

Designing and developing the new instruments and interactive spaces is not the most difficult part. 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 discussed in Chapters 2 and 3, not only the physical interface is designed but there is also more freedom in the *mapping*, because of variety in parameters of the processes controlled. Mapping is the link between control from the outside and display from the inside the computer. In the PC pointing task the mapping is quite fixed, but mapping could actually be free in other applications. We need to think about what might be displayed through the many possible computer output modalities, what it is we perceive, in order to establish an interaction with all the input modalities.

As an example of an alternative mapping, consider the world presented to us by the computer in the desktop 'metaphor', which is a flat world. This corresponds with the movements of for instance the mouse or track pad, but strictly speaking not with the rotational movements one makes with a trackball. I have therefore proposed to make a sphere desktop to match the ball input, such as with the Philips / IPO trackball[7]. The movement of this spherical world relates in an intuitive way to the movement of the trackball.

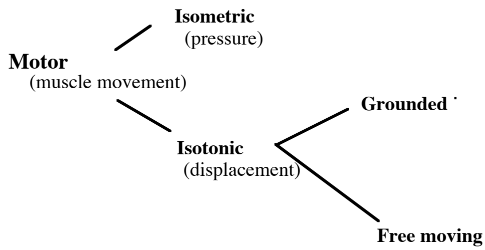
The design of the input device (or element) is strongly related to the effect it is mapped to. An example is the scroll-wheel, a real-world interface element that is mapped to the functionality of scrolling in the virtual world. In the complex situation of for instance the *e*-cology many interaction elements are needed. The interface parameters have to be mapped to the many functionalities that need to be controlled. In chapter 8 I will present recent research, applying the Multimodal Interaction Space framework, which involves many mapping issues.

The mapping between the measured movements in real space and changes inside the computer is not part of the Design Space. There are many different mappings possible, and the whole point of this description is to leave freedom for developing mappings in new paradigms. In certain applications the mapping can be mentioned, for instance for 2D pointing devices or text input devices.

A fascinating example of the power of mapping in pointing devices is the work of Koert van Mensvoort. In the several demonstrators he developed, the cursor is not only controlled by the movements of the mouse or other input device, but also influenced by visual contextual elements in the virtual world or even by hidden laws of movement. The result is a simulated active haptic feedback feeling, which is surprisingly effective[8].

6.1.4 History of PIDS

The first attempt to organise input devices (also with haptic feedback) in a taxonomy was undertaken at Philips, as part of a survey of interfaces in 1997[9]. Starting from the human movement, I discerned two categories: *isometric* (eg. no movement) and *moving*, and the latter further divided into *grounded* and *free-moving* as shown in the diagram below:



Resolution was also included in the description, which was then summarised per device in a short notation I proposed as shown in the example below of a standard mouse.

	movement tracker	switches
Degrees of Freedom:	2, translational	*n*1, translational
Movement:	isotonic, grounded	
Resolution	continuous	discrete (on/off)

Later I realised that, as always, the categories identified were not isolated but rather extremes on a continuum. This led to the PIDS dimensions *range* (starting from zero, the isometric situation) and *haptic feedback* to describe the feel of the element (form contactless, no feedback, to mechanical contact). The *precision* parameter of PIDS is an extension of the resolution parameter in the old taxonomy. The PIDS parameters are described in more detail in the next section.
I have followed the original taxonomy to classify individual sensors in a publication in the IRCAM e-book on Gestures in Computer Music[10]. For more complicated interface elements however it was needed to develop the taxonomy into a design space.

6.2 PIDS Dimensions

The Design Space is described along several dimensions, related to the modalities of interaction between humans and technological environment. We express ourselves though movement and sound (human output modalities) and perceive our environment through several input modalities, as described in Chapter 4. The proposed Design Space is therefore inherently bi-directional. PIDS emphasises the physical interaction and is therefore mostly describing movement, both human output as well as human input – the sense of touch as addressed by computer output devices. Other human input channels could be described as well as discussed in section XX below.
For the issue of movement, the most relevant one for physical interfaces, for each Degree-of-Freedom the proposed dimensions of the Physical Interface Design Space are:

range, in distance or angle.

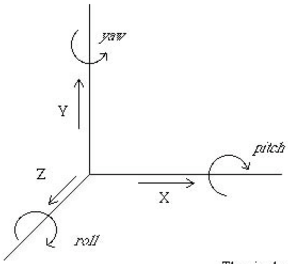
precision, number of bits used from two for a switch to 12 bits or more for analogue sensors, speed and accuracy. These are all factors more dependent on the hardware interface and driver software than on the actual sensor.

haptic feedback, which reflects the *effort* to be put in the movement. This is often *passive*, such as the normal force perceived from the weight of the device. But it also includes *active feedback* when the system is generating forces and vibrations.

In the future the design space has to be further developed in order to include other computer output modalities, briefly described in the section XX but not further discussed within the context of this chapter.
A clear distinction has to be made between feedback and presentation. Feedback is most relevant for articulation and interaction at the physical level, rather than presentation which has to do with the higher levels of interaction. Haptic feedback (and feedforward, see below) is included in the current version of PIDS because it is the most important channel

6.2.1 Degrees-of-Freedom

The diagram in the figure below gives the definition of the six Degrees of Freedom that describe movements and orientations of objects in three-dimensional space. There are three lateral movements along the X, Y and Z axes respectively, and three rotational movements around those axes notated as rX, rY and rZ. For the rotational degrees of freedom often the terms pitch (rX), yaw (rY) and roll (rZ) are used, terms which are common in the fields of robotics and aviation.
Most input devices suggest a standard orientation, but it remains a bit arbitrary which orientation of the axes is defined. It is common however for a table top based device such as the mouse to describe its two degrees of freedom as movements along the X and Y axes.



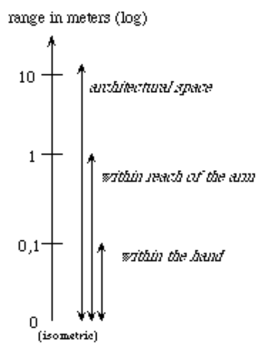
The six degrees of freedom

6.2.2 Range

The range of a sensor is defined in distance for the lateral degrees of freedom and in angle for the rotational degrees of freedom. The range can be continuous, such as in the case of turning a potentiometer (typical range is 270°), or discontinuous, which means the user can jump between values such as on a tablet. The range can be 0, as is the case with a force or torque sensor, this is called isometric case, to a few millimetres, to several metres[11]. We describe three spaces of the human scale: within the hand, within reach of the arms and within reach of the moving body.

- the *intimate* (isometric / 0 - 10 cm), close to the body, for instance within the hand or mouth. Examples of interfaces on the 'intimate' scale of the human hand are the trackpad, a Data Glove such as the one from Laetitia Sonami. Computer interfaces that use the extreme sensitivity and fine control of the human mouth are rare, but many traditional musical instruments such flute, trumpet, saxophone prove the value of this channel.
- the arm range or *body-sphere*, within the reach of the whole arm or feet (0 - 1 metre). Often desk based devices such as the mouse or joystick, or foot pedals that are used to control the computer with the feet.
- the architectural, or *spatial*, body movement - locomotion and location in space (0 - 10 metre). This is the scale of interactive architectural spaces, where the system senses the presence of humans in space. The area of ubiquitous computing or 'intelligent houses' often operate on this scale.

As is often the case with measuring quantities on human scales it is best plotted against a logarithmic scale. In the Design Space the range of a sensor or (part of an) input device is put on the Y-axis as shown in the figure below.



The Range parameter of the Design Space

In architecture it is common to distinguish even bigger scales, from the urban to the global scale. However, direct manipulation would rarely occur on such a scale.
If the device works in an incremental way, a larger 'virtual distance' can be covered by repeating the measurement of the actual distance covered. The standard mouse works this way, measuring relative position. This is a software issue, mapping the real movement to the pointer movement.
In this chapter it is proposed to measure a rotational degree of freedom in lateral distance, so that it is more easily comparable with the lateral DoF's and for instance includes the leverage effect introduced by the size of the dial of a potmeter. This is shown in the example Illustration 2 (Section 6.3.2 below).

6.2.3 Precision

In the *precision* parameter issues such as resolution, sample rate and latency are included. For resolution, the simplest case is the *switch*, with two positions which can be read into the computer in one bit: on / off. Rotary encoders and some other sensors output *pulse trains*, the pulse width can be proportional with the physical quantity measured. Analogue sensors are read through an A/D converter with a given resolution (number of bits used to describe each sample) and sample rate. Depending on the application there are several levels of software drivers involved each with their own delays and round offs. It is therefore almost impossible to quantify this parameter in machine terms. In the context of the PIDS it is proposed to use a human movement based measured figure that gives the ratio between the slowest and the fastest movement. This number then indicates the speed and precision of the whole chain from actual movement to effect in the computer, before it is mapped to a task. It is a measure of potential *expressiveness* of an input device. In the Illustrations below in section 6.3 examples are given, and a study has been carried out which attempts to measure this parameter for a range of standard pointing devices[12]. For the moment however the resolution (in bits) is used to describe precision, as it is the most important factor.

6.2.4 Haptic feedback

An important feature in the description of any physical input device is how it *feels*, particularly how much effort has to be put in the action. Any manipulation upon or with an object or artefact in the real world is guided by touch, in other words any movement measured is influenced by the haptic feedback or articulatory feedback. The term *haptic* is used here because it encompasses the many elements of the human sense of touch as discussed in Chapter 5. Haptic feedback is mostly about the display of (normal) *force*, but *texture* and *shape* play a role too.

Through actuators the computer can display physical quantities that can be perceived by humans, actively addressing the user's sense of touch. Vibrotactile actuators can generate virtual textures, and through motors for instance forces can be generated which address our kinaesthetic sense as described in Chapter 5. Within the context of PIDS this is called *active feedback* as opposed to the inherent and *passive feedback* that an object or artefact can give by itself.

Examples of commercial devices are the Phantom, force feedback joystick and the Logitech force feedback mouse (which has been discontinued in favour of the iFeel vibrating mouse). The Philips / IPO force feedback trackball is a good example of a device capable of generating precise haptic cues and feels.

This parameter of the Design Space also deals with the difference in free moving (a gesture tracker) or grounded (where the input device has a fixed connection or mechanical linkage).

The values on the force axis range from 0 (no feedback, free moving) to ∞ (no movement, isometric force). The value can even be negative, when the device actively guides the user by pulling rather then pushing against the movement. This case is called *feed-forward*.

In the next paragraphs the issues of force, texture and shape are further described.

Force

When one moves an input device, forces are experienced due to the inertia and friction of the device. These perceived forces are dependent on the mass of the object and friction of the contact surfaces. The mass is therefore an important parameter. The average mouse weighs about 100 grams. To illustrate the importance of this parameter we can look at the difference in feel between the mouse that comes with Wacom Graphire I and the one of the newer type II. The new one somehow ‘feels better’ when moved, not so much because it is slightly smaller but because it is a bit heavier. Inside the new type a round metal weight is placed of about 25 grams, responsible for the difference in weight between the old model (55 grams) and the new one (80 grams).
Another example is a foot pedal shown in the picture below. I designed around 1995 for musical purpose, and it has three rotational degrees of freedom[13]. The working range of each of the rotational DoF's pitch, yaw and roll is mechanically adjustable, and the *friction* can be adjusted resulting in a variable amount of effort to be put in. The range of most DoF's is adjustable in order to match the non-orthogonal nature of the human foot joint.

Texture

When moving a standard mouse we may perceive the texture of the mouse mat or another surface, which is actually not related to the parameters in the virtual domain being interacted with. An example of more meaningful feedback is the clicks often felt when rotating a scroll wheel on a mouse. This is still passive feedback however, generated by a mechanical spring loaded small ball that drops in the notches. It gives feedback about the steps made which maps to scrolling steps on the screen for instance.
With small vibrotactile actuators an active texture feedback can be generated by the computer, in which case it is possible to link the feedback to the processes in the virtual domain in order to transfer information to the human as described in Chapter 5.

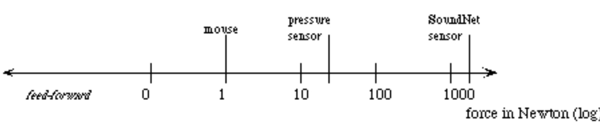
Shape

The form factor of an input device is difficult to quantify but very important. For instance, technically all parameters of both the original Apple iMac mouse[14] are the same of those of an average Logitech mouse at that time (not surprising because the Apple puck is made by Logitech). The difference is in weight (the Apple puck is a bit lighter) but particularly in shape. The round shape made it more difficult to use, because it was more difficult to orientate the device. The rationale behind this design must have had to do with the urge to make a mouse that was the result of 'thinking different'. The evolution of the shape of the Apple mouses over the years would make an interesting design case in itself, from the little rectangular box in the eighties to the rounded shapes in the last years.

In other classes of input devices the form factor would influence the counter force perceived because of for instance a leverage effect. An example is the size of a trackball. The small ball (17mm) found on the old Apple PowerBook Duo can be manipulated with movements of just the fingers, the Logitech Trackman FX (ball diameter 52,3 mm) involves movements of the wrist and 16cm diameter toy controllers from Microsoft and Philips involve movement of the whole arm. A bigger ball (of about 50 mm) has to be used as a rotational controller, while a small ball would be rotated by making almost lateral movements with the hand. The latter would then match better with the flat world of the screen, and the lateral movements of the pointer.

Haptic Feedback in the Design Space

If *force* is the most important parameter for the haptic dimension of PIDS, the Haptic Feedback parameter can be expressed on the X-axis, again logarithmically, from 1 Newton range of moving a light object like a mouse of about 100 grams (which depending on the friction would roughly translate in 1 Newton) to the range of for instance the index finger (< 20 N), the 'power grip' of the hand (< 150 N), arm force (< 250 N) or forces generated by the whole body (< 2000 N) such as in the case of the SoundNet described in Chapter 2.



forces displayed on the Haptic Feedback axis

Rotational DoF's would be expressed in torque, which is the product of the force and the arm. To be able to compare input devices or sensors across DoF's, it may be necessary to define a uniform parameter for all DoF's that also include form factor issues (at least the leverage arm, and friction) and texture.

6.2.5 Related work

Design spaces for interfaces usually reflect the state of the devices of their time. Looking back on the seminal work on organising interfaces in design spaces of Jim Foley[15] and Bill Buxton[16] in the eighties we can see that they were dealing with a much smaller set of devices, the Data glove being the exotic one.
Jim Foley and his group described 'trees', linking functions via interface elements to devices. The taxonomy proposed by Bill Buxton describes 1 - 3 dimensions, rather than the DoF's. The 'property sensed' (of the human movement) in this taxonomy is divided in *position*, *motion* and *pressure*. The human movement can be sensed with an absolute sensor (eg. a slider) which measures *position*, or a relative sensor (such as the rotational sensors in the mouse) which senses *motion*. Within PIDS this issue is relevant but of another order, it is a mapping issue. The distinction between absolute and relative operating modes of an input device is not necessarily a characteristic of the sensor, but is determined by the mapping inside the system. For instance, the rotational sensors that track the movement of the ball inside the mouse measure absolute angle (360°, continuous), which is in software translated into relative movement of the cursor[17]. The issue of *pressure* is also included in the range parameter of PIDS, the isometric case at one extreme of the parameter. The taxonomy of Bill Buxton makes a distinction whether the 'transducer' is *directly operated* or through a *mechanical intermediary*, the essence of this issue is dealt with in PIDS framework by the haptic feedback parameter.
Another important contribution to the field of classifying interfaces comes from the researchers Mackinlay, Card and Robertson (then at Xerox PARC)[18]. Their aim was to include a semantic analysis (or mapping), and introduced an extensive textual notation. They would start their articles about the Design Space for Input Devices around 1990 with the statement "A bewildering variety of devices for communication from humans to computers now exists on the market". Fifteen years later the would-be Linnaeus encounters even more interface forms and shapes that have emerged (evolved), especially when one includes expert fields. Still, millions of years of biological evolution gives a far more stable system to analyse than the present technological situation.
The earlier work described included the higher levels of the interaction: Bill Buxton's "lexical and pragmatic considerations" and Mackinlay, Card and Robertson's "semantic analysis". I describe such layers of the interaction in the MIS framework, while PIDS focuses on the layer of physical interaction at an appropriate level of detail.
A recent overview of input devices is presented in a chapter by Ken Hinckley in the HCI Handbook[19]. Among other things it is describing a number of relevant technical issues, and a discussion on mapping. It is however rather limited to input devices, and mainly pointing devices and keyboards. A confusing issue is the difference between active and passive system feedback. Although *active haptic feedback* is discussed in the same meaning as in this chapter (ie. generated by the system), Hinkley uses the term *passive feedback* for what is described as the "industrial design suggests the

purpose and use of a device even before the user touches it". This is what we would call affordances. Within the description of the PIDS framework the distinction between active and passive refers to whether the feedback is generated by computer/system, under control of the software and therefore the ability to represent meaning depending on the input or the internal state of the system.

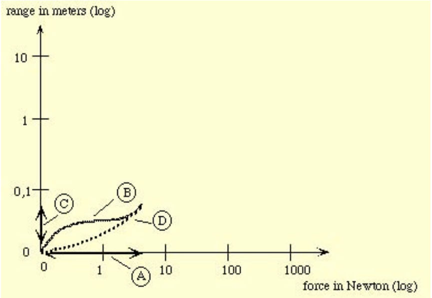
A taxonomy of input devices requires a higher level of description because they are often composite devices and relate to a certain task. For instance the class of '2D pointing devices' can be subdivided into 'mouses[20]', 'trackballs', 'joysticks', 'drawing tablets and trackpads'. But the most interesting devices, those which are the more difficult to classify, always end up in a rather large category of 'other'. These are the devices with many combined degrees of freedom, enabling a rich control, incorporate active haptic feedback, operating from the intimate to the spatial scale, often distributed, all essential elements of the interactions taking place in an *e*-cology.
Comparative studies about the effectiveness and efficiency of input devices seem to be only conducted within narrowly defined classes of existing input devices (ie. trackballs, mouses, joysticks) or with a clearly defined task with measurable goals.
By taking the most 'exotic' interfaces known at this moment as a starting point rather than the mainstream computer mouse, it is expected that the design space presented in this chapter can be used to classify a larger range of interfaces.

6.3 Illustrations

To illustrate the dimensions of the proposed Design Space I have carried out some studies which are described in the next sections, particularly focussing on issues concerning the Range and Haptic Feedback. Not all elements can be sufficiently described in some cases, which suggest directions for further development of the Design Space. I tried to choose a variety of input devices, such as separate sensors (Illustration 1)[21], a small custom built instrument (Illustration 2), a standard input device (a Wacom tablet, Illustration 3), a musical instrument with many DoF's (the Lady's Glove in Illustration 4) and an architectural project (in Illustration 5).

6.3.1 Illustration 1: pressure and close proximity sensing

To illustrate the importance of the haptic feedback parameter as a descriptive and discriminating factor in the Design Space, an experiment has been performed using the following materials: a resistive pressure sensor, an infrared proximity sensor, and a piece of foam. The other parameters of the PIDS are illustrated in this study too.
The pressure sensor (Interlink) translates mechanical force (from a weight from 0 to a few grams to 2 kg.) into a change in electrical resistance (from ∞ to 1MΩ to 5kΩ respectively) in a continuously changing value. This is an *isometric* event, no displacement takes place. In the diagram it is shown where in the PIDS this sensor would be placed (A). When mounted on a piece of foam (30 mm), the working range of the sensor does not change, it still senses the same forces, but in this case there is a displacement and a different trajectory of passive force feedback. This would move the sensor / foam contraption accordingly in the design space, as shown in the diagram (B).



The infrared proximity sensor (Honeywell HOA 1397) outputs a beam of infrared light from an emitter, and measures the amount of infrared light reflected off an object within a few centimetres by a receiver in the same housing. It has a working range of about 1- 3 centimetre, which would place it in the Design Space as shown in the diagram (C). When the pressure sensor is placed on a piece of foam (30 mm), the range remains the same but now there is a passive force feedback introduced by the foam (D).
Two of the four cases described here overlap in begin and end point, yet they are different. The purpose of the Design Space is to identify these subtle differences in trajectory.

6.3.2 Illustration 2: the Loop Box

Illustration 1 showed how an individual sensor can be put in PIDS. In this section a combined device is described with multiple control elements, of different form factor.
The Loop Box is an interface element from the modular set of interfaces of the Video-Organ instrument for the live performance of audio-visual material (which will be described in more detail in Chapter 7). This 'instrumentlet' is used to control audio loops in real time. Every knob (of the potmeters) has a different shape to facilitate distinguishing between them, and therefore their functions. To set the loop begin and end point, two small pots are used. The biggest knob is to control looping speed, and there are pots for controlling parameters of a filter (gain and resonance) and a slide pot for volume of the loop. Actuation forces of the potmeters are not known at present, but are all within the range specified for within-hand control (a few Newton) and multiplied by the arm (the leverage caused by the diameter of the knob) a certain torque is the result. In this Illustration I am looking at the effect of knob size on control range, which is summarised in the table.
The formula for the range is:

$$\text{Range} = 2\pi R \times 270/360 = \pi Ø \times 0.75$$

Where R is the radius which equals half the diameter (Ø), and the travel of the potmeter is 270° of 360°. Using the formula the sizes of the knobs and their ranges may be translated in distance, as shown in the table below.

knob	*diameter (mm)*	*range (mm)*
Loop set	10.5	24.9
Loop speed	31,5	71,2
Filter gain and resonance	13,3	31,2
Volume		26,4

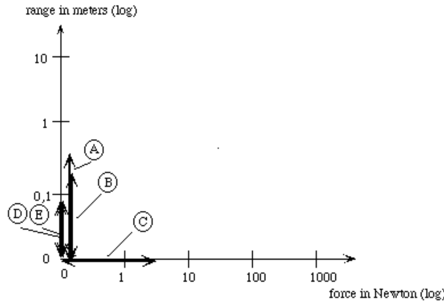
6.3.3 Illustration 3: a drawing tablet

For this illustration a commercial input device with many different degrees of freedom is studied.

The Wacom Intuos A4 drawing tablet has a working area of 304.8 x 240.6 mm and a resolution specified as 100 lines per mm. The stylus has a pressure sensor in the tip which has a 10 bit resolution, and tilt is measured around two axes with a range of ± 60° (120° in total).

The stylus tracking principle of this device is based on a fine array of lines which create an electrical field above the tablet, in which the movement of a coil is tracked. The coil is built inside a stylus (or a mouse). This combination also acts as energy transducer, which provides the power supply for the stylus' internal electronics, which then transmits values of measurements from inside the stylus (such as tip pressure and key presses) to the tablet.

The movement along the X and Y lateral DoF's is mapped in the Design Space as shown in the diagram (A and B respectively), the force is an estimate based on the sliding friction force of the 13 gram stylus (determined by tilting the tablet and measuring the angle under which the stylus starts to slide by itself) which is 0.06 N. The 10-bits pressure value (0 - 1023) corresponds with a tip pressure of 0 - 4N, an isometric event which translates into the Design Space as shown in the diagram (C). The rotational degrees of freedom have a range of 120°, and as the perceived radius is the centre of the grip point at about 4 centimetre, the distance covered can be calculated (using the formula from section 6.3.2) as 84 mm. The result is shown in the diagram (D and E).



6.3.4 Illustration 4: the Lady's Glove

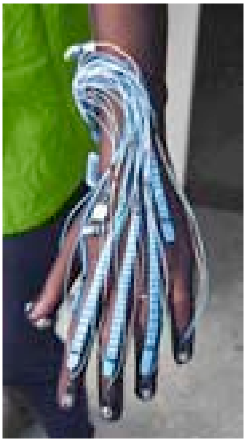
An input device with many non-orthogonal degrees of freedom is the Lady's Glove developed and designed with the artist Laetitia Sonami, as described in Chapter 2. It consists of several sensors (such as bend sensors, tilt switches, accelerometer) sewn directly onto a custom made lycra glove.

The bend sensors measure from 180° to past 270°, in practice the range is limited by the (individual!) maximum bend of the particular knuckle of the finger. Normally these sensors have only this one degree of freedom, over the full length of the sensor, but for this application a centre tap electrode was applied dividing the sensor into two separate sensitive areas. For the wrist, which can move up and down, two sensors are mounted back to back, to inverse the working range of one of them so that they complement each other's range. In this application it seemed inappropriate to translate the circular movement from degrees to meters (distance) as it is dependent on too many other factors. Also the force needed to bend the sensors has not been determined, as it is depending not only on the flexibility of the sensor (covered in shrink wrap for protection) but also the friction as it slides. An estimate could be made though. This is an important issue because it indicates the difference in feel between different gloves or constructions as presented elsewhere.

On the thumb a neodymium magnet is sewn, which influences the magnetic (linear Hall effect) sensors sewn on the fingertips, through which the proximity between thumb and fingers can be measured. This measurement is logarithmic, due to the nature of a magnetic field, which is compensated for in the software.

On the nails little button switches are mounted with a specified 3N 'actuation force'[22], and another switch on the side of the hand with a 1.3 N actuation force. A (mercury) tilt switch detects change in angle.

Position is sensed in one degree of freedom through an ultrasound system, measuring the distance between the hand (where the transmitter is placed) and the waist and the foot (where the receivers are placed). A sensitive accelerometer on the side of the hand measures the acceleration in two directions, and the rotation of the hand due to change in angle with the earth gravitational field. The table below shows an overview of the sensors and their ranges, and the precision which is determined by the sensor interface hardware and the MIDI communication protocol.



sensor	*amount*	*range*	*precision*	*haptic feedback*
index, middle, and ring finger bend sensor	6	90°	7 bits	
wrist bend sensors	1	180°	8 bits	
index, middle, and ring finger hall	3	2 cm	7 bits	
switches on all finger nails	5	0.1 cm	1 bit	3N
switch on hand	1	0.1 cm	1 bit	1.3 N
tilt switch	1	180°	1 bit	
pressure sensor	1	0	7 bits	0 – 100N
accelerometer	1	±2g	7 bits	

To show these parameters in a table is not ideal. It is really necessary to develop a notation method displaying all the parameters at a glance, with their range, precision and feedback, and most importantly their relationship. For instance, in the Glove the index bend sensors and proximity sensors on the fingertip are often related through the movement of the finger, though they can be influenced separately. The tilt switch and gravitational angle sensing of the accelerometer are often influenced by the same physical parameters too. The reference plane of these sensors is the earth surface and motion, while the other sensors depend on the posture of the hand, arm and body.

6.3.5 Illustration 5: Muscle

As an example of an interface on an architectural scale a recent project with the Dutch architect Kas Oosterhuis is described. This one is called Muscle and as described in chapter 3 it is a structure that can move and change shape, using pneumatic 'muscles'. The project was developed for the 'Non-Standard Architectures' exhibition in the Centre Pompidou in Paris (November 2003 – February 2004). The structure is balanced by the pressure of an air balloon which is spanned by the pneumatic muscles. The pressure of the balloon volume is constant, while the tension of the muscles can be varied in real time under computer control by changing the air pressure of each individual muscle, resulting in a dynamic system of pushing and pulling forces. The size of the structure is 10 x 4 meters with a height of 2 meters. The controlling computer system and the valves that regulate the muscles are inside the balloon.

The Muscle structure

The Muscle Sensor Disk

On the cross points of the pneumatic muscles eight sensor disks are mounted. Each sensor disk contains a proximity sensor, a motion detector, and a touch sensor. Through these disks the audience is able to, explicitly or unconsciously, interact with and influence the behaviour of the Muscle ‘body’.
The haptic feedback is either 0 in the case of the free movement and motion detector, or the normal force in the case of the pressure sensor which measures the touching of the audience.

sensor	*amount*	*range*	*precision*
proximity	8	0.1 – 1.2 meters	7 bits
motion	8	10 meters	1 bit
touch	8	0	7 bits

6.4 Discussion and conclusion

In this chapter a framework has been introduced for the description of a wide range of interfaces, from the intimate to the architectural scale. The Illustrations have been included to illustrate and further discuss the parameters and issues of the design space.

6.4.1 Future work of PIDS

It is necessary to further develop uniform and descriptive units for each of the parameters of the Design Space. Range has the unit of distance in Metres, and it is proposed to translate rotational DoF's into this linear distance although this is not always possible such as illustrated in the case of the bend sensors on the fingers of the Lady's Glove. Moreover, it may be necessary to introduce the factor *time* in this parameter to adequately describe a non-linear trajectory a sensor might have, and the issue of discontinuous ranges[23].

The Haptic Feedback parameter has been expressed in Newton in the examples in this paper, but that covers only force and not texture or form factor. The issue of torque for rotational DoF's has been mentioned. Perhaps this parameter is better expressed in Work (to include distance, Work is the product of displacement and the force along that displacement, in joule) or even Power, which introduces the element of time (the amount of work done in a time interval, in watt) . Further research is needed, also with more precise force measuring devices.

The Precision parameter is difficult as it involves many machine factors. It is suggested to summarise Precision in one unit including resolution, sample rate and latency[24]. To get a better idea of the problem and how to solve it, it is necessary to carry out experiments with various input devices and hardware protocols which enable real time human movement measurements with a relatively high accuracy[25]. The unit could be expressed in a ratio, but the problem is that a clear benchmark is not available yet.

6.4.2 Other Modalities

It may be necessary to extend the PIDS framework with other system output modalities, such as visual and auditory. Other modalities less common in human-computer interaction today, such as olfactory display, temperature etc. could also be included.

A lot of research has been done particularly on the issues of visual and auditory display and feedback[26]. Some main parameters are summarised below for these modalities, these suggestions have to be worked out further.

Visual display

The visual modality could be described in the following basic parameters of the display:

<u>size</u>, of the screen or projection, as it appears to the user – including 3D projections,

<u>resolution</u>, the number of pixels (eg. XVGA resolution of 1024 x 768 pixels)

<u>colour depth</u>, the number of different colours that can be displayed (one-bit: black and white, 8 bits grayscale or colour, to 24 bits over 16 million colours), and

<u>refresh rate</u>, how often the screen is redrawn.

Auditory display

The display of sound, usually through loudspeakers, can be described in the parameters (for each source):

<u>frequency range</u> in Hertz and

<u>sound pressure level</u> in decibel.

6.4.2 Conclusion

The PIDS framework can be used to describe the physical level of interactions and could also play a role as a design aid. It should further evolve, in order to deal with the shift in the general human-computer interaction paradigm from the insular desktop machine to a situation where our whole technological environment becomes networked, sensitive, with multiple and multimodal displays, and the general notion of ubiquitous computing and even more particularly the *e*-cology. Technologies of the successive historical stages, as described in Chapter 1, increasingly merge due to the unifying role that the (embedded) computer plays. This encourages an approach which treats the interaction with our technological environment as a whole, as an emerging electronic ecology. As argued in more detail in Chapter 1, the computer effectively has disappeared and the research field of ubiquitous computing deals mainly with a new interaction paradigm. This ubiquitous interface paradigm is a shift from thinking in devices, even information appliances[27], to thinking in *functions*. With the interface physically detached from the actual devices (which are after all ubiquitous), we interact with the system through ethernet and USB (all wired) or WiFi, Bluetooth and soon Zigbee (all wireless), from the intimate scale of the Personal Area Network (PAN) to the architectural scale of the house, and beyond. These protocols enable the same shift that happened in the field of electronic music, where the MIDI protocol facilitated a renewed focus on the interface independent of the rest of the instrument - the sound source. This brought about new problems, such as unclear mapping between interface parameters and the functions controlled, which have been at least partially dealt with over the years. This awareness and other experiences from the electronic arts fields is applied in PIDS, providing a different starting point. Other approaches have been described using one interface to control multiple or networked devices[28]. To design such a generic or 'meta-interface' a bewildering amount of functionality has to be dealt with. In Chapter 9 this will be further discussed. I am expecting that, in addition to the design methods that deal with the higher levels of interaction such as the semantic, task and goal levels such as the MIS framework, the PIDS framework can play a role in the research and design of physical interfaces for the *e*-cology. The PIDS framework indicates opportunities for new devices not yet existing in the design space[29].

The PIDS parameters of range, precision and haptic feedback were chosen based on many experiences of developing new instruments, interfaces, and interactive spaces, as well as studying existing interfaces. The Illustrations in Section 6.3 showed how the parameters apply to practice. In the next Chapter, in section 7.2 describing the structured design approach of the Video-Organ instrument, the PIDS framework is further applied and validated.

[1] In the paper for the NIME conference about the Video-Organ [Bongers and Harris, 2002], and in a paper for the Organised Sound Journal on audio-visual spatial instruments [Harris and Bongers, 2002].

[2] I will come back to Device Parsing in Chapter 9.

[3] See for instance *Sensors and Transducers* [Sinclair, 1988].

[4] By Douglas Engelbart.

[5] As described in Chapter 1, by researchers of Xerox PARC.

[6] 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 for instance Stephen Pheasant's book, *Ergonomics, Work and Health* [1991].

[7] In fact, one of the interaction styles as described in Chapter 5 in the Philips / IPO multimodal interaction project, was a spherical representation of content (in this case, television channels). It was a joint effort of Berry Eggen, Steffen Pauws and myself, later a patent was applied for this interaction style. A visualisation was made in 3D by Paul Thursfield at Philips design, which can be played in QuickTime VR.

[8] Although ideally the feedback is really haptic (as described in Chapter 5), this work is very interesting. Several demos developed by Koert in Shockwave (working directly in the browser window) of this 'active cursor' are available at the web site www.koert.com, including a game which shows the stickyness infuriatingly well. Also see the paper *What you see is what you feel* [Mensvoort, 2002].

[9] Published in a Philips internal report (company restricted, as it contained a description of a new device we were working on) *A Survey and Taxonomy of Input Devices and Haptic Feedback Devices* [Bongers, 1997].

[10] *Physical Interaction in the Electronic Arts* [Bongers, 2000].

[11] This case is sometimes labelled as 'isotonic', however strictly speaking this refers to the situation where tensions or forces are remaining equal.

[12] The study and the results have not yet been published. The data show how little precision there is with standard input devices when moving fast.

[13] For the Clavette instrument that I developed for Sonologist Harold Fortuin, a keyboard with over hundred keys enabling the player to work in alternative tunings. A pair of pedals were added to allow the player to add expression to the keys, which were on/off. The pedals were built with the help of mechanical engineer Theo Borsboom. Another pair was later built for a theatrical piece by the American composer Naut Human.

[14] The little round 'puck' that caused quite some criticism from an ergonomic point of view

[15] See [Foley et al., 1984].

[16] Bill Buxton published an article about his proposed taxonomy in 1983 in the Computer Graphics Journal, *Lexical and Pragmatic Considerations of Input Devices* [Buxton, 1983]. It is summarised in the introduction of the Haptic Channel (Chapter 8 in *Readings in Human-Computer Interaction* [Baecker and Buxton, 1987].

[17] This mapping is non linear in most modern computers (standard in the Mac OS and an option for Windows since '95) which means that the distance covered by the screen pointer is proportional to the *speed* of the movement of the mouse.

[18] The team of Jock Mackinlay, Stu Card and George Robinson [Mackinlay et al., 1990], [Card et al., 1990].

[19] In the Human-Computer Interaction Handbook edited by Julie Jacko and Andrew Sears, chapter 7: *Input Technologies and Techniques* [Hinkley, 2003]. A new version of the chapter, to appear in 2006, can be downloaded from the web site of Hinkley: research.microsoft.com/users/kenh/. In this version the discussion on various modalities is much extended, among other things.

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[20] Usually the plural from of mouse when it concerns the computer input device is 'mouses', leaving the term 'mice' for describing the actual animal. However, Apple uses 'mice'.

[21] More detailed descriptions of the sensors can be found in my chapter in the IRCAM e-book [Bongers, 2000].

[22] Other commonly available actuation forces are 1.3 N, very light, and 5 N, heavy.

[23] The Xerox team couldn't resolve this issue either [Mackinlay et al 1990, page 161].

[24] Particularly difficult is the *jitter*, the variation in latency over time.

[25] This is currently under investigation in the European Cost-287 action, ConGAS Gestural Control of Audio Systems (see www.cost287.org).

[26] See for instance the yearly conferences on Auditory Display, starting in 1992, www.icad.org.

[27] As described by Donald Norman in *The Invisible Computer* [1998].

[28] A very good example is the Pebbles project of a team led by Brad Myers at Carnegie Mellon University in Pittsburgh, PA. They mainly use PDA devices to create a Personal Universal Controller (PUC) [Myers, 2002].

[29] Baeker and Buxton speculated this already in the description of their taxonomy, comparing it to "the way Mendeleev's periodic table predicted new elements" [1987].

Part IV
Explorations

In this part further experiments and projects, ‘explorations’, are described. Interaction paradigms as put forward in the previous parts are illustrated and further developed in practical experiments, performances and demonstrators in architecture, music, video art and general HCI.

7.
Art and *e*-cology
Interaction from the Intimate to the Architectural Scale

In order to further investigate interactive environments or *e*-cologies, a number of art projects have been developed which are described in this chapter. In these projects I have been exploring the interaction from the intimate to the architectural scale, by developing interfaces and researching the mapping between the real world variables, virtual world parameters, and back again. The examples used are drawn from a personal experimentation in the contemporary problematics of technology in the arts.
The structured design approaches, the process and the outcome of these experiments are described in this chapter. A historical context is described in section 7.1. The transition is described from *static – temporal – dynamic – interactive*, including the changing roles of composer, performer, and the audience.
With the **Video-Organ**, a new modular instrument for the live performance of audiovisual material, a number of performances have been produced whilst further developing the instrumentarium as described in section 7.2. In these performances sounds and moving images were used to alter the architectural space, culminating in the **Inside-Out** performance in which a building was 'interactivated' and turned inside out. It also led to the **Video-Walks**, using a mobile set-up carrying a video projector, sensors, computer and sound system, enabling us to explore inside and outside spaces by walking, merging with the landscape. This is described in section 7.3. The **Meta-Orchestra**, described in section 7.4, is a continuously changing multidisciplinary group of musicians, artists, architects, technologists and others investigating the role of the computer in a group performance setting. The Orchestra is using an added communication layer by linking the member's computer set-ups in a high speed (partially wireless) network through which the participants can influence each other's setups. The network also enables us to distribute the members through a building, with the audience moving, leading to a different way of dealing with the architectural space and the performance paradigm.
The projects described are often developed in parallel, influencing and inspiring each other. The example projects have been developed in collaboration with the musician and visual artist Yolande Harris since 2000[1].
Section 7.5 discusses and reflects on the issues brought up of the potential non-disciplinary nature of electronic art, the relation with technology and group performance.

7.1 Introduction

Through the use of computer technology it has become increasingly feasible to create time-based art works, playing sound (music) and light (images, video) and placing them in real-time in the architectural space. In order to enable people to access and manipulate the materials inside the computer, interfaces are needed and many artists have developed their own solutions. In this chapter the interface is described as an 'interactivated space' to encompass both the intimate scale of a performer manipulating the materials through an on-body interface, and the larger in-space interface where the work is shared with the performers and audience[2].

In contemporary music and arts practices the previously distinct roles of composer and performer have become increasingly conflated, catalysed by the use of computer technology. Based on our own experiences we identify and describe the newly combined *roles* of composer and performer that are assumed by one or more people or computer systems, and *actions* including preparation, organisation and presentation that take place during the creative trajectory from the first gathering of material to the final presentation. In situations such as discussed in this chapter, this is not a linear process, the roles and actions influence each other in a continuous 'plaited' development over time. People or other entities such as computer systems can take on roles and perform actions in various orders and combinations sequentially or simultaneously.

Throughout this development the traditional idea of an instrument has evolved to become the interface between human and computer technology, a state that includes previously less common actions, such as gathering, processing and placing sonic or visual material. This is paralleled by the conceptual change in the role of a score which, due to the mingling of composer/performer roles, is emerging as a dynamic interface capable of continuous communication. The scale of these two interfaces, instrument and notation, ranges from the intimate to the architectural. This Chapter describes in detail the elements of the proposed approach to creating interactivated spaces.

The computer as a tool or meta-medium has not only influenced existing disciplines such as music (Chapter 2) and architecture (Chapter 3), but also plays a unifying role *between* disciplines and this is where new art forms seem to arise. A central notion in my approach is the breaking down of the boundaries between disciplines, advocating a *non-disciplinary* art form.

The developments described in this Chapter are carried out together with a team of people in this field, and can serve as illustrations of the issues at hand. Over the last five years, we have developed a number of projects in which experiments are taking place which investigate the interaction with computers.

In order to better understand the current developments it is helpful to look at another period in history where similar processes occurred. Industrialisation and mechanical reproduction had a strong influence on art and design at the beginning of the 20th century, particularly challenging and transforming the role of craftsmanship. A somewhat similar questioning and confusion of the issue of the role of craft arises towards the end of the century under influence of digital technology.

Of course the use of the computer as new media has led to the development of a number of new art forms, often called 'media art', 'electronic art', or 'net art'[3] when the Internet is used as a medium[4]. However, our interests lies in a new art form that deals with sound, moving image and physical space mostly in a performance setting, that conflates the previously separate disciplines. In such a complex environment, the demands on the *interface* as a facilitator of high bandwidth interaction are enormous.

7.1.1 Modalities and time

We can describe art forms using the terms common in HCI as defined in Chapter 4 on multimodal interaction. Starting with the traditional art forms: music is primarily about the *auditory modality*, while the *visual modality* is addressed in painting (two dimensions[5]) and sculpture and architecture (three dimensions)[6]. Music, unlike the visual arts, traditionally requires performance, as does theatre and opera. This has to do with the *time based* nature of music, and before the invention of recording techniques (as described in Chapter 2) music would literally disappear as soon as the notes finished sounding (although remaining in the minds of the listener). *Scores* were invented in order to preserve the music, more like a recipe describing a process than the actual music itself. A number of translations then take place, from sound (first in the mind of the composer), to image (the score), and to sound again by a performer who will inevitably interpret and alter it to at least to some extent. This last phase of the process is often a group process, such as an ensemble or orchestra, led by a conductor.

Unlike music, painting is non-volatile, changing only slowly changes over time[7]. This is most fortunate, imagine this was not the case..... we would need a group of specially trained artisans, an orchestra of painters, that have to re-create for instance a monumental work like Rembrandt's Nachtwacht every time an audience wanted to see the painting. Jackson Pollock however could be considered the equivalent of an improvising musician in his 'action paintings'.

In the visual modality, time has been introduced in a similar role as in (recorded) music, through film and later video. Early film (further discussed below) was often abstract, because the language of what was to become *cinema* still had to be developed.

There is an element of time in any painting as well of course. The longer one looks at a painting, the more details, the more story, the more experience can be unveiled and evoked in the perceiver, possibly happening at several different layers of interaction as described in Chapter 4. For instance it is hard to grasp at once all the action going on in a painting of Brueghel[8] for instance, or to take a more recent example, the work of David Salle who uses mixed techniques to create an enormous density as can be seen in the picture below of *Mingus in Mexico* (1990)[9].

a work by David Salle

In many examples in the work of Andy Warhol in the sixties *repetition* is used to create density.
The experience is again different in the case of minimal art, but even in this case it definitely takes time to take in for instance the impressive works of Mark Rothko or Barnett Newman.
Examples in the textual modality are the reading of books and poetry, where the story unfolds over time.
Other modalities than sound and vision are rarely used. For instance smell, however important as an added modality (implicitly or explicitly, for instance the scent of candles and incense in the church during a service, or the use of smells in a theatre piece of Dick Raaijmakers in the 1990's) does not often occur as a stand-alone art work. Except perhaps for cooking, which one can call culinary art[10]. A good cook may create a fine meal and beverages, addressing not only the olfactory but also gustatory and it has tactual element in it in the composition of textures of the materials prepared. A cook can also create a recipe to be carried out by other cooks (the recipe as the score), and the food served by waiters who are the performers, for an audience who will hopefully appreciate the food.
Tactual art is rare too. STEIM has a travelling exhibition called *Touch*, first presented at their *Touch festival and symposium* in Amsterdam in 1998. In the exhibition a number of installations and instruments are shown – and can be touched or are touching the audience[11].
There are more exhibitions and books on 'touch' and 'feel'[12]. In 2004 the *Feel* exhibition in Belgium[13] presented some art works involving 'feeling' in the broader sense, with one clear example of a real tactual art work which included even the sub modalities of pain and temperature (usually not addressed in computer interfaces, see Chapter 4). This work is called 'Pain Station', where two players are engaged in an

installation which is a remake of the classic computer game 'Pong', however they are physically punished for losing points by heat, electric shocks and a small whiplash![14]

The Pain Station

Experiencing loud music from large loudspeaker systems such as used in pop concerts, techno and raves, has a significant tactual element in it. The music is felt through the body, which seems to be essential in order to appreciate the music (and dance to it).
This power is taken to an extreme by the Austrian duo Granular Synthesis, their audible sound levels are not that high but the amount of energy conveyed in the low frequencies (definitely addressing the tactual sense) is impressive and very effective[15].
Another example is *kinetic art* which has been around for a long time, for instance the work of Jean Tingeuly, or the mobiles of Alexander Calder.

a mobile of Calder, sculpture in Palma de Mallorca

7.1.2 Time and interactivity

In the previous section the issue of *time* has been discussed. Taking in a work of art always takes time, also in the case of '*static*' art. In recorded art such as music and video, and in performed art, the progression is normally fixed and linear. When the delivery can be influenced by the audience, it could be called *dynamic*. In other words, the issue of time brings in the question of *who* is in charge of the time[16].

There is a difference in the relationship that a creator has with a system (for instance a musical performer with an instrument) and that an audience has with a system (for instance listening to a performance). Often they can influence each other directly, often using another modality of interaction (applauding after or during the performance), or even through (mediated by) the system. If the creator and audience are not present at the same time or place, the situation is again different, as in the case of a listening to a record, watching a video, or reading a book[17]. This is what I call *dynamic*, where the audience can influence the delivery but cannot change the content[18].

After the transition from *static* to *time-based* and *dynamic*, the next transition is to *interactive*. Interaction can be defined as 'mutually influential', that is, both partners in the discourse (whether machine or human) will have changed state, frame of mind, or views after the interaction. Most interactions with computer systems however are merely *reactive*, including some so called interactive art works, and therefore may fit better in the category of *dynamic*. At the other extreme, computers offer many possibilities to generate a world of their own with possibly only minimal or no explicit control or influence of people. This is something that many installation art works and instruments are based on. An interactive system enables the audience to participate[19].

Interaction can only take place if the technology has means to sense, process, and act. Examples of this are the algorithmic composition systems that musicians have developed to interact with, such as Jonathan Impett (with his Meta-Trumpet instrument, described in Chapter 2) or George Lewis[20]. Another example is the Koan software for generating music, related to the ambient music of Brian Eno[21]. In visual art, John Maeda creates complex images that are produced as results of the computer programs he writes[22]. In the case of interactive art the outcome is not predetermined, the content is not fixed by the artist but instead the algorithm, the *process* is the work of art. Every audience member, every spectator or every perceiver actively creates their own unique experience in an *e*-cological way[23].

7.1.3 Art at the beginning of the 20th century

Music has traditionally always been *abstract*. After the invention of photography in the early 19th century and subsequent further perfection of photographic technology, painting lost (was freed of) the need to literally represent reality[24]. This brought about a increased number of styles dealing with the *interpretation* of the reality (impressionism), bringing out or *expressing* the otherwise invisible or unperceivable (expressionism), combining *multiple viewpoints* in one image (cubism), and completely *abstract* painting[25]. The development of Piet Mondriaan, which can be seen chronologically displayed with a series of paintings of a tree in the Gemeentemuseum in The Hague shows this very clearly, almost like an animation in slow motion of a transition from figurative to abstract[26]. In the pictures below a few of these paintings are shown.

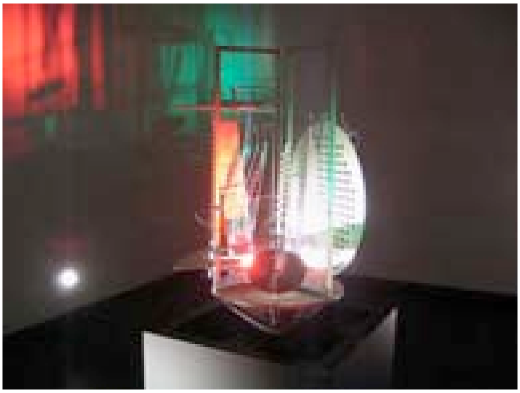
The red tree (1908), The grey tree (1911) and Flowering apple tree (1912)

Among the first abstract (or non-figurative or non-objective) art were Wassily Kandinsky's paintings of around 1910, in which he attempted to create 'colour-music'[27].

Lyrical (1911)

In a way, one could say that visual art was trying to become abstract by emulating music. This was generally a period of intense interest in the relationship (or translation) between visual art and music[28]. Other experimentation took place in this period too, most notably by artists involved in the Bauhaus founded in 1919 in Germany[29], attempting to deal with a changed world under influence of the industrialisation which brought about mechanical, electrical and chemical means for reproduction. The role of craft was changing under this influence, and Bauhaus was trying to deal with this. At the end of the 19th century the Arts and Crafts movement led by William Morris had approached this issue too.

At the Bauhaus, colour was researched and described by Josef Albers and Johannes Itten[30], the founder and director Walter Gropius was an architect who brought together visual art and design, the painter Kandinsky carried on his experiments on the relationship between music and abstract art, László Moholy-Nagy worked with chemicals and created kinetic sculptures (which didn't survive entirely, but the Van Abbemuseum in Eindhoven in the Netherlands has a restored version of one of the sculptures as shown in the picture below), the painter and sculptor Oskar Schlemmer fostered cross-overs to performance and dance with the costumes for dancers in the Triadic Ballet and mechanical performance in the Mechanical Ballet (a reproduction of this installation exists) and in Paul Klee's visual work the influence of his musicianship was apparent[31].



It was also a period of great political turmoil in Germany, in transition from separate states to one country, between two world wars, all happening under influence of ideologies as diverse as fascism, communism and socialism. This situation was reflected in the Bauhaus developments in various ways. When the Nazis finally managed to close it down in 1933[32], many artists and designers involved moved to the US, where they would teach at various universities (Gropius at Harvard for instance) or set up the New Bauhaus in Chicago (Moholy-Nagy)[33].

7.1.4 Art in the sixties

Another period of intense developments happened in the sixties, partially under the influence of the rise of mass-media with its faster developments in communication rapidly inducing many new insights[34]. Further liberated from the need to be figurative, artists still sought for new possibilities and purposes. By exhibiting everyday objects, Marcel Duchamp led the movement that *anything* can be art. This redefining 'art as something made by an artist' is a tautology of course, as an artist is defined as a person who makes art. This acquired freedom however inspired (or drove) artists towards using new materials and many new art forms were invented[35]. For instance 'happenings', where an *act* was the essence such as in the many Fluxus performances often initiated by a few lines of instruction (a score, in a way) such as "draw a line and follow it"[36]. There is a video of Nam-Jun Paik performing this piece by dipping his head in a pot of paint and using his hair as a brush to draw the line (and inherently following it).
It was also a period of protest, political and or socio-cultural, for instance Pop Art as a reaction against the consumerist society. Suddenly, all materials, media and tools could be used to make art. In addition to traditional materials such as oil paint or bronze, artists started to use found objects, waste, plastics, food, air, light, sound, fire, explosions, landscape, whatever. New media needed to be explored, such as video particularly when the equipment became cheap enough to be used by anyone. Early

pioneers such as Nam Jun Paik or Bruce Nauman picked up the camera exploring its possibilities and developing languages. More often than not, art works were not what they seemed at first glance such as in the Pop Art of Andy Warhol or Roy Lichtenstein.
After some historical examples of works that were neither painting nor sculpture, such as El Lissitzky's 'Prounenraum' as a three-dimensional version of one of his well known abstract paintings[37] from 1923, 'installations' became a popular art form in the sixties[38]. Lucio Fontana's well-known slashed and pierced canvasses were a clear attempt to escape from the two-dimensionality of the painting and to step outside of the frame.
In 'conceptual art' the work involves an active role for the audience to reveal the ideas behind it[39].
But it can also be a pitfall, not having to deal with the details of creating the work, the craft needed and so on. After thirty years of conceptual art one might wonder why this is really the most prevalent art form[40]. It certainly has to do with the decreased emphasis on skill, the 'de-skilling'. Purely conceptual art is at odds with the craft and skill of Bauhaus and the expertise needed in the use of digital technologies at present[41].
Another fascinating art form that started in the sixties took art even further away from the museum and galleries, and is often called 'land-art', environmental art or earthworks. Famous examples are the works of Robert Smithson, James Turrell, Richard Long (see the picture below), Andy Goldsworthy and the wrapping of buildings, bridges and landscapes and other works by Christo and Jeanne-Claude[42].



7.1.5 Art and technology

Art has always had an intense relationship with technology. Artists use technology, subvert it, take it to previously unexplored extremes and the results might then, in turn, influence other disciplines or applications[43]. Everything that is man made, all artefacts, have to do with technology. Painters in previous times had to make their own paint, and needed to possess a profound knowledge about chemistry comparable with scientists[44]. Nowadays technology has become increasingly complicated, in the culmination of all the different technologies (as described in Chapter 1) and the digital computer technology with its extreme layer of complexity due to its programmability. Yet I still believe, and try to prove in my work, that by understanding technology (as a means, not as a goal in itself as the engineer might treat it) the final results can be much more powerful. Developing a concept and instructing technicians to carry it out often leads to sub-optimal results, unwanted alterations or even failures. However complicated and powerful, the current technology does not enable one to do just everything[45]. Choices need to be made, options have to be worked out, inventions need to be done in order to reach the desired result through several iterations[46]. In the ideal situation, a strong concept is worked out with the right application of technology. These two issues, idea and technology, are in my opinion thoroughly intertwined and cannot be treated separately. Artists and designers therefore often work in teams, the Meta-Orchestra as described below is an example of that. There are also historical examples, such as the group EAT, Experiments in Art and Technology founded by the artist Robert Rauschenberg and engineer Billy Kluver in the late sixties[47].
A recent initiative that attempts to deal with the relationship between art and contemporary technology is called Dorkbot, which started in New York in 2000 and now has local activities in many cities around the world[48].

A good example of the interrelatedness of art and technology can be found in printing. Every printing process or technique has its own virtues and restrictions and therefore specific effects, for example wood cut, the movable type printer[49], lithography based on slabs of limestone, screen-printing, off-set printing and so on. Graphic design, particularly typography, was strongly influenced by the transition from printing with lead, to a photographic process for a short time during the 1970's, and further transformed with the introduction of the computer. The photographic method brought great freedom to the designers, cutting and pasting letters and figures all over the place, in spite of complaints that it was also difficult to keep lines straight. Perceived as another problem was that the tools were developed by engineers and not by typographers[50]. In the last twenty years, desktop publishing using computers has become the norm. The flexibility and control are big, but the designer or artist is often literally out of 'touch' with the final product....
Another example of the relation between art and technology, or more specifically the relation between the tools and materials used, can be found in the work of the English sculptor David Nash[51]. He used to work with wood only with hand tools on principle, but in 1977 started to use the chainsaw and produced a piece called *Block on a Tripod* which is now in the Guggenheim museum in New York. This technique influenced his work drastically, the chain saw became his sculpting tool. Many works followed, including using techniques like charring to change the colour. Time plays an interesting role in David Nash's sculptures. The wood used is sometimes very young, and the cuts made in such a way that the shapes slowly change over time such as in

Crack and Warp Column (2002) and *Rip and Crosscut Column* (1999, see picture below[52]). Another example is Nash's work *Boulder*, a wooden boulder of about 1.5 metre diameter which slowly moved through the woods following a stream starting in 1978 and finally reaching the tidal sea in 2004 where it eventually disappeared. He also 'sculpted' with trees for instance in a work called *Ash Dome*, planting them in a certain pattern and shaping them over time to grow in a certain way starting in 1969 and still going on[53].
All three examples have an important *time* factor in it, as discussed in section 7.1.2. The work with the growing trees and the wooden boulder take decades to develop. The *Cracking* pieces develop over time too, due to the nature of the wood, cracking and warping in various ways.

David Nash' Rip and Crosscut Column

Yet another example is painting with spray cans. Paint is not mixed but comes in a variety of cans, and the surface is not directly touched by the painter.


The work set up and tools of a spray can artist working on a 'tag'

Art and technology are strongly connected, and it is important to be aware of this in order to avoid art being driven or even taken over by technology. The same is true for the discipline of design, traditionally more closely related to technology than art, but also reaching further extremes. Design is a discipline that can be placed somewhere along the line or the continuum from engineering to art, as a discipline design draws knowledge from both art and engineering.

7.1.6 Multi-art

As described in section 7.1.2, we can organise the arts in *static* (2D or 3D, painting, sculpture, architecture) – *time based* (music, film, video, kinetic art) – *dynamic* (the audience can change the delivery of the content but not the content itself) – and *interactive* (involving the perceiver in an active role, co-creating the content, the work is a process or an algorithm). It is relevant to keep a clear overview, when boundaries and disciplines start to blur. After a long period of specialisation (explosion) I believe it is time to integrate (implosion) the previously separate disciplines. There are romanticised historical images of that, such as the Renaissance man like Leonardo da Vinci, or the (now regarded as somewhat naive) proposal of the Gesamtkunstwerk of Wagner, and we can see that art forms like theatre and opera are already compounding various other forms in them. Moholy-Nagy's proposal for a form of theatre in the spirit of the Bauhaus, shows his approach of extending and merging art forms[54]. In fact, Moholy-Nagy thought that artists should not confine themselves to only one medium[55]. Today the term 'multimedia' seems to suggest we're already there, but in its current interpretation (text, sound, pictures and video) in the computer world it is far too limited.

Many of the successful video artists and pioneers in that field, such as Bill Viola, Nam-Jun Paik and Gary Hill, have a background in music. This underlines the transition in visual art to a time-based and performative medium. Another more recent example is the film *Timecode* by Mike Figgis from 2000. What is special about Timecode is not only the fact that the screen is split in four simultaneous streams, but that the four cameras weave different viewpoints of the same story together *in real* *time*. They had to develop special contraptions, and rehearsals to 'perform' the filming with the camera, coordinated by the joint time code, a score, and other cues. Mike Figgis is best known as a film director, but he has a background in music[56].

two screen shots of Timecode of Mike Figgis

All this is not to suggest that the best approach to new media is through music, as every existing medium also has its limitations. It is not an extension in a linear way of any traditional medium[57].
In the next sections some projects are described and reflected on in discussions about this kind of multi-art.

7.1.7 Roles, actions, interfaces, and the camera as instrument

From the experience gained by the projects as described in this Chapter and in Chapter 2, it seems essential to understand changes in traditional terminology used to describe the creative process behind an art work. Instead of thinking of the composer or author as an exclusively specialised person, it is seen as a role that can be taken on by one or more members of a creative team. The same is true for performers. In this sense the same person can be both performer and composer, the roles are not necessarily mutually exclusive but rather extremes on a continuum. Improvising musicians have always been taking positions throughout this whole continuum, in the last decades also increasingly influenced by computer technology. This has unbalanced the reliance on scores to communicate between composer and performer, although these scores are taking on new qualities[58].
In either of these roles the person can perform actions including *preparation,* gathering or synthesising material, the *organisation*, processing and development of the material and interfaces, and the *presentation* which externalises these elements within a performance setting. In our own case of the Video-Organ (as described in the next section) these actions are usually the following. Preparation includes recording sounds and moving images from various real places; organisation includes the editing of these raw images and sounds into useful, manageable clips, and mapping these to gestural parameters that are then made into small instruments and used for further editing; presentation includes the analysis and placing of the video and sound within the specific space of the performance, a phase which can completely change the way

the material comes across. All of these 'actions' happen throughout our process towards the final performance, we may gather material as late as the day before or even during the performance, whilst we may have experimented for a considerable time during the early stages with placing the material in the specific space. These three actions are constantly present, 'fluidifying' what was previously segregated within the creative trajectory.

The sound and image materials must inevitably go through the computer. Corresponding with the actions above, in order to get the material in the computer, then manipulate it and then bring it out in a performance, *interfaces* are required. These interfaces between human and computer often have to be specially developed for a specific artistic purpose or to achieve a particular result. The interface modules or 'instrumentlets' developed for the Video-Organ (described in Section 7.2) are examples of this, where an interface is designed and built to match a certain human gesture or action to the manipulation of a piece of audio-visual material. These instrumentlets are often used not only in the presentation stage of the project but also in the organisation phase as editing tools. The design and development of these instrumentlets both influences and is influenced by the material, therefore becoming part of the artistic process. This is true not only for hardware development, but also for the software development involved which seems a more widely accepted notion[59].

It is helpful to expand the idea of an instrument as illustrated by the following examples. The digital video camera is 'played' in time, somewhat like an instrument in the process of gathering material with a specific effect or image movement in mind. The camera is used as an instrument.

This is for instance demonstrated in *Timecode* of Mike Figgis, where he calls it 'camera dancing'. Another example is the video work *Catch* of visual artist Steve McQueen, first shown at the Documenta X in Kassel in 1997. The artist and few other people pass on the camera, throwing it in a somersault from one to another.

Dan Graham, who is very well known for his installations based on half-mirroring glas (as can be seen below on the roof of the Diacenter for the Arts in New York) has done several pieces in the late sixties using 8mm film cameras and describing the movements of the film camera 'performers'.

To investigate the meaning and relevance of this work Yolande and I recently performed Dan Graham's piece Helix / Spiral in a field and the woods in the Belgian Ardennes[60].

At the same time, the architectural space exhibits specific qualities that become part of the instrument to be played. Aspects such as projection surfaces, dimensions and lay-outs are considered parameters of the instrument, for instance in one Video-Organ performance the ornamented stucco walls were chosen to be used for projection, considerably influencing the moving images projected. Both of these 'instruments', the interface and the space, are described in this Chapter.

In the Meta-Orchestra (described in Section 7.3) not only are the roles of composer, performer and conductor continuously blurred but also the members can (to a pre-defined extent) influence each other's performance set-ups. Some parameters of the processes that are used in the presentation can be influenced by others over the network, thus extending the notion of an instrument.

I felt it was necessary to actually take part in performances as an essential element of my investigations, using the interfaces and audiovisual materials in live concerts as a performer[61]. The following sections describe the projects of the Video-Organ, the Video Walks and the Meta-Orchestra, as personal accounts of the complex situations created by the use of computer technologies. The research approach is more artistic than scientific, with the aim of broadening the *e*-cology debate into creative circumstances. The projects should be considered in the context of the historical and theoretical background in the arts and technology.

7.2 The Video-Organ

The Video-Organ is an instrument for the live performance of audio-visual material. To design an interface we applied a modular approach, in an attempt to split up the complex task of finding physical interfaces and mappings to control sound and video as generated by the computer. Generally, most modules, or *instrumentlets* as we call them, consist of a human interface element mapped to a certain effect. In the design process of the instrumentlets the Physical Interface Design Space (PIDS, as described in Chapter 6) is used. This design space consists of the parameters range, precision and haptic feedback, for each degree-of-freedom. The approach is addressing the notion that traditional approaches to composition are challenged and changed in this situation, where the material is both audio and visual, and where the design and development of an instrument becomes involved in the process of performing and composing.

7.2.1 Development

To develop a new instrument form from the ground up is not an easy task. In the case of traditional instruments the shape and form factors of an instrument have always been dictated by the physical process to be controlled, such as a vibrating string. This has been discussed in Chapter 2. The virtue of electronic instruments is at the same time the problem: their total freedom to be shaped in any form. It is only obvious to take human factors as a starting point, which calls for analysis and study of human motion and intent. Especially when attempting to include the latter, human intent, which in this case can be called 'composition' or at least 'inspiration', the issue gets notoriously difficult and is often (unknowingly) avoided. In this Section a modular design approach is presented, which attempts to deal with the complexity by breaking down the problem into smaller bits.

Interaction has been defined as 'mutually influential'. In order to make a truly interactive instrument, it seems to be necessary to take a step back and develop the necessary -reactive?- groundwork which will provide a base for building up a more balanced, truly interactive level of discourse between human (whether performer, composer, or audience) and the art work.

Since the year 2000 I have collaborated with the musician and visual artist Yolande Harris on the development of the Video-Organ as a flexible instrument for the live performance of image and sound. The aim is to create a gestural performance interface to enable speed, direction and combinations of image and sound to be controlled live. The development of a tool for live video performance takes this time based medium to another level, incorporating a dynamic interpretation of space. Several experiences and performances with the video-organ, as described below, have helped us to assess the reasons, problems and benefits behind the move towards performance and the live possibilities of video and sound placed in space.

Part of the Video-Organ control surface

7.2.2 Background

Using the computer as a tool to play, edit and synthesise image material is becoming increasingly possible with the current state of processor power, memory sizes and encoding / decoding algorithms. Video editing is now catching up with audio editing and computer music. However, the real time or performance setting of video, although increasingly common, lacks a tradition of live performance. An interesting analogy can be made with tape-music: electronic music was for decades a purely non-performance idiom as described in Chapter 2. Technological developments in the eighties helped the re-discovery of live performance for electronic music, and a similar transition seems imminent in video art. VJ's in popular (club) culture are experimenting with this issue, and other initiatives often come from the field of electronic music, for instance programs like Image/ine, Isadora and Jitter[62], rather than from the field of video-art.

Historically, there appears to be a close relationship between technological developments and the activity of bringing together music and visual art. At the end of the 19th century when electricity became widespread 'colour organs' were developed, for instance by the inventor A. W. Rimington as well as the well known example of Scriabin's *Prometheus*[63]. In the 1920s to 1940s several instruments were developed by cinematographers like Thomas Wilfred, Kurt Schwitters and Oskar Fischinger. It was an active period of abstract films of for instance Oskar Fischinger and Hans Richter. Painters were influenced by music too as can be seen in the works of Wassily Kandinsky or Paul Klee. Currently, the rapid pace of development of digital technologies plays a role in the intensified interest in the relationship between the visual and the auditory[64]. Dick Raaijmakers traces a technological and artistic progression over the last century towards a *morphological* view of the previously

distinct disciplines of music (electronic sound), image (photography) and architecture (liquid)[65].
The Video-Organ is using sampled image and sound material (one could call this *video concrète*), rather than synthesising such as in the case of colour organs. These 'colour organs' range from the Ocular Harpsichord built around 1730[66], to the examples given above of the early 20th century, to more current work such as the Dichromacord[67]. Although different from the Video-Organ, these interesting cases investigate the relationship between tonality in sound and the colour spectrum of light, pitch/timbre/envelope versus colour/hue/shape. With the Video-Organ, we are not trying to translate sound into image or vice versa.
With an instrument as described in this chapter, it becomes apparent that the previously distinct acts of composition, performance, involving the modalities of music and video, conflate into one. Moreover, we assert that the actual building of the elements of the instrument become an important part of the compositional process. This notion becomes increasingly common in this field, as described at the beginning of this chapter.

7.2.3 Approach

To handle the complex situation of performing and composing with audio-visual material we employ a structured approach based on the deconstruction into separate issues, and then building a new situation from the ground up. The shape of the instrument itself has to emerge from its parts, which we call *instrumentlets*. These instrumentlets, or little instruments, are parts of the human interface that perform only one or a few sensing tasks (but can be highly sensitive with many different Degrees-of-Freedom, DoF's) and which have a certain shape. We research the mapping between the manipulation of each instrumentlet and sound and/or image. The composition therefore is built up from the stage of instrument building and the collection of sounds and images. Closest to traditional composition is the making of short clips, consisting of image and sound. Each clip has its own movement characteristics that suggest ways of controlling them with gestures and actions, which are the design parameters that shape an instrumentlet. Sounds, images, and combined clips with sound and image form part of the compositional palette, as well as the sensors to capture the performer's gestures, and the ability to place the material in architectural space. The composition builds up from these elements. It is not technology driven, but rather interface design and mapping become part of the compositional process. The Video-Organ as an instrument is different from traditional instruments in that it is being developed, designed, built, and composed for, all at once allowing rapid iterations towards solutions in the process.
Traditional instruments are an important source of inspiration and heuristics, knowing that the historical development of such instruments including their performing practice, institutionalised teaching, and composing, happened at a very different pace. The technology of our time develops at a high pace, and we can build on the accumulated knowledge and skills over many years. It is therefore reasonable to assume that the instruments of our time (including the aspects mentioned) can develop at a much higher pace, reaching a point where instruments are usable within a few years rather than centuries. However, even if all ergonomic considerations have been satisfied in the design of the instrument, we still have to work and perform with them

for many years in order to develop a proficiency to make relevant communications. The simplicity of the approach towards all material of the Video-Organ is a conscious reflection of these ideas and is in constant development.

7.2.4 The Video-Organ Set-Up

The software and hardware, including the human interface, evolved and changed over the course of the performances, based on the Max/MSP programming environment on Apple PowerMacs. Most image material is created using a DV camera (Canon MX1), and video-editing and morphing programs.

Hardware
Generally the performances take place using two Apple PowerMac G4's (and later two G4 PowerBooks) and several projectors connected to the monitor output, the images are Quicktime format clips. It was found that with fast G4's a resolution of 640x480 and full frame rate (25fps) is just about possible to play correctly when using the Sorensen codec. To have the highest possible frame rate is essential because we often slow clips down to access the individual frames - much like a flipbook.
In the earliest performance, a PowerMac G4 with Media100 hardware was used enabling a high image quality. However, it was found that the Media100 proprietary codec (coding/decoding algorithm) was more suited to constantly moving images rather than individual frame access and progressions as needed in our situation, due to interlacing. A workaround was to disable the use of fields, so that frames are individual and not relying on information of the next or previous frame.
By contrast, in another performance (of the piece called *BAT*), we used an iMac DV and a G3 PowerBook and had to work with a considerably lower image quality. Currently we use Apple G4 PowerBooks, fast enough to actually play multiple streams of video material of the required quality, which can then be mixed.

Software
All sounds and images are played and manipulated from the Max/MSP programming environment, according to mappings defined in the program. For sound manipulation we are using MSP, and for images the first the standard 'Movie' object and later the 'Movieplus' object written by David Rokeby, which has extended features for image manipulation and is easier to use with multiple files.
Since it came out in 2002 we have been using Jitter, an extension of Max and a set of objects for real-time manipulation of video material[68].

Interfaces
To enable control over the sound and image material a number of instrumentlets were developed, ranging from simple push sensors, turnpots and sliders to more complex combinations. The interface will be described in more detail in the next sections.
In most cases two Sonology MicroLabs[69] were used to read the signals from the sensors, in a customised version of the general purpose interface box with 32 analog inputs, switch matrix for 16 switches and one ultrasound distance measuring channel. All values are sent to the computer in MIDI note numbers and control change values of maximum 7 bits. Furthermore, general MIDI controllers are used too, such as a 2-

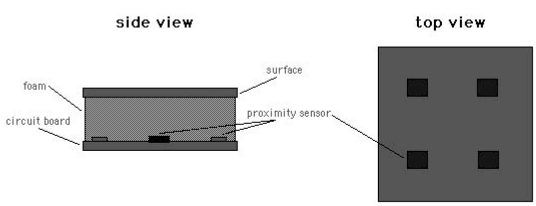
octave keyboard and a touch/fader box, and several (modified) USB input devices such as keyboards and a drawing tablet.
Generally there is no other visual feedback than the images produced during a performance. Only during development we use the visual interface objects in Max, and at some of the later performances with just one player the PowerBook's internal screen gives feedback (the computer is in dual screen mode).

7.2.5 Video-organ instrumentlets

In the table below a concise overview of the Instrumentlets developed and used is given, described in the parameters of the Physical Instrument Design Space.
In the next sections some instrumentlets that illustrate the design approach as outlined in this chapter are described.

name	*DoF's/amount*	*Range*	*Precision [bits]*	*connection*	*material*
Squeezamin	pitch, roll, Z	90°, 26mm	7	MIDI	A
Knobbiesbox	yaw/3	270°	7	MIDI	A
Knobbiesbox++	yaw/5, Y	270°, 26mm	7	MIDI	A
Knobbybox	yaw/1, Y/2	270°, 1mm	7, 1	MIDI	V
Estrella	Z	0	7	MIDI	A/V
Presmorphs	Z	0	7	MIDI	V
Turnamin	pitch, Z	360° ($_{cont}$), 26mm	7	MIDI	A/V
Tabletring	X, Y	130mm, 90mm	9	USB	A
Faderbox	Y/10	60mm	7	MIDI	V
Keyboard	Z/60	8mm	1	USB	V
Keyboard	Z/18	3mm	1	USB	V
Keyboard	Z/24, pitch/2, yaw/8	12mm, 180°, 270°	7	MIDI	V
Accelring	X	± 2G	7	MIDI	V
Sliders	Y	50mm	7	MIDI	V
Pankeys	Z/6	1mm	1	MIDI	A
Stompin' Pedal	pitch, roll, Z	60°, 22mm	7	MIDI	A/V
Gesticulator	X	1000mm	7	MIDI	A/V
Drum 'n Bass Stick	ptich, roll, Z/22	150°, 1mm	5, 1	USB	A

The Squeezamin
To honour the oldest and still most widely known and used electronic controller, the Theremin, we often paraphrase this name with a word that describes the properties of the instrumentlet. The Squeezamin allows for manipulating material in the computer by squeezing sponge-like material with sensors embedded. It consists of two rigid plates of about 5cm x 5cm, a 3cm thick piece of foam in between, and four sensors placed so that movement down is sensed (lateral movement along one axis) as well as inclination of the top plate (rotations around two other axis). These three DoF's are usually mapped to volume and panning of four sound tracks, and with separate switches different sound sets can be selected.



Knobbiesboxes

Using an assembly of several potmeters, the Knobbiesboxes are applied to control several closely related parameters in a more precise way.
There is one bigger knob which controls looping speed in a sound sample between loop points set with two smaller knobs. In a later version two more potmeters evolved which control filter parameters and a slide pot which controls volume. The smallest one, the Knobbybox, contains just one pot, the movement of which is mapped to playback speed of a clip. Several clips can be selected with two buttons on the side of the box.

The Turnamin

The Turnamin (or Turn 'm In) is inspired by the use of turntables by DJ's. Spinning a little wheel influences the playback speed of a sound sample ('scratching') *and* video clip. It is based on a small motor which acts as a dynamo, and generates a movement speed dependent voltage which is fed into the Microlab. A few diodes limit and split the voltage (which reverses polarity depending on the direction of turning) into two separate channels. It was found that the range of the readout was a lot smaller than the real vinyl record player[70] (limiting factors are A/D conversion and the MIDI protocol) so a small slide pot had to 'grow on' to control a multiplication factor. Usually the sound consists of some loud and clear drumbeats, which work well when played very slowly and are more rhythmic when played fast.

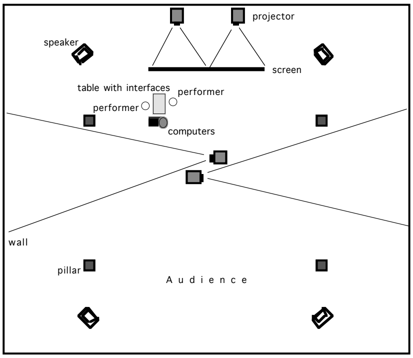
Sliders
For playing very short clips (about 5 seconds or 125 frames[71]) we often use simple slide potentiometers, that travel smoothly and play the clip just like the flick of movement of the performer.

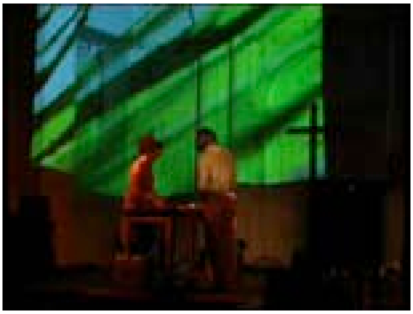
Gesticulator
To allow for gestural control of a long clip with its sound the ultrasound distance measuring channel of the MicroLab is used. To overcome the limited range (128 steps on 1 metre) a simple algorithm is implemented that determines when the *speed* of the movement gets past a set threshold, as an 'escape velocity' that makes the clip jump to another range. This way there are two modes of interaction, small range with high precision and long range, within the clip.

Tabletring
The Tabletring is an example of the use of an existing computer input device with some modifications. It is based on the hardware of the Wacom Graphire drawing tablet, with a sensing surface of 9 x 13 centimetres tracking the movement of a stylus. We use the coil from the stylus which is the actual object that the sensing surface tracks (and communicates its information through in this transponder technology), which is placed in a ring on the finger (as shown in the figure) of the player while the rest of the electronics were placed in a bracelet. Using Richard Dudas 'wacom' object for Max the movement of the finger is read in 9 bit values in Max. These values are used to control the parameters of a resonating filter.

7.2.6 Performances

A number of compositions have been developed with the video-organ, all in varying circumstances reflected in the use of different material, making a total of eleven performances. The first performances, with the Meta-Orchestra, represent the video-organ in its very early development stage and the role is that of a member of a larger group of improvisers of music and dance. The subsequent performances have been 'solos', one amongst a series of solos with Metapolis Media House, and a final one as a member of another Meta-Orchestra in Barcelona.





The lay-out of the space for one of the pieces *Video-Organ performance in Dublin*

There are video documentations of most of these performances. The most important and elaborate performance was of the piece MediaEval at the Metronom festival, and is documented in the yearly publication of Metronom[72].

7.2.7 Conclusion and future plans of the Video-Organ

In this section we have mentioned that developing a new instrument is not an easy task, and introduced a structured and modular approach. By focusing on the *content* of the compositional material rather than on the interface, we felt it was possible to perform with the instrument even from its most rudimentary state. After several successful performances (from audience feedback but certainly as performers / composers) we can conclude that this approach is valid, also feeding back the experiences of performing with the instrumentlets into the design process.
We found that in working with these media the issue of *movement* was central and present in many ways, derived from the original material:

- movement of the camera/microphone or capturing movement within the raw image
- pre-editing (before live editing) whether in morphs or simple dissolve effects, and selection of clips
- mapping of certain movements to gestures in the instrumentlets, for example, a circular movement is mapped to a circular turning gesture
- placing in space by movement between screens and speakers, for example, by panning the sounds in relation to the four points of the Squeezamin or moving the image between two screens

It has become clear by now which elements may be combined into shapes tending towards a more concrete new instrument form, though many pieces of the puzzle are still missing. Experiments with finding forms that reflect anthropomorphic shapes, as shown in the figure below, have been conducted.

Development of new instrumentlets is still going on, also ones that are outside of the performance model. Many demos have been given with the Video-Organ as a development principle at the new Metronom Electronic Arts Studio, also for groups of school children. This was a valuable source of feedback, and we are currently working on a stand-alone instrumentlet (a subset based on the list in Section 7.2.5) for this purpose, with specially made content. Another spin-off project uses a modified existing gestural game controller to play sounds in an installation in Barcelona[73].

The modular approach to instrument design enables an evolutionary development, yet is flexible enough to allow more radical changes and improvements. The Physical Interface Design Space is useful for structuring the developments and suggests parameters of new instrumentlets.

7.3 Video Walks

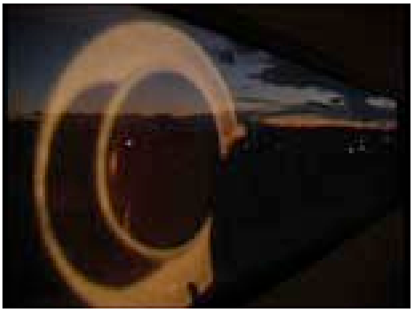
A major aim of our work is to get away from the square, flat video image that reminds us of black boxes such as television or cinema. This is done by changing the shape of the projection, projecting on a variety of surfaces, and working with reflections and translucent materials. The research question is how video projections behave in such an environment. To find out, a number of experiments have been carried out throughout the projects described in this Chapter, and particularly in this section.

So far all performances had taken place inside buildings, making use of the properties of the architectural space. But we realised the outside space could be addressed as well, to extend the *e*-cology outside of buildings. We performed some early experiments first in Cambridge in early 2000 and later in the summer in Dartington during the first Meta-Orchestra workshop (see below) when we took the projector outside at night on a long cable. Depending on the material the results were very fascinating, and it became clear it was possible to do it but that it needed quite some work on the material as well as on the equipment to make it portable. This will be described in section 7.3.2. First in section 7.3.1, there is a description of the intermediate stage, a performance mode that addressed both a building and its context, projecting sound and images from inside the building to the outside.

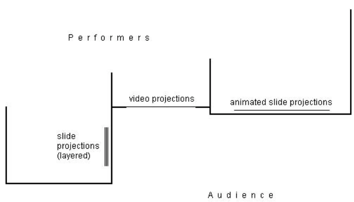
The aim is to create audio-visual-spatial interventions in the natural or urban environments, art as part of the electronic ecology.

7.3.1 Inside Out

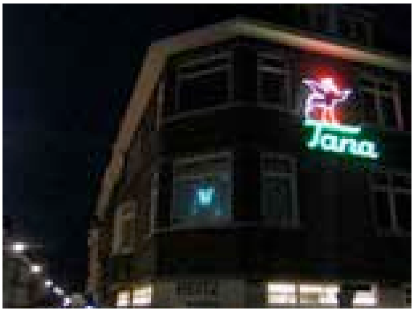
The public performance *Inside Out* took place in July 2002 in the artist residency Nau Côclea in Camallera, near Barcelona[74]. The aim of the performance was to *interactivate* the building, from the inside where the performers were, to the outside, where the audience was. Sound was projected from inside the building, generated in real time using computers and the Rebellious Flute[75]. Images were projected on three surfaces using a computer with a video projector and several slide projectors.
The idea of an *interface* between the performance and the audience was highlighted in the physical space by the placing of the screens and sounds on the boundary between the private part of the house and the public. These surfaces were semi-transparent and constantly changing their appearance. Sounds and images were used including those that were captured in this location during a work period preceding the concert, and dusk was chosen to have maximum impact of environmental sounds and images (birds singing, sun setting, moon rising, trains passing, the Pyrenees in the distance, etc.).
The house is set isolated in some woods on a hill and the effects were visible from a large distance, drawing the audience to the spot. An inhabited house was revealed in its environmental context through the performance, during the transition from day to night.
We had to work with the available equipment: one video-projector and several slide projectors. One slide projector was a professional Kodak carrousel type, but more interesting were the six very simple projectors, from a Russian make, that could only switch between two slides. A new instrumentlet was developed to control an array of these six slide projectors, set in a row projecting the images onto a long thin window. One set of images, '*day*' - *outside*, consisted of sunflowers photographed in a field by daylight nearby, and the other set, '*night*' – *inside*, consisted of pictures of differently coloured light bulbs (and a coffee cup). The instrumentlet consists of an assembly of mercury switches which act as tilt sensors, each designated directly (through a solid state relay) to an individual projector. By moving the instrumentlet in the hand through various inclinations and movements, projection patterns were generated which were effectively 'animating' the long window space. One slide projected through the screen onto the trees behind the audience (the coffee cup). The simplicity and robustness of this electro-mechanical technology was quite a contrast with the computer technology.



The main gateway was filled with a projection screen, moving slightly in the wind like a sail highlighting the fluidity of the inside – outside spaces, with high quality video projections generated by the computer and manipulated by us through the instrumentlets. In some parts of the work live video images taken by the us from inside the house, revealing the activity of the performance were projected outside, effectively folding the space in time. The third projection in the doorway of the studio space used still images taken during the process of creating the piece, projected on three layers of semi-transparent gauze. This allowed a glimpse through the doorway to the performers in action thus superimposing layers of time.
The work took the intimate from inside the house to the architectural and environmental scale outside the house. A short video impression is available, with a publication in a journal in which this piece acted as an illustration of the ideas[76].



In the autumn of 2004 we performed several experiments in our Lab in Maastricht, projecting from the inside on gauze on a window facing the river Maas and the bridge[77]. To do this in an urban and public place is quite a different experience to work out. People are very sensitive to movement, so the motion of the video attracts the attention – people stop and look, as if it is open air cinema. It could be seen from across the river[78]. During the evenings of the recent art event 'Kunsttour' in Maastricht, when many art and design studios and institutions have open house, videos were played mostly of moving landscapes from the train. This was in May 2006.



Inside out projections from the MaasLab

7.3.2 The Video-Walks

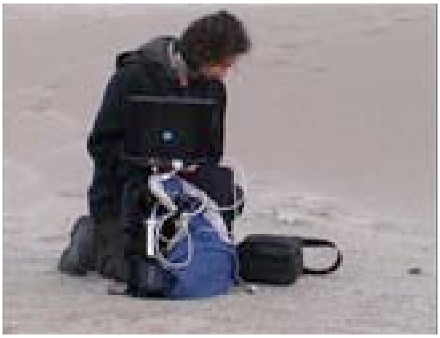
The logical next step after Inside-Out was to take a performance 'out' entirely. During another residency at Nau Coclea and later experiments we developed a portable video projection system, which enabled us to take the video images into a natural or urban environment and make interventions in these sites[79].
The projector instrument set-up consists of a portable battery-powered data projector, displaying images from a computer worn on the back, controlled by sensors (for instance motion, pressure, tilt). These sensors enable the player to choose content, select sources (own image banks, remote video), mix and manipulate images and sound.
We found that projecting of video images is possible on all sorts of surfaces, in our experience for instance on trees, the beach, waves, snow, buildings. Often these surfaces distort the images, which can be a feature in some cases, while it can be electronically balanced for in other cases.
Going for Video-Walks draws inspiration in the work of several land artists, such as Richard Long's walks (see Section 7.1.4 above)[80].

Explorations
The first investigations and trials took place in Catalunya, Spain, in Spring 2003, taking Nau Coclea in Camallera as a starting point. The set-up consisted of a backpack containing a battery (12V DC, 24 Ah), power converter (300 – 600 Watts, for 220V AC), computer (Apple PowerBook G3, operating in 'clamshell mode'[81], running Max/MSP software), sensor interface, and a hand held XVGA projector with the sensors and switches attached to it. The backpack usually weighs over 15 kilos.
For the first two walks we went into the woods surrounding the building. This gave us the opportunity to get used to how the projections worked in the environment, and improve some technical issues. It was found to be problematic to document the experiences, it was very difficult to capture on video the images projected as well as the environment.

The sensitivity of a video camera (even the semi-professional one used) is very different to the human visual perception, which has a much bigger dynamic range. The images captured were often very dark, or only showing the bright projections but not the environment. Therefore the experiments and performances are preferably carried out at dusk. Under these lighting conditions the projections are clearly visible for the human eye as well as for the video camera, which then also captures the surroundings.

Beach

The next exploration took place on a beach, at the Costa Brava in Catalunya. For this occasion I made a setting on the computer that forced the image to be squashed on the x-axis, to compensate for the stretching of the image occurring when projecting on the ground in front of you. We started at the end of the afternoon, it was still quite light but the images were already visible and became clearer and clearer from that moment on. Walking around, I could explore the effect of projecting on the sand, the dunes, the waves etc. It worked very well, and this time the video recording clearly showed what happened providing a useful documentation for further analysis. Yolande filmed, and it already started to become more like a duet – for projector and camera. The walk lasted about forty minutes.



Preparing the projection set up on the beach

Between Two

The first public performance of a Video-Walk took place in Maastricht, in December 2003. It was an inside space, but very large (3000 m^2), a disused gallery space[82]. This time we were both projecting as a duet. As always, we collected video material and used our existing material for the performance. The instrument sets were identical, with the same banks of material, to be played following a choreography / composition which determined where to be in space at what time. We also included sound this time, both set ups included a speaker. The piece was called *Between Two, a duet for mobile video players*[83].

Due to problems with the batteries (too heavy, and not lasting very long to power the borrowed projectors) we decided to do most of the performance on mains power, with long lightweight cables. This enabled us to do more rehearsals and experiments in the days before the concert without being restricted to the maximum 45 minutes of battery power. The long wires worked reasonably well. The audience was invited to explore with us, following us around in the space, or going their own way as the projections reached far across the open spaces of the disused gallery.

Project Relay

"Imagine people entering the public space, carrying portable video projection systems (a Projector), or a camera system (a Relayer), connected with a high speed wireless network to each other, to a base station, and to the Internet, playing, streaming....."

There seem to be roles for two players in the Video Walks, one projecting the image (Projector) and one filming (Relayer). This idea was developed further, using a fast wireless network link between the two players, and *relaying* the camera image to a remote location where the audience is. This location would preferably be nearby, so that the audience can also see the performance directly, the projections disappearing in the distance while staying with the audience at the same time on a local screen. This plan is also referred to as the *Chiringuito scenario*, after the Spanish word for beach hut, as a potentially interesting location to do such a performance.

The idea was tested in a Meta-Orchestra performance in Maastricht, at the Intro | In Situ organisation for new music in March 2004 (described below). On this occasion the Video-Organ was extended with live streams, directly connected to the set up as well as streaming over the wireless network. At the end of the performance, we stepped out of the performance space with the video projector set up as a Projector and a Relayer following with the camera sending the images back into the performance space. An exploration of the garden and small house followed.

The most successful performance of Project Relay was in the Meta-Orchestra performance in Genk, Belgium in May 2005 (described below). In the disused industrial building in the old coal mining area, we had four floors of 5000 m^2 each at our disposal. There were hardly any walls, so the audience could see me as the Video-Projector walk around in the distance, simultaneously relayed back to a screen in the main space by Yolande Harris as the Video-Relayer. The audience could follow as well, and many did (but not everywhere for safety reasons). For this occasion prerecorded material on a DV tape was used, the Projector following a predetermined route and timing so that more or less the right images would appear at the right places. The material was recorded earlier in the project, of the musicians playing, particularly the trombone player as he couldn't be there at the performance. I carried a high quality loudspeaker[84] as well, projecting the sound of the players. I felt empowered, taking the role of the musician, walking the trombone sound around and projecting the person in the space, and due to the dimensions of the space the image blew up to vast projections. We received positive responses to this action.

Earlier that week more experiments were carried out. Some things that worked well weren't used in the performance so I will describe these here. One was walking down

a long dark corridor (through which the miners would go to the lifts), again placing images of the musicians, which gave a very strong effect. Outside experiments were carried out too, projecting on the building's facade and on the old big white metal lift tower, placing a clearly visible figure at the top.
In 2004 the Project Relay proposal was sent in for a competition *Fused Space*. Partially due to the overwhelming amount of submissions the project was not awarded, but it was put in an interesting exhibition. The picture below shows the exhibition in September 2005 at the Stroom gallery in The Hague[85].

Project Relay in the Fused Space exhibition

7.3.3 Discussion on projecting

Video projectors tend to be fixed, often even built into a case to avoid theft. They are quite expensive still, starting at 600 euros at present. They are also quite fragile – the critical part is the lamp of a special mercury type which cost about 500 Euros, nearly as much as the price of the whole projector. But when handled with care they can be used to carry around without problem, there is so much potential for exploration. The first time I was able to pick up the projector while playing video images and walk out of the door it felt like a liberation, and it still does every time.
Video-projectors are designed for offices to give presentations, and for the home to play films or DVD's. These are static situations and very different from using it as an instrument, for instance the inflexibility in starting up and shutting down[86]. This is always the situation of course, using technologies developed for other purposes to do something new with is often problematic. However with projectors there is surprisingly little variety, professional projectors are mainly bigger and better quality, with better and more flexible optics, but similar inoperation and limitations. It seems as if in a very short while video projectors have converged to one type. I have seen an old one, miniature (about the size a book) with two halogen bulbs. Although it doesn't give enough light, it can be useful for some unconventional and experimental situations[87].
To deal with these problems there are examples of 'home made' projectors, for instance with a small LCD screen mounted in an old slide projector, or a bigger LCD fitted on an overhead projector[88].
Some projectors draw too much power for the battery to last a reasonable time, others have noisy fans or other quirks and undocumented features. Due to these

unpredictable differences we found it essential to have our own projector (since the last project) so that we can always rely on the same set up. It is a small and relatively cheap Hitachi, it can be switched between 1500 and 1200 Lumens which also lowers the fan noise.
Recent developments of LED based (instead of mercury lamps) projectors look very promising, the light levels are low however (typically about 15 lumens) and still expensive, but no warm-up or cool down time and often battery powered.
One thing we want to experiment with more is the shape of the image, often the square shape is very inappropriate and it is better to use images with different shapes. It could also be programmed in software, like the squashing of the image for the experiment on the beach, creating different shapes. This is not always satisfactory, because the 'black' around the shape of the image is not really black, but rather dark grey and visible in the projection. The only way to achieve it then is with mechanical means.
Just as in the case of traditional Land Art, the issues to be addressed are what to take home, what to put in the gallery (what to sell?), how to convey the experience, and how to document it. Richard Long and Andy Goldsworthy produced glossy books and photographs for museums (and smaller pieces consisting of rock and wood), and so did Christo and Jeanne-Claude, who make available signed and packed parts of the material used for the installations. Our main objective is to capture the walks for documentation, dissemination and analysis.

7.4 The Meta-Orchestra

Starting as a European Project in 2000, the Meta-Orchestra is a changing collective of about fifteen musicians, visual artists, dancers, engineers, researchers, designers, etc. All members of the Orchestra are individual in their computer/instrument set-up and the material they choose to use, but collaborate to make performances where each member is networked allowing the sharing of material. A number of significant issues are brought up by such a situation. These include control, access to private work, sharing, and how to develop a coherent structure. Like the Video-Organ it is an ongoing project and a large scale 'score-space' is being developed to add a layer of communication to the ensemble[89].

7.4.1 Background

The members of the group come from diverse backgrounds, both culturally as well as disciplinary. The unifying factors are the use of (networked) computer based equipment and performance.
The goal is the establishing of an artwork that is *non-disciplinary*, rather than multi-disciplinary with its inherent nature of juxtaposition rather than fusion. It is often based on, but not tied to, traditional art forms, including the more recent ones such as video art, multimedia art, or net.art.
It was realised that the complexity of this endeavour is high, and therefore it was approached as a research project right from the beginning. The Meta-Orchestra is not a fixed group of performers that can come in a venue and deliver a pre-defined performance. Usually, a period of experimentation in workshop format is required. It is also not an ensemble that a composer could 'write a piece for', as with the established and clearly defined formats like string quartet, symphonic orchestra or theatre company.

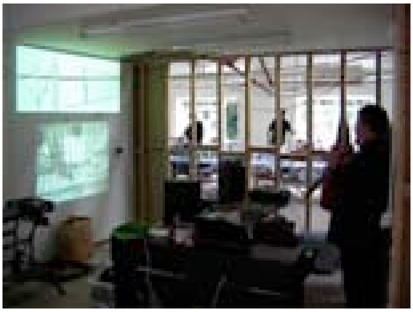
7.4.2 The name

The term 'meta' is used for two reasons, firstly because of the variety of backgrounds of the people involved and secondly because of network used to link the members of the group. Traditionally, communication within a group goes through several parallel layers and modalities, such as sound, gestures, a score or other predefined instructions etc. In addition to this, with all the members of the group using computer based set-ups, the network enables a new layer of communication. To an extent members can influence each other's instruments and set-ups.
The term 'orchestra' was chosen, not to emphasise the musical background or approach of some of its key members but because an orchestra is a complex asymmetric body that constitutes of many different roles all necessary to create the final result[90].
The Meta-Orchestra was set up a total of five times in various places and assemblies. In the sections below they will be briefly described.

7.4.3 Hypermusic and the Sighting of Sound

The first incarnation of the Meta-Orchestra took place as a European project in 2000, founded and directed by Jonathan Impett[91] and myself, with initial meetings in the member states. The other members were Nicola Bernardini from Italy (the Conservatory of Padova), Ludger Brümmer from Germany (ZKM Karlsruhe), Richard Barrett from the Netherlands (the Sonology department at the Conservatory in The Hague), and a group of nine 'apprentices' brought in by the members.
In the year before Jonathan and I were teaching a joint workshop on live electronic music at the Dartington International Summer School[92] in Devon, England. We were approached by Gavin Henderson, the director of the school, to put in a funding proposal in the Culture 2000 scheme of the EU[93]. The theme of this project was *Hypermusic and the Sighting of Sound*. This referred to the previously described notion of the conflation of roles of performer and composer ('hypermusic') and the relationship between image and sound ('sighting of sound') researched in the project.

The funding was awarded[94] and in the spring of 2000 several initial meetings took place to get to know each other and the ideas, and to develop the concept of the Meta-Orchestra. These small workshops took place in Padova and The Hague. The main workshop took place in August, for two weeks at Dartington. For this occasion, we had a space of over 700 m^2 in an old water mill building The Tweed Mill. The whole space was used for setting up the various activities, and work (mostly created during this period) was presented in three concerts. For one of the concerts improvising musician Evan Parker came as a special guest, participating in several pieces and collaborations. This initial phase, including the workshop and concerts, are described in an extensive report that we created for the EU[95].



the first concert at the Tweed Mill (left), and Evan Parker rehearsing a video-score of Yolande Harris (right)

The Meta-Orchestra web site was set up at the same time, as a central hub for communication[96]. Although it potentially can also be used in performances to connect remote performers, the prime location for a Meta-Orchestra is in the real world.
After the workshop another concert with the same group took place in at Felix Meritis in Amsterdam in 2001, co-organised by the contemporary music institute De IJsbreker.

7.4.4 The Metronom Meta-Orchestra

In the context of the Metronom festival *New instrument, new music new paradigms* in January 2002 in Barcelona as described in Chapter 2, all participants of the festival were brought together in a group performance. There was a total of 12 performers including two dancers, media artists, live video, lights, and several musicians. This event is documented on the DVD of the yearly report of Metronom[97].
In a sense this was an a-typical Meta-Orchestra, because although most of the participants were present during the whole week, everyone had been very much occupied with their own performances. As a result, there was only a short rehearsal time on the morning of the final presentation. Some people were tired, and also some were surprisingly conservative about for instance the lay out of the space. My idea was to fill the space, starting from the corners and create clusters of activity. In the end however the whole group formed as it were one line across the space. It started on one side with a dancer on the stairs gradually moving into the space, then musicians, Video-Organ, the other dancer and the media performance at the other end. There was a diva insert of the cello player, appearing from the side to a central place, with a strong presence and playing her instrument and exited again. All in all it was a successful event, it showed that even in an almost entirely improvised situation the Meta-Orchestra's objectives still stand up.

7.4.5 The Meta-Orchestra workshop in Maastricht

In March 2004 a Meta-Orchestra workshop and performance took place in Maastricht, organised by Yolande Harris who had been involved from the beginning of the Orchestra. It was funded by the Jan van Eyck Academy, the City of Maastricht and by the host, Stichting Intro | In Situ. The Jan van Eyk Academy is a studio based artist residency, where young artists, designers and theorist can develop their research for two years[98]. Intro | In Situ is a contemporary music foundation in Maastricht which organises many concerts, often at specific locations (in situ), and just moved to a larger space inside the building where they were already housed (the contemporary art foundation and exhibition space Mares)[99]. The Meta-Orchestra workshop was to inaugurate this new space, bringing together musicians, researchers, video, an architect and two graphic designers. After a week of experimenting, researching and developing (at Intro but also one session in the MaasLab for specialist work) an informal performance was presented on the last evening.

Research question
The specific research question and aim addressed in this workshop were how to incorporate new technologies (specifically wireless networking and video streaming) into the Meta-Orchestra concept, and to develop a (rudimentary) score form that would act as a medium between performers and other roles.

Being Meta
One of the two main reasons to use the word ‘meta’ in the name of the Meta-Orchestra is the networking of everyone’s individual electronic set-up. It was using a wired network (Switched Fast Ethernet), for which we had decided to make a deliberate visual presence underlining its relevance by applying bright green cables. This was in

2000. Since then wireless networking became easily available and widespread, which enabled us to apply WiFi (IEEE 802.11, or Airport as Apple brands it) to make our network wireless. Indeed, all techniques we used in the past, such as file sharing, using OSC for real time data communication between Max and other applications, and audio and video streaming, proved to work in the new situation[100]. There was a wired and a wireless part, which worked seamlessly, and (as before) some ad hoc good old MIDI connections for those who couldn't incorporate OSC for resource reasons.

Having looked for wireless sensor solutions for years (most sensor converters work with MIDI which is very difficult to transmit wirelessly as it has no error detection), we found an application for wireless ethernet to send performance information from a remote and mobile location using a portable computer.

The network was used, as before, in layers of content:

- Performance data: information about the real world (gestures of players or audience activity) captured by sensors and instruments, used to control other players' process parameters. For instance the slide of the trombone (which has a sensor) would control a sound in someone else's set up, or the breath pressure of the recorder would control the intensity levels of one of the video channels.
- Audio: We tried to use OSC for audio streaming but couldn't get it to work reliably – that is, without lag or quality loss. It did work with QuickTime streaming (see below)
- Video: This was entirely new for us. Using QuickTime Broadcaster we could do simple streaming from one computer to another (with a fixed IP address)[101]. We then read the broadcasted video and audio stream into a Jitter object in Max on the recieving computer.

Quite soon we realised that the limited size of the workshop space would be problematic for the performance as there was no room for the audience. It was decided to extend it by applying the surrounding spaces in this interesting building. The vaulted basements areas were discovered, other spaces in the house normally used for exhibitions were explored, and the deep garden and garden house with its own basement[102]. We set up two Airport base stations, to cover almost the entire area, and when moving around the system would allow roaming – the connection was kept even when the mobile station (an Apple PowerBook) would hop from one base station to another[103]. The whole network was connected to Intro's ADSL router so that we were all connected to the Internet[104].

Merging the multiple disciplines

The other main characteristic of the Meta-Orchestra is its multi-disciplinary nature. In the past this was mainly limited to adding video and dance to the musicians in Dartington, and more of these elements were present in the Barcelona event but still the Orchestra is very much biased towards music. This is definitely a strength, as there is a solid backbone of very experienced and broadly interested improvising musicians, but perhaps also a hindrance. I wish that other disciplines were as strongly present in the group. We proposed to include an artist in the group who creates fascinating 3D architectural models inside the computer, but eventually realised this was too big a topic to properly address in such a short time.

Two designers joined the group, because we strongly believe that design is not something that can be slapped on at the end but that it has to be part of the whole process. This means that the designer, just like the architect, the engineer, the painter or whoever, has to be part of the Orchestra[105]. In the first half of the week we saw some interesting developments by the designers, owing to their different approach to the matter. They zoomed in, as it were, on elements of the working environment and the processes, visualised them, explaining by bringing hidden things in the open, at other times alienating by decontextualising elements.

In the second half of the week however the virtue of differing working styles turned less optimal, group communications relied upon between musicians (or friends) caused diversions and the designer elements didn't develop much further. They were however present in the final performance, where their work was presented[106].
The artist/architect who joined the group later in the week brought in fresh and useful ideas about the layout of the space – including basement and garden, using mirrors and projections to deflect or place viewpoints. He also filmed the performance in a way that showed deep involvement and understanding of the issues dealt with by the Orchestra. Documenting a performance like this is absolutely vital as it is outside (and between) people's expectations and experiences. The audience is without the necessary knowledge unlike in the traditional art forms. It is extremely difficult for an audience, everything moves around, we play with light, image, sound, motion, and many elements are improvised and often they cannot be rehearsed (a sun set happens only once a day). A second camera was used by one of the designers who mainly made close-ups revealing otherwise invisible things, and provided a wider coverage that included the different spaces where the performance took place simultaneously[107].

The workshop
During the week the plans grew about how to use the spaces. A suitable 'trail' seemed to emerge, we linked the spaces for this trail by audio and video projections from the main space, and with the wireless network which enabled streaming back audio and video to the main space. The trail was to take people through the spaces. On the last day the space was 'interactivated' by laser beams paired with light sensors that would bring environmental data and audience presence into the system. The laser beams were visible to the audience, and the system could track activity in certain areas which was then linked to content parameters.

The Video-Organ set up was kept quite simple. Like in the Gaudeamus concert about half a year before, we mainly used some existing MIDI control surfaces – a mini keyboard triggering video fragments applying note number and key velocity, the potmeters on this device were used to mix the video streams (including a live Firewire camera), the touch sensitive fader board controlled videos and a few separate sensors for certain effects. Some of the video parameters were linked to the spatial sensors (the lasers), and some to musician's actions sent through the network. The latter proved to be essential – it made the musicians be involved in the visual elements. This cross-over was always thought of as being essential in the Meta-Orchestra, and we try to involve people who have a broader interest and experience than their own discipline. A good example was the stroboscope light effects that the trombone player brought in.

It was interesting to see how the instruments of the musicians had evolved over the years. The Tromboscillator[108] was re-built at STEIM and now even extended with strobe lights, and the bass-recorder now has a screen attached to it so that the player can get visual feedback on the processes controlled (the samples for instance) without having to look at the computer directly which is often awkward on stage (see Chapter 2)[109].

The Concert

Knowing that the space was not altogether very suitable to do a traditional concert, we announced the event as an open workshop. The pressure of having to do a full concert would have been a bad influence on the free experimentation of the workshop week, while on the other hand we know from experience that to have some form of presentation at the end gives the workshop an aim, forces us to focus rather than to be all over the playground we created. There was not enough time to do a run-through of the whole performance, and we didn't want to loose the freshness anyway, but it meant we had to deal with some unexpected situations here and there.

The concept of a special guest 'star' was kept alive this time by inviting Jonathan Impett who only could make it to the afternoon and evening of the performance. Even though he couldn't bring his Meta-Trumpet extended instrument (see Chapter 2), he brought in fresh energy at a moment when it was much needed, and with his musicianship and knowledge of the Orchestra as one of the founders, he made a valuable contribution and it provided continuity.

There were in fact several possible 'trails' that emerged, and in the end we had to live with a kind of double start. First the audience was invited in the main space, but without the musicians present. The musicians were playing acoustical instruments elsewhere in the building and had to be fetched by Yolande, a process which was relayed to the main space by video streaming. She also introduced the project from the starting point of her trail, in the attic overlooking the garden with a view on the little garden house[110]. After her talk she went on her trail, encountering the trombonist in the next door room of the attic, then the recorder player creating wicked multiphonics on his instrument downstairs, and then took them on a trail through the garden. The performers were now also visible directly by the audience. Jonathan was found making deep growling sounds with his trumpet in the basement of the garden shed. All the musicians then paraded from the back of the garden into the main space, where they kept playing in the same fashion as before. We now had all the players present, but we had to switch: from acoustic to extended instruments, from video-streaming computer to Video-Organ, and for the audience to experience the trail of coming in through the basement areas[111].

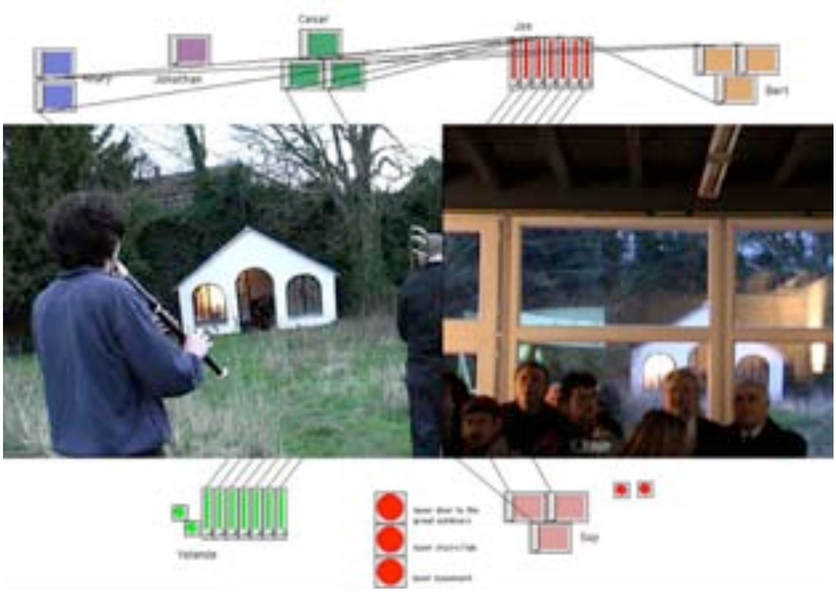
The second trail was for the audience to explore. Through a staircase from the foyer area they had to descent into the basement, where they would find a projection relaying video and sound from the performance space, the reading table with information about the project and the Orchestra members[112], and the work of the designers on display. They could then come up through another staircase and surface into the performance space. Now we played as a group, with all the extended instruments, live video, lights, receiving information about the audience movements through the space from the laser sensors, all networked to each other, and integrated by the score. The use of the cameras (live, streaming, and recording), gave a fascinating effect of layers upon layers of imagery[113].

The performance ended with a Video Walk. I unplugged my PowerBook (but kept it running) and put it in my backpack, switched the video projector to the battery power pack and converter in the backpack, and walked out projecting images from the Maastricht carnival around the garden and facades. The musicians followed, with their acoustic instruments, and Yolande with the video streaming camera. It was dark enough to see the projections and still the surroundings, we went all the way to the garden shed basement and back. It was a very quiet, subtle ending of the evening.

Video projection on the facade of the garden house

The Score

As the Orchestra is maturing over the years the need for a Score System becomes stronger, to get the joint work more coherent and as a medium for all participants to communicate. The traditional notion of a score, as a medium between composer and performer, is too limited as we are challenging these very roles. Ultimately such a score would be audiovisual and therefore dynamic in time, rather than on a piece of paper, spatial rather than on a screen, and interactive rather than fixed[114]. The first two are relatively easy to achieve, the latter more challenging both technically as well as conceptually.



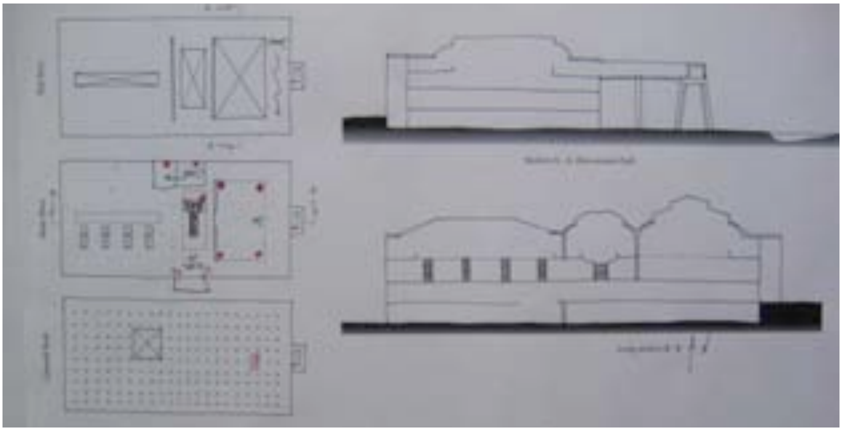
the Meta-Orchestra score system, with live and streamed images

Results

The audio and video streaming, as well as live cameras, were successfully integrated in the performance set-up.
It remains difficult in some cases to unite different working styles, this time between disciplines. It doesn't help of course that there always seems to be a lack of time, or rather that we are too ambitious (eager is a better word) and cram many issues that we want to address in every workshop.
The video documentation shows the whole performance very well, leaving us with something tangible after the performance. There is a journal paper published about the experiences of this workshop, and a small booklet all made by Yolande[115]. In the paper the situation is described and analysed on the levels of social, technical and the aesthetic.

7.4.6 The Facelifters Meta-Orchestra

The last and in many ways the most challenging performance of a Meta-Orchestra took place in Genk, Belgium in April 2005. It was part of a project by the small arts initiative TOR in Genk and Stichting Intro | In Situ in Maastricht and funded by a grant from an 'interlimburg' fund[116]. The project was mainly thought up by TOR and was called *Facelifters*, aiming to be a 'platformatorium for interface research'[117].
It was the smallest group of people ever, the shortest time available (five days) and the biggest space (about 20,000 square meters). The performers were placed far apart, there were projections stretching through the building, an Audiovisual Walk (as described earlier in Section 7.3.2, Project Relay), sounds distributed, sensors in the space, and several installations for the audience to explore. The building was highly interactivated, in addition to its rather overwhelming physical presence as it was. There is no room here to fully describe the whole project, there is a massive amount of photos, video material, sound recordings, drawings, notes, impressions, audience testimonials. The post-production is currently underway, some information can be found on the web site[118].

7.5 Discussion and Conclusion

In this chapter I have described the extension of the idea of the creative trajectory leading to a work of art which includes instrument design and performance context. This is of course not new, however it is clear that under the influence of the emerging new computer technologies the traditional boundaries between the arts seem to be disappearing. A new kind of art has come about which freely uses elements from other disciplines and although the boundaries disappear, a lot of knowledge from traditional disciplines may still inform the electronic arts practices. This movement calls for an approach which must be generalist and at the same time have specialist elements, in order to merge the multiple disciplines involved.

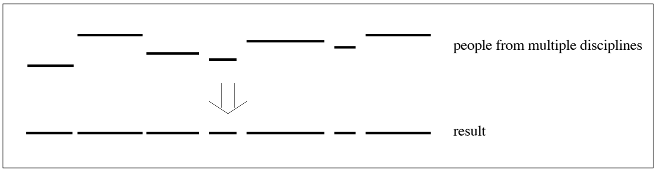
An issue that remains clear is that computer technology is still in its infancy. This is particularly true for all user interfaces that might give access to and control over the rich and increasingly powerful capabilities of the computer. The ever increasing speed and capabilities of the computer, roughly following the prediction of Moore's Law which states that the density of logic circuits doubles every eighteen months, is out of step with the developments of its accessibility for the human. The developments of machine factors that are related to the human interface, such as screen size and resolution, number of degrees of freedom of the input devices, senses addressed such as the tactual, are not even remotely following Moore's Law. As a result artists cannot rely on standard software, hardware and interface technologies available, and have to know how to use the technology and develop their own solutions for instruments and notation systems that enable control over diverse and complex elements.

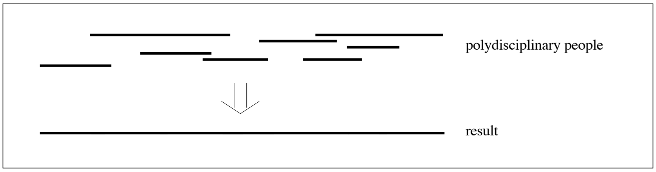
7.5.1 Media

Throughout this chapter I have tried to describe an emerging art form based on computers. Placed in a historical context it can be called non-disciplinary, which I think is the best approach at present. It is bringing together many media new and old, many materials, skills, techniques and approaches.
The arts have developed from *static*, to *time based*, *dynamic* and *interactive*. Electronic art can bring together various modalities and can include behaviour of a system and an interface to facilitate interaction. It can also be performative.
An interesting example of a merging of various kinds of art modalities as described in this chapter, is Dziga Vertov's 1929 silent film *Man with a Movie Camera* combined with live music. The film remains, but the music was not specifically composed and recorded at that time. The screening of the film would be accompanied by live players. This film is still popular among musicians to improvise with[119]. The film itself however, although it is very musical has many visual rhythms, is *time based* but not *dynamic*. Tom Cora, an improvising musician, played his cello to this film in over 35 performances and writes about it that at some point he said: "OK, tonight you listen to me. I've been looking at you for two weeks. Now it's your turn to listen to me."[120] Of course it didn't, and what he describes is the tension between *time-based* and *dynamic, interactive*. Our own performances with the Video-Organ started therefore from a situation where we would have control over all material. With this material we address the architectural space, and later also the natural environment with the Video-Walks.

7.5.2 Roles and groups

An approach to deal with the complexity and the overwhelming amount of possibilities in interactive electronic art is to work with a group, often in a combination of a research period, performance and publication of reflection and documentation. The participants in the Meta-Orchestra projects come from many backgrounds. They are using computer technology, are linked in a network, and find a common ground in performance. The potentially successful member of such a Meta-Orchestra is likely to have a broad set of skills, and knowledge or at least interest outside their own discipline. Successful merging of multiple disciplines can only be achieved through polydisciplinary members. That way, communication between disciplines will become easier. In the diagrams below this is illustrated, in a somewhat simplistic way:





The members not only come from different cultural backgrounds, they are also of different age - this mix has proved to be successful in the projects mentioned in this chapter where the members of the group came from many different countries and ranged in age from early twenties to late forties. The role of director of such an orchestra is more like a conductor in the literal sense of the word, the role is that of a *coach* rather than a composer. On the other hand there is an increasing need for a compositional structure for the performances. For this we are developing an interactive and multimodal score system, as a communication medium between a composed structure and between the performers who can influence the score system in real time.
In this Chapter I have given some ideas about a non-disciplinary art form, based on further demystification of computer technology as prepared in the previous chapters. The conflation of roles of composer/performer and the idiosyncratic relationships with computer based instruments, changes the nature of traditional interfaces such as the instrument and the score. As a result it is not possible for an external composer to "write a piece for" the Video-Organ or the Meta-Orchestra in the traditional sense. It is a collaborative process, interweaving roles and actions, and the result is directly related to the members of the group.

7.5.3 Art and interaction in the *e*-cology

By looking at artistic developments I have illustrated how artists have dealt with the progress in technological possibilities from a historical point of view. The recent technological situation as studied in the field of HCI can be influenced by the insights gained from artistic explorations, such as presented in this chapter. New modalities and modes of interaction have been explored, supporting the developments of the foundations of an *e*-cology, extending the range to the environmental, the ambient, and the architectural. These issues have been illustrated with examples from practice, which are explicitly described as ongoing projects, suggesting directions rather than end goals.
Artist have always explored the possibilities of technologies, in all the successive and concurrent phases as described in Chapter 1. Art is pushing the boundaries and sometimes subverting technology. One of the aims of these processes is finding new

forms of expression. With the current electronic technology the possibilities are bigger than ever, including the possibility of behaviours emerging from the machine world, potentially leading to an electronic ecology of people and systems. However, due to the decreased visibility and increased complexity (as discussed earlier), it has become increasingly difficult for artists to grasp, handle, explore and subvert technology. Intense activity happens in the field of 'net.art' and there are many virtual reality art projects. But *e*-cologies of hybrid spaces, merging real and virtual worlds, are more difficult to establish. The key issue is the interfacing, facilitating a rich interaction. In this Chapter I have shown several projects that explore the artistic possibilities of new technologies, applying knowledge on physical interaction from the field of HCI and at the same time through these explorations contributing to it.

[1] The background section 7.1.7 on Roles, Actions and Interfaces comes from an article for the Journal of Organised Sound [Harris and Bongers, 2002]. The Video Organ has been described in a paper for the first conference on New Interfaces for Musical Expression (NIME) in Dublin [Bongers and Harris, 2002].

[2] These issues have been introduced and described in Chapter 2 on musical instruments.

[3] An extensive description and overview of the 'net art' field can be found in the book *net_condition*, by the ZKM (Zentrum für Kunst und Medientechnologie, Centre for Art and Media technology) in Karlsruhe, Germany, edited by Peter Weibel and Timothy Druckrey [2001].

[4] However it remains relevant to distinguish between using the computer as a *tool* and it actually becoming a *medium*, as Christiane Paul describes in the book *Digital Art* [2003].

[5] Painting is not strictly two-dimensional of course, often when paint is brought up in thick dabs the painting enters the third dimension influencing the texture and the way the light works on the surface.

[6] In Computer Graphics images that create depth by their geometry (and introduced in painting from architecture in the renaissance, with the invention of perspective painting) is often called 2.5D.

[7] A process of chemical degradation, and after centuries it is often necessary to restore a painting which finally also is a process of interpretation and potentially altering.

[8] Pieter Brueghel the Elder, well known for his paintings like *The Tower of Babel* and *The Peasant's Wedding* and many other busy scenes of people on ice or in a village, in the mid 16th century.

[9] When I saw several of his works in the Saatchi Gallery in London in 1998, I noticed that however long you look at it you keep discovering new details, creating a sense of falling... The picture shown here is from a postcard of the painting.

[10] Or is it design?

[11] A description of the Electro Squeak Club, as it is called, can be found at www.steim.org/steim/piepen.html.

[12] For example, in 2005 there is an exhibition in the Victoria and Albert Museum in London, called *Touch Me - design and sensation*. I haven't been there, from the description I gather that it treats the topic rather in a metaphorical way and deals mainly with the passive feel of materials and textures.

[13] The exhibition *Feel, Tactiele Mediakunst* (tactile media art) took place in Hasselt in 2004, organised by the arts institute Z33, www.z33.be. See also the special issue (in Dutch) of the magazine AS – Mediatijdschrift nr. 169, published by the MuHKA museum in Antwerp (www.muhka.be) [van Bogaert, 2004].

[14] The PainStation was developed by Volker Morawe and Tilman Reiff from Cologne, see www.painstation.de. The first version was a great success at the Dutch Electronic Art Festival (DEAF) in 2003. In their new version, the metal whip is replaced by a rubber one making it a bit less 'user- hostile'. The images on the publicity material of the Feel exhibition showed rather badly injured hands of former players who didn't do well in the game (the photos can be seen in the 'hall of pain' section of the PainStation web site), however with the new version as exhibited in Hasselt such injuries will not occur.

[15] As an audience member one gets the feeling that you can 'lean into' the music (everyone is standing). The group's name comes from a technique to create sound from little loops from samples made so short ('grains')that a new sound emerges, called Granular Synthesis. They use this technique for video as well, resulting fast but not radical image changes projected on huge screens. Not everyone appreciates the sensorial assault, but I liked it when attending a concert at the ISEA festival in Manchester in 1998.

[16] Being in charge of time, responsible for the delivery of the content, is a relative issue of course and depending on the *intention*. An audience can always interfere with a performance, by booing or applauding, throw rotten eggs and fruit, or in other ways influence the delivery of

the content. The question is then whether this is intended by the artist or not (although in some cases we can never know for sure).

[17] I wrote about this in *Interaction in Multimedia Art*, in the journal of Knowledge-Based Systems [Bongers, 2000] and would like to expand this in the future.

[18] Although there are films and books where multiple plot changes are presented, in some cases even under audience control.

[19] Audience participation has been explored a lot in the sixties. Frank Popper in his book *Art of the Electronic Age* [1993] makes a distinction between participatory and interactive art. It also ties to the notion of 'media hot, media cool' as Marshall McLuhan describes it in *Understanding Media* [1964]. Hot media are very intensively addressing the senses of the audience (often using multiple modalities) with little room for participation, such as the television. Radio would be a cool medium, in the example McLuhan gives, because the listener has to be more involved and fill in more from their own imagination for the missing modalities.

[20] An American composer and trombone player well known for his work on algorithmic composition, first based in San Diego, CA, now at Columbia University. See www.music.columbia.edu/faculty/lewis.html.

[21] The Koan software is developed by the Sseyo company founded by Tim Cole in 1990. Brian Eno was involved in this project, and he used the software on one of his albums. See www.sseyo.com.

[22] Described in *Design by Numbers* [Maeda, 1999]. In *Maeda on Media* [2000] many results are shown and an overview of his work until then. Originally he intended to develop a computer program to create the book but he writes that he didn't manage that. Maeda has a mixed background in art, design and computer science. See also www.processing.org for a later project of Maeda on algorithmic generation of content.

[23] This comes *in addition to* the fact that the way a work of art (or anything perceived for that matter) is a personal issue, the traditional ecological relationship. This includes an element of time too, the appreciation of for instance a piece of music can be influenced by previous listening to it.

[24] Eventually photography became an art form of its own right, pioneered for instance by Man Ray in the 1920's.

[25] These developments are eloquently described in Ernst Gombrich's book, *The Story of Art* which first appeared in 1950. I have read the sixteenth (!) edition in a 2001 reprint [Gombrich, 1995]. By the way, Ernst Gombrich was a good friend of J. J. Gibson, and he refers often to Gibson's work his book *Art & Illusion* [Gombrich, 2002, first edition in 1960] and a further debate through articles they wrote in the Leonardo journal around 1970. This is described and discussed in Gombrich's essay *The Sky is the Limit: the vault of heaven and pictorial vision* he wrote in 1971 [MacLeod and Pick, 1974, pp. 84-94].

[26] Currently it is shown at the Gemeentemuseum, which has a large collection of Mondriaan's paintings, not as a progression of the *Tree* paintings but his paintings in general. There are also landscapes, windmills and the tower of the town of Domburg all in various levels of abstractionism. See www.gemeentemuseum.nl.

[27] See *The Story of Art* [Gombrich, 1995, p. 570]

[28] This will be further described in the Video-Organ section 7.2.1. *Synaesthesia* is an important issue here too, where the senses may 'cross over'. This is an individual thing, most words have a colour for me, for instance.

[29] Bauhaus was first in located in Weimar and later in Dessau, and during a short afterlife in Berlin

[30] Rather independently of each other, Albers came to Bauhaus in 1923 (although he studied there earlier) and Itten had left in 1922. They both wrote well-known books on colour published in the sixties.

[31] See the book on Bauhaus by Frank Withford [1984].

[32] In fact they closed Bauhaus Dessau down as soon as they gained power in mid 1932, as they considered the place definitely 'entarteted' (degenarated). The architect Mies van der Rohe, then director of the school and not being the prime target of the nazi's, managed to prolong

it by acquiring a building in Berlin and continuing as a privately funded institution but this shortlived attempt came to an end in mid 1933.

[33] Described in detail as an 'epilogue' in the book on Bauhaus by Elaine Hochman [1997].

[34] A 'global village' started to arise, as described by Marshall McLuhan [1964] in such an insightful way, continuously extrapolating the then current situation (helped by his knowledge as an historian), that a lot of his writing is still relevant – my copy is a reprint from 2002. Of course it helps that his descriptions and aphorisms are often vague and subject to many interpretations, like other influential prophesy-esque writings such as parts of the New Testament of the Bible or the quatrains of Nostradamus (for reasons of avoiding persecution......), or *Mille Plateaux* by Deleuze and Guattari.

[35] *Art Since 1960* by Michael Archer is an authoritative book first published in 1997 [Archer, 2002].

[36] Attributed to the American composer Lamonte Young.

[37] The Van Abbe Museum in Eindhoven, the Netherlands, known for its good collection of El Lissitzky (and had a big exhibition of his works in the mid nineties) has made a replica of the Prounenraum.

[38] See for an overview and reflective texts (by Michael Archer) the book *Installation Art* [Oliveira et al, eds., 1994].

[39] In fact, one of the first times I appreciated contemporary art was on a school visit to a museum, I must have been around 12 years old, and the works I remember best were the conceptual works. Perhaps for their humour, they made a good story to remember. I think it was the Boymans – van Beuningen museum in Rotterdam. I saw a black and white video of a group of official looking and smartly dressed young gentlemen, one of them pouring out a bottle of lemonade in the sea (Wim T. Schipper's famous act from 1963), and the other one was a small display fridge with ice in it, with above it mounted on the wall a bit of white fluff, the whole thing was simply called 'Polar Bear'. I still don't know whose work it is.

[40] I remember getting a bit cynical with the amount of conceptual artworks at the Documenta X in Kassel in 1997, curated by Catherine David (who was often criticised for not having any paintings in the show), but in the end I do appreciate that I have been put on the wrong foot several times (and so have others).... This is emphasising the often ludic nature of many conceptual artworks – for instance on top of the Documenta pavilion were put big neon letters reading KINO ('cinema' in German) by Austrian artist Peter Friedl who had more surprises in the city.

[41] Malcolm McCullough addresses the issue in his book *Abstracting Craft, The practised digital hand* [1996], but even he in the end rather reasons away the issue of physical skill and craft in the case of computer based tools, instead of offering new solutions. The emphasis should be on the development of rich physical and multimodal interaction, and therefore interfaces that facilitate that.

[42] See the book *Land and Environmental Art*, edited by Jeffrey Kastner with a 'survey' written by Brian Wallis [Kastner and Wallis, 1998] for an extensive overview and reflection. In his book *The Nature of Landscape, a personal quest* the architect Han Lorzing analyses the interaction that has taken place for centuries between people and their natural environment (making it more artificial) [Lorzing, 2001]. The pictures of Christo are of the project *Over the River*, Colorado, 2000, taken with permission at TEFAF art fair in Maastricht in 2006, at the Annely Juda Fine Art (London).

[43] Bear in mind the broad definition of technology in my approach, as described in Chapter 1.

[44] Johannes Vermeer's bill at the local chemistry ('apotheek') suggests that he bought his raw ingredients here to make his own paint, as well as buying his pigments, as Anthony Bailey describes in his book *A View on Delft, Vermeer then and now* [Bailey, 2001, p. 87]. In this book as well as in others [Broos and Wheelock, 1995, p. 172] it is assumed (although there is no hard evidence) that Vermeer knew Anthonie van Leeuwenhoek and that the latter even posed for the paintings *The Geographer* and *The Astronomer*. The level of accuracy with which the scientific

artefacts are displayed is high [Bailey, 2001, Ch. 9]. This illustrates the relation between art and science in that period.

[45] A favourite point of Ton van Halm, the technical advisor at the Rijksakademie for printing and a notorious technophobe when it came to computer technology, was that no ink jet or laser printer at that time could print gold or silver 'colours', which he could achieve with the old printing techniques. This was when I was technical director at the Rijksakademie, around 1998, and the point still holds.

[46] Often it may seem that I am taking a position against the current state of the art with its emphasis on The Concept, which is shying away from technology (or more often than not, even *reasoning away* the necessity for it!), but as I stated above I am very fond of the conceptual art of the sixties like Fluxus.

[47] There are several sources of material about EAT, most recently the outcome of the research at the Daniel Langlois Foundation in Montreal, Canada, see www.fondation-langlois.org /flash/e/index.php?NumPage=1716.

[48] See www.dorkbot.org.

[49] Which existed in Asia for centuries, and was developed in Europe in 1440 by Gutenberg as mentioned in Chapter 1.

[50] The Dutch graphic designer Piet Schreuders wrote an influential pamphlet *Lay In – Lay Out* in 1977. This was during the 'interbellum' as he calls it in his reflection (notes and postscript added) on the text in the re-publication in 1997 (and reprinted in the Dutch design magazine Morf, May 2005), between photosetting and metal setting. Because letters always look worse when photosetting was used instead of the original metal letters, he argued that it was better to design new letter types for this medium rather than using copies of the old.

[51] I saw his work in a solo exhibition in Tate St Ives, Cornwall in the summer of 2004. A lot of the background comes from an interview with David Nash by the curator Susan Daniel-McElroy [2004]. Nash lives in a rural area in North Wales.

[52] The picture of the sculpture is taken with permission at TEFAF art fair in Maastricht in 2006, at the Annely Juda Fine Art (London).

[53] The interviewer explains how horrified she is by this 'pure torture for the tree' [Daniel-McElroy, 2004]. I think is this odd, and as Nash explains in his answer man has influenced the natural and living environment for centuries in similar or far more brutal ways. It is an interesting debate in the realm of Land Art however.

[54] *Theater, Circus, Variety, Theater of the Bauhaus* was written in 1924 and translated in English in 1929. It can be found in the Multimedia reader of Randal Packer and Ken Jordan [2001].

[55] He was very much fascinated by photography (the results of many of his chemical experiments still remain), then the 'new medium', and considered artists who knew nothing about it as 'visual illiterates' [Whitford, 1984, p. 125].

[56] Mike Figgis is well known for his movie *Leaving Las Vegas*. In a documentary accompanying the *Timecode* movie on the DVD, Figgis goes as far as introducing himself as "a trumpet player" and that "his day time job is being a film director". His real passion is making music, and originally had thought of *Timecode* as a performance piece. Indeed he and his crew used several techniques borrowed from music to accomplish the project, such as written instructions on music paper acting as a score during the 'performance' of shooting the film. The documentary also shows the instrumentarium and other tricks they used to make the film. They used handheld digital cameras, somewhat like the ones which already caused the whole development of Dogma filming. The film brought out was the 15th take, the first take is also included on the DVD and it shows how much is improvised in the process – like in music.

[57] As Lev Manovich points out in his book The Language of New Media [2001], although he very much takes cinema as his starting point. Michael Rush often reasons from film and theatre in *New Media in late 20th century art* [Rush, 1999].

[58] Yolande Harris has been developing graphical scores for this purpose for many years. First drawn or painted, later using video and audio allowing real time manipulation.

[59] See for instance *The Art of Programming* [Evers et al, 2002], the proceedings book and DVD of the Sonic Acts conference on "digital art, music and education" and festvial in Paradiso, Amsterdam in 2001.

[60] This piece is from 1973, originally for two 8mm film cameras. See for instance a book on Dan Graham [Brouwer, 2001, p. 143]. We used DV camera's, which act differently as an instrument. One performer makes a 'Spiral' movement around the second performer, pointing towards the centre of the circle. The second performer is making a 'Helix' movement with the camera around her own body pointing outwards.

[61] In my experience, the participation in the compositional process and performing in live concerts is an essential element of the research, without claiming to be an artist myself.

[62] Image/ine was developed by Tom Demeyer at STEIM (www.steim.org) in the mid nineties and is not really supported anymore but lives on in the program KeyWorx of the Waag Society for Old and New Media (www.waag.org) in Amsterdam. Isodora is a program developed by Mark Coniglio of Troika Ranch in New York City, see www.troikaranch.org/isadora.html. Jitter is the video processing extension of Max/MSP graphical object based programming language for multiple media, see www.cycling74.com.

[63] A good concise overview of these developments can be found in an article *Instruments to Perform Color-Music: Two centuries of Technological Experimentation* in the Leonardo Journal [Peacock, 1988].

[64] The book *Sons et Lumieres* of the exhibition in the Centre Pompidou in Paris in the autumn of 2004 gives a very good overview (unfortunately I have not been to the exhibition).

[65] The morphological view is descirbed in his book *Cahier 'M', A Brief Morphology of Electric Sound*. The typical style of Dick unfortunately has not been preserved very well in the translation of the book, which is originally written in Dutch as *Kleine Morfologie van de Elektrische Klank*,. [Raaijmakers, 2000]

[66] Often mentioned as the first colour organ, a 'harpsichord for the eyes', developed by the Jesuit and mathematician Louis-Bertrand Castel, this is even before electric light! A very good source of information is the web site www.rythmiclight.com by Fred Collopy who is very involved in these developments, and has an extensive bibliography (including downloadable PDF's of articles and books that are out of print).

[67] This instrument is also described in the Leonardo Journal [Conrad, 1999]

[68] More information about Max, MSP and Jitter can be found at www.cycling74.com.

[69] Developed by Lex van der Broek and Jo Scherpenisse at the Institute for Sonology at the Royal Conservatory of Music in The Hague, see www.koncon.nl/microlab.

[70] For instance a Technics SL1200MkII turntable.

[71] As MIDI is 7 bits, there are maximum 128 values from one potmeter.

[72] Book and two DVD's documenting the season 2001-2002 [Metronom, 2005], see also the web site www.yolandeharris.com

[73] Using a MacAlly USB game controller with a motion sensor, the Airstick, for triggering and manipulating sound samples (and potentially video too). The sounds are mainly bass guitar and drum loops, hence the name Drum 'n Bass Stick. It was made for the *Walk In Orchestra* at the Zeppelin Festival at the CCCB in Barcelona, 2002. See www.fiftyfifty.org /walkin/indexEng.html.

[74] We were invited by Nau Coclea's director Clara Gari, to come and work there for a week and present a piece in the last evening. See www.naucoclea.com.

[75] The flute of Yolande extended with various sensors.

[76] Journal of Organised Sound, special issue on Interactivy on the CDROM [Harris and Bongers, 2002].

[77] The mediaeval 'Servaasbrug', connecting the two parts of the town.

[78] 'Tana' means Technology, Art, Nature and Architecture, although rumour has it that 'Tana' has something to do with shoes.

[79] Other artists and researchers have experimented with this as well, particularly in urban environments. Quite well known is the work of Rafael Lozano-Hemmer since 2003, here a projector of 110,000 Lumens was used. see www.fundacion.telefonica.com/at/rlh/proyecto.html.

[80] This is direct development from Yolande's previous work such as a walk for four days and three nights through Dartmoor (Devon, England) as *A Performance for an Absent Public*.

[81] Apple PowerBooks go to sleep automatically if you close the lid (actually by a small reed switch and a magnet), but can be set up in such a way that the internal screen is not activated and that all video processing power is used for the external display – in this case the projector.

[82] It was the old building of the Bonnefantenmuseum for modern and contemporary art, which moved to a new place.

[83] The building was known as *Entre Deux*, which handed the title for the piece for us. There was a dismal shopping centre included on the premises, the whole thing has been torn down soon after. During several months in 2003 the building was used for the *Entre Deux Series*, exhibitions and performances organised by the Jan van Eyck Academy.

[84] A Genlec active studio monitor speaker.

[85] See www.stroom.nl.

[86] The fan has to run in order to cool down the lamp, but this time is always fixed and it cannot be interrupted, not even to turn the projection back on again.

[87] At the end of the nineties a small Sony projector with a round shape was very popular for art installations.

[88] The LCD has to be see through, often the circuitry is in the way and the flat cables too short. There are descriptions of these projects on the Internet.

[89] *Score Space* is the ongoing research project of Yolande Harris, see www.janvaneyck.nl/~yolande/score_spaces.htm.

[90] We could of course have chosen any other complex situation like a film set, theatre play, or urban planning.

[91] See the section on Hybrid Instruments in Chapter 2.

[92] www.dartingtonsummerschool.org.uk/

[93] Or CONNECT 1999 as it was then called.

[94] A total sum of about 160,000 €, but a substantial part of this was used by the summer school to fund another project.

[95] The graphic design and editing of the report was done by Yolande and myself, and consists of 93 pages including individual reports by the members, an audio CD of the concerts and a 30 minute long documentary of the process and the performances [Bongers et al., 2001]. A paper was published about the project at the ICMC [Impett and Bongers, 2001].

[96] The Web site is now www.meta-orchestra.org.

[97] The report of the season 2001-2002 [Metronom, 2005].

[98] The Academy has a system of funding internal projects with a strict assessment procedure through a 'editorial board'. See www.janvaneyck.nl

[99] See www.stichtingintro.nl

[100] Including being able to receive e-mails during the show.

[101] Multicast is possible too with QuickTime Broadcaster, we didn't explore this but want to do that in the future particularly to extend the performance over the internet.

[102] The basement had been used for storage of the barrels when it still was a beer brewery

[103] We also know that antennas are available that extend the range of the base station coverage, this is another way of extending the range.

[104] So that we could check our e-mail during the performance.

[105] This is the reason why Yolande and I always had designed all the flyers, web sites, CD covers and reports of the project ourselves.

[106] They had also set up a basic web site for this occasion, and produced a logo, but were not involved in the post-production process.

[107] A short video (13:34) has been edited by Yolande showing the whole performance.

[108] Hilary Jeffery's trombone extended with sensors, something we have been working since the Dartington workshop in 1999.

[109] The audience might think that the performer is reading his e-mail....

[110] We hadn't thought of a way of communicating from the main space back to her, so she had to guess when to start. When this was taking a bit long, which was awkward, I gave a

pre-introduction to the people in the main space where I was, describing some of the ideas behind it all.

111 There was a pause here and the audience had to leave the room. It felt bad to kill the magic moment that was built up after the first trail...... The audience clearly had to get used to the concept of having to move around and explore, something we always end up doing in a Meta-Orchestra performance.

112 The reading table has become quite a tradition in these projects, and is inherent to the nature as a research workshop of the Meta-Orchestra.

113 We had also found out that a recording DV camera (the semi-professional Canon XL1) could be connected to the Video-Organ set-up through FireWire to act as a live camera input into Jitter – while it keeps recording. We didn't use it during the performance in the end, but it is an interesting possibility.

114 See the description of the *Score Space* www.janvaneyck.nl/~yolande /score_spaces.htm

115 The article is *The Meta-Orchestra: research by practice in group multi-disciplinary electronic arts* in the Journal of Organised Sound [Harris, 2004] which also includes a CDROM with a compressed version of the video documentary on it. The book is a small edition and hand-made, containing biographies and reports with reflections of the participants and various drawings and other material, as well as a DVD.

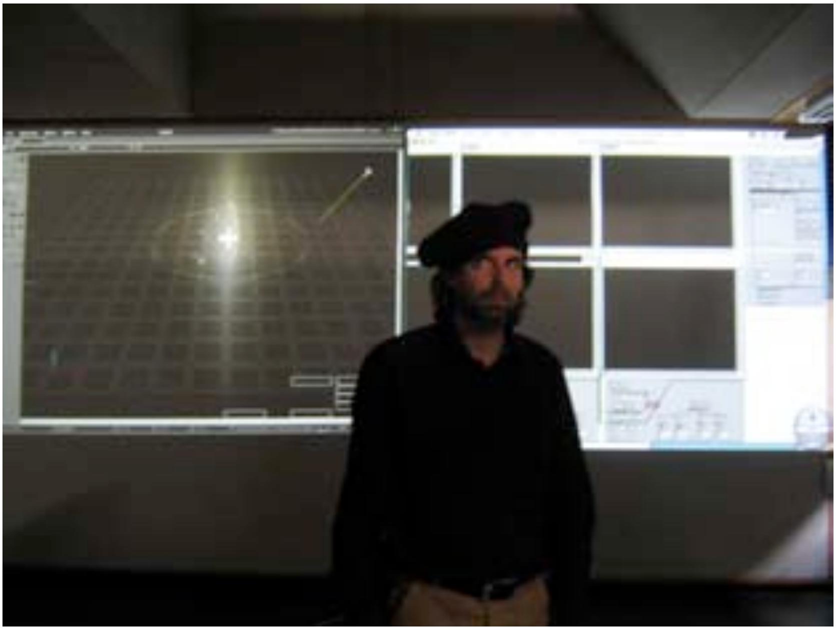
116 Established to foster collaborations between the Flemish province of Limburg and the adjacent Dutch province with the same name.

117 It is also a variation on the quote in my *e*-cology booklet, "a fresh start is needed rather than another *interface-lift*".

118 See www.meta-orchestra.org. The photograph at the bottom right hand corner is made by Gilles van Wanrooij. The drawings are made by Sebastian Harris.

119 I have seen some screenings of *Man with a Movie Camera* with live music, and have a DVD of the film with accompanying music of the Cinematic Orchestra from 2002. The film basically is about the relationship between people and their technological environment and as such very inspiring.

120 I have not seen this performance, but have seen Tom Cora play on other occasions (with the Dutch punk-band(!), *The Ex*). He died young at 44 in 1998. The quote is from the Metrònom Catalogue of the season he played there, before my time unfortunately [Metrònom, 1997, p. 179]. In his text he also mentions that after this he started to work with a French group of live film makers Metamkine.



8.
Multimodal Interaction Styles
Interactivated Environments

This chapter investigates solutions for interaction problems in more mainstream applications than the arts. The presented interaction styles combine several modalities, both input and output, in order to enlarge the 'interaction bandwidth'. The projects described can be seen as direct implementations of the frameworks and ideas put forward in the chapter on Multimodal HCI (Chapter 4 in Part III), and as such served as a testing ground of the ideas. The projects described are not scientific experiments, but rather proof-of-concept examples in order to illustrate and further develop the MIS framework.

After a short introduction in section 8.1, two projects are described, of different contexts. The first project concerns the development of multimodal interaction styles for the **Protospace** multiplayer architectural design environment at the Technical University of Delft with Kas Oosterhuis and is described in section 8.2. From this research the notion of *interaction palettes* arose, and the application of a dedicated 'interaction computer' dealing with most of the human control and feedback. The Protospace combines gestural interaction, speech input, control through sensors, and auditory articulatory feedback. Several new 'interaction appliances' have been developed. The second project, described in section 8.3, is the **LaserTouch Pointer**, at the HCI research group of Gerrit van der Veer at the Vrije Universiteit in Amsterdam, is an investigation of spatial interaction through a laser pointer, combined with fine control and haptic feedback. A short reflection on the interaction styles and implications is in section 8.4.

8.1 Introduction

The question addressed in this chapter is how to 'interactivate' an environment, and what interaction styles could be applied in order to support the design process and to fulfil tasks in such an environment. The goal is to create a rich 'multimodal interaction architecture', with an emphasis on the real world where the interaction takes place after all, including the physical aspects. In the previous chapter is described how this is developed for in the context of the electronic arts, but there are many other environments with high demands on the interaction.
In the next sections two example projects are described that deal with the development of multimodal interaction architectures. The first one is on an architectural scale, the second one is on both the intimate and the bodysphere scale[1]. These projects are about the coupling (or mapping) of a palette of interactions with the functionalities.

8.2 Multimodal Interaction in Protospace

At the architecture department of the Technical University of Delft a new interactive space has been set up in the last years called Protospace, by the Hyperbody research group of Kas Oosterhuis[2] in collaboration with the MaasLab. Rather than the Virtual Reality (VR) approach with its emphasis on the world *inside* the computer and projecting this outwards in order to involve human interaction[3], the emphasis in this research is on merging the virtual with the real, leading to a mixed or augmented reality, including a dynamic architecture[4].
The aim of this space is that through multiple, full field of view and eventually 3D projections (using polarised light), teams of designers can work collaboratively on the creation of structures and environments. The parametric nature of these kinds of architectural designs is particularly well suited for interactivating, that is, actively being interacted with by the users through sensor systems. For Protospace a system has been developed consisting of a combination of on-body and in-space sensing techniques, to control the virtual worlds and elements.
The group often uses games as a metaphor for the collaborative design activity, so below we often use terms such as player instead of user.

8.2.1 Design Approach and Process

The design and development of such a complex and new interactive system preferably takes place in an iterative way, in a combination of *bottom up* (technology driven, engineering) and *top down* (visionary, intuitive) approaches. A modular approach has been applied, similarly to the design process of the Video-Organ instrument described in Chapter 7. We made an overview of system functions, controls, and feedback. These are organised in *palettes*. The elements of the palettes are linked through experimentally established *mappings*. In this chapter the focus is on the palette of interfaces or *interaction appliances*. Every interaction appliance is linked to a certain (set of) functions in the design environment, and combined with the appropriate feedback. This is in fact similar to a traditional workshop, such as a mechanical workshop, a dentist, or an instruments builder's atelier. What you'll see here is a set of tools, arranged in a spatial manner supporting overview and availability. A professional developer or designer in a traditional workshop has a tool at hand for any (set of) tasks or operations to be carried out, rather than having one general purpose tool (Swiss army knife, Leatherman). Bill Buxton has made this comparison, between the "strong specific" and the "weak general"[5]. With the computer the standard paradigm is a one-interface-fits-all, general purpose interaction style. In experimental interactive environments such as Protospace it is possible to apply many different interaction styles.

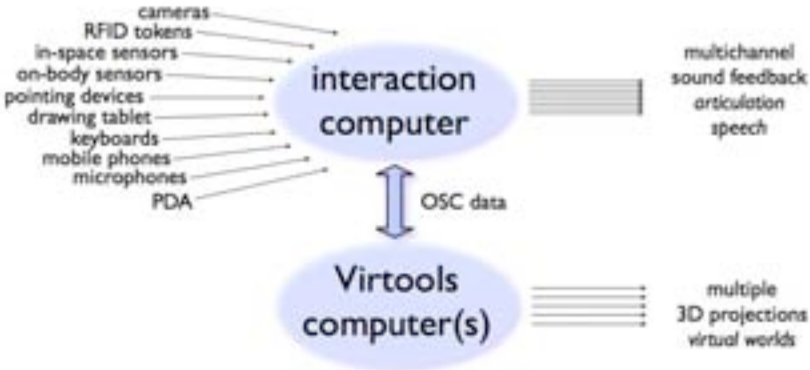
Previously the interaction styles developed in Protospace were based on wireless game controllers and various sensors. The game controllers are quite versatile, they contain a number of buttons for mode switching or other actions, and two small analogue joysticks and a slider used for navigation and manipulation. The mapping between these input elements and system parameters is not the most intuitive, but it works and multiple devices can be used. Various sensors are placed in the space, such as switch mats in the playing field and photocells and motion detectors which enable a spatial control of switching on / off parameters, combined with proximity sensors that would allow continuous changes in the space. This choice of input modes was felt to be too limited[6].

In the recent phase of the project, a team of people have been working on researching gesture tracking and speech recognition. First a thorough investigation and overview was made of existing speech recognition and video tracking. For the latter the particular focus was on systems developed for the performance arts such as music and dance[7]. Most systems were tested out and worked with in both labs, including comparing latency issues of various hardware and software elements (different cameras, connections, drivers and applications).

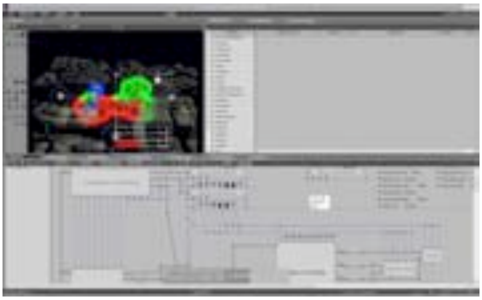
We have developed and implemented a system which is highly flexible and scalable. Our aim was not to solve one particular problem (which would be, after all, inherently unknown) but to create a platform, a set of tools to work with, an expandable palette of interaction possibilities. The investigations and choices have been driven by the practice of a collaborative architectural design environment. Most of the developers in this project are themselves part of the group that is going to work in this environment.

8.2.2 System Overview

The system developed consists of a separate 'interaction computer' for real-time data, audio and video manipulation, communicating with one or more 'parametric architectural model computer(s)'. The interaction computer is an Apple PowerMac G5 (2 GHz, dual processor), running the Max/MSP/Jitter graphical programming environment. Max is particularly developed for handling real time data, MSP is the sound processing extension, while Jitter has many objects for real-time video processing. The interaction computer can receive all performance data from all the sensors, the various input devices, cameras and microphones, so that it can *interpret* and relate all data to individual player's actions. It then passes on *semantic* data to the system that generates and manipulates the real-time parametric architectural models on PC computers running a real-time rendering environment called Virtools[8], which projects the parametric architectural models (potentially in 3D) in Protospace. The interaction computer generates the direct feedback on the player's actions, to facilitate articulation and guiding.



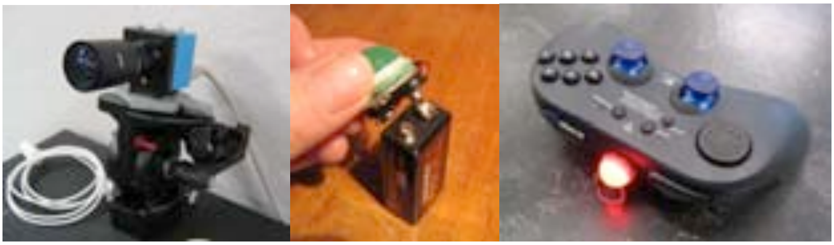
The reason for introducing a separate computer to handle the interaction with the people is that this way it is ensured that all timing requirements are met. We know that in order for the user experience to be convincing, and to make the interaction optimal, at least the articulatory feedback has to be presented within the time accuracy of the various human perceptual systems. For instance, for a trained musician the time discrimination lays in the order of tens of milliseconds in the most extreme cases[9]. Haptic system operates optimally under similar conditions. The Max environment has a precision of 1ms., and will not be interrupted by any other task carried out by the operating system (Mac OSX). Max also runs under Windows XP, but more objects are available for the Mac version, there was more experience with running this environment under the MacOS, and it is a far more stable operating system.
The communication between the interaction computer and Virtools computers is done using OSC, Open Sound Control. OSC works over Ethernet (also wireless) and is suitable for the transmission of high bandwidth real time data. The experience from the Meta-Orchestra is applied here. We are using an OSC 'building block' for Virtools[10].
Previously the communication took place via MIDI, as there is a MIDI input 'building block' for Virtools. However the bandwidth is limited, there are some persistent problems with the Virtools MIDI building block, and there is no MIDI out version so the (at some point essential) communicating back to the interaction computer cannot take place.
The screen shot below on the left shows a part of the Virtools graphical editing environment, with its building blocks at the bottom and the final image produced at the top left. The picture on the right shows an early stage of the Max/MSP/Jitter 'patch', with the objects and images grabbed from the camera input.
The goal of the Virtools program is to render real-time images, and is very much time based which is expressed in frame rate. The Max environment was chosen for the interaction computer because it is very suitable for manipulating real-time data.



8.2.3 Gesture Tracking

The video tracking is done with industrial zero-latency Firewire (IEEE 1384) cameras[11], the image of which is interpreted in software. Before developing the semantic layer(s) in the gestural interaction, we first concentrated on making an optimal continuous mode of interaction for direct manipulation and navigation. To make the gesture tracking more precise and responsive, optical 'beacons' are used. These are small tracking objects with lights, gentle glowing coloured jumbo-LEDs and infrared LEDs. They are combined with a small battery, or mounted on the game devices and powered from the internal battery. Using these beacons, the system can be used under realistic conditions, ie. not disturbed by other movements, against any background and under various lighting conditions. Experiments have been carried out with coloured or reflective material but this didn't work so well. Another camera is equipped with infrared filter material which blocks all visible light, enabling more accurate tracking of infrared beacons undisturbed by other light sources or conditions.

Tracking speed and latency are important issues at this level of interaction. The common technique of analysing the difference between two successive frames is done in Jitter, by the *FindBounds* object. At a frame rate of 25 fps (at a resolution of 320x240 of each camera) each frame is already 40 ms long, and with a minimal amount of processing time a response time of below 100 ms should be obtainable, which is an acceptable value for continuous control and feedback. The interaction computer generates real-time auditory articulatory feedback generated by MSP, and passes the data on in real-time to the Virtools environment which visually represents the changes in the architectural model's parameters as well as generating visual articulatory feedback on the screen The auditory feedback uses the parameters of pitch, volume, timbre and panning related to the movements and identity of the individual players. The role of the audio feedback is mainly to support the articulation of the gestures. The overall sound level was kept low, giving peripheral rather than overly explicit feedback.

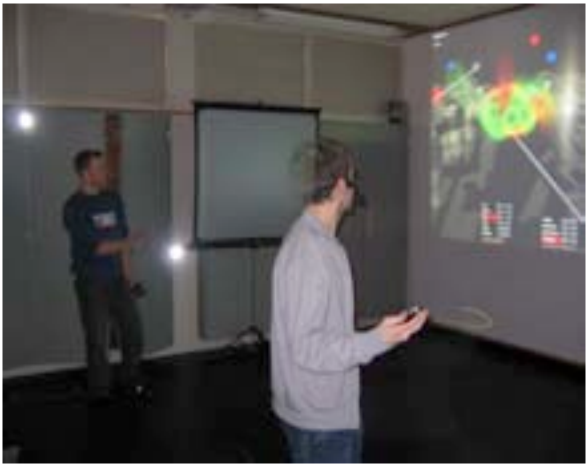


8.2.4 Speech Recognition

For the speech recognition a Max object (called *Listen*) is used. This object communicates with the Mac OSX built in recognition system. The OSX recognition system is particularly well suited for this application as it doesn't require training so that it can be used by different players. Apple's speech recognition is speaker independent and adaptive[12]. At the current stage in the Protospace project it is only used for recognising single words as commands, the lexical level of interaction. The words to be recognised are defined in Max. The head mounted wireless microphones we use makes the speech recognition more reliable, and less obtrusive for the user[13]. Feedback is generated by the Mac OS recognition system, but could be generated from within Max as well. There are Max objects that can analyse (voice) sounds and determine through Fourier analysis the frequency distribution and amplitudes. For instance, the ~fiddle object was used to extract basic pitch and map that to a parameter of the system[14]. This way, the voice is used in continuous control interaction mode. It was found however that architects seem to be reluctant to use their voice in this mode[15]. The command mode works very well though, with different speakers.

8.2.5 Demo

A demo has been developed in Virtools showing the interactions and behaviours of the models. In the demo a team of people with different roles such as designer/architects, a project leader, an economist, a client etc. all have their own ways of interacting with the system while working on a collaborative architectural design[16].
The approach was to think and develop in *palettes*. There is a palette of interaction modalities, a palette of feedback modes, and a palette of parameters in the modelling environment. Between these palettes *mapping* is worked out, finding the optimal interaction style for each task. In a next phase, we not only want to add more to the palette but particularly further develop the application of the tools in a practical and realistic environment. This way a large part of the Interaction Space is covered.
With this stage of the project a basic system has been implemented and convincingly demonstrated. From this further developments are possible, particularly to further involve actual design teams to carry out work in this environment.



8.2.6 Current work

In the current phase of the project more interaction styles are developed, driven by the insights gathered from a concurrent project in which a Case Study is being developed. In the case study a group of designers and developers work on an actual urban planning project called Technopolis, a developing area of high tech companies and research institutes on the campus of the Delft University of Technology. From discussions within the group of designers and developers we have already established a list of generic actions and operations[17]:

- pointing
- navigating
- manipulating
- selecting
- storing and retreiving
- moving

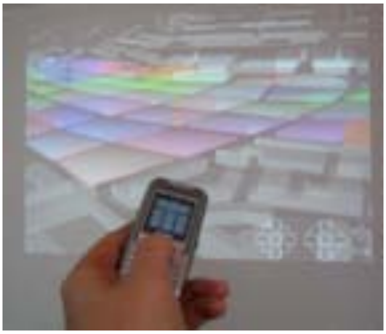
A number of new Interaction Appliances have been developed to enable these operations, which will be applied in the Case Study.

The audio feedback system is now extended to six channels (mid and high frequencies) and one channel of low frequency sound (subwoofer). This enables us to place articulatory feedback sounds in 3D space. The speakers are professional speakers (JBL) and very suited for this type of sound. The speakers will also be used for synthesized speech feedback (using the 'Mbrola' Max object[18]) for the symbolic interaction mode.

New and more flexible sensor converters are used, including the extension through wireless sensor networks, extending the approach of the 'interaction computer' with a distributed computing layer[19].

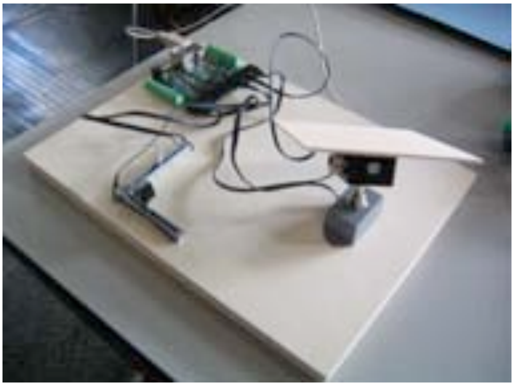
Linking real world objects to the system through RFID tags enables us to link to the underlying data structures with a token-based interaction. When a player wants to interact with an appliance on a particular screen, the appliance (which contains an

RFID tag) is held near the reader below the screen (on the picture below on the left). The system then links the interaction appliance to the chosen screen[20].
Environmental parameters such as light, humidity, and temperature are sensed and represented in the virtual worlds in an implicit way. A number of standard input devices are added to the palette, such as keyboards for text entry, and a drawing tablet for the continuous mode of interaction (and also for the symbolic mode through character recognition). Bluetooth devices such as GSM phones can be used as control devices as well now, which enables the incidental visitor to participate in the design process with limited functionality (shown on the picture below on the right). A handheld miniature computer (PDA) is used for interaction, to send commands from the touch screen to the system and receive visual feedback on the internal screen, extending the interaction space. This is an example of the distributed nature of the interaction appliances, as part of the *e*-cology. Another examples of such private presentation of information (as opposed to public, on the main screens and / or speakers) that we have incorporated in Protospace are the use of a Head Mounted Display, giving a small window in the field of view of the player, and wearable wireless headsets for audio.



Several new interaction appliances have been developed for specific functions as requested by the design team. In several environments of the urban planning Case Study the participants need to quickly adjust a number of parameters. For this I developed the 'menu rollator', an assembly of two wheels (rotary encoders), to be manipulated with the thumb of the right hand. One wheel, with the up/down movement (rotary DoF around the y-axis) is used to select the parameters which are arranged in a vertical list on the screen. The other wheel, with a left/right movement (rotary DoF around the Z-axis), sets the value. The wheel movements and the effects are enhanced with auditory feedback, little clicks that support the motion.

Another purpose built interaction appliance has several sensors to control the orientation of the reference plane in the 3D virtual world. It consists of small wooden plate attached to an assembly of an upside down 2 DoF joystick mounted on a potmeter (for the third DoF). The joystick is mounted upside down, by request of one of the designers, it turned out the inclination of the real object then corresponded better with the inclinations of the virtual world. A slider is added for a zoom function.



Within the system the communication takes place using OSC. Now we need to fully work out a protocol describing the interactions at the semantic level. OSC only provides the physical and data layers[21].
This would be the Interaction Appliance Protocol (IAP), describing for instance the movement a player with a navigation device makes a change in camera view in Virtools. Another example: when the key labelled "P" on a keyboard it has the meaning of the character "P" throughout the system. Though in combination with the Command (or Control on a PC) the "P" key means the Print command. This depends on the computer it is connected to. So for our distributed system, the data from the interaction appliances is read and passed on as meaningful data using the IAP. In the case of standard input devices, such as the situation with the keyboard described above, the meaning of the input data assigned by the operating system (standard HID protocol for USB devices for instance) is first taken away in Max and than added when passed on throughout the system.
If, for whatever reason (driver incompatibility for instance) an input device has to be connected in the distributed system to another computer than the G5 Interaction Computer, the data is passed on to the G5 and there the meaning is assigned to it according to the IAP. This ensures consistency of semantics and availability of the data of players actions and feedback throughout the system.
For interaction in Protospace a number of different generic functions are identified. For each function then, we find or develop the most suitable interaction style. We are also partially going towards a modular approach such as in the Video-Organ (see 7.2). In this situation, players can pick up interfaces and carry out certain functions linked to those interfaces. These are the interaction appliances, as a combination of an interface matching the human output modalities, linked to system functions, and addressing human input modalities through presentation and feedback.

The interaction appliances currently developed will be tested and developed further in the Case Study, where a professional design team consisting of several roles will work with the system.
It is also important to note that Protospace will move later in 2006 to a new building. This building, the iWeb, was originally designed by Kas Oosterhuis and ONL for the Floriade exhibition in Holland in 2002, and now acquired by the University in Delft and put up in front of the Architecture department. In the iWeb building Protospace will occupy a pentagonic space, surrounded by five screens. Some of the interaction styles (such as the screen linking to appliances through RFID) have been developed with this situation in mind.

8.3 LaserTouch Pointer

Another example which explores multimodal interaction styles is the LaserTouch project at the Vrije Universiteit Amsterdam. Here a gestural controller is used based on a laser pointer and a camera tracking system, with added tactual feedback and with the explicit aim to interact with both the virtual as well as the real world.

8.3.1 Laser Pointer Tracking

To use video tracking of the dot of a laser pointer is a well known technique[22]. A recent paper by researchers from the Human-Computer Interaction Institute at CMU gives a good overview of such systems, and reports critically on the low accuracy of the laser pointer based interaction due to the 'magnification', the leverage of hand instability when operating over a larger distance. The paper further investigates the influence in the shape of the pointer on the accuracy, and compares the laser pointer technique with other input modes[23].
Others have developed real world exploratory applications of this idea, for instance to apply as a aid for blind people[24], currently with auditory feedback and potentially with tactual feedback too. However it proves difficult to replace the traditional 'cane' with all its richness and various modes of interaction, as can be read on an internet forum discussing this research. This gives considerable insight in the actual issues involved (including social) in using such a cane including the safety issues related to waving around laser beams (by both blind or sighted people).

As often, it seems that by focussing on overcoming the limitations of existing technologies or interaction styles, as those certainly present in the case of the 'cane' (for instance its limited length), the inherent strengths may disappear too. In the case described below, we therefore first approach the interactions not possible before and from there hope to include the established layers.

8.3.2 Remote touch and ubiquity

The reason for us to use a laser pointer is to explore the possibility to point at *both real and virtual objects*. The virtual objects are projected by a video projector, and real objects such as light switches and loudspeakers are present in the space. If the camera tracking system knows the coordinates of these elements in space appropriate responses can be generated. In the ubiquitous computing paradigm after all, the parameters of various systems would all be controllable through one interface. The parameters of these objects, whether real or virtual, can then be manipulated.
As it has been found in other research including our own, presenting *active tactual feedback* to the user helps the articulation process as discussed in Chapter 5. We therefore include a small vibrotactile actuator in the device, enabling a kind of *remote touch*, feeling the pixels on the screen as in the Palpable Pixels described earlier, as well as other objects in space. This research is an extension of the earlier work with a mouse with active tactual feedback, now in a situation of unguided gestural control where only the kinaesthetic awareness is involved which is informed by the internal signals in the human body (by the proprioceptors and efferent copy). With the LaserTouch Pointer the textures can be felt. It is expected that under these circumstances the added feedback will play a great role in the improvement of the articulation and steadiness of the control function.

8.3.3 System set-up

Again in this project we use a 'patch', a program written in the Max/MSP/Jitter software, for the video tracking (Jitter) and handling other sensor input (Max) through a Teleo USB module[25]. The tactile feedback is generated as low frequency sound by MSP, and linked to the textures projected by the computer. For the gesture tracking a Firewire camera is used, in this case an Apple iSight. The camera has a filter to block environmental light, and is precisely tuned to the wavelength of the laser pointer so that only the dot appears in the system[26]. There are of course some sources in the environment that include the same wavelength, for instance in strip lights, these show up on the image.
The camera with the filter are shown in the picture below. The other picture shows the quick assembly on a carton pipe with laser pointer, selection switch, and a small loudspeaker as tactile element[27].

8.3.4 Demo and experiences

To try out this combination of modalities a demo was created to gather some experiences. The system serves as a proof-of-concept demonstration, and communicates the possibilities. We compared to the laser pointer system to another gestural controller, a Gyropoint gyroscopic 'air mouse' that I am frequently using for presentations. The laser pointing technique seems to work fine, with the added benefit of extending the operating range outside the projected image. The tactile feedback seems helpful, although the speed of the optical tracking needs to be improved in order to create a convincing experience.
Currently this contraption is wired, but could quite easily be made wireless in a next phase using Bluetooth technology. We have investigated this, and using the recently introduced hifi headset profile sound quality would be good enough to accurately display vibrotactile cues (the standard headset profile is found to be not good enough).

8.4 Summary

In this chapter I have presented the development of several interaction appliances, to enable interactions in an electronic ecology.
For the development of interaction styles we think in *palettes*. These palettes contain the interaction modalities and system parameters including presentation and feedback, which have to be mapped onto each other. This mapping is depending on the 'task' or application and context, which varies over time and therefore a flexible, scalable and configurable system is being developed.
The interaction system in Protospace is developed at a proof-of-concept level, based on the anticipated needs of a design team. Most of the interaction appliances can be applied in the Case Study. In the next phase we are going to conduct more thorough work sessions in space with multidisciplinary teams of designers. This will inform the development of the suitable mappings, guided by the interaction framework as outlined in Chapter 4 and illustrated here. The system is scalable enough to be further expanded to include more interaction styles in the future, without performance degradation that would influence the interaction. The concepts of a separate 'interaction computer' works well, it handles all interactions (input and feedback) in real time.

The new interaction style of the LaserTouch Pointer, combining gestural spatial control with vibrotactile feedback, looks promising but has to be further improved before the necessary user tests can be carried out.

These and other developments of multimodal interactions will continue to inform the development of the Multimodal Interaction Space.

[1] Reflecting the 'range' parameter of the PIDS described in chapter 6.

[2] As described in Chapter 2, and see www.hyperbody.nl. The team working on Protospace further consists of Hans Hubers, Dieter Vandoren, Tomasz Jaskiewicz, and Yolande Harris (from the MaasLab).

[3] For instance as described in a recent article *Interactive Immersion in 3D Computer Graphics*.[Rosenbloom, 2004]

[4] This has been described in Chapter 2 including references [Zellner, 1999], [Jormakka, 2002].

[5] See the article on his web site www.billbuxton.com/LessIsMore.html, and another version [Buxton, 2002] published in the book *The Invisible Future* [Denning, 2002]

[6] I participated as a sensor engineer and interaction consultant for the first phase of Protospace (1.1). This set up is described in several research papers by one of the Delft University researchers, Hans Hubers [2005].

[7] A 46 page report was produced edited by myself, *ProtoSpace 1.2 Multimodal Interaction* finished in January 2005.

[8] Virtools is intended for game development, see www.virtools.com

[9] See the article by OSC developers from the University of Berkeley, David Wessel and Matt Wright *Problems and Prospects for Intimate Musical Control of Computers* presented at the first NIME workshop [Wessel and Wright, 2001] for more discussion of the timing requirements.

[10] The OSC Virtools building block is developed by Xavier Benech of ONDIM in Paris (www.ondim.fr), one of the collaborators in a large project called *Phase*, by IRCAM [Rodet, 2005].

[11] From the company Imaging Source, with branches in Europe (Germany) and the US. See www.theimagingsource.com.

[12] The way Mac OSX speech recognition works is that it first analyses the incoming audio spectrum by comparing every phoneme to stored statistical models, and then analyses its grammar to make a more solid guess of what has been said, using the stored grammar (Finite State Grammar). The drawback is that it can't recognise words that are not in the grammar. There is also a feature called Semantic Inference, where the system tries to understand the utterances based on its meaning rather than its grammar. The technology is described in *Are You Talking to Me? Speech on Mac OS X*, O'Reilly Mac Development Center on the web [Kermadec, 2004].

[13] Professional Shure headset.

[14] The ~fiddle and other objects are described in an ICMC conference paper [Puckette et al, 1998]

[15] *The Singing Architect....*

[16] The demo was presented for an audience at the Architecture department including the dean of the department, reactions were positive which resulted in the approval for funding for further development.

[17] In an earlier project I was involved in at Philips / IPO we defined a number of 'generic operations' in this case for another complex application, a multimedia home entertainment system (see also section 9.1.3). The team published the findings in an internal report [Eggen et al, 1996].

[18] This is the result of an ongoing academic research, to create a speech synthesizer that can deal with prosody, pitch, rhythm etc. for various different languages. See http://tcts.fpms.ac.be/synthesis/mbrola.html.

[19] See for instance articles in the recent IEEE Computer Special Issue on Sensor Networks [Culler, et al, 2004].

[20] This interaction appliance was developed by two student interns on the project, Bas Botemans and Dick Rutten from the department of Industrial Design in Eindhoven. They also worked on the PDA interaction and other issues.

[21] It has been often noted that the layers in the interaction from an HCI point of view are somewhat similar to the layers of the OSI model describing the communication between computers.

[22] As described for instance in a recent CHI paper, *Laser Pointer Interaction*, [Olsen, 2001].

[23] The article is *Interacting at a Distance: Measuring the Performance of Laser Pointers and Other Devices* [Myers et al, 2002].

[24] In a paper for a conference on 3D sensing [Yuan and Manduchi, 2004], but there is critism on this approach as well as can be read in an on-line article www.engadget.com/entry /1234000690023779

[25] Sensor interface hardware, see www.makingthings.com.

[26] Thanks to Mr. Eric-Jan van Duijn from the Laser Centre of the Atomic Physics Group at the VU, who helped with the laser light filter.

[27] It is actually a toilet roll. The pointer was made by student interns Bart Gloudemans and Sylvain Vriens, and in the VU HCI-Lab we often deliberately try to work with low tech materials whenever possible.

Part V
Directions

In this part the journey, from the stepping stones to the foothills and further explorations, has to come to an end. I am rounding off and bring together the theory and practice. Elements of an approach to research, development and design of interactions are presented and discussed.
After that I indicate a number of issues that need further exploration, outlining further research to be undertaken. This outline is only a sketch, indicating directions, notions of goals, but not precise details of the routes to take…..


CHECK IN
CHECK MAIL

9. Interaction with the Electronic Environment

A Shift in Thinking - From Devices to Functions

In the previous chapters I have outlined an approach to deal with the potentially bewildering complexity of designing for interactive environments or *e*-cology of people and technology. Several frameworks have been developed and illustrated.

The traditional coupling between devices and functionality is disappearing as the appliances as such disappear. In the research and design processes, having an overview of all functionality of the systems is important, which can then be mapped to a selection of the whole palette of interaction styles now available or in development. I have presented this interaction space along the dimensions of senses, modes and levels in order to indicate how vast this space potentially is, and therefore the potential mappings possible. This becomes an essential element of the design process which needs to be approached with an open mind and deep knowledge of all options, combining ratio and intuition. Both this *multimodal interaction space* (MIS) and the *physical interface design space* (PIDS) are inspired by (in addition to HCI) the electronic arts, music and architecture. I have included the issues of intimate, spatial, and haptic elements in the interaction which I think are increasingly relevant for general HCI, such as the architectural design practice and the extended desktop.

In this chapter the proposed shift in thinking from devices to functions is discussed, as illustrated by the example projects in Part IV, and numerous projects in the general field of HCI research around the world. The notion of *device parsing* is described, as part of the interface paradigm that is based on functionality rather than devices, analysing the workings of technology possibly literally by taking it apart. The practical element is also found in the prototyping stage of the design process, discussing the notion of *extreme rapid prototyping*.

This thinking in functions may lead to *interaction appliances* in a modular approach, through which one potentially can interact with the whole technological environment or *e*-cology. This works from the *intimate* and *bodysphere* interaction scale of the personal area network (PAN) which connects functionalities, controls and displays distributed over the human body and our clothing, to the *spatial* of the home network and beyond. When devices become dispersed, their functions need to communicate through a protocol between the elements. The functions need to be aware of each other and their environment, which can be enabled by communication of information between the parts. This distributed and aware functionality may increase the interaction bandwidth between people and their increasingly complex technological environment.

9.1 The ubiquitous interface

An 'interface' can be most narrowly defined as a line or plane. A connection area placed between two or more 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.

9.1.1 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 one wants, 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 string player would invest more in the bow - just the bow - than the value of a whole Silicon Graphics workstation[1]. 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. In fact this even goes for any tool a craftsperson would use. A good set of Gedore or PB screwdrivers, Lindström pliers, Belzer spanners, or the Weller soldering iron, all these tools I use are worth more than even the most expensive mouse and keyboard combination. Each.

The other reason for the ignoring of physical interaction is more difficult to solve. Since the industrial age, with its division of labour for the hands (blue collar workers) and the head (white collar workers), there has been a tendency to think that working with ones hands is inferior to working with ones head. The Victorian disliking of the human body didn't help either. Since then, 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[2]. It is as if when one can work with the hands, one can't be good at working with the head[3]. I strongly disagree. It is not mutually exclusive, in fact we know that theory can be developed through practice and physical interaction, and therefore that both the head and the hands are important. The Cartesian split between mind and body doesn't exist. Thanks to the current view on the interaction between people and computers, as being more mental than physical, a *neo-cartesian split* has been introduced. This split too has to be solved.

Within the research field of HCI there is currently an increasing interest in physical interfaces. For instance, there is the notion of the TUI (Tangible User Interface) as successor of the GUI[4], as discussed in Chapter 4. There is also the notion of 'embodied interaction' as Paul Dourish calls it[5]. There are several recent publications describing how to achieve physical interaction through the use of hardware interfaces[6].

9.1.2 The hybrid nature of current products

Products and devices nowadays are not only a combination of hardware and software, they are often also part of a service or other infrastructure. The success of the Apple iPod is not just due to the nice and effective design of the (range of) physical products, it is also because of the integration with other media: the iTunes software application to store and organise music on an Apple Macintosh or Windows PC, and the most recent addition to the complex and innovative business model: the web site through which music tracks or albums can be purchased[7]. The strength lies in the combination, the cross-media or hybrid nature of the whole product and process.

Hence my re-definition of Industrial or Product Design at present, as the discipline involved in the *design of interactive products and processes*.

Another example is any mobile phone, which is a combination of the phone device (hardware and software) and a service to connect the thing to the network, and the owner and maintainer of this network. However, unlike the iPod saga, the provider of the device and the service are usually different companies, with different interests and business models[8].

The interaction with the functionality, the experience of using the 'product' is determined not only by the device but also by the service. If the manufacturer wants to introduce new features, they are depending on the service providers to support this and vice-versa. Sometimes they do collaborate, for instance at present with phones that can take pictures and send them over the network. There was a mutual interest, the service provider and network owner want to sell bandwidth, and the device companies want to sell new phones.

It is still odd however. For years I've been arguing that what people want is a simple and effective way of communicating through text messages, not as clumsy as SMS and not as elaborate as the e-mail medium, but something in between. Instead, every phone now comes equipped with a camera. The camera functionality is inherently difficult to use properly, but with more megapixels than the average proper digital camera – numbers count. The functionality of SMS was conceived as a niche. What would have happened if something like SMS would have been properly designed for its current function, as a text message communication medium?[9]

9.1.3 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. This particularly goes for mainstream products, while in the HCI research labs other approaches prevail.

Examples of these multifunctional appliances are the fax/copier/printer combined device, or an iron with built-in telephone as shown in the cartoon by a young Dutch designer to emphasize that combinations of functions can turn out to be mutually excluding[10].

These resulting multifunctional appliances are usually harder to operate. 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 this 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 situation 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.

The figure below shows a drawing I once made when working on these issues at Philips around 1997. We identified generic functions such as navigation, and I am distinguishing between a navigation or manipulation *upon* or *within* an content object. The lower part of the drawing gives some examples.

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)? They look more and more similar, but the way to interact with the respective devices remains different and not just because of the different medium they are part of. The answer is that they come from different engineering and product design disciplines. It takes many years for these differences to iron out, if at all.

The car shows inconsistencies in the interface that have to do with technical and historical issues, as described in Chapter 1. When technology matures it starts to overcome this.

9.2 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) 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 first been designed to perform well mainly for its primary function[11]. 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. The alarm clock is awkward to use, tucked away in the menu item 'extras' so it takes many key presses to set the alarm.
The same is true of course for the now omnipresent camera in every phone. Although manufacturers are trying to make the camera functionality more usable it will always remain a secondary function.
One the other hand, my digital camera does not contain a telephone[12]. And as a camera, the dedicated interface makes it very easy to use[13].

I have often used student exams as probes for ideas. To find out whether the idea of thinking in functions in an *e*-cological way was acceptable, I asked a group of students what they thought was the most important element of a computer or a mobile phone. I receive a wide variety of answers which could be categorised as shown in the table below (in percentages)[14]:
I had expected that the storage of personal data would be the most important function – put the SIM card in another GSM phone, or the hard disk in another computer, and the devices changes character. This was not the case, as can be seen from the figures below. But at least the interface scored quite high (reflecting the focus of the course).

function	*computer* %	*phone* %
interface	39	38
processing	38	5
power supply	10	7
miscellaneous	9	12
storage of information	3	7
communication	1	31

9.3 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[15], 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[16]. This is what I call the *interaction appliance*. 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 as described in Chapter 2. Communication standards such as Bluetooth and Zigbee have the potential to fulfil the same role in interaction appliances. Linking the PAN (Personal Area Network) with the local networks and beyond is essential in this approach.

If we have a good overview and structure of the functionality of the device(s) or ubicomp surroundings, it is easy to identify a number of generic operations and interactions (such as 'play', or navigation) for which interaction appliances can be developed which are generic. This 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.

To develop this idea of the generic interface further, I defined and coached a student project for five months in which the group developed several concepts for controlling the functionality in the home environment. I called this the 'überzapper' [17]. The group developed eight concepts, one for each 'mentality' group of the target audience[18]. The picture below shows four of the eight überzapper mock-ups of the concepts, of the first series (provotypes, provisional prototypes, including a cardboard house and home appliances, all this already gave an impression of the interaction experience). The row of pictures below that show the second generation of prototypes.

One of their concepts was developed as an actual working prototype. In the preliminary user test and during an exhibition it was found that even though it was a complex interaction appliance it was greatly appreciated. This positive reception was partially due to the richness in interaction modalities and the playfulness. The picture below shows the final prototype, in a poster as a mock-up advert (the Philips company acted as a client for this project).

9.4 Vision

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. This is often that one ‘killer app’, or it enables something to be done that wasn’t possible to do before, or in a different way.
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 in an *e*-cology.
In the sections below I will give two examples of contexts where an electronic ecology manifests itself.

9.4.1 Eyes Everywhere

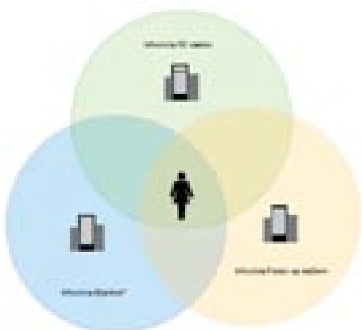
Over the last ten years the mobile telephone has become an omnipresent (ubiquitous) device in our society. We can communicate with voice everywhere anytime. This means that we can put our ears everywhere, and our mouths everywhere, in order to converse with other people (provided we have something to say, although this doesn't seem to be strictly necessary). Combined with other communication media, what we may be creating is a global consciousness of people being connected to each other and communicating continuously. What will this do (or has already done) to our minds?
Now that most phones come with a built in camera, technically we are enabled to put our *eyes* everywhere. The cameras in the phones have been put there by manufacturers, 'encouraged' by the telecom companies (service providers) who want to sell more bandwidth. It is not functionality that the costumers have asked for, or have a clearly defined purpose for. We can however expect that new and unforeseen applications will emerge, just like previously for instance happened with SMS.
Here is an example of a function that I think will emerge. Imagine one has the need to peek into a remote location. Perhaps to see the weather at a place to visit, or the traffic density on the nearby motorways before entering them, or to see if a shop is still open. Usually at any location where people are present many of them will have camera-equipped cell phones. They can share their view, so I can gain the wanted information. I am even prepared to buy the picture from them.
Mobile phone networks such as GSM and even UMTS however, are inherently too limited to offer the required bandwidth at low costs to many users for streaming video or continuous connections. At the same time wireless network access though WiFi becomes more widespread. Too often (particularly in the Netherlands) the networks are not accessible for everyone, and even for those authorised it is often cumbersome to actually connect. This is due to the reliance on old business models and bureaucratic structures. It is expected that soon these structures are bypassed by open networks, of other providers and even whole cities to be covered by a wireless network[19]. Several cities around the world are currently providing this service. This offers the opportunity to realise an *e*-cology not just beyond the desktop, but past the limitations of buildings. Models and frameworks developed to analyse and develop for interaction, such as the ones described in this thesis, are developed with these applications in mind.

9.4.2 The InfoZphere

The notion of the *e*-cology is illustrated by what I call the *InfoZphere*. My latest research at the Vrije Universiteit in Amsterdam is based on the idea that objects, buildings, people and other entities can 'radiate information' about themselves. For instance, a train station could 'radiate' the scheduled and actual departure and arrival times of the trains. A shop could have an InfoZphere revealing its opening times, special offers and other details. Perhaps a device like a lamp could radiate its amount of Watts or lumens, number of hours of use, etc. The InfoZphere of a dimmer switch could make available its number of states and power rating, to facilitate a process of becoming associated with the lamp.

Existing wireless technologies can be used, WiFi for longer range (the architectural scale) and Bluetooth or Zigbee for the close range (the bodysphere and within a room)[20]. This close range and the use of Bluetooth is also envisioned to be used for exchange of information between parts of devices. For instance, adding a full keyboard to a device would change its configuration, so that it can adjust the way it presents it information.

To demonstrate InfoZphere, together with group of students at the VU we developed an application using an Apple Airport WiFi base station, simulating a source of 'radiating' information. The person who is interested in the information uses an electronic device (a laptop computer, or a WiFi enabled PDA or phone) to explore the InfoZpheres in the vicinity. Information about a location will then appear. The simulation is made in Flash with some custom software to find the WiFi base stations, and runs on a PC laptop. In the picture below on the right a simulation is shown of a mobile device, displaying in this example all relevant information of a London Underground station. The picture on the left shows a visualisation of the principle[21].



The information displayed can be based on a web site, but particularly tuned towards the mobile user near the actual location. Sometimes it can be useful to connect to an InfoZphere that is not nearby. Such a remote location could also be selected on a map, which will then make their information available.

A protocol needs to be developed to describe the information radiated, at different spatial scales. The personal scale, for instance using Bluetooth, is already known as the Personal Area Network (PAN). An example of information radiation could be to display the contents of a person's wallet on a display worn on the wrist (which is usually displaying the time, currently known as the wrist-watch) or to exchange information to another person in the vicinity, if wanted[22]. This relates to the work on the Interaction Appliances Protocol described in Chapter 8.

9.4.3 Conclusion

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.

As discussed, computers are not only the most complex and most powerful artefact ever invented by the human race, but at the same time they are the most invisible kind of technology. 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 this chapter on a positive foot, 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 about interactive applications – all these seem to have gone 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.

[1] Bill Buxton explained this in his talk at the first Doors of Perception conference in Amsterdam [Buxton,1994].

[2] 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*. [1996].

[3] 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.

[4] As supported by Hiroshi Ishii and his group at the MIT Media Lab [Ulmer and Ishii, 2000].

[5] Paul Dourish describes this in his book *Where the Action Is, the Foundations of Embodied Interaction* [2001], which actually also does discuss the old but relevant philosophical debate of the mind / body relationship

[6] For instance the book *Physical Computing* written by Tom Igoe and Dan O'Sullivan from the Interactive Telecommunications Program at NYU [2004], the forthcoming book by Nic Collins *Handmade Electronic Music: The Art of Hardware Hacking* [2006], and my own chapter in the IRCAM cdrom book [2000]. The popularity of the new magazine *Make* from the US is another sign that hardware is becoming more popular. The magazine started in April 2005 and already there is a related book published called *Makers* [Parks, 2006] and a Maker Fair planned in 2006. See www.makezine.com.

[7] As described in an article for the Dutch magazine for the IT professionals, *de Automatiseringsgids* by Gerrit van der Veer and myself, 29 April 2005 39/17, p. 15.

[8] And differing in market or user understanding....

[9] I have discussed the functionality of SMS and its suboptimal interface in a part of my *e*-cology booklet [Bongers, 2004] in *Modern Thumbing – text messaging on the mobile phone*. Richard Harper has in his research addressed the use of SMS [Harper, 2003]. SMS text entry has been described at the keystroke level by I. Scot Mackenzie [2002].

[10] Eelke Veenstra, illustrations in the Dutch design magazine *Morf*. This one is called "combine two products that render each of them useless".

[11] John Heskett mentions in his book that phones exist with over 80 functions, and refers to this as "feature creep" [Hesket, 2005].

[12] I can't even use it as a clock (or alarm!) even though it knows the time in order to time and date stamp the photos.

[13] Although when one wants to use the camera in manual mode, setting all variables quickly by hand, it is poor compared to the classic SLR camera – this is the topic of Joep Frens' research at the Industrial Design department of the Eindhoven University of Technology.

[14] About 90 students participated in the exam in June 2004. The course was called Human-Computer Interaction, for the Bachelor in Media Technology at the Utrecht polytechnic school in the Netherlands.

[15] As proposed for instance by Donald Norman in *The Invisible Computer*, [1998].

[16] The Pebbles project has shown the strength of such an approach, based on handheld PDA devices. See Brad Myers, *Mobile Devices for Control*, invited talk at the Mobile HCI Conference, Pisa Italy, [2002]. The Philips *iPronto* is an example of a commercially available device, but again the physical interface is limited to a touch screen. Besides, the Pronto is not so much a consumer device but part of a service industry that installs multimedia control systems and domotics in people's houses.

[17] Four second year students of the bachelor course in Industrial Design (ID) at the Eindhoven University of Technology worked from February to June 2005 on this project: Wouter Reeskamp, Niko Vegt, Dick Rutten and Eric Toering. The project was presented at an exhibition of ID projects at the university in October 2005 as part of the Dutch Design Week. It was also presented as a poster at the Designing Pleasurable Products and Interfaces conference, see www.dppi05.id.tue.nl/program3.html.

[18] The group came up with this based on a model developed by the marketing company Motivaction (see www.motivaction.nl) which divides the society in eight different 'mentalities'.

[19] The company Tropos in the US is developing such 'metropolitan-scale Wi-Fi mesh networks, see www.tropos.com.

[20] For an overview of current and emerging technologies for wireless networking see an article in the *IEEE Computer* magazine by researchers from the Intel company [Schilit and Sengupta, 2004].

[21] The project has been carried out by Evert-Jan Oppelaar, Elbert-Jan Hennipman and Wouter Broekhof, Bachelor students of the Multimedia & Culture program. They also made the visualisation.

[22] Safety and privacy issues have to be worked out, 'BlueSnarfing' is already a problem with Bluetooth enabled devices.

10.
Seeds
A Research Agenda

I have chosen a broad approach to this thesis, developing frameworks and assembling theory, informed by experiences and experiments of various nature in several fields. Inevitably this work is unfinished. Even when many problems are solved, there are always new issues to explore, and new questions to answer. In this final chapter I give an overview of my work so far, and a preview to further work. This is outlined by the frameworks, and illustrated with some new research projects and aims.

10.1 The results of the journey

In this thesis I described my research and developments as a journey, not strictly chronologically following my explorations and experiences to allow some iterations. I have used the metaphors of *stepping stones* (describing musical instrument building, development of interactive architecture), *foothills* (the research into multimodal interaction including haptics), *explorations* (experiments and developments in the arts and new interaction styles), and this final chapter, which contains the *seeds* for further research. It is clear that I'm not yet finished, and in this last chapter I want to envision the further journeys and explorations ahead.
In the preface I have given an overview of my intended contributions to the field of HCI. I will summarise my findings in this chapter, and indicate how I will proceed with the further developments.

10.1.1 Frameworks

A. *four frameworks for describing and analysing (and possibly extending) interactions:*
- *A1.* *a categorisation of technologies and their functions, relevant for HCI*
- *A2.* *a framework for describing interaction styles*
- *A3.* *a design space for physical interfaces and a taxonomy of interface elements (sensors)*
- *A4.* *a classification of media*

Categorisation of technologies (A1)
The categorisation of technologies and technological functions has been introduced in chapter 1 and used to describe various technologies. I have identified the main functions of technology as *supply, processing, translating and storage* of both *power and information*, and described in these terms the successive technologies of *mechanical, electrical, software, chemical, magnetic* and *optical.*
The framework was used to classify musical instruments in chapter 2, including electronic instruments as an extension of the 'electrophones' category in the classical Hornbostel-Sachs model.

Framework for multimodal interaction (A2)
In chapter 4 I reported the investigation into human interaction modalities, related to information and communication theories. System output is now described in the classes of *presentation* and *feedback* and further subdivided. The Multimodal Interaction Space (MIS), to describe interaction styles, is made up along the dimensions of *modes, modalities* and *levels of interaction*. I have applied this framework in the research projects described in chapter 8, illustrating its use and indicating further development. A notation system or graphical representation of MIS would be useful. In chapter 4, I propose only two of the dimensions in a diagram, focusing on the human output in relation to other input modalities (human or system).
The MIS system shows how many more interactions are possible; this is what I intent to investigate in the near future.

Design space for physical interfaces (A3)
Focusing on the physical and haptic interaction, I have developed a framework for categorising interfaces. For this Physical Interface Design Space (PIDS) I have identified the parameters *range*, *precision* and *haptic feedback* in chapter 6. The approach for PIDS is to decompose the interfaces in individual sensors and actuators, which can then be classified. This design space can be used to place individual sensors in a taxonomy, and I have referred to another publication where I successfully carried this out.
The *precision* parameter needs to be further defined. It is dependent on a number of system factors, both in hardware and software, such as sampling rate, number of bits, latency, variation of latency etc. Some of these factors can only be experimentally determined. It may be possible to define one factor for precision which reflects all variables. Further research into this is necessary.
In chapter 6 of this thesis I have illustrated the PIDS framework by several examples, analysing interfaces. In chapter 7 I have introduced a structured design approach applying the PIDS framework in the development of a new instrument for audio-visual performance, the Video-Organ. This was a first step in the validation of the framework.

Classification of media (A4)
The immaturity of many 'new media' is reflected in their names. Often the name of a medium is referring to the carrier ('CDROM', 'Internet') or ill-defined ('multimedia'). By analysing artistic media, which have gone through a long and thorough development, I proposed in chapter 7 a classification of media based on the dimensions (2D or 3D), modalities, and time: *static*, *time-based*, *dynamic* and *interactive* media. This may lead to the introduction of new media, such as the video-book described below.

10.1.2 We are Multimodal

B. an approach to study human perception and action in the context of multimodal HCI, to firmly include the somatic senses, and the research question of whether haptic feedback can improve interaction.

Most of the interactions that take place in everyday life, between humans and technological and natural environments, involve multiple modalities. Interaction using a single mode or modality is scarce. Monomodal interaction is rather the exception than the rule. However, interacting with the current (or rather, *past*) generation of computers often involves only a few modalities, and one at a time.
Traditional HCI textbooks often treat the topic of multimodal interaction in the later chapters, together with other issues that are considered 'exotic'. Coming from musical instruments, crafts and other rich interaction situations I have realised that HCI should be approached from a different stance, starting with rich multimodal interaction instead of ending with it. This led to the slogan *We are Multimodal*[1].
This particular multimodal approach, based on experiences in the arts, music and architecture, has been described in Chapter 4.

In Chapter 5, I reported about experiments to gain knowledge about the role of the sense of touch in improving interaction. For this purpose I developed several haptic feedback devices such as the *tactile ring*, the *vibrotactile mousepad*, and the *tactile explorer* on a pointing device. In the experiments it was found that haptic articulatory feedback can help improving the interaction in more complicated tasks. It is expected that the improvement will be more clear when the tactual feedback is added in free moving gestures. Some preliminary experiments have been carried out but it has to be studied in more detail.

The multimodal approach to HCI has been applied in my lecture series and workshops at various universities and schools in the Netherlands, most extensively at the Vrije Universiteit Amsterdam. Through this teaching valuable feedback was gathered from the lectures and student presentations, coursework, exams and essays, which enabled me to refine the content[2].
For instance, one of the exam questions challenged the students to come up with novel uses of human output modalities[3]. The majority of proposals involved speech, gestures, facial expressions, writing, and body language. But there were many less common modalities mentioned such as sweating, spitting, growling, smiling, crying, smell, excretion, winking, dancing, burping, sighing, or a pad on the shoulder. This latter one is interesting because it emphasises the importance of the role of the receiver to give meaning to the interaction. It shows that people can be very aware of the many modalities available for interaction. However using body electricity or brain waves were never mentioned in this case.

Interfaces on the physical level should facilitate a rich and multimodal interaction, with multiple degree-of-freedom input, and including active haptic display of information and feedback.

10.1.3 The *e*-cological approach

C. a design approach based on bringing together and in harmony our natural and our artificial environment through the embedded interactive computer technology (ubiquitous computing), forming an electronic ecology or e-cology.

The *e*-cological approach is one of the main topics of this thesis. It encourages an ecological way of thinking about interaction with the electronic environment. In the fields of Ubiquitous or Pervasive Computing it can already be seen that most of the

research efforts are about developing solutions for interaction in such an environment, but I find it often still too limited to the computer technology. The *e*-cology places the interaction in a wider context, as I have shown in several research projects and developments described in this thesis.. In the sections below (10.2.3 and 10.2.4) I will give some examples of current and future research directions driven by this approach.
A research direction is the implementation of (wireless) sensor networks, extending the work in the Protospace project (Chapter 8) and the Meta-Orchestra (Chapter 7).

D. the proposal of Interaction Appliances as distributed and modular facilitators to support the e-*cological design approach, and the thinking in* functions *rather than* devices.

In Chapter 1, I have discussed the importance of the interface in the situation of the disappearing computer. I introduced in Chapter 7 the structured modular design approach of the Video-Organ, and described the 'instrumentlets'. The properties of the audio and video material inside the system are mapped to the physical design of the instrumentlets. This led to the design approach of the Interaction Appliances, discussed in chapters 8 and 9.
When devices disappear and become part of the environment, all we are left with is the interface. This leads to a shift in thinking, in *functions* rather than in *devices*[4] as discussed in Chapter 9.
We can see that the last remaining devices have many functions crammed in which all have to be accessed with the one interface. For instance the case of the mobile telephone, it has an increasing amount of other functions but the interface remains the one that was developed for the phone functionality. As an approach to deal with the complexity I proposed *device parsing* in chapter 9. This approach is about analysing the functions of a device or system, if necessary by literally taking the system apart. I gave the example of 'parsing' a mobile phone. Furthermore, I have partially tested the approach by assigning numerous students in the past two years in workshops and lectures to parse devices of their own choice. With simple devices this was sometimes felt as rather pointless by the students, while in more complex cases it helped them to analyse the complexity.
I will apply the device parsing approach further in future research in order to validate it.
A solution I proposed for interacting with complex systems is to develop *interaction appliances*. These are interface modules that give access to, and enable control over, the system's functionality. This can be part of the functionality, or in the case of a *generic interface* controlling the whole environment.

The modular approach of interaction appliances calls strongly for a protocol for communicating between the interface elements, and system parameters and content. The development of such an Interaction Appliance Protocol is something I intent to work on in the future. In the Protospace project described in chapter 8.2 we are already creating an overview of the parameters.

10.2 Research agenda

E. a research agenda for further study and developments.

Several directions for further research are already indicated above. There are some more research proposals that follow from the work described in this thesis. In this section I will describe some current work and ideas for further exploration, based on the notion of multimodal interaction in the electronic ecology.

10.2.1 The interaction between people, technology and the arts

In this thesis I have approached the field of Human-Computer Interaction (HCI) broadly, to include the interaction in general between people and their technological environment. Due to fact that the computer has become increasingly embedded in (and intertwined with) other technologies, and has become increasingly networked, the notion of Ubiquitous Computing has come about. When interacting with our technological environment we form an electronic ecology or *e*-cology. This involves many different technologies, as described in the first chapter.
I will have to look more thoroughly into the research field of the relation between man and technology. Particularly relevant seems to be the work of Lewis Mumford between the 1930's and 1970's[5]. The technological stages I described in Chapter 1 should be linked to the various industrial revolutions, first based on machines, and later on information processing.
The arts in the broadest sense are a source of inspiration, as artists often apply and subvert technology to reveal new possibilities. The generic interface (as described in Chapter 9) has been present in the world of electronic music for decades, partly due to the development of the MIDI protocol as described in Chapter 2. Historically there has been a lot of attention for the relation between art and technology, by eminent thinkers and writers such as Siegfried Gideon[6], Walter Benjamin[7], Jean-François Lyotard, Michael Fried[8] and Pierre Francastel[9]. The role of 'craft' is particularly relevant and as mentioned in Chapter 7 it is a subject of debate since the industrialisation, and questioned again and even more vigorously in the current computer age.
We need a rich, multilayered and multithreaded physical interaction to enable us to be fully part of the *e*-cology.

10.2.2 Modes

The human perception and action as described in Chapter 4 should be studied in more depth. Through electronic sensing technologies the human state, intentions and actions can potentially be used as control signals. At the same time electronic actuators enable addressing the human senses in new ways, enriching and extending our perception. I have described that a further symbiosis of man and machine may lead to an extension of our nervous systems, and our abilities to sense and to act, and to store and process information. This requires a thorough understanding of the functioning of the human, both physically as well as mentally, not just studying people or their functions in isolation but in context, in situ, ecologically. I expect that studying particularly the somatic senses and processes will lead to new ways of interaction.

There are many indications that the human mind is capable of perceiving and processing much more information than one is consciously aware of. There are some popular notions about this[10], but thorough scientific research has been carried out resulting in proof of what we often refer to as intuition and such[11]. The bandwidth of information entering through our senses is much bigger than the processing capacity of conscious thought, and the unconscious may play a big role in processing this information. The question then is how we control this capacity?[12] Understanding this may (and should) lead to applications in the interaction between people and technology.

The current computer user interface paradigm is very much based on single channel and explicit actions. A lot of HCI research in the last years involved applying multiple senses and modes, including more implicit ways of presenting information. Research institutes participating in the European framework on Enactive Interfaces[13] focus on the original ideas of Jerome Bruner on learning, which led to the development of the GUI as we know it. I have described this in chapter 1 (Section 1.3.3), and as stated there new combinations of technology and human abilities are possible.

J. J. Gibson's work remains a rich source for inspiration, because of his focus on ecology rather than isolation, and therefore involving interaction. For instance, we can apply his definitions of higher order modes of activity of the human such as attentive, investigatory, executive and performative, always involving both perception and action[14].

In summary, my research directions are aimed at how to incorporate in the MIS framework the following:

- lower level modes of the unconscious and involuntary
- the place of emotional and rational modes (affect vs. effect)
- learning, the development over time
- higher level modes of activity

10.3 The VideoBook

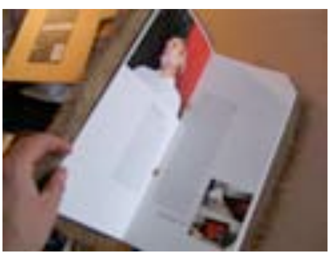
One of the aphorisms of the first Doors of Perception conference held in Amsterdam in 1994, voiced by John Thakara, was: "The book is dead". Presumably this was mainly to evoke discussion around this statement[15]. My own work is thoroughly involved in exploring and developing the possibilities of new and newer media, and interaction modalities. But I still like books, because of their tangibility, unity of content and 'interface', the conciseness, allowing traces of use and quick alterations (dog-ears, annotations), the multilayered interaction including implicit information, portability, etc.

Rather than replacing the book, I will strive to enhance it[16]. I am working on this at present in the MaasLab. Sensors and displays can be built in a book together with processing capabilities and data storage (ie. a computer with hard disk or RAM).

10.3.1 Examples of enhanced books

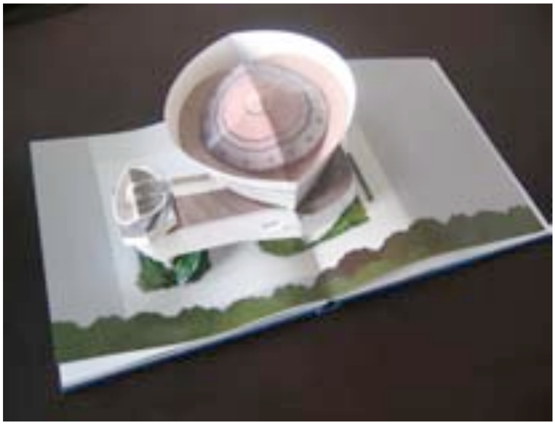
When books were still written by hand they were often elaborately 'illuminated', and often bound in a leather cover, laid in with gold, with metal hinges. The pictures below show such books, and it can be seen that pages are marked with physical elements.

After the introduction of the printing press and further industrialisation books became more standardised and developed as a medium for text and images.
However nowadays many artist books are developed in low volume, often involving new materials and manual work. The pictures below show a book from 2005, to accompany an exhibition on the work of the designer Gaetano Pesce. The cover is made of pigs hair and coconut, and silicone rubber has been applied which act as a spring on the binding. All pages have a unique perforation along the edges, so that the pages can be torn to personalise the book.



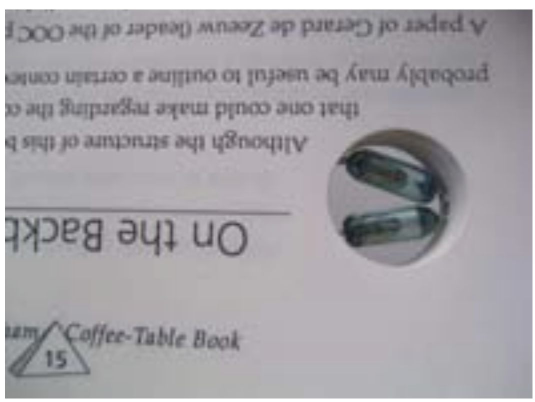
Actar from Barcelona published a book which contains a photo camera as shown in the picture below. The purpose of the camera (in fact one that shoots multiple images at the same time) is for the readers of the book to create their own pictures to add to the existing content of the book[17]. These books are of course more expensive to make.

There are many children's books that nowadays contain sound samplers and other kinds of electronic additions. Other examples of extended books are pop-up books, not only for children – the picture below shows my Frank Lloyd Wright pop up book[18].



10.3.2 A book with sensors

A good example of an electronically enhanced book is a book for a research group at the University of Amsterdam in 1991, which contained electronics that I developed.[19] It contained a small melody-chip and piezo speaker playing a rather annoying tune, which would switch off at a certain page through sliding contacts. When the book was held (or stored) upside down the tune stopped, switched off by two mercury tilt sensors. The sensors were visible throughout the book, they were mounted in a hole punched through all the pages. This can be seen in the pictures below.



10.3.3 The VideoBook

My aim with this thesis is to create a book on paper that integrates video, audio and interaction. Often time-based content is put on a CD which is put in the sleeve of the book, such as in the case of my little *e*-cology book. However the step to put the disk in a player or computer appears to be too cumbersome to most people, and still the distance between the media is too big.

It is possible to build a small LCD screen and loudspeakers in the book, which can be seen and heard through openings on the pages. Ideally, through sensors the built-in electronics will know what page the reader is on and display the appropriate content[20]. It will be powered by rechargeable batteries.
There is a lot of development in flexible displays at the moment, but I don't want to wait for that[21]. The resolution and refresh rate are currently insufficient.
I have also experimented with a head-mounted display, which creates a moving picture somewhere in your field of view. This works well, but apart from the costs the disadvantage is that you loose the unity with the book.

The point is that the media are *integrated* which is already possible with the current technologies. I have built a prototype, shown in the pictures below. It is currently based on a computer, in order to be able to be flexible about the design of the interaction, and once this is established with the current state of technology it is possible to build all the components inside the book.
The result is a *merged-media* book. It contains text, high resolution images and graphics on paper, moving video and animations on the built-in screen, and sounds played from the speakers. The mixed or merged-media book is still a self-contained object, portable and interactive.

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[1] To put the statement about multimodality as a slogan was the idea of Kees Dorst, after discussing with other involved researchers (Berry Eggen and Sietske Klooster) the approach to teaching my workshop at the Master's course Industrial Design and the Eindhoven University of Technology.

[2] At the Vrije Universiteit, Marcin Wichary (student intern of the post-graduate course of User-System Interaction of the Eindhoven university) carried out research on the student's opinions and learning experiences as part of his research into creating an e-learning environment for our HCI course at the VU [Wichary, 2005]. He also developed the current course web site, as an e-learning environment for HCI. See www.cs.vu.nl/~mmc/mci.

[3] About 90 students participated in the exam in June 2004. The course was called Human-Computer Interaction, for the Bachelor in Media Technology at the Utrecht polytechnic school in the Netherlands.

[4] In some cases (old) devices are used as a metaphor as discussed in section 1.3.3, or token-based interaction as discussed in section 3.3.

[5] Particularly relevant seems the book Technics and Civilization from 1934 on the history of technology in a new perspective, the two volumes of *the Myth of the Machine* from 1967 and 1970 of which I am now reading chapters in the Lewis Mumford Reader [Miller, 1986]. Also the book *Art and Technics* [Mumford, 1952] is a good source which already has helped me to start rethinking a number of issues.

[6] Writing about the notion of *space-time*.

[7] *Art in the Age of Mechanical Reproduction*.

[8] *Art and the Objecthood*.

[9] Francastel's book *Art & Technology* has been translated from French (1956) into English in 2000.

[10] Such as 'speedreading', and for instance the book by Malcolm Gladwell *Blink, the Power of Thinking without Thinking*.

[11] There is scientific research carried out to investigate the relationship between the conscious and the subconscious, see the book *The New Unconscious* [Hassin et al, 2005]. Particularly the work of Ap Dijksterhuis at the University of Amsterdam (see the chapter *The Power of the Subliminal: On Subliminal Persuasion and Other Potential Applications* (pp. 77 – 106) on subconscious perception, and their recent article *Think Different* about unconscious thought and decision making [Dijksterhuis, 2005]. The relationship between the emotional and the rational is also a topic in the *The New Unconscious*, as well as the well known book of Don Norman *Emotional Design* [Norman, 2004].

[12] This is the topic of the chapter in *The New Consciousness* [Hassin et al, 2005] by Daniel Wegner, *Who is the Controller of Controller Processes?* (pp. 19 – 36).

[13] ENACTIVE (Enactive Interfaces) is a Network of Excellence under the EU's Sixth Framework Programme - IST (Information Society Technologies) thematic area. See www.enactivenetwork.org.

[14] These modes are described in *The Senses Considered as Perceptual Systems* [Gibson, 1966, p.45].

[15] John Thakara since wrote several books himself. A transcript of his talk can be found on the Doors of Perception 1993 report on CDROM.
It is also on the web site http://museum.doorsofperception.com/doors1/doors1index.html

[16] In a sense this is the same as the discussion about Virtual Reality (VR) versus augmented reality.

[17] There is a reference made to the Lomographic style of making photo's, which is deliberately low-tech, quick and dirty – see www.lomography.com. The web site of the publishers is www.actar.es.

[18] The book is called *Dimensions of Frank Lloyd Wright, six of his greatest buildings paper engineered* [Thomson, 2002].

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[19] The book was called *Addenda & Errata*, a 'coffee-table book' to present the scientific ideas of the research group of Prof. Gerard de Zeeuw. It was edited by Jacqueline de Jong, with whom I devised the concept [de Jong, 1991]. See www.cict.demon.co.uk.

[20] There have been several other projects about electronic books, such as the Listen Reader of Xerox PARC [Back et al, 2001] and a book that links to a PDA for displaying content [Klemmer et al, 2003]. The Listen Reader book uses RFID tag reader technology and Qprox capacitive sensing. These are technologies that I have been experimenting with, as well as reed switches (magnetic) and optical means.
In these projects the book acts as a control device. In films we have seen merged-media books, such as the family album of Harry Potter with moving images, and the foldable screen book in the last Hitchhikers Guide to the Galaxy movie.

[21] See for an overview the article *Big and Bendable* in the IEEE Spectrum of September 2005.

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Voorbeeldig onderwijs; voorbeeldgestuurd onderwijs, een opstap naar abstract denken, vooral voor meisjes
2004-08 Joop Verbeek(UM)
Politie en de Nieuwe Internationale Informatiemarkt, Grensregionale politiële gegevensuitwisseling en digitale expertise
2004-09 Martin Caminada (VU)
For the Sake of the Argument; explorations into argument-based reasoning
2004-10 Suzanne Kabel (UVA)
Knowledge-rich indexing of learning-objects
2004-11 Michel Klein (VU)
Change Management for Distributed Ontologies
2004-12 The Duy Bui (UT)
Creating emotions and facial expressions for embodied agents
2004-13 Wojciech Jamroga (UT)
Using Multiple Models of Reality: On Agents who Know how to Play
2004-14 Paul Harrenstein (UU)
Logic in Conflict. Logical Explorations in Strategic Equilibrium
2004-15 Arno Knobbe (UU)
Multi-Relational Data Mining
2004-16 Federico Divina (VU)
Hybrid Genetic Relational Search for Inductive Learning
2004-17 Mark Winands (UM)
Informed Search in Complex Games
2004-18 Vania Bessa Machado (UvA)
Supporting the Construction of Qualitative Knowledge Models
2004-19 Thijs Westerveld (UT)
Using generative probabilistic models for multimedia retrieval
2004-20 Madelon Evers (Nyenrode)
Learning from Design: facilitating multidisciplinary design teams

2005

2005-01 Floor Verdenius (UVA)
Methodological Aspects of Designing Induction-Based Applications
2005-02 Erik van der Werf (UM))
AI techniques for the game of Go

2005-03 Franc Grootjen (RUN)
A Pragmatic Approach to the Conceptualisation of Language
2005-04 Nirvana Meratnia (UT)
Towards Database Support for Moving Object data
2005-05 Gabriel Infante-Lopez (UVA)
Two-Level Probabilistic Grammars for Natural Language Parsing
2005-06 Pieter Spronck (UM)
Adaptive Game AI
2005-07 Flavius Frasincar (TUE)
Hypermedia Presentation Generation for Semantic Web Information Systems
2005-08 Richard Vdovjak (TUE)
A Model-driven Approach for Building Distributed Ontology-based Web Applications
2005-09 Jeen Broekstra (VU)
Storage, Querying and Inferencing for Semantic Web Languages
2005-10 Anders Bouwer (UVA)
Explaining Behaviour: Using Qualitative Simulation in Interactive Learning Environments
2005-11 Elth Ogston (VU)
Agent Based Matchmaking and Clustering - A Decentralized Approach to Search
2005-12 Csaba Boer (EUR)
Distributed Simulation in Industry
2005-13 Fred Hamburg (UL)
Een Computermodel voor het Ondersteunen van Euthanasiebeslissingen
2005-14 Borys Omelayenko (VU)
Web-Service configuration on the Semantic Web; Exploring how semantics meets pragmatics
2005-15 Tibor Bosse (VU)
Analysis of the Dynamics of Cognitive Processes
2005-16 Joris Graaumans (UU)
Usability of XML Query Languages
2005-17 Boris Shishkov (TUD)
Software Specification Based on Re-usable Business Components
2005-18 Danielle Sent (UU)
Test-selection strategies for probabilistic networks
2005-19 Michel van Dartel (UM)
Situated Representation
2005-20 Cristina Coteanu (UL)
Cyber Consumer Law, State of the Art and Perspectives
2005-21 Wijnand Derks (UT)
Improving Concurrency and Recovery in Database Systems by Exploiting Application Semantics

2006

2006-01 Samuil Angelov (TUE)
Foundations of B2B Electronic Contracting
2006-02 Cristina Chisalita (VU)
Contextual issues in the design and use of information technology in organizations
2006-03 Noor Christoph (UVA)
The role of metacognitive skills in learning to solve problems
2006-04 Marta Sabou (VU)
Building Web Service Ontologies
2006-05 Cees Pierik (UU)
Validation Techniques for Object-Oriented Proof Outlines

2006-06 Ziv Baida (VU)
Software-aided Service Bundling - Intelligent Methods & Tools for Graphical Service Modeling

2006-07 Marko Smiljanic (UT)
XML schema matching: balancing efficiency and effectiveness by means of clustering

2006-08 Eelco Herder (UT)
Forward, Back and Home Again - Analyzing User Behavior on the Web

2006-09 Mohamed Wahdan (UM)
Automatic Formulation of the Auditor's Opinion

2006-10 Ronny Siebes (VU)
Semantic Routing in Peer-to-Peer Systems

2006-11 Joeri van Ruth (UT)
Flattening Queries over Nested Data Types

Samenvatting

Interactivering
naar een *e*-cologie van mensen, onze technologische omgeving, en de kunsten.

Dit proefschrift handelt over de relaties en interacties tussen mens, technologie en de kunsten. De auteur beschrijft in enkele hoofdstukken zijn ervaringen als ontwerper en ontwikkelaar van nieuwe elektronische muziekinstrumenten, videokunst en interactieve architectuur. Deze ontwikkelingen vormen de basis van een nieuwe benadering van het vakgebied van Human-Computer Interaction (HCI). Enerzijds wordt HCI verdiept door bijvoorbeeld de interactie tussen een musicus en instrument of de interactie tussen mens en architecturale omgeving als inspiratiebronnen te nemen. Anderzijds wordt het vakgebied van HCI verbreedt zodat ook andere technologieën omvat worden. Computers worden steeds kleiner, en steeds meer ingeweven in onze directe technologische omgeving. Dit wordt wel 'ubiquitous computing' genoemd, de alomtegenwoordige computer. Deze technologische ontwikkeling heeft enorme sociale en maatschappelijke gevolgen. Hoe gaan we daar mee om? Een benadering wordt voorgesteld en uitgewerkt die dit geheel opvat als een elektronische ecologie, de '*e*-cologie', waar mensen en hun technologische omgeving een geheel vormen. In dit proefschrift worden diverse raamwerken en categorieseringen gepresenteerd om de interactie tussen mensen en de technologische omgeving te onderzoeken en te ontwerpen, vanaf de fysieke en dicht bij het lijf gedragen interfaces (geïnspireerd door ontwikkelingen in de elektronische kunst en muziek) en de ruimtelijke interacties (geïnformeerd door de architectuur). Haptische terugkoppeling speelt hierbij een belangrijke rol, zo wordt aangetoond. Het ontwerpen van de interfaces vanaf de fysieke lagen tot de mentale lagen, heeft als doel het *interactiveren* van de technologische omgeving.

De contributies van dit proefschrift zijn hieronder omschreven.

A) Diverse raamwerken en taxonomieën voor onderzoek en ontwikkelingen van interactie zijn ontwikkeld, te weten: een categorisatie van technologieën en hun functies (A1, geïntroduceerd in Hoofdstuk 1 en toegepast in hoofdstuk 2 over muziekinstrumenten), een raamwerk voor het beschrijven van interactiestijlen (A2, deels gebaseerd op de interactieve architectuur beschreven in hoofdstuk 3, en verder ontwikkeld in Hoofdstuk 4), een ontwerpruimte of taxonomie voor fysieke interfaces (A3, beschreven en toegepast in Hoofdstuk 6) en een classificatie van media (A4, geïntroduceerd in Hoofdstuk 7 dat over nieuwe mediakunst handelt).

B) We are Multimodal: Een benadering van de bestudering van de menselijke perceptie en handelen in de context van multimodale interactie, met de nadruk op de somatische zintuigen (Hoofdstuk 4). In Hoofdstuk 5 worden diverse onderzoeks-projecten beschreven die het aanspreken van de menselijke tastzin mogelijk maken, en

aangetoond wordt dat dit de interactie kan verbeteren. Verschillende nieuwe apparaten en technieken worden geïntroduceerd.

C) De *e*-cologische benadering: een ontwerpaanpak die de natuurlijke en kunstmatige omgeving samenbrengt. Deze elektronische ecologie of *e*-cologie kan ontstaan doordat de interactieve computertechnologie in de omgeving infiltreert. Hoofdstuk 8 geeft hier voorbeelden van.

D) Het voorstel om te werken met zogenaamde Interaction Appliances (interactie-apparaten) als modulaire en gedistribueerde interface elementen in de *e*-cologische ontwerpaanpak. Dit is gebaseerd op projecten beschreven in Hoofdstuk 7 (uit de video-kunst) en hoofdstuk 8 (architectuur), en uitgewerkt in Hoofdstuk 9.

E) Een agenda voor verder onderzoek, omschreven in hoofdstuk 10

Curriculum Vitae

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Education:

1999 *Master of Science degree*, Ergonomics / Human-Computer Interaction, Psychology Department, University College London.

1989 *Bachelor of Science degree*, Electrical & Computer Engineering (Technische Computerkunde) at the Rijswijk Institute of Technology (Technische Hogeschool) in Rijswijk, the Netherlands

1983 *Pre-University study* (VWO / Athenaeum), Haags Montessori Lyceum, The Hague, Netherlands.

Publications:

Book and book chapters

Interaction with our electronic environment – an *e*-cological approach to physical interface design, *Cahier Book series* (no 34) of the Faculty of Journalism and Communication, Hogeschool van Utrecht, April 2004 ISBN 90-77575-02-2

Palpable Pixels: A Method for the Development of Virtual Textures, chapter in the book *Touch, Blindness and Neuroscience* Madrid 2004

Physical Interaction in the Electronic Arts: Interaction Theory and Interfacing Technology, Chapter in *Trends in Gestural Control in Music* CDROM edited and published by IRCAM (Institut de Reserche et Coordination Acoustique / Musique), Fr., ISBN 2-84426-039. April 2000.

Journal papers

Towards a Multimodal Interaction Space: Categorisation and Applications. with Gerrrit van der Veer. *Journal of Ubiquitous and Personal Computing*, special issue on Movement-Based Interaction. [conditionallly accepted and re-submitted] 2006

The PhotoMirror Appliance: Affective Awareness in the Hallway, Panos Markopoulos, Bert Bongers, Erik Van Alphen, Jasper Dekker, Wouter Van Dijk, Sebastiaan Messemaker, Joep Van Poppel, Bram Van Der Vlist, Dirk Volman, Gilles Van Wanrooij. *Journal of Personal and Ubiquitous Computing*, 2005

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Interaction in Multimedia Art, *Knowledge-Based Systems journal*, special issue on Creativity and Cognition. Elsevier Press, ISSN 0950-7051, Volume 13, number 7/8, December 2000, pp. 479 - 485

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<u>*Conference papers*</u>

Towards a Multimodal Interaction Space - Categorisation and Applications, *Gesture Workshop* proceedings, May 2005

CHI 2005 Workshop "HCI PhD Education" White Paper, with Gerrit van der Veer, April 2005

Sensing Systems for Interactive Architecture, short paper, *Symposium on Gesture Interfaces for Multimedia Systems,* Leeds UK, March 2004

Improving Gestural Articulation through Active Tactual Feedback in Musical Instruments, short paper and demonstration, *Symposium on Gesture Interfaces for Multimedia Systems,* Leeds UK, March 2004

Interacting with the Disappeared Computer, short paper for the *Physical Interaction Workshop on Real World Interfaces* at the Mobile HCI conference, Udine Italy, September 2003.

Using Electronic Musical Instrument Design Techniques for Measuring Behaviour, Proceedings of the *Measuring Behavior* Conference, Amsterdam, August 2002, pp 22 - 25.

Interactivating Spaces Symposium on *Systems Research in the Arts*, 14th Annual Conference on Systems Research, Informatics, and Cybernetics. July / August 2002, Baden Baden Germany.

A Structured Instrument Design Approach: The Video-Organ, with Yolande Harris. Proceedings of the Conference on *New Instruments for Musical Expression*, May 2002, Media Lab Europe, Dublin Ireland.

Hypermusic and the Sighting of Sound, A Nomadic Studio Report, with Jonathan Impett. Proceedings of the *International Computer Music Conference*, September 2001, Havana Cuba.

Global String, A Musical Instrument for Hybrid Space, with Atau Tanaka. Proceedings of the Cast01 Conference on Communication of Art, Science and Technology, September 2001 / GMD - Schloss Birlinghoven, Germany.

Using Haptic Feedback to Enhance Computer Interaction for Motion-Impaired Users, with Simeon Keates and John Clarkson. Paper proposal for the International Conference on *Disability, Virtual Reality and Associated Technologies*, September 2000, Sardinia, Italy [accepted]

Exploring Novel Ways of Interaction in Musical Performance, *Creativity & Cognition* ACM conference proceedings, Loughborough, UK. October 1999 ISBN 1-58113-078-3/99/10, pp. 76 – 81

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The Use of Active Tactile and Force Feedback in Timbre Controlling Musical Instruments, Proceedings of the *International Computer Music Conference* (ICMC) in Århus, Denmark. September 1994.

<u>*Consultancy and (internal) reports*</u>

Multimodal Interaction in Protospace, report for and with the Hyperbody Research Group of the Delft University of Technology, 50 pages in colour, January 2005.

Interactivating Technology, Modular Human Interface System, research report for FoAM Brussels, 18 pages A4, September 2002

Metronom Studio, Laboratory for the Electronic Arts. Set up phase report, 68 pages A4/A3, illustrated, Barcelona March 2002

Physical Interaction Systems for the Metapolis Media House, 18 pages colour A4/A3, August 2001

Metronom Electronic Arts Studio, project proposal, 19 pages A4, illustrated, February 2001

Heptameron Sensorik, 15 pages A4/A3 + appendices, sensor and interface technical advice for the Heptameron opera commissioned by the Munich Biennale, ZKM Karlsruhe, January 2001

HyperMusic and the Sighting of Sound, project report and CD's for the European Commission, together with Jonathan Impett and Yolande Harris, February 2001, 91 pages full colour (available on line at www.Meta-Orchestra.net)

Threshold Levels of Tactual Sensitivity of Motion-Impaired Users, internal report, Engineering Design Centre, Cambridge University, June 2000

Investigating the Role of the Sense of Touch in Multimodal Human-Computer Interaction, unpublished MSc. thesis, The Hague / London. September 1999.

Physical Interfaces in the Electronic Arts, Workbook for the Rijksakademie van Beeldende Kunsten, September 1999.

Technische Werkplaatsen Beleidsplan, with Willem Jan Gasille (ed.), Rijksakademie van Beeldende Kunsten, 53 pages A4, Amsterdam, August 1998

A Survey and Taxonomy of Input Devices and Haptic Feedback Devices (Philips Report, company restricted) Nat.Lab Technical Note TN-298/97. October 1997

WWICE User Interface Concepts (Philips Report, company restricted). Richard van de Sluis, Bert Bongers, Han Kohar, John Jansen, Steffen Pauws, Berry Eggen en Huib Eggenhuisen. September 1997

Multimodal Interaction Styles: 1996 Year End Report Philips report (company restricted). David Keyson, Bert Bongers, Berry Eggen and Pete Dixon. January 1997

Ease of Use programme, phase two multimodal interaction styles: Expert Appraisal, Philips report (company restricted), Pete Dixon and Bert Bongers. 1996

Key Concepts of Multimodal Interaction, Project Definition. Philips report (company restricted), Berry Eggen, Bert Bongers, Don Bouwhuis, David Keyson, Jan Odijk, Steffen Pauws and René Scheffer. 1996

Magazines etc.

Een computer moet je kunnen voelen, Automatiseringsgids feature article, with Gerrit van der Veer, May 2005.

Interactivating Spaces *L'Arca Edizione* architectural magazine, essay accompanying images of projects of Sonia Cillari, June 2003

An Interview with Sensorband *Computer Music Journal.* 22(1). MIT Press, ISSN 0148-9267. Spring 1998 pp. 13- 24 and front cover. Available on line at http://mitpress.mit.edu/journals /COMJ/sample-article.html.

Applying Technology in Music: Where It Came From and Where It Should Be Going IndieVisions Newsletter for Artistic Technologists, Pavo Inc. Seattle, WA, August / September 1997

New Electronic Musical Instruments, Restoring the Relationship Between Sound Source and Control *XOOtic Magazine*, magazine of the association of alumni and students of the Post-masters programme Software Technology, 4/2, December 1996.

Lectures and Presentations

Invited lecture at the **Designed Intelligence** group at the Faculty of Industrial Design, Eindhoven University of Technology, June 2005

The Aesthetics of the Interface Conference, University of Århus, Denmark. Keynote Speech *"e-cology: The Electronic Ecology"* and workshop leader *"Interfaces: from the Intimate to the Interspace"*, November 2003

Medialogy department of the Aalborg University Esbjerg, Denmark**.** Lecture with Yolande Harris, November 2003.

STEIM, discussion evening with Yolande Harris about our Arts Practice and Research, Amsterdam, The Netherlands, 7 January 2003

Elisava Design School, Master in Interface Design for Multimedia, Barcelona, Lecture with Yolande Harris on Instruments & Scores, November 2002.

Vrije Universiteit, Master in HCI, Multimedia & Culture, Amsterdam. Lecture on interfaces, November 2002.

Lecture *New Instruments, New Music, New Paradigms*, with Yolande Harris, festival **Musica a Metronom, Barcelona**, 16 January 2002.

Metapolis / MIT Media Lab Think Tank, Museu de la Ciència, Barcelona. Lecture *Interactive Structures*, 26 September 2001.

Concordia University, Montreal. Public lecture at the Design Art department, 28 June 2001

Audio-Visual Institute, Universitat Pompeu Fabra, Barcelona, Master in Digital Arts program. Lecture *Physical Interfaces in the Electronic Arts*, 27 April 2001.

Birmingham Institute of Art and Design, England. PhD and staff, Lecture *Feeling Sound and Textures in Electronic Instruments*, and demonstration, 19 May 2001.

Seminar *Interactivating Spaces* for the postgraduate course **Advanced Architecture for Digital Cities**, Metapolis / Universitat Politecnica de Catalunya, Barcelona, one week, March 2001

Dartington College of Arts, Devon, UK. Lecture "*Building Interactive Interfaces (DIY)*", as part of the Staff Digital Seminar Series, invited by Scot Delahunta and Jo Hyde. March 2000

Engineering Design Centre, University of Cambridge, lecture "*Physical HCI - for Motion-Impaired Users ?!*" March 2000

Computer Laboratory, University of Cambridge, UK. Lecture "*The Role of the Sense of Touch in Multimodal Human-Computer Interaction*", seminar for the Rainbow Group. November 1999

Royal College of Art (RCA), Master in Computer Related Design, London. Lecture on Electronic Musical Instruments and special guest in students crit. December 1997

Helmholtz Institute, Physics of Man department, University of Utrecht. "*Electronic Musical Instruments and Haptic feedback*". 1997

Royal College of Art (RCA), Master in Computer Releated Design, London. Lecture on Electronic Musical Instruments and individual talks with students. January 1997

Philips Research Labs, Redhill, UK. Delivered lectures "*Electronic Musical Instruments*" and "*Multimodal Interaction*". January 1997

IPO (Institute for Perception Research), Eindhoven, NL. Lecture: "*User Interfaces for Musical Applications*". October 1996

Pro-Audicom Seminar, Rotterdam, NL. Delivered lecture and demonstration of electronic instruments. September 1994.

AES (Audio Engineering Society) meeting Royal Conservatory, The Hague. Lecture on new electronic musical instruments. Dec. 1993

Performances

<u>Video-Organ with Yolande Harris</u>

Between Two, Duet for two mobile video players, in **Entre-Deux**, Maastricht, The Netherlands, December 2003.

Gaudeamus International Music Week, August 2003, ‘Kraakgeluiden’ concert at STEIM, Amsterdam.

Inside Out, **Nau Côclea**, Camallera Spain, July 2002

Paradise, **NIME conference and festival**, Dublin Ireland, May 2002

STEIM, Studio for Electro-Instrumental Music, presentation, Amsterdam, March 2002

MediaEval, **Alicante Casino**, Alicante Spain, January 2002.

MediaEval, **Musica a Metronom**, Barcelona, January 2002.

Painting Music, Centre for Contemprary Culture Barcelona (CCCB), with the Ensemble Barcelona Nova Musica of Christiaan de Jong, at the Festival de Cinema Independent l'Alternativa, 20 November 2001

Metapolis Digital Day @ Media House, Mercat de les Flors, Barcelona. Four performances, September - October 2001.

BAT, **Metronom, Barcelona**, 21 June 2001.

<u>Meta-Orchestra</u>

Facelifters, Koolmijn Waterschei, Genk, Belgium, April 2005

Intro | In Situ, Maastricht, March 2004

Metronom Festival *New Instruments, New Music, New Paradigms* Barcelona, January 2002

Felix Meritis, Amsterdam, organised by the **IJsbreker**, February 2001

Dartington International Summer School, England, August 2000