Designing Kinetic Objects for Digital Information Display

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Bachelor of Fine Arts in Industrial Design
University of Michigan, 1995

Submitted to the Program in Media Arts and Sciences,
School of Architecture and Planning,
in partial fulfillment of the requirements for the degree of
Master of Science in Media Arts and Sciences at the
Massachusetts Institute of Technology

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abstract

We have access to more and more information from computer networks. However, the means of monitoring this changing information is limited by its access through the narrow window of a computer screen. The interactions between people and digital information are now almost entirely confined to the conventional GUI (Graphical User Interface) comprised of a keyboard, monitor, and mouse, largely ignoring the richness of the physical world.

As a critical step in moving beyond current interface limitations, this research is attempts to use many parts of our environment to convey information in a variety of ways. Rather than adding more video terminals into an environment, this thesis examines how to move information off the screen into our physical environment, where it is manifested in a more physical and kinetic manner. The thesis explores how these kinetic objects can be used to display information on a more visceral cognitive level than afforded by the interfaces of generalized information appliances like the computer.

The approach in this thesis is through several exploratory design studies. A geography of the design space of kinetic objects as digital information displays was developed through this series of design studies so that it can be used in the development of future kinetic displays.

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contents

1 introduction

Video display screens have proven to be flexible multipurpose display mechanisms. However these video screens are lacking as an output mechanism with respect to the rich modalities possible between people and physical objects. *"Screens continue to grow larger and more dominant – signaling a decrease in the significance of the bodies on which these dynamic surfaces lie, gradually rendering them meaningless."* (Maeda and MacGee 1993)

A vast amount of digital information is presented on small rectangular windows. This information is presented on two dimensional computer screens that must be in the center of a user's focus to be processed. The interactions between people and digital information are now almost entirely confined to the conventional GUI (Graphical User Interface) comprised of a keyboard, monitor, and mouse, largely ignoring the richness of the physical world.

Taking inspiration from the kinetic art movement of the early 1900's (Burnham 1968), using a broader view of display than the conventional GUI, I am attempting to make use of the entire physical environment as an interface to digital information. Instead of various information sources competing against each other for a relatively small amount of real estate on the screen, information is moved off the screen into the physical environment, manifesting itself as changes in light, sound, color, smell, temperature, or movement.

These kinetic displays are well suited as a means to keep users aware of people or general states of large systems, like network traffic and weather in a manner that is more instinctual and natural than current methods of display. I believe that this approach will be a critical step in moving beyond current interface limitations. Kinetic displays are envisioned as being all around us. They are suited for the home environment and everyday life. People have a need to feel connected to others, especially loved ones, and ambient displays can aid in this connection. Other well suited spaces include highly specialized environments where many streams of information need to be persistently monitored.

1.1 motivation

The advent of smaller microprocessors, sensors, and actuators is allowing computers to be embedded within the physical world in ways that have not previously been feasible. However, the utilization of this technology is often limited by preconceived notions of what computer technology is useful for, based upon how computers are currently used. For example, currently, almost all objects with embedded microprocessors have tiny LCD display screens and speakers as their primary, if not sole methods of display. *"As technology advances towards greater possibilities for realizing dynamic forms, for example as depicted by microrobotic and nanotechnology research, it is inevitable that most objects that we use will become increasingly dynamic"* (Maeda and MacGee 1993)

We have access to more and more information from computer networks that is continually changing. However, the means of monitoring changing information is limited by its access through the narrow window of a computer screen. To address this problem, current graphical user interfaces use several layers of graphical windows on a computer desktop. Yet, this does not allow us to stay connected to the general state of these various information sources simultaneously. In addition, information has to be accessed deliberately, rather than being continuously displayed. Rather than having the information shown through narrow windows of the computer screen, it is possible to have many different channels distributed within our physical environment to convey this information.

1.2 thesis scope and overview

In Human Computer Interaction (HCI) research, the word display is commonly used to describe a computer screen or video terminal. I am using the broader definition of a display.

Display \Dis*play"\, n. An opening or unfolding; exhibition; manifestation.

-Webster's Revised Unabridged Dictionary (1913)

Removing the narrow definition of the term display in the context of a computer, it is possible to consider using many parts of our environment to convey information in a variety of ways. Rather than adding more video terminals into an environment, I am moving information off the screen into our physical environment, where it is manifested as changes in sound, smell, temperature, color, light, and movement.

This research does not seek to replace current computer displays. Instead, my goal is to develop new types of displays that can allow the creation of environments that can keep us connected to information in a more aesthetically pleasing and humane way than is afforded (Norman 1988) by current model of on screen information display.

In the Tangible Media Group at the MIT Media Laboratory my research examines how kinetic physical objects in an architectural space could be used to convey information. In the scope of this thesis, I am addressing the use of movement and light as methods of display. While I acknowledge that sound smell and temperature could all be viable and interesting methods of display, they will not be focused upon in this thesis work. There is a body of work addressing these areas or perceptions, which I will discuss in the following chapters. The selection of movement and light has allowed me to use my experience in designing visuals and physical form. *"Designers have powerful abilities to convey complex non-obvious information using shape and color."* (Smets, Overbeeke et al. 1994)

I am exploring how these kinetic objects can be used to display information on a more visceral cognitive level than afforded by the interfaces of generalized information appliances like the computer. Computers are capable of giving us exact quantities or very specific information. Specific data is not what is always needed, or even desired. Instead, there are times when we would like to receive the "gist" or a summary of information, rather than the detailed data. In this thesis, I approach these issues through several exploratory design studies.

Rather than designing these kinetic displays specifically for the mapping of a particular information source, with these studies, I start with intuition and inspiration to develop new and provocative objects. I then explore how these physical kinetic objects can be used to convey information. These design studies also bring to light other ideas about the use of kinetic objects. The design centered research method allows me to see possibilities beyond common assumptions about what a computers are and how we should interact with them. Allowing me to develop a map of the design space for physical kinetic displays.

1.3 accomplishments

Before I go further into this thesis I would like to state what has been accomplished in this research.

1. I Developed a personal methodology for design research and explain a solidly design focused research approach.

2. Broke new ground in the development of new forms of information display in the physical world, with the idea of kinetic information displays.

3. Designed more than 7 examples of physical kinetic information displays.

4. Developed a map of the design space for kinetic information displays.

5. Envisioned and built expressive and emotive physically kinetic objects for information display

6. Documented several possible directions for research to follow in this arena

7. Developed the notion of a Multi-Locational Object for use as a haptic communication channel.

2 background and related work

2.1 integrating computation into our environment

Two main bodies of work influence my research with respect to integrating computation into our environment. Mark Weiser's vision of Ubiquitous Computing (Weiser 1991) explored the need to have computation more transparently integrated within our environment, though it relies on the interface conventions of graphical user interfaces. However, the concept of integrating computation more seamlessly into our environment is a key concept that informed our research.

Our work in the Tangible Media Group at the MIT Media Laboratory take this integration further, by blurring the boundaries between the computation and our physical environment. Ambient Displays are part of our broader "Tangible Bits" vision that blurs the boundary between the physical and digital worlds to create an "interface" between humans and digital information in cyberspace. We are turning each state of physical matter - not only solid matter, but also liquids and gases - within everyday architectural spaces into "interfaces" (Ishii and Ullmer 1997).

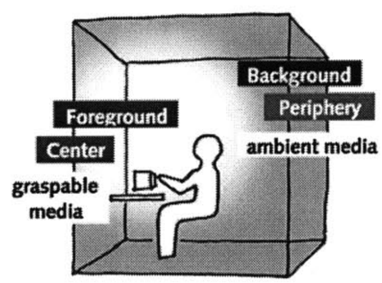


Figure 2.1
The Tangible Bits vision blurs the boundary between the physical and digital worlds to create an interface between people and digital information.

The key ideas of "Tangible Bits" are concepts of graspable media and ambient media (figure 2.1). We are developing ways to allow users to grasp and manipulate bits (digital information) with their hands at the center of attention, and enable users to be aware of background bits at the periphery of perception using ambient media.

2.2 awareness in HCI research

Awareness is the state of knowing about the environment in which you exist, about your surroundings, and the presence and activities of others. Awareness is essential in collaboration to coordinate the activities in a shared workspace. Awareness support discussed in the Computer Supported Cooperative Work (CSCW) community has focused on the representation of the state of collaborators in a geographically distributed context. Technological devices such as remote cursors, multiple scroll bars, audio cues, and low framerate video have been proposed to support the awareness of remote collaborators' activities. Dourish and Bly's Portholes project (Dourish and Bly 1992) is an example of an awareness support system using low resolution, low framerate video.

My notions of awareness through Ambient Display Media are in part, inspired by the Fields and Thresholds work of Dunne and Raby (Dunne and Raby 1994), the Live Wire of Jeremijenko (Weiser and Brown 1995), and the Pillow of Dunne (Dunne and Gaver 1997). As well as our Ambient Media research in the Tangible Media Group at the MIT Media Laboratory (Ishii and Ullmer 1997 ; Dahley, Wisneski et al. 1998; Ishii, Wisneski et al. 1998 ; Wisneski, Ishii et al. 1998) . These projects explored a theme of peripheral awareness of external activity, especially of activity attributable to people. The AROMA project (Pedersen and Sokoler 1997) further investigates ideas of peripheral awareness. These researchers share many of our (Tangible Media Group's) ideas, especially with respect to the use of subtle and abstract displays.

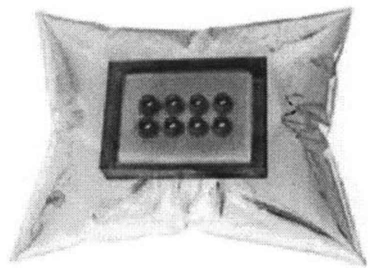


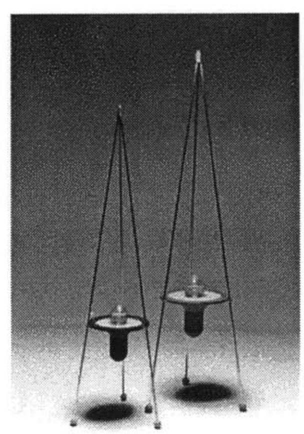
Figure 2.2
The Pillow designed by Dunne, is an unusual and provocative idea for a display device.

2.3 kinetic displays

The body of work in kinetic sculpture (Burnham 1968) as well as Live Wire and Sound Furniture are an inspiration in respect to my ideas about using kinetic physical objects as information displays.

Live Wire (Weiser and Brown 1995) is a device created by Natalie Jeremijenko while an artist in residence at Xerox PARC. The Live Wire is a rubber tube that hangs from a small motor mounted on the ceiling. The Live Wire is connected to the Ethernet network such that network traffic causes movement of the rubber tube. The movement of the wire is visible and audible through its environment. This work was an inspiration for the notion of displaying digital information through physical devices. It has a dedicated single function to react based upon the network traffic. Its physical form and method of movement express this link to the information being displayed.

Figures 2.3 and 2.4
The Live Wire (above) and the sound furniture (below) are interesting kinetic displays.



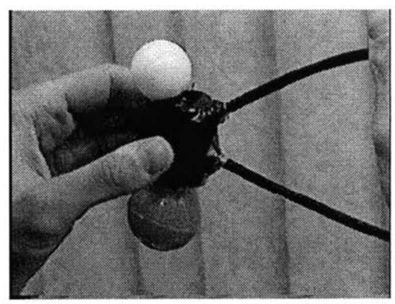
Sound Furniture (Hosoya 1996), designed by Tamon Hosoya, is a group of explorations in physical audio displays. These devices are connected to an input source and through physical means create sound that corresponds to the input phenomena. The designer's process tightly coupled the aesthetic and function design of the object. The functional goal of this project was not to create practical devices. The goal instead, was to gain insight into how an object could possible display information though the process of design.

2.4 haptics

In teleoperated control systems, a user manipulates a control device that is linked to a distant slave robot. To improve the performance of the operator, forces exerted on the slave are often "feedback" to the controller (Hannaford 1991). Such bilateral (two-way) force-feedback systems can be extended in a way similar to that suggested by Synchronized Distributed Objects if a second user physically interacts with the slave robot directly. These systems, however, are not intended for such use and thus lack the elegance desired in a device for interpersonal communication.

Much of the current research in haptics involves creating virtual objects with form, mass, and texture that can be felt with the help of a force-feedback device. In these systems, the force-feedback device (e.g. Immersion Corp.'s *Impulse Engine* or Sensible Devices' *PHANTOM*) serves as haptic portal to the virtual world much, as a monitor serves as visual portal. By contrast, inTouch, discussed further in chapter four serves not as a portal to another world, but as a link between objects in the real world.

A few projects have explored the design of haptic interpersonal communication systems. *Feather, Scent, and Shaker* (Strong and Gaver 1996) consists of a pair of linked "shaker" objects. Shaking one object causes the other to vibrate, and vice-versa. *HandJive* (Fogg, Cutler et al. 1998) is a pair of linked hand-held objects for playing haptic games. Each object has a joystick-like controller that can be moved vertically or horizontally. A horizontal displacement of the local object causes a vertical displacement in the remote object, and vice-versa. In this way, the input and output spaces are on the same object, but largely de-coupled—a design choice seen as an advantage by the designers since it prevents "fighting" over the state of the object. *Kinesthetic Constructions* (Schena 1995) is the only example known to the authors of applying bilateral force-feedback to interpersonal communication. Schena describes a network of large modern sculptures distributed around the world where parts of each sculpture are hapticly connected to sculptures at other locations.



Figures 2.5
The HandJive is a concept for a haptic communication/game device.

3 approach: design as research

The majority of research on human-computer interaction (HCI) is restricted to the fields of computer science and psychology. The work is done following scientific traditions, aiming for an objective stance in which practitioners articulate, analyze, abstract, and facilitate perceived users' needs. (Dunne and Gaver 1997) This is an extremely important and valuable method of study, which has brought HCI quite a long way. It is an excellent method to measure a quantifiable hypothesis. However, it is more difficult to evaluate qualitative ideas with this scientific method. It is not always the best method to generate new ideas. Idea generation is can be an ad hoc, or magical process. Using scientific methods ideas have to be developed before the research is even considered to begin.

Design methods can be extremely valuable research tools both for developing hypothesis and evaluating qualitative ideas (Lambourne, Feiz et al. 1997). The design process is a method for inspiration as well as validation (Burns 1998). There is a defined process for the generation of ideas. The intention of design research is not to measure or prove a hypothesis but to raise new questions and issues about how we *could* interact with technology. It is an exploratory method in which the goal is to realize new possibilities. No single solution is considered 'correct', but instead designers tend to explore many ideas and concepts related to a subject before developing any given possibility (Dunne and Gaver 1997). The scientific method and design base methods can be complementary methods to approach research.

The research topic of this thesis is relatively new, I am still trying to define the problem space and determine the questions to be addressed. I believe that using design methods is an appropriate approach to further the development of new ways to think about the display of information within the physical environment. In the following sections I will attempt to explain the design process and how I consider it be used as a method to approach research. I will emphasize the difference between design and design research, as similar processes but with different goals in mind.

3.1 design process

Defining the comprehensive meaning of design is not my intention. A complete definition of design would be an extremely large undertaking not done justice in a chapter of a thesis. I am giving an introduction to the design process to give context to my use of design process as a research method.

I believe that Paul Rand has written an excellent concise description of design.

"To design is much more than simply to assemble, to order, or even to edit; it is to add value and meaning, to illuminate, to simplify, to clarify, to modify, to dignify, to dramatize, to persuade, and perhaps even to amuse. To design is to transform prose into poetry. Design broadens perception, magnifies experience, and enhances vision. Design is the product of feeling and awareness, of ideas that originate in the mind of the designer and culminate, one hopes, in the mind of the spectator." (Rand 1993)

Victor Papanek's definition also an excellent explanation with a slightly different tone.

"Design is the conscious and intuitive effort to impose meaningful order. It is only in recent years that to add the phrase "and intuitive" seemed crucial to my definition of design. Consciousness implies intellectualization, cerebration, research, and analysis. The sensing/feeling part of the creative process was missing from my original definition. Unfortunately intuition itself is difficult to define as a process or ability. Nonetheless it effects design in a profound way. For through intuitive insight we bring into play impressions, ideas, and thoughts we have unknowingly collected on a subconscious, unconscious, or preconscious level." (Papanek 1984)

As Papanek mentioned, the process of design is difficult to explain. When it is done well the process is a fairly subconscious, and in the background. Driving a car is a worthwhile analogy. Once a person develops the skills they don't really consciously think about driving, it becomes natural and instinctive. The process is internalized. "You just drive." The only way to develop these skills is to practice. It is difficult to teach someone to drive with a lecture or by having him read a book about driving. It's more feasible and effective for the instructor to get in the car with the student and go along for the ride their first few times, guiding them out along the way. After a while, as a person practices driving they do not always have to concentrate as much on the process of driving and it becomes natural, almost subconscious. When you make a left turn you don't think about how far to turn the steering wheel, and when to straighten it, instead you just make a left turn. Design is a very similar in this respect. An instructor can guide the student through the process but the best way to learn is to try the task. Once a person goes through the design process many times they stop thinking so much about it and start to internalize the process.

"The most valuable part of the design process is that which goes on inside the designer's head and partly out of reach of his conscious control. Despite its 'irrational' assumption, this black box view of

designing can be quite clearly expressed in cybernetic or physiological terms: we can say that human designers, like other animals, is capable of producing outputs, or actions without being able to say how these outputs were obtained. When the mysteries of creativity are expressed in this way we can see that they are only a special case of the equally mysterious way in which we produce most of our outputs, or actions, without being able to explain them. The apparently simple action of writing, and even simpler action of reaching for a pencil without looking at it, are just as inexplicable as is the composing of symphony, perhaps more so." (Jones 1992)

When driving in an unfamiliar environment the driver use the same driving skills and experience. It is just a new context for applying those skills. The driver learns how to navigate through the new environment using his/her driving skill set. The driver concentrates on the new environment much more than the lower level task of driving. This is analogous to approaching a new design task. The designer uses the same design process and skills developed but in the context of a new problem.

I would like to further explain the design process as it is used for product development which I learned in design classes and as a practicing designer.

The design process is somewhat of an oral tradition that is handed down to designers in training, however there have been some excellent writings attempting to define the process (Asimow 1962; Gregory 1966; Papanek 1984; Jones 1992; Spreenberg, Salomon et al. 1995). There is only a rough consensus on the explanation of design process (Jones 1992) All have a fairly common theme but variations in how the process is divide. I do not believe that there is one single correct answer. I discuss my current view of the design process which comes from an assimilation of several sources (Asimow 1962; Archer 1965; Jones 1992; Spreenberg, Salomon et al. 1995; Lambourne, Feiz et al. 1997) as well as my own experience. In order to explain the process, I divide it into six phases; research, conceptualization, refinement, simulation, evaluation, and finalization.

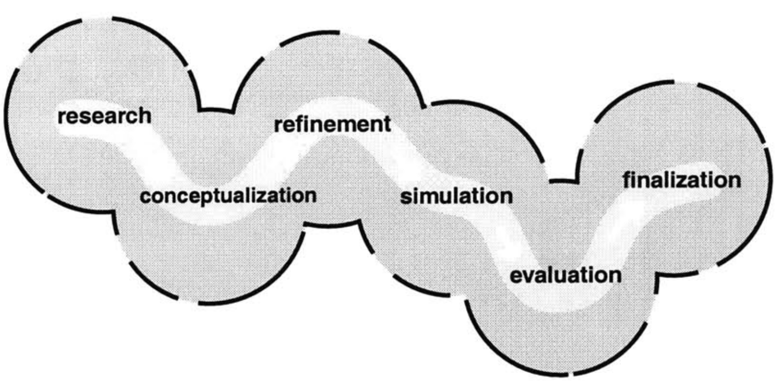


Figure 3.1
A diagram explaining the generalized process of design. Though it shows six discrete phases, the process is much more fluid then it is portrayed in this diagram. This is for the sake of more clearly explaining the fundamental process before getting to caught up in the more subtle details of the process.

3.1.1 research phase

In the research phase a designer needs to identify, define, understand, and agree on the nature, context and content of a design problem; as well as on the general and specific factors which impact on it. This is called problem identification (or more positively called opportunity identification). Design problems can de defined by the forces that directly or indirectly impact on and shape them, and the context in which they exist. Research affects and guides the designer's attitude and approach to a design solution. At the end of the research phase, criteria for a design are established, based upon the gathered knowledge.

3.1.2 conceptualization phase

In this phase, the designer translates the contents of the design research and criteria into initial design concepts, usually 2 dimensional concept sketches. The process involves exploring as many permutations of the effects of a problem's components, conditions, and forces as possible. Concepts perceived as interesting, promising, or merely provocative can be identified and selected for further consideration and evaluation through additional conceptualization. From the various concepts a single final design concept evolves.

3.1.3 refinement phase

When a concept is selected it is then explored more thoroughly. This is done through more in-depth study of the concept. The designer brings more detail to the design concept. The concept is put through another round of development, identifying alternative directions. Preconceptions or limited design exploration can lead to compromised decisions and predictable, or even unsuccessful design.

3.1.4 simulation phase

Once a design concept is developed enough, we can enter the simulation and prototyping phase. In this phase a model of the design is built. The goal is to create a feel for the actual design. These models may be very rough mock-ups of designs, that need some imagination to visualize the complete design scenario, or completely functional prototypes, or anything in between. The level of refinement mostly depends upon the amount of time necessary to create a model and the necessary level of visualization.

3.1.5 evaluation phase

Examining the prototype, the design's performance is appraised. Its effectiveness in achieving planned objectives. If there are problems the design can go through various levels of redesign. Eventually these problems are resolved, and the design can be finalized.

3.1.6 finalization phase

All the details are determined and resolved. The design is completed and realized in its final form. It goes to the presses, manufacturing line, written onto disc, burnt onto a chip, or uploaded to the web, depending on the medium.

3.1.7 complicating the process model

Though I am describing these phases as an extremely linear process, this is only a starting point to explain the process. Often there is not such a strong delineation between the phases. One phase might blur into another, or the designer may not always follow the process in a completely linear fashion. The designer may decide within the simulation phase that new ideas arise and it is necessary to step back to the conceptualization phase to develop these new ideas. During the research phase, the designer might decide that it is important to jump forward to the simulation phase to understand some idea. Though the linear model of the design process gives a strong spine to the activity of design, it is used in a flexible manner to avoid impairing innovation and creativity.

3.2 design research

I want to clarify that design research and the initial phase of the design process are two separate ideas. By design research I mean using the entire process of design used as a method to approach research.

In general the goal of design is a final product or object, to be produced, sold and used. It is assumed that this is the goal for any designed object. The designer is trying to find a path through the design space to a successful solution. However, this is not the goal of design research. In design research, the goal is the learning that comes about from the process of designing an object rather than the object itself. The designer is attempting to take many different paths through the design space to map out its "geography". The goal as a research process is to understand as much as possible about the design space. Philips Vision of The Future Project is an example of the use of design as research (Lambourne, Feiz et al. 1997).

In design as product development, more time and resources are spent towards the end of the process. This is due to the fact that the final object of design is the goal of the process. However, in design as a research process more time and resources are spent in the beginning of the process because a great deal of the ideas and learning come from the beginning of the design process. The goal of design research methods is to raise questions, issues, and explore possibilities beyond current notions. This focus on design research methods is especially important in new fields or research in which the research issues and possibilities are just surfacing.

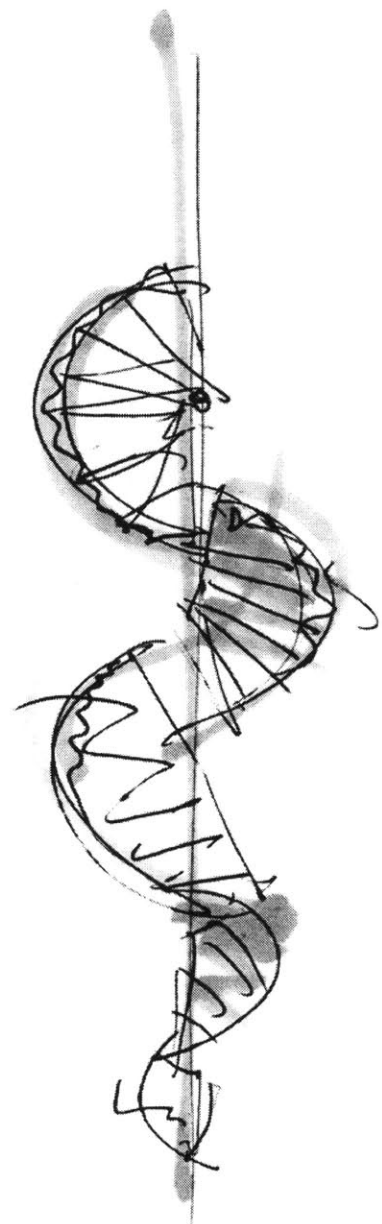
3.3 understanding the medium

Designers (and researchers) must understand the underlying technology of the objects they create, just as craftsman understands his tools and materials (McCullough 1996). For example, if an artist is carving in wood and does not understand techniques to sharpen his chisels, then their effectiveness will be lessened. The artist must also understand the material, and what its properties allow. Without this experience and understanding the material will determine more of the final design than the artist. The final work will not be what was intended.

In exploratory design research, it is important for the designer not to be bound by arbitrary design constraints, especially in the development of entirely new types of technological artifacts. Previous notions and misconceptions of the composition of technological artifacts should not be reinforced in early phases of idea generation otherwise, the product of an uninformed process will tend to follow in the footsteps of past developments. The material of the design will rule the final outcome.

This understanding of the medium has been a very important part of my process in the development of the design studies in the following chapter. Using conventional divisions of disciplines, these design studies involve concept design, system design, industrial design, interaction design, mechanical design, electronics, and software design. I am considering all of these aspects in order to create the design studies addressed in the following chapters of this thesis. Therefore it is important for me to make all design decisions, understand every piece of code, and the entire layout of the electrical circuit as well as entirely handle the mechanical, industrial, concept, and system design.

4 design studies



The design studies as treated in this thesis are the results of the design research process. The design studies are explorations manifested in a form that allow experimentation with a concept. These development of these design studies is used as a process to start to understand the design space for Kinetic information displays. Often in industrial design, a design study is a 3-dimensional model or a sketch, normally not functional. Often form is one of the primary elements being explored in industrial design. However, these design studies have been created to focus much more on interaction as well as movement and changes in form over time rather than static form design. Each study can be seen as an evolution or experiment with ideas from previous design studies, as with Braitenberg's Vehicles (Braitenberg 1984). Thus most of them are functional prototypes, or at least articulating mock-ups rather than highly refined physical form designs.

"When you make a thing, a thing that is new, it is so complicated to make it that it is bound to be ugly. But those that do it after you, They don' t have to worry about making it so they can make I pretty, and everyone will like it, when others make it after you" Pablo Picasso (Gedo 1982)

I use initial observations, creative inspiration, and intuition as a starting point for these design studies. Through the design process, over time tacit knowledge is built up about the design subject matter. This is sometimes called a "designer's intuition." The design studies are a vehicle to externalize this tacit knowledge (Polanyi 1983) and communicate it to others. Designers develop and communicate ideas and address through these objects just as an artist does through a work of art.

4.1 ambient room

In the ambientROOM project, as part of the Tangible Media Group, we explored how an architectural space could be used to convey information to a user and have that information smoothly transition from the user's center of attention when needed and fade into the periphery when not in use (Wisneski, Ishii et al. 1998) (Ishii and Ullmer 1997) (Ishii, Wisneski et al. 1998). This work was a preliminary investigation into background, or peripheral interfaces.

We developed the ambientROOM as a platform supporting the expression of on-line digital information with "ambient media" – ambient light, sound, airflow, and physical motion used as peripheral displays at the background of user attention.

4.1.1 implementation of the ambientROOM

The ambientROOM is based on the Personal Harbor™ product from Steelcase Corp., a 6'x8' enclosed mini-office installation (figure 4.1). The ambientROOM surrounds the user within an augmented environment – "putting the user inside the computer" – by providing subtle, cognitively background augmentations to activities conducted within the room.

figure 4.1
The ambientROOM is a platform to explore how architectural space could be used to convey information in a users periphery. It is based upon the Steelcase Personal Harbor™.

The implementation of the ambientROOM is designed to support quick prototyping. The ambientROOM is enabled with a host of products such as samplers, synthesizers, lighting-control boards, and software that allows easy synchronization of many media elements. Sensing and display in the ambientROOM are coordinated with Opcode's MAX software running on a Macintosh. MIDI-controlled dimmers adjust room lighting, a sampler manages sound playback, and rotation and electrical contact sensors monitor manipulation of the clock and bottle. An electric field sensing unit was used to monitor human movement in surrounding spaces. Video projectors augment the ambientROOM's clock, walls, and desk surface.

4.1.2 hamster physical icon

One display in the ambientROOM allows the user to have some awareness of the activity of a distant loved one. For our first instance, we expressed the activity of a resident hamster in our laboratory, for which cage temperature, light level, and wheel motion had already been instrumented and displayed on a web page. A small, motorized representation of the hamster phicon (a physical icon) (Ishii and Ullmer 1997) was built and configured to vibrate as the hamster's wheel rotated. The hamster phicon displaying through vibration was fairly awkward. The vibration was not an ideal mapping of the real hamsters activity however, vibration can be an excellent method of display in other situations. Pagers are an example, using vibration to alert the bearer of an incoming message without disrupting others.

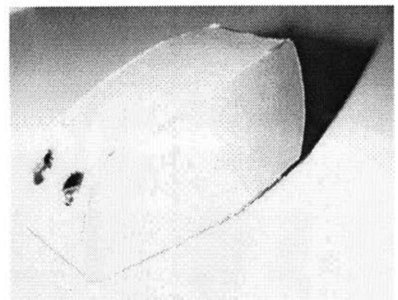


Figure 4.2
The hamster phicon (physical icon) is a small motorized representation, which vibrates when our real hamster is active.

The hamster phicon display was very much in the foreground of a person's perception, and thus did not meet our goals as a subtle ambient display. Although this is not the most successful example it made me start to consider the notion of physical kinetic display devices. The hamster phicon was a persistent display mechanism. It was single object with a single output function and it continually displayed its information source. This is different from current model of information display with computers, in which almost all information comes through a main foreground display screen. The information is not constantly presented. It must be accessed, rather than simply being able to shift your attention to another information display.

The hamster phicon display proved somewhat intrusive, so alternate display mappings were explored. The hamster representation could be grasped by the user and pointed at the ceiling of the room. The hamster phicon can be thought of symbolically as an information container where information can be transferred from one container to another.

4.1.3 reflecting water ripples

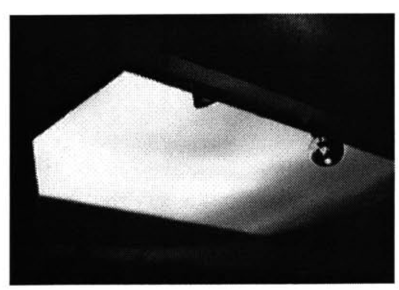


Figure 4.3
Water ripples reflect upon the ceiling in the ambient room actuated by an information source.

The action of pointing the hamster phicon at the ceiling transfers the mapping of the hamsters activity to the ceiling and the hamster phicon stops displaying the information. A small solenoid is actuated and taps in a shallow water tank. A lamp reflecting off of the water then produces rippling shadows on the ceiling.

4.1.4 active wallpaper

Another display also provides awareness of the physical presence of others. Electric field sensors are used to measure the level of human activity in a work area. This activity is represented by a pattern of illuminated patches projected onto an inner wall of the ambientROOM. The boarders of the projection are not visible. This removal of the rectangular frame makes the projected light patches appear to be a part of the wall rather than a projection. This perception is important in keeping the display a subtle integrated part of the environment, only calling attention when information is important.

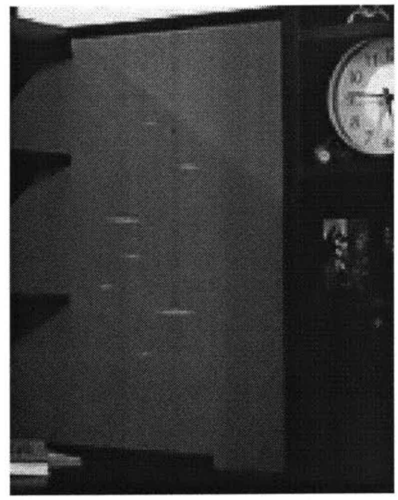


Figure 4.4
Active wallpaper: light spots are projected upon the wall of the ambientROOM. These spots indicate the activity level of the entrance way to our work space.

When activity is low, the movement of these spots is minimal, but as activity levels increase, so does the motion of the spots, providing a visual display of remote activity. This display did not give details about exactly how many people were in the space or who was there. Instead, it gave a more general notion of activity in the space. This level of monitoring is much less intrusive on person's privacy by only giving a general level of activity change, rather than specifics of who was where and when.

4.1.5 ambient sound

Auditory displays have been implemented as well. A series of sounds arise out of activity on the digital whiteboard in our group's workspace. When the board is in use, the sounds of the dry-erase pens rubbing against the board are transmitted into the ambientROOM in a low-volume, subtle way. This gives the inhabitant of the ambientROOM some awareness of activity in the central workspace. However, repetitious sounds can easily become annoying.

4.1.6 controls

To provide a means of controlling the ambient activity displays, several activity controls were deployed in the ambientROOM. Small physical bottles are employed as a graspable "containers" for digital content such that opening a bottle "releases" information into the ambientROOM. One bottle contains information about the load on our computer network, and when opened, that data is represented in the ambientROOM as the sound of vehicular traffic.

Figure 4.5
A small physical bottle in the ambient room was uses as a graspable control. Opening the releases the information "contained" within the bottle

A second activity control, a large wall-mounted clock with exposed hands, allows navigation through temporal events. A user recently absent from the room might wish to review activity displays from the past few hours, or skim forward in time to peruse anticipated events. In response to manipulation of the clock's time, the ambientROOM prototype shifts through the ambient sound and lighting displays of past hours.

We attempted to build controls to be self-explanatory. The gesture of opening and closing a bottle is a simple way of accessing information. The physical rotation of clock hands is equally simple and powerful. We envision that physical controls will be widespread in future environments, and will incorporate easy-to-use, gestural interfaces like the ones found in the ambientROOM.

4.1.7 applying the ambientROOM

The "awareness of people" application can be extended to monitor large systems of people, or behaviors that arise out of other large systems. Ambient displays could be suited to display general trends of stock values for a trader, network traffic information for a system administrator, or other information sources.

Another particularly interesting application to display is information about natural phenomena, such as atmospheric, astronomical, or geographical events. Displays such as these can give people an indication of the state of the world around them.

The ambientROOM contains a subtle but audible soundtrack of birds and rainfall, whose sound volume and density are modulated in conjunction with variations in room lighting. Thus, approximate quantities can be monitored with this display, for instance, the number of unread email messages or the level of a stock portfolio. Also, in this instance, the lighting in the ambientROOM changes according to the time of day.

It should be noted that GUI interfaces and ambient interfaces do not comprise a dichotomy of purpose and function. Subtle, background ambient displays are meant to coexist-exist with, and complement, foreground tasks. Also, background displays can move into the foreground, and vice versa. Users control this through their personal state of awareness, and sometimes, through physical controls.

4.2 ambient fixtures

Ambient fixtures (Dahley, Wisneski et al. 1998) are standalone ambient media displays. The ambientROOM was a exploratory platform to try to develop an understanding of how we could use ambient displays. My work in the ambientROOM lead me to create the ambient fixtures. I wanted to take the concepts developed within the ambientROOM and move them from the personal workspace context of the ambient room into an open space. In the ambientROOM, the user is "inside the computer," while ambient fixtures allow us distribute ambient displays throughout an architectural space for access several people at once. This is significant because it takes a step further away from the convention of a computer display as a device for a single person at a time. Instead, the ambient fixtures can be used by many people.

4.2.1 ambient fixture conceptualization

I spent a couple of days in the conceptualization phase sketching ideas for physical ambient displays.

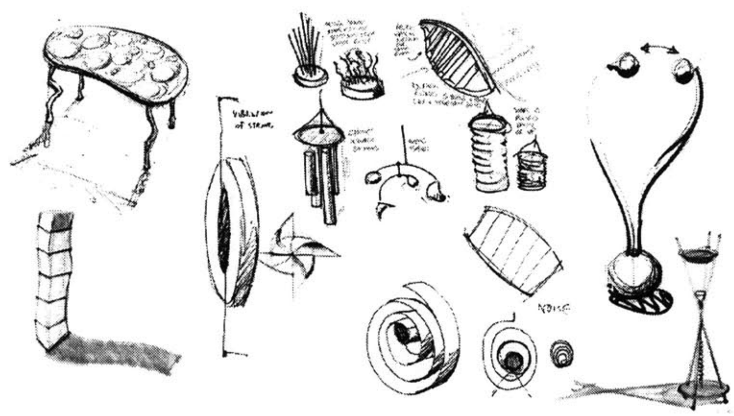


Figure 4.6
Conceptualization sketches for physical ambient displays

I selected three of my ambient fixture concepts for further development. The Water Lamp is an extension of the ceiling water ripples of the ambientROOM (Ishii and Ullmer 1997) and the Pinwheels explore the ideas of physical movement caused by invisible information flow. Both are designed based on the metaphor of natural physical phenomena. While the spline moves toward a provocative new direction of expressive kinetic motion, abstracting an information source.

The ambient fixtures, are based upon a common control platform- the iRX 2.0 PIC micro-controller board (Poor 1997) designed at the MIT Media Lab by Robert Poor. The iRX boards each accept commands over a serial line from a computer to control each fixture.

Each fixture, or cluster of fixtures have their own iRX board. This is a flexible prototyping system to allow us to distribute fixtures throughout our research space. TCL-based or visual basic software I used to send commands to the fixtures from a computer. Information can be relayed from the internet or other networked information source through the computer and be routed to the appropriate fixture.

4.2.2 the water lamp

Water ripples created by raindrops on the surface of still water was the starting point of the *water lamp* design. Instead of physical raindrops, imagine that "bits" (digital information) falling from cyberspace could create physical water ripples. The digital bits can be thought to manifest themselves as physical rain drops in our water lamp.

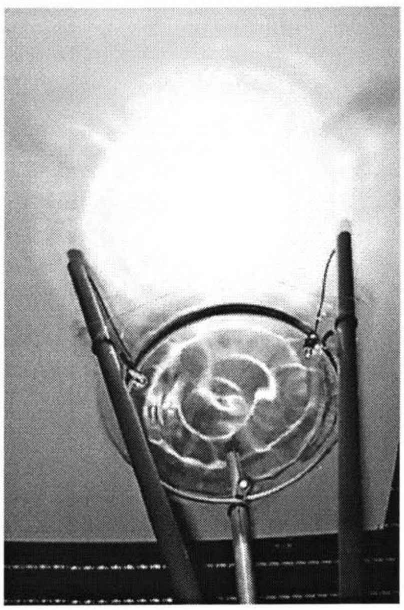


Figure 4.7
Detail of the water lamp reflecting upon the ceiling.

The water lamp is a free-standing floor lamp that I designed and built to display information through water ripples (figure 4.8). The water lamp is composed of a wooden base, 3 aluminum tubes and an acrylic water basin. There are 3 small solenoids mounted above the water basin. These solenoids are controlled through a single iRX micro-controller board. When actuated, the solenoids tap on the surface of the water in the tray, causing ripples in the waters surface. A light projects reflections of the water ripples onto the ceiling creating a very subtle and elegant display. (figure. 4.7).

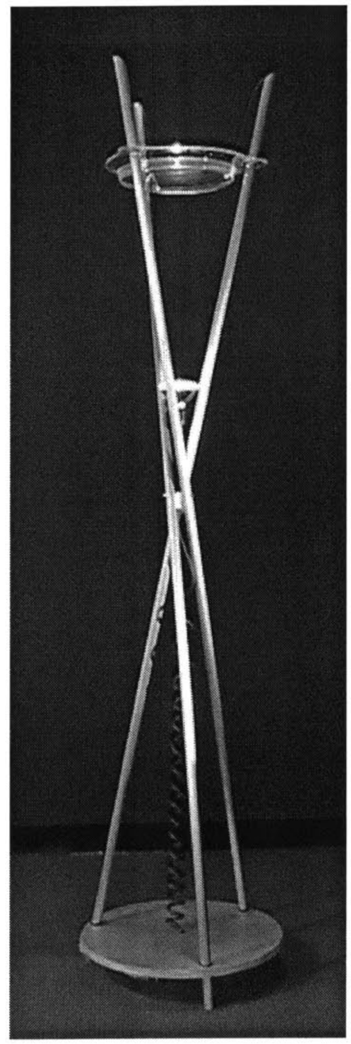
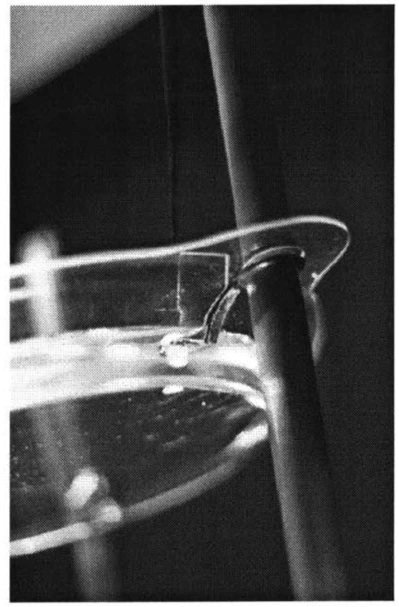


Figure 4.8
The water lamp is a free-standing floor lamp that can create subtle reflections of water ripples upon the ceiling based upon an information input.

There were several issues involved in the physical design of the water lamp. I needed to keep the light far enough away from the water tray to avoid overheating the tank and evaporation, or boiling the liquid. Yet the light needed to be bright and focused enough to created well defined reflections throughout the water. The aluminum tubes design allowed the heat from the bulb to dissipate while still allowing us to set the appropriate focal length between the light bulb and water tray. The aluminum tubes also worked well in routing the various cables though the lamp.



In the design of the water lamp I did not attempt to hide the mechanism or water but expose them to further express the functionality of the lamp. In the ambientROOM the water mechanism was completely hidden, disconnecting the user from the display mechanism. The Water Lamp is not tied to a single physical location because it is a standalone object, unlike the water display we implemented in the ambientROOM. This gives flexibility to experiment with different architectural contexts for the Water Lamp like the home, hallways, and public spaces, rather than focusing on the context of the personal work space as in the ambientROOM.

After building the water lamp I discovered that the three solenoids were not nearly as effective as simply taping on the aluminum support tubes of the lamp. The three solenoids created confusing and less dramatic water ripples. The water would also evaporate rather rapidly. The display on the ceiling was very ambient, perhaps too ambient. In our research space, people rarely looked up to the ceiling to observe the water reflections. From these issues I sketched ideas for a redesign of the water lamp. The second version was a hanging lamp. A more subtle light pointing down through water could be more effective than the reflections on the ceiling. I also made the liquid tray enclosed to avoid loss of liquid through evaporation and spillage for safety. I planned to use a liquid other than water that will not evaporate and condense, perhaps mineral spirits. I also put only a single solenoid actuator that taps on the enclosed container itself to create the water ripples. This keeps the electronics well isolated from the liquid.

Arrays of multiple water lamps could also be very interesting, however the time involved in fabricating several lamps was not possible in the time scope of this thesis.

4.2.3 the pinwheels

The *pinwheels* evolved from the idea of using airflow in the ambientROOM. The flow of air itself was difficult to control and to convey information. As an alternative, we envisioned that a visual/physical representation of airflow based on the "spinning pinwheels" could be legible and poetic. The pinwheels spin in the "bit wind" at different speeds based upon their input information source.

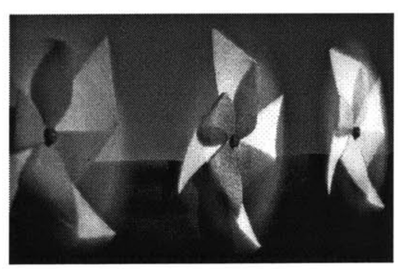


Figure 4.11
Pinwheels are both a visual and physical representation of airflow spinning at different speeds based upon a "bit wind"

These pinwheels could be connected to the audio levels the lecture hall or classrooms to allow someone to be aware of a meeting starting, through the subtle increasing speed of the pinwheels. This awareness could come from either feeling the airflow created by the pinwheels or viewing their increase in speed.

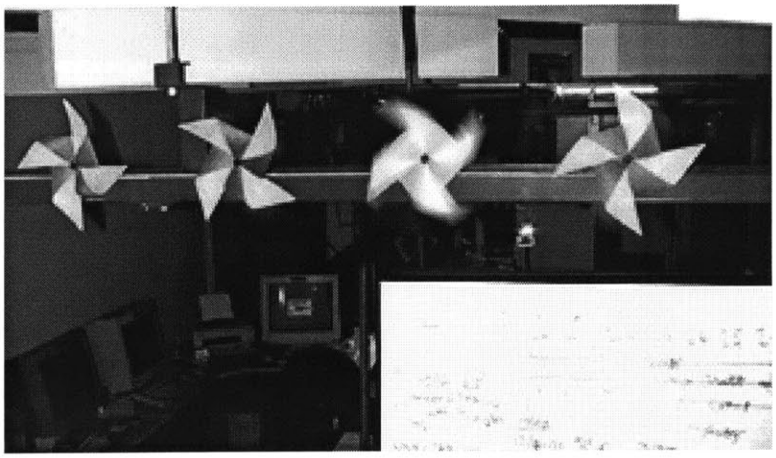


Figure 4.12
Pinwheels in use in the meeting space of the Tangible Media Group.

The pinwheels are made from folded fiberglass mounted on the shaft of a small DC motor. Four pinwheels are connected to a single iRX micro-controller. Pulse width modulation controls the speed at which the motors spin. The speed of each of the pinwheels is controlled by a computer through serial communication.

4.2.4 the spline

The *spline* is constructed from a piece of flexible springsteel mounted to five stepper motors in a row (Figure x). Rotating the motors causes the springsteel to flex into various expressive curves. The design of the spline afforded a much more abstract representation of the information source than the other ambient fixture design studies. Determining mappings to the spline that made sense was much less straight forward than with the other ambient fixtures. Yet I found the expressive and sculptural nature of the spline's dynamic movement very provocative and intriguing. For me this pointed toward interesting notions of more expressive objects that react to information in a qualitative manner rather than simply displaying it.

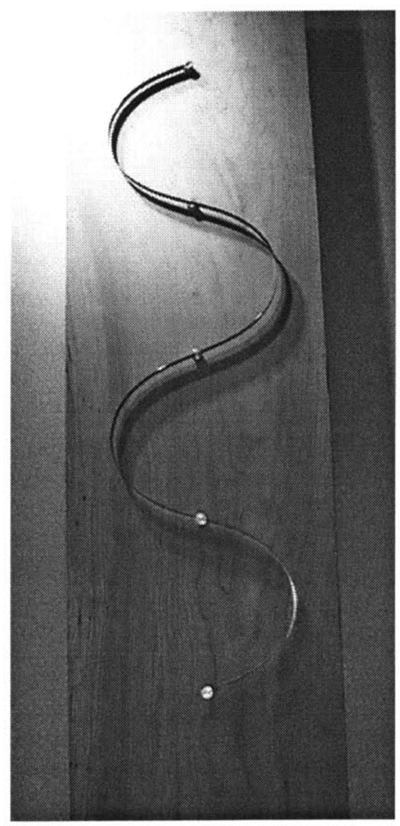


Figure 4.13
The spline is a flexible piece of springsteel with five rotary control points. It suggested intriguing ideas about more expressive and abstract physical displays.

4.3 the wobble lamp

After being inspired by the expressive nature of the spline, I developed several new expressive kinetic display concepts through sketching.

After generating these concepts, I showed them to several people to get their input on which idea I should pursue. Based upon their feedback and my own opinion I selected a wobbling lamp concept as the most potential.

The *wobble lamp* design study is a table lamp augmented with a microprocessor and the ability to physically move. The tilt direction of the lamp and light brightness can be computationally controlled. I created various patterns of movement and light change. The physical motion of the wobble lamp can be expressive. These expressive motions evoked a sense that the lamp was alive. This lead me to ideas about creating more social (Reeves and Nass 1996) methods to convey connotative information in our physical world through the use of expressive motion.

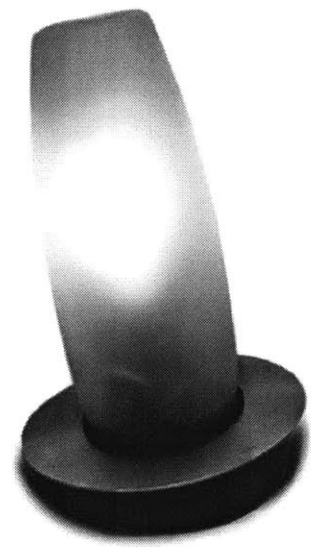


Figure 4.14
The wobble lamp is a table top lamp with the ability to physically move, or gesture.

The earlier design studies with Ambient Media Laboratory (Wisneski, Ishii et al. 1998) (Ishii and Ullmer 1997) (Ishii, Wisneski et al. 1998) mapped raw data to ambient display devices, leaving interpretation mostly to the user. However, the wobble lamp is able to react to data inputs in a qualitative manner, gesturing with patterns of physical movement and light rather than displaying raw data. For example, the lamp moves in a jittery fashion to convey nervousness or anxiety, or have smooth rhythmic movements and changes of light intensity to express happiness to an information state. These reactions of the lamp are then mapped to various input data alerting the users of the overall qualitative status of the data. In this way, the user is not required to always be aware of the various information sources, but instead, can perceive the more qualitative display of the wobble lamp.

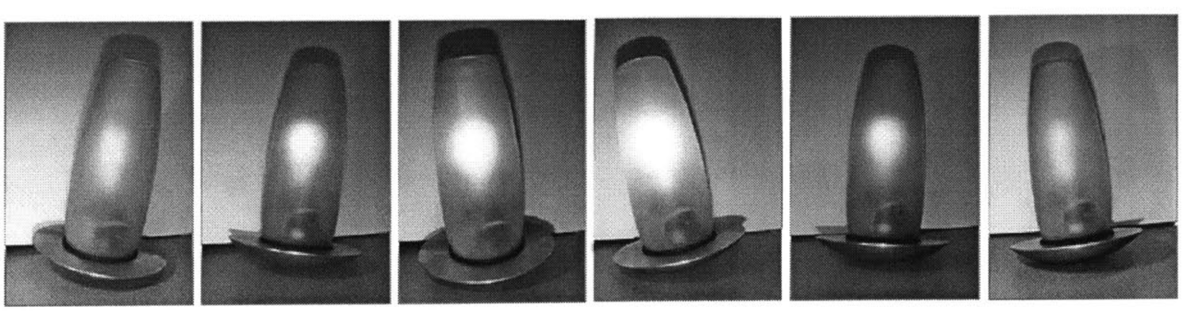


Figure 4.15
The wobble lamp is a series of movements. It reacts to an information source with varying patterns of motion and changes in light brightness.

4.3.1 implementation of the wobble lamp

The wobble lamp is composed of a frosted glass shade over a dimmable light bulb and a rounded aluminum base (Figure 4.17). An eccentric weight is mounted on the shaft of a stepper motor within the base. The stepper motor rotates the weight, shifting the center of gravity of the lamp, causing it to change its direction of tilt on its rounded base. Both the light and stepper motor are controlled using a PIC microprocessor circuit connected to a computer through a serial connection. Variation of the light brightness and changes in position, speed and acceleration of the weight allow the creation of a variety of different patterns of movement and light.

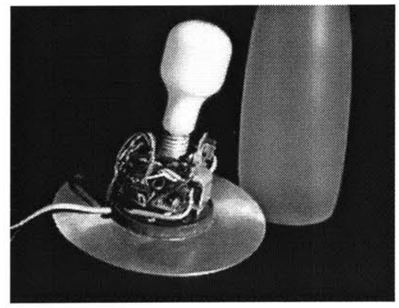


Figure 4.16
The internals of wobble lamp. The aluminum base contains an eccentric weight attached a stepper motor. The stepper motor and light are controlled by a PIC microprocessor

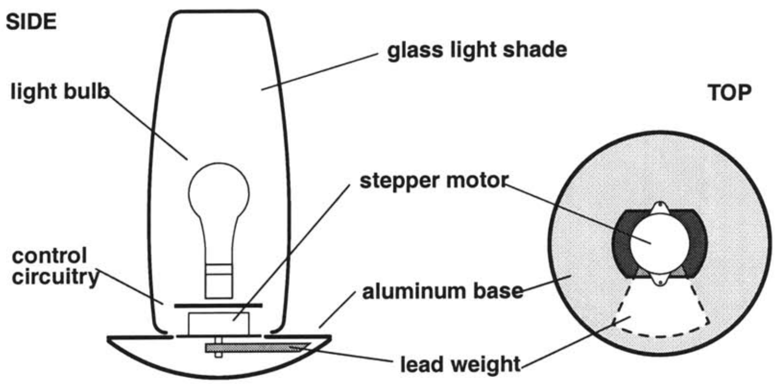


Figure 4.17
This illustration shows the basic components of the wobble lamp.

4.3.2 applying the wobble lamp

Initial experimentation with movement of the lamp showed that people projected feelings and emotions onto the lamp due to its various motions which we are calling gestures. "*We assign identities and emotions where none exist. And we make the world over in our image.*" (Arnheim 1974) The abstraction of the lamp's physical form from a living creature also emphasizes the motions themselves as gestures that convey emotion. *"When the detail comes off of an object, such as a photo-realistic face vs. our two dots and lines, we are able to see ourselves in the object, projecting emotions and various qualities. As one pulls away the veneer of an object, the movement becomes more prominent and the affordance of emotion is evident."* (Vaughan 1997) In general, jittery motions of the wobble lamp looked nervous, while smooth, rhythmic movements appeared happy, and fast jerking motions looked aggressive.

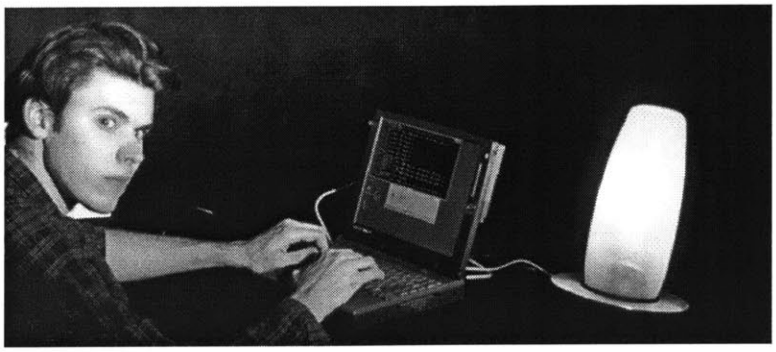


Figure 4.18
Me working hard with the wobble lamp.

The movement of the lamp is not precisely controlled due to the dynamics of the system, with open loop control. The stepper motor was not strong enough to counteract the momentum of the lamp's movement for the creation of precise and accurate changes in movement. However, this added to the quirky character of the lamp's movement, emphasizing the notion of the lamp having character or personality. It would react slightly differently each time a command was sent, it appeared as if it had a mind of its own. This coincides with Arnheim's observations in *The Art of Visual Perception* that objects that have more mechanical movements display less emotion, or expression than objects that can move in more complex or organic ways. (Arnheim 1974)

Beyond ambient information display, other interesting scenarios of use arise with the addition of sensors to give the lamp information about its physical environment. It could act as an artificial pet similar to a Tamagocchi, yet reacting with expressive movement to physical interactions with a person and its environment. This notion of the wobble lamp as a creature gives a more satisfying and social interaction (Reeves and Nass 1996) than current computer controlled lighting systems and various other information appliances.

"Designers of media can profit from reliance on what people do best. Machines will be more approachable, content more understandable, and interfaces more sensible if they follow the rules of social and natural world. People already know how to be polite, they know about personalities and emotion, and they are aware of how objects work in natural environments." (Reeves and Nass 1996)

4.4 dynaLux

The *dynaLux* is a table lamp augmented with a microprocessor, sensors, and the ability to physically move it is an evolution from the wobble lamp. The wobble lamp showed how minimal and abstract movement could be extremely expressive. However I did not have the desired level of control over these expressive qualities. I could only control the direction of tilt not the angle for the wobble lamp. I felt that it was important for the lamp to be able to stand up straight, as well as vary its angle. Otherwise the only possible movements are varying symmetrical rotation.

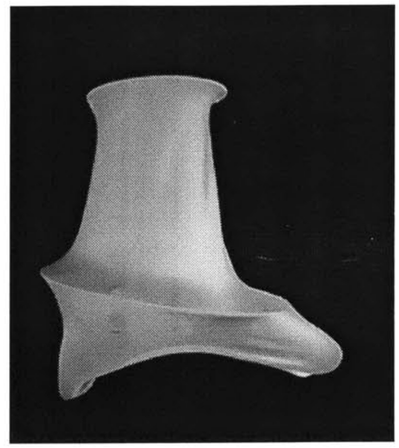


Figure 4.19
The dynaLux is a n expressive kinetic lamp. It is an evolution from the wobble lamp.

The wobble lamp was very symmetrical in form as well as movement. The abstract nature of its expression was compelling. Even though the form of the lamp was abstract, observers would often anthropomorphize the lamp in their minds as soon as it started to move. I observed that people needed to reference the motions in respect to a front of the lamp. Being symmetrical the wobble lamp did not have a front. The motions could be less clear without this reference. I did not want to create a literal face with eyes, a nose, and a mouth, yet some form vocabulary to establish the lamps orientation was needed. For example, was it leaning backward or tilting to the side? This uncertainty of orientation could make interpretation confusing.

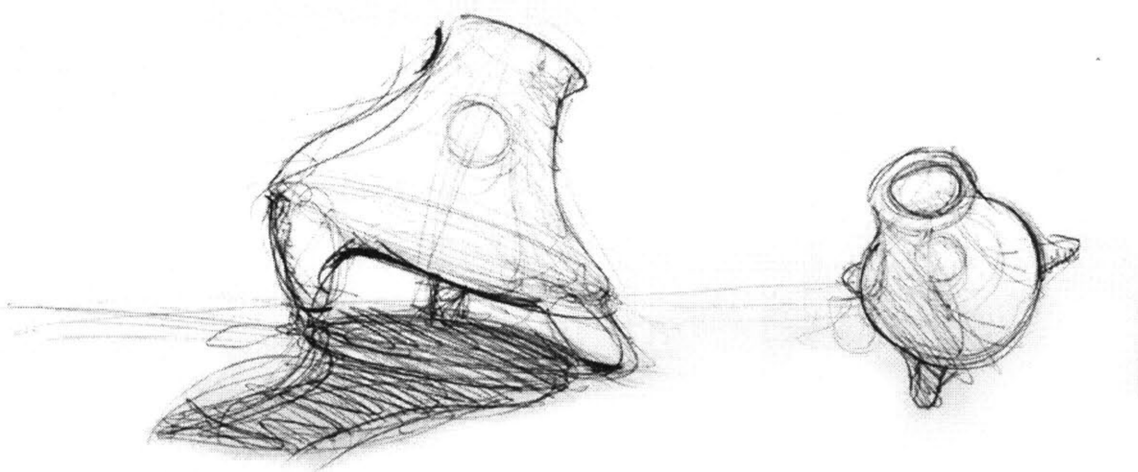


Figure 4.20
Sketches of the dynaLux concept

Taking these goals into consideration I started to develop some new ideas through sketching. I was trying to develop configurations that would allow for more expression and control over the qualities of expression. Early in the process I decided to constrain my concept exploration to the use of servos motors as the mechanism of actuation. More specifically, the type used in radio-controlled model cars to adjust steering. I will explain this decision further in the implementation section.

4.4.1 designing dynaLux

I decided that dynaLux was the concept that seemed the most promising. The concept involved using three servos mounted under a base. A foot was connected to each of the three servos in a tripod configuration to independently raise, lower and tilt the base. The lamp would mount above this base platform. I built a moving prototype out of foamcore and the RC servos to try out the movements. I used a radio control transmitter and receiver, similar to the type used for remote control hobby planes and cars. The control of the mockup was manual rather than computer control, yet it let me quickly experiment with the movement possibilities of the design. I refined the shape and proportions of the feet and base to get us much dynamic range of motion as possible.

Figure 4.21
The dynaLux in action, evoking emotion from its gestural motion.

I was concerned though that the movement of the three feet was to robotic or insect-like. This was not the goal. I wanted something much more approachable or friendly. I was afraid that the design was becoming more of a robot that lit, while my intention was a lamp that moved. This might seem like a subtle distinction at first but I think that it is an important one. The internally hidden source of the motion that gave the wobble lamp such a sense of magical life was missing. The mechanism of motion was much more exposed. I decided it was important to give the dynaLux the same sense of magic. I started to experiment with wrapping the entire lamp including the moving feet with a stretchable fabric. The fabric gave the lamp a flexible organic skin. The form of the lamp stretches as the lamps feet move.

4.4.2 implementation of dynaLux

The final implementation of the dynaLux is comprised of a sheer stretchable lycra based sock stretched over an acrylic frame. The light in the dynaLux is a 12 volt DC halogen bulb. The three servos mount underneath the base of the lamp with an acrylic foot attached to each servo.

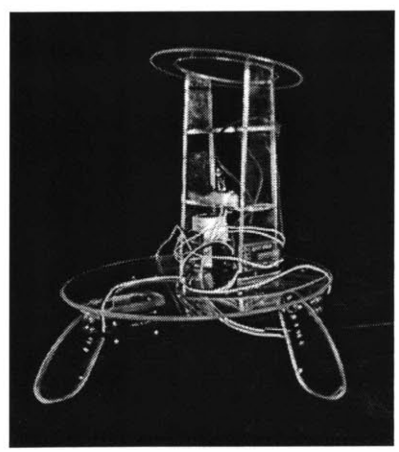


Figure 4.22
The internal components of the dynaLux.

The servos contains an integrated circuit and potentiometer are used to implement a closed-loop position control system. (Jones and Flynn 1993). A servo motor takes a 20 millisecond period, train of pulses of varying widths. The width of the pulse is the code that signifies to what position the shaft of the servo should turn.

I choose these servos for several reasons. The first was their combination of compact size to torque ratio. Most motors are extremely high speed and low torque. However, the servos have a built in gear box, giving relatively high torque for the size of the package. The servos also have internal feedback so that their position is controlled rather than their speed, or increment. The servos hold a position well. The speed of the servos is fairly fast, but slow movements can appear jittery due to the resolution of the position control. The commercial RC servos have a 180 degree range of motion. They cannot continuously rotate. The servos also make a bit of a noise when there is a resistance to their movement.

The lamp also contains two sensors; A two–axis tilt sensor and a pyroelectric sensor to detect motion near the lamp. The tilt sensor is used to read the angle of the base, or determine if the lamp has been picked up or tipped over. The motion sensor is used to allow a dimension of interaction with the lamp. A PIC microcontroller circuit is used to control the light brightness, servo positions and read from the sensors. The PIC microcontroller is programmed in C for low level control of the servos and light. The PIC relays the sensor readings to a computer through a serial connection. I use a Visual Basic application on the computer that takes the dynaLux sensor readings along with other inputs from the computer to and sends a series of basic movement commands over the serial connection to the PIC. The PIC in turn makes the adjustments to the positions of the three servos and light. The PIC could be used to higher level control, however it is much quicker and easier to change the code on the computer rather than on the PIC. The difference in functionality is only apparent when one looks at the underlying system; it is seamless to users of the lamp. The Visual Basic application allows direct control of the light and servo movement, patterns of movement with control over some parameters, scripted movements, or movement based upon varying information inputs to the program.

4.4.3 experimenting with dynaLux

The range of expressive motion possible with the dynaLux was very satisfying. It gave me the ability to accurately create a variety of motion patterns. The lamp's movement and changes in light brightness can be very expressive and gestural. The sound created by the servos was also interesting. Originally I was worried that the servos would be too loud and disruptive. However, the squeak of the servos went well with the movements of the lamp, emphasizing its motions. I found it very interesting that programming the motion control for the dynaLux was similar to expressive graphics programming that I had previously done in JAVA. For example, mapping sign waves to the position of the feet was similar to some onscreen motion control algorithms I have used in the past.

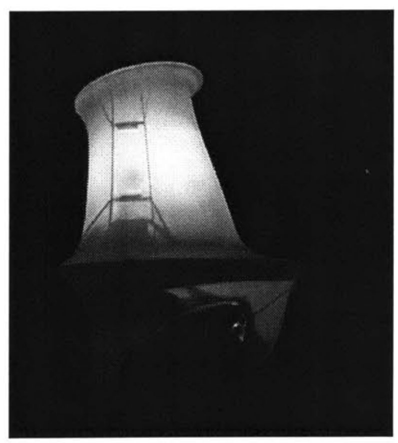


Figure 4.23
The dynaLux standing at attention.

It was compelling how emotive the lamp could be. From experimentation with various patterns of motion and listening to comments from observers, I have determined some basic correlations of movement and expression. Jittery motions look nervous, while quick abrupt accelerations look angry or irritated. Quick, bouncy rhythmic motions with gradual accelerations tend to look happy, while slow movements look sad or tired. These are preliminary observations that point to the need for further in-depth study of how people interpret these qualities of motion.

I was surprised how much of a sense of life people, including myself, projected onto the dynaLux. Observers of the lamp studied it trying to understand why it was reacting, and empathizing with it when it appeared nervous or tired. If it fell over they would rush to its aid. When I opened its fabric cover to adjust something inside, observers almost always insisted that I take time to carefully "redress" dynaLux before continuing. Observers were also be saddened when I turned off dynaLux, as it fell limp in front of them. I found this very provocative and feel that the physicality of the dynaLux emphasizes this sense of life in a way that would not be possible with an onscreen character.

Figure 4.24
The dynaLux, lit and moving about.

Previous kinetic displays that I created did not allow feedback from users. They were solely displays. I put a motion sensor in the dynaLux to allow direct feedback from users. This allows the display to be much more compelling. Rather than being only an output device, reacting to an information source, it allows a person to interact with the dynaLux's display of information source and perhaps even the information itself.

As expected, there were feedback problems with the motion sensor. The motion sensor value fluctuated with the brightness of the lamps internal light. To deal with this problem, I calibrated the sensor thresholds based upon the current brightness of the light. In future iterations, I am considering using a different motion sensor like the LazyFish (josh), which would remove the feedback problem as well as give higher resolution and more dimensions of input. I am also interested in adding a microphone for audio feedback. I would also be interested in adding a colored light to the dynaLux. However, even with the current dimensions of actuation there is a great deal more to explore.

4.5 inTouch

From infancy, we use touch to discover our environment. Through fingers, mouth, and skin, we obtain signals about the physical world. As we mature, we discover also that touch is a powerful means for communication. The strong handshake, the nudge for attention, and the gentle brush of a shoulder all convey a vitality and immediacy at times more powerful than language. Touch can instantly indicate the nature of a relationship; it is sincere, immediate, and compelling.

Yet while many traditional technologies allow communication through sound or image, none are designed for expression through touch. Telephones, videoconferencing tools, and email systems stimulate the ears and the eyes, but not the hands. The visual and auditory extension of space has been a focus of telepresence research (Ishii, Kobayashi et al. 1994). Likewise, graphical user interfaces focus on the visual while largely neglecting the tactile. The inTouch project reflects an attempt to address this limitation of current communications technology.

4.5.1 inTouch design concept

Our aim was to allow two distant users to sense each other's physical presence. In approaching this one might attempt to simulate direct physical contact across distance, transmitting *all* of the tactile information associated with such an interaction. However, this task is far beyond the current state of the art.

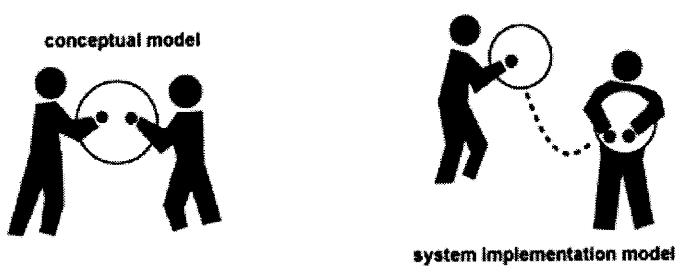


Figure 4.25
Design concept: object mediated communication through a shared physical object.

Instead, we employ the concept of a "shared physical object." When in close proximity, two people can also communicate hapticly through simultaneous manipulation of a common object—a book, a picture frame, or a toy, for example (figure 4.25). Such an object serves to mediate the exchange of haptic information. Simulating object-mediated communication across distance is technologically feasible, as the object's dimensions and its degrees of freedom can be constrained.

We can create the illusion of a shared physical object across distance, by employing computer-controlled sensors and motors to synchronize the physical states of two separate identical objects. This virtual connection allows manipulation of one object to affect the state of the other distant object, and vice-versa. We call such coupled objects, "Synchronized, Distributed Physical Objects" (figure 4.25).

inTouch is one example of Synchronized Distributed Physical Objects. In our design, the objects each consist of three cylindrical rollers embedded within a base (figure 4.26). The rollers on each base are hapticly coupled, such that each one feels like it is physically linked to its counterpart on the other base. Two people separated by distance can then passively feel the other person's manipulation of the rollers, cooperatively move the "shared" rollers, or fight over the state of the rollers. The presence of the other person is thus made tangible through physical interaction with the seemingly shared object.

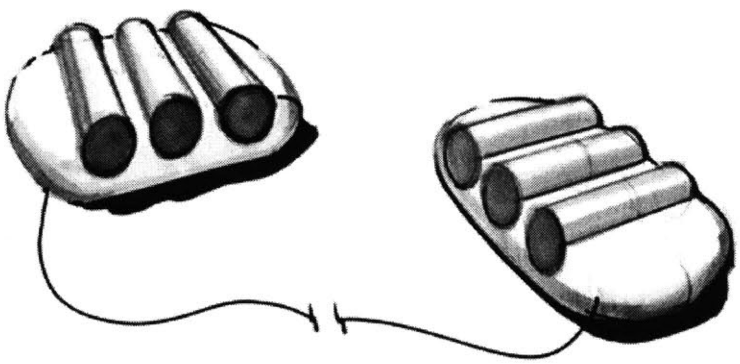


Figure 4.26
Concept sketch for the inTouch

4.5.2 design of the inTouch

seamless transition from active to passive interaction

Rollers were chosen as the manipulable part of the shared object was because they allow both passive and active interaction between users. A user can actively "grab" and manipulate the rollers by applying enough contact force to minimize slippage under the hand. In this way, the motion of the hand is directly translated to the rollers and the interaction is a kinesthetic one. If both users manipulate the rollers in this way, the interaction is fairly equal and mutual, like a handshake or a hug. Alternatively, one user could allow the rollers to slide comfortably beneath the hand, interacting in a more tactile and passive way, feeling but not affecting the motion of the rollers—like getting a pat on the back.

Interactions falling between these two extremes, reflecting various levels of engagement with the rollers, are also clearly possible. To compare an object like a joystick is most likely to be used only in an active way, since it requires the user to grab the device. The roller can be engaged more passively than a joystick shape because of its symmetry along the axis of rotation (degree of freedom). When the roller's state changes, it moves, but the general shape is unchanged. This allows a users hand (or other body part) to remain at a constant position relative to the device and simply feel the movement. As you can imagine, passively feeling a joystick would be quite difficult.

type of motion

The type of motion capable with the device can have a large effect on the expression and interpretation of emotions. It may, for example, be difficult to express anger in a device with a half-inch linear range of motion. The boundaries of the motion can also be very important. The choice of rollers as the manipulable part of the object was, in part, for this reason. The rollers can be rotated in either a clockwise or counterclockwise direction forever. Unlike a joystick or throttle, for example, where the motion of the device is bounded, the roller affords more fluid and continuous strokes (figure 4.27) (Fogg, Cutler et al. 1998). Although the roller has the potential to be manipulated aggressively, thrashing between bounds is not possible.

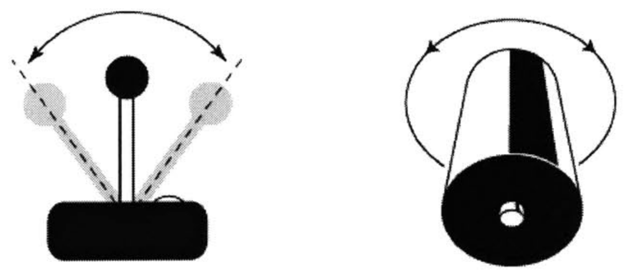


Figure 4.27
A joysticks motion is bounded, while a roller allows for more continuos and fluid motions.

For this reason, we felt that the motion of the roller was more appropriate for the expression of subtle emotion states than a bounded motion. The bounds on the motion could also be more complicated that this affording different types of interactions. One could imagine a joystick-like device with a circular instead of square boundary that affords both more aggressive thrashing from one side of the circle to the other and more fluid strokes around the perimeter.

mechanical complexity

We made the decision to use *three* rollers for a combination of functional and aesthetic reasons. We wanted the user to be able to feel or activate all of the rollers simultaneously, with one hand, the more rollers within the object, the smaller each roller had to be. Three was chosen as a compromise between the higher spatial resolution provided by more rollers and a greater surface area to "grab" and interact with possible with fewer rollers. The three rollers also gave a visual balance to the design, suggesting its rotational movement and drawing people to touch the rollers.

There are three main aspects of movement that a user may want to express through a device: position, motion, and expression. Each of these different aspects is afforded differently by the mechanical complexity of the design.

The higher the number of degrees of freedom in an object, the more complex the motion that can be translated. inTouch is composed of three one-degree of freedom objects, each object allowing only simple linear motion. A joystick, a two-degree of freedom device (e.g. *Impulse Engine*), allows for more complex planar motions. If two three-degree of freedom devices (e.g. *PHANTOM*) were connected you could translate 3D motions. You could imagine up to six degrees of freedom allowing for x, y, z, roll, pitch, and yaw. The more degrees of freedom, the more complex the motions can be.

The complexity of the motion, however, is secondary in importance to the expression of the motion. With only one degree of freedom, it is possible to have an infinite number of intricate motions (imagine all of the different ways you can interact with a roller). The resolution of the device is a reflection on how intricate the motions can be. If the device is capable of producing only two magnitudes of force, the ability to translate an expressive motion is diminished. Another aspect of the resolution is the position resolution. The device may, for, example, have discrete positions in which it can be stable (e.g. *HandJive* (Fogg, Cutler et al. 1998)). We could imagine that, instead of a smoothly rotating roller, we could have a roller that moves in discrete increments of 10 degrees. This would likely also decrease the ability to translate the expression of the motion. A separate issue that also has an effect on the expression is the maximum force output. If a motion is occurring at forces above the maximum force output, all expression in the motion (including the intricacies) are lost as the device will be "maxed out".

A device can have any number of objects (with any number of degrees of freedom and resolution) spatially arranged on it. inTouch has three one degree of freedom high force and position resolution rollers arranged in one possible configuration. The larger the number of objects on the device, the more precise the translation of position. The spacing and location of the objects, also obviously affects what can be translated. Imagine a wall with a number of pegs, modestly spaced, protruding from it. If the pegs moved in and out (and also possibly turned) you could translate motion and expression on a singular peg, and position by interacting with different pegs. This notion of position includes not only position of a motion, but the position of the body in relation to the object. Imagine a hand-sized device with a 100x100 grid of pins. Such a device would be good, not only at translating the position of a point motion, but the position of part of the body itself since the entire hand, for example, can interact with the device at once. The peg wall, given its topology, could not translate the position of the hand, but could maybe translate the position of the entire body.

4.5.3 mechanical model: inTouch-0

To get a basic idea of what the interaction through a "shared" physical object would ideally feel like, we built a mechanical model of inTouch, inTouch-0, that created a real physical connection between corresponding rollers. The model, which used flex shafts to mechanically link the rollers, is shown in (figure 4.28). This is clearly not the preferred method of connection over any reasonable distance; however, the mechanical prototype was sufficient to begin experimentation with the concept.

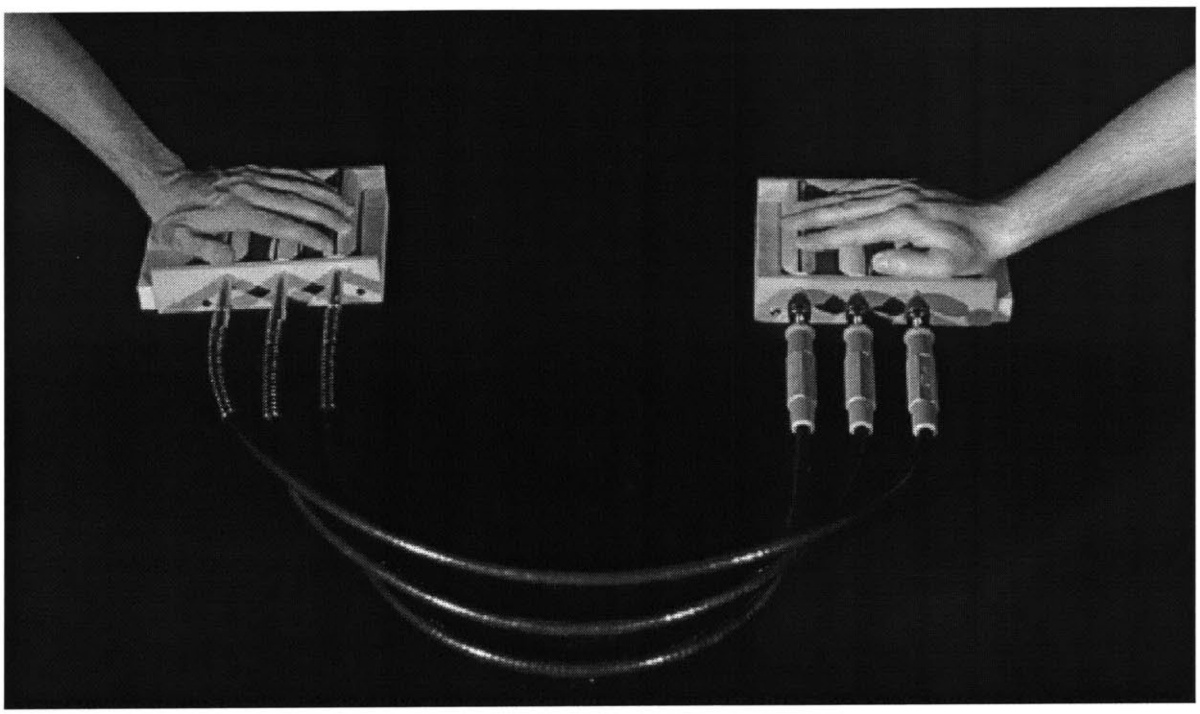


Figure 4.28
InTouch-0: Mechanical model of inTouch used as a physical benchmark to test the basic concept.

This model was implemented in a graduate course at MIT on interface design, in October 1996, and was presented in class. Initial observations of students in the class interacting with the device showed general excitement in the interaction. Users often described the interaction as fun or playful, with one user relating the experience to he and his sister using a broom to play tug-of-war as children. Some remarked that the lack of ability to pass concrete information made the medium uninteresting. Others, however, applauded the subtle and abstract nature of the interaction, while admitting that it was most applicable to close personal relationships.

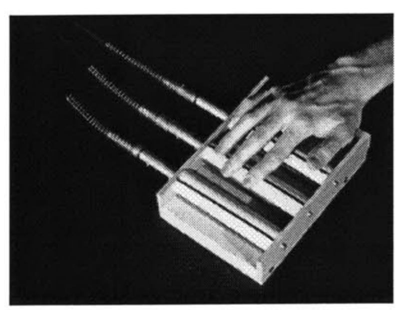


Figure 4.29
The mechanical model of inTouch allowed us to quickly try the idea.

4.5.4 standalone design: inTouch-1

The mechanical connection used in inTouch-0 is clearly not the preferred method of connection over any significant distance. InTouch-1 (figure 4.30) was created next to implement the connection between rollers, virtually, using force-feedback technology. The goal is to have virtually connected rollers that behave identically to the mechanically connected rollers in inTouch-0.

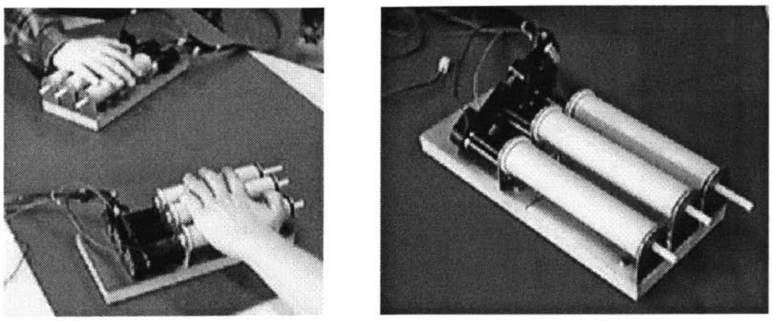


Figure 4.30
InTouch-1: computer controlled prototype.

The system architecture for inTouch-1 is shown in fig x. Hewlett Packard optical position encoders were used to monitor the physical states of the rollers (positions were read directly, other values were interpolated) and high performance Maxon DC motors were used to synchronize those states. A 200MHz Pentium PC controlled all motor/encoder units (one unit for each roller) using Immersion Corporation's Impulse Drive Board 1.0 boards and 2-Axis Card 1.0 ISA cards. InTouch-1's system architecture is shown in

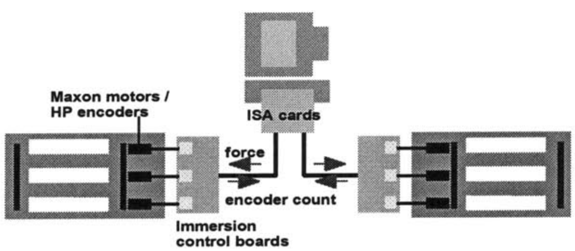


Figure 4.31
InTouch-1 system architecture (standalone design).

The control algorithm (Brave 1998) that ran on the host PC takes the average position of each pair of "connected" rollers and applies a restoring force on each roller proportional to its offset from the average, to bring the rollers together. It should be noted that the algorithm is symmetrical, giving no roller any advantage over its partner roller. It should also be noted that this algorithm is easily extendible to synchronize more than two objects.

Figure 4.32
InTouch-2 refinement of the mechanical design and form.

4.5.5 inTouch user reactions

The first prototype of inTouch-1 was completed in March 1997, and has been demonstrated at sponsor meetings and tested internally. People who knew the previous version, inTouch-0, were extremely surprised how closely the interaction matched the mechanical mockup. In fact, when we lined up the two inTouch-1 objects and covered the gap with a cloth, people who saw the rotating rollers believed them to be two ends of three long rollers and, in some case, held this conception even under initial haptic manipulation. These people also unanimously commented on how smooth the interaction was and how easy it was to feel even very subtle motions of the other person's object.

In experiments using inTouch-1, in conjunction with audio communication, for longer periods of two-person interactions, subjects often noted that the haptic interaction with inTouch-1 was distracting at first, but later fell more into the background of perception. When this happened subjects felt that the interaction became more natural and smooth. Subjects also general felt that the haptic channel presented a "subtle but deep and revealing" addition to audio communication. More specifically users commented that the haptic channel allowed them to get a better sense of the other person's emotional state and sincerity. Finally, some users expressed feelings of awkwardness when interactions with an acquaintance became more rhythmical, since they associated such movements with more intimate relationships.

5 discussion

Many ideas, as well as issues and questions about kinetic displays were developed through the development of the design studies described in the previous chapter. These design studies have allowed me to start to map out the issues of the kinetic displays design space.

5.1 mapping the design space

Many attributes or characteristics were evolved throughout the various design studies, while other new attributes arose through the development process. The original attributes were focused around developing ambient displays that would be distributed through our physical environment. These displays were to be subtle and intuitive, not intruding on a users foreground activity yet allow him to keep be aware of information in the background. However, new attributes developed dealing with physicality of the displays, persistence displays, further abstraction and more qualitative displays, as well as kinetic and expressive methods to display information in our environment. By discussing and mapping out our design studies with these attributes we can start to understand the design space for kinetic displays.

5.1.1 ambience and persistence

This research started with ideas centered around displaying information in an ambient manner. Allowing people to focus on a foreground task yet *constantly* be aware of background information sources. However, through the development of these design studies I have felt that persistence of the displays is more important than ambience. By persistent, I mean that the display should constantly be functioning, displaying an individual information source and allow a user to view its activity by simply shifting his focus to the location of the display. A user learns where to "look" for the information within the environment. The information does not have to be accessed through a computer interface, instead the user simply has to shift his focus of attention. The user is not necessarily always aware of the state of the information, as in the ambient view. However, the effort to review the information is greatly reduced, from conventional means of directly accessing it through a computer. It is persistently available through a dedicated display channel.

A clock is an example of a dedicated channel of information. A clock continually displays information about time. We can easily remove clocks and say that they are unneeded, because computers have clocks on their screen. We could easily get rid of clocks as a physical device, and rely entirely on time display on computers. However, we find that it is much more convenient and useful to have the time constantly available within our environment, where it is easily accessible by simply glancing over at it.

In this way I am removing most of the interface between the person and a desired information source. In place of a conventional interface in which a user would directly call up a particular information source, persistent single information source displays are placed throughout a space allowing access to the information be simply shifting focus. Since theses devices have a signal continual function they can be modeless, removing the need for awkward or confusion interfaces.

5.1.2 physicality

The idea that persistence if fairly important brings up the value of physicality (Csikszetmihalyi and Rochberg-Halton 1981). Physical objects are much more tangible and persistent than conventional video displays. Each kinetic display can take a different form allowing a user to easily differentiate between the different display objects. If several video display terminals are used, their form says little about the content being displayed. Thus making it more difficult to quickly find the intended display. He differences in the various physical kinetic displays help a user differentiate the outputs, they know which device does what. This is not so simple with video displays in which all the displays can transmit information in an identical manner. Variety is a good thing.

Another interesting reason for physical kinetic displays is the possibility for a variety of channels for information display throughout an environment. This can help limit confusion between displays because their method of output could be easily differentiated. For example, if a user had a wobble lamp and a waterlamp in their office. The differences between changes in the wobble lamp's brightness would be very different from changing light patterns from the waterlamp.

In contrast to the large arrays of focused pixels of a video display screen, the kinetic displays can be thought of as a much less dense group of "pixels" that are broadcast throughout the physical environment to be more easily perceived. If a user is not looking almost directly at a video display, it will be difficult to perceive changes, especially changes in small details. This idea of widely projected display is illustrated in figure 5.1. Though it is important for me to clarify that this use of the concept of a "pixel" is an example in which a pixel could be physical movement rather than color or light on a video display.

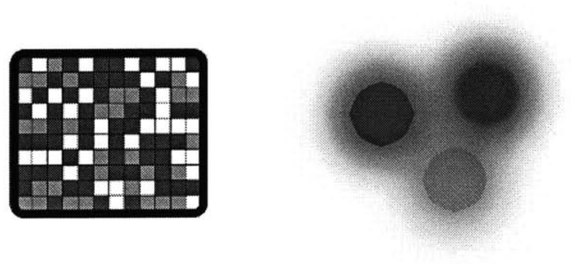


Figure 5.1
The image on the left represents the high resolution display of a computer monitor, while the image on the right explains kinetic physical displays as being lower resolution pixels that project throughout a space.

The physical kinetic display projects multimodally due to its physicality. As the display moves the visual cue as well as all the effects it has on the physical environment enrich the output of the display. For example, the spinning of the pinwheels can be heard, and the airflow they create can be felt. These multimodal outputs could be simulated to accompany a conventional visual display, however it would be difficult for the various outputs to have the quality feel of the real physical device. True this is an aesthetic argument, however I see it as similar to the way people value the use of real wood in a piece of furniture over simulated wood.

5.1.3 literal to abstract

Rather than conveying information concretely, the intention of kinetic displays is to be fairly abstract. By the term abstract, I mean that they will not show information in detail, but the essence of the information in a summary form or simply a connection to changes. Unimportant details are omitted and essential information is focused upon in the display.

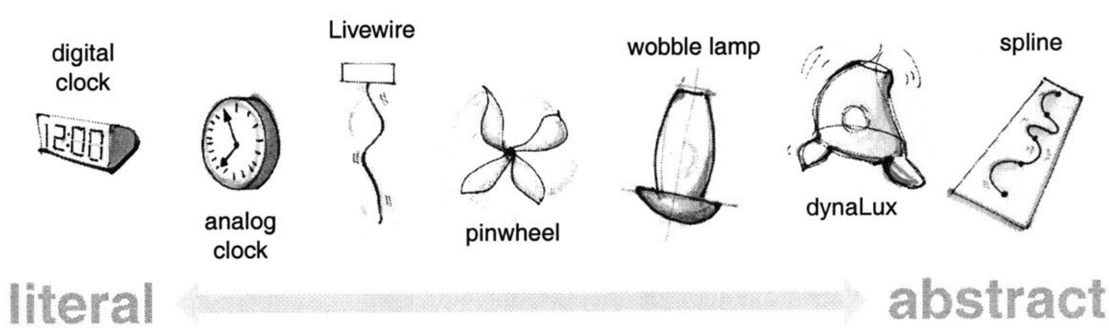


Figure 5.2
Putting various displays into this mapping of the level of abstraction we can get a better understanding of the design space as it relates to abstraction in a display.

In this way they will be displays that take a low cognitive toll allowing people to work on other tasks in their center of attention while still keeping an instinctual grasp on the background display.

This efficiency with the user's cognitive bandwidth will also allow for more displays to be used effectively in an environment without sensory overload.

This dedicated functionality, or persistence of the display's content allows the use of fairly abstract representation yet still have the user retain an understanding of the meaning of what is being represented. If these dedicated displays were very literal they could become monotonous and annoying. The abstraction allows the newly created reactive environment to be subtle and non-obtrusive.

If we used many very literal displays they could get very monotonous and boring seeing large digital readouts continually changing on you wall, for example. Instead abstraction allows the displays to be less intrusive and more subtle.

5.1.4 quantitative to qualitative

While quantitative information is most readily deliverable by computers. Quantitative data is not what is always needed, or even desired by humans. Instead, there are times when we would like to receive the "gist" or a summary of information in a qualitative manner, rather than receiving exact numbers (Tufte 1983). In the design of the kinetic design studies, I tried to create more qualitative displays. The difficulty in creating qualitative displays lies in the fact that the information to be displayed is in a quantitative form that must be translated through some sort of mapping to a qualitatively interpreted display.

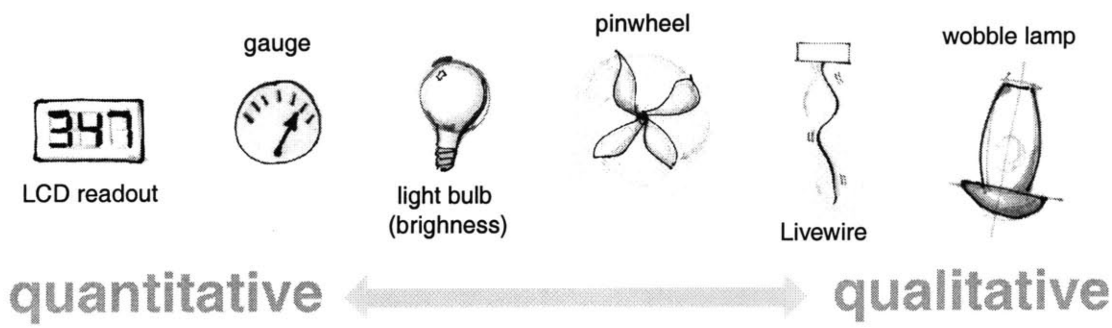


Figure 5.3
sorting several different displays in respect to how quantitative, or qualitative their display methods are.

One method to create this shift to a qualitative display is demonstrated by the pinwheels. A varying quantitative value is used as an input to the pinwheels. Perhaps a value from 1 to 1000, though any range is usable. This is then directly mapped to the speed of the pinwheels rotation, the pinwheel spins extremely slow when a value of 1 is input and runs at maximum when a value of 1000 is input. The user views the spinning pinwheel and than evaluates how fast it is going. While the pinwheel is spinning at a rate proportional to the input, the value is not exactly know, the user has a more qualitative understanding that the pinwheel is moving slow, or fast. In this way the pinwheels are still actually quantitative gauges of the information source but do to the interpretation necessary by the user the become a sort of "fuzzy" gauge.

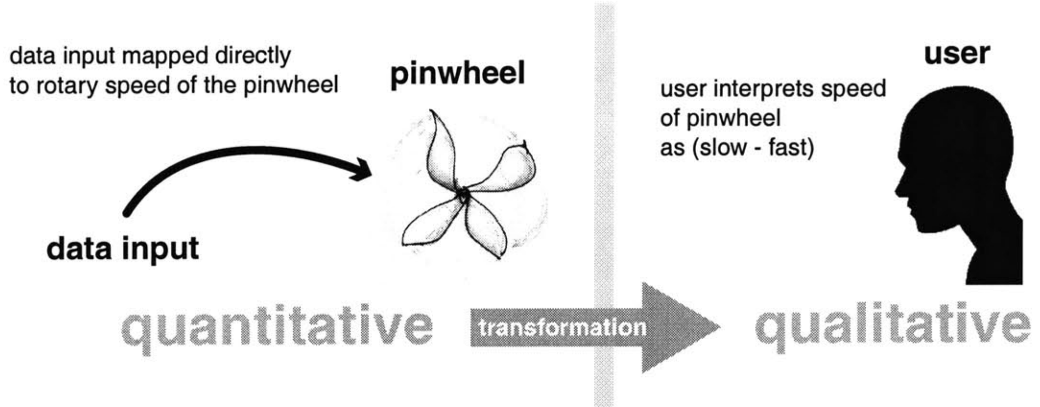


Figure 5.4
Allowing the perception of the user transform the quantitative data into qualitative value, through the pinwheels.

The wobble lamp and dynaLux demonstrate another method for qualitative display. These objects can be used more truly as qualitative displays. The value for an information source or group or sources are input into a mapping filter which based upon a set of rules and thresholds, determines a pattern of motion (a reaction) that the lamp outputs. These patterns of movement could be a simple wiggle or gesture, or a pattern that emotes nervousness, or happiness. These motions are then interpreted by the user. The lamp can be thought to be reacting expressively to the information source rather than simply displaying it. The user then interprets the meaning of the reaction. This similar to the way a living pet dog barks at strangers, or farm animals act strange when a storm is coming. We learn to interpret these reactions and their cause.

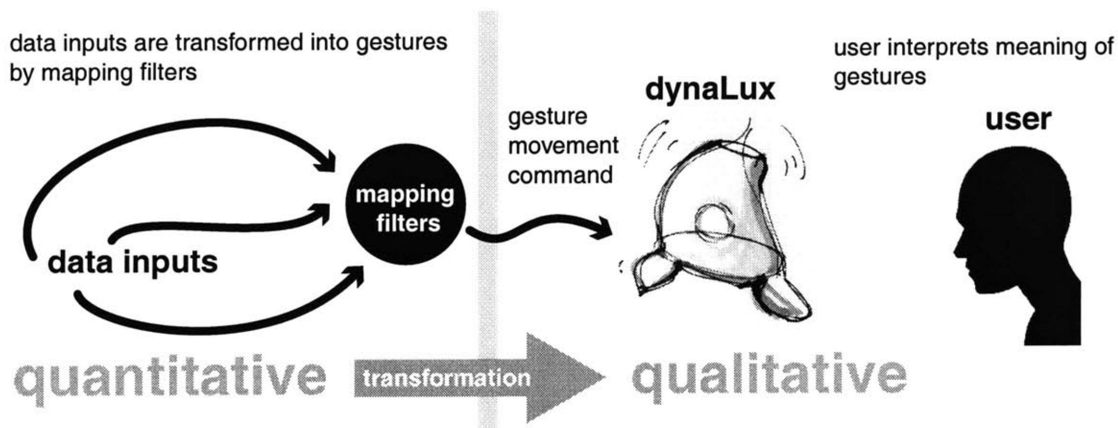


Figure 5.5
Mapping the data to qualitative motions before the user interprets them, with the dynaLux.

5.1.5 expressiveness

The notion of kinetic displays displaying information using expressive qualities, arose during this project. While we could imagine ways to try to make almost any display expressive, some displays afford more expressive qualities than others. For example, you could change the mapping of the pinwheel from a direct correlation to the data input, and instead have the pinwheels spin back and fourth in varying patterns of motion. However this is not nearly as evocative, or expressive as the movement of an object like the wobble lamp. The form of the pinwheel and its motion does not lend itself to ba a successful expressive display. The continuum below demonstrates some of the varying expressive aptitude for expressive display.

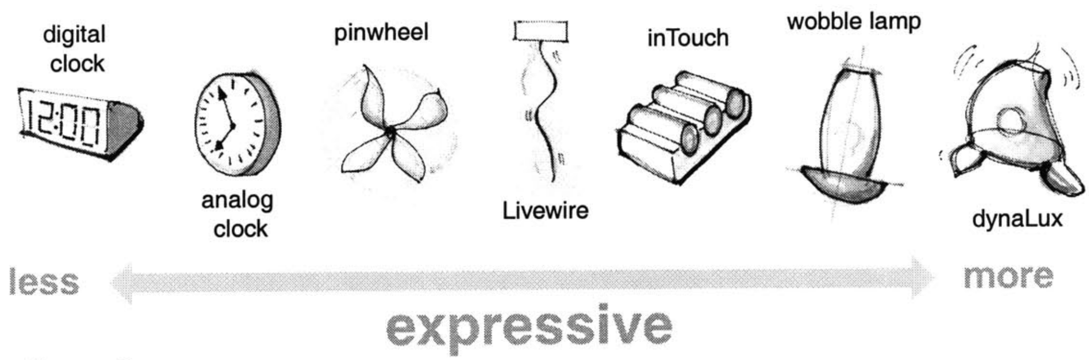


Figure 5.6
Understanding what makes a display expressive, through the classification of several different displays.

5.2 designing displays from a user context

From the development of the design studies discussed in this thesis I have been able to develop a summary understanding of the design space. This has allowed me to develop a set of guiding questions to use as a tool in the development of future kinetic displays based upon user needs. The basic questions are as follows. *Who* is the user, or users of the display. *What* is the actual information source, what information is needed and desired. *When* is the information needed. *How* should the information source be sensed, interpreted, and displayed. *Where* is the display in the environment.

5.2.1 Who

Who will use the display? Is it for an individual or a group of people? Are their important differences between various users? All of the following questions closely tie to who the user is due to fact that this approach is user focused.

5.2.2 What

What is the actual information source? What about that information source is needed, useful or desired by the user (users) and what is unwanted? The user might want to know when the information source reaches a high threshold, low threshold or both; when there is change in the information source; the general level (quantity); or perhaps actual values.

5.2.3 When

When is the information needed? Is it used during certain time of day? Does the user need to be continually aware of the information source ambiently, always have the source persistently available, or should the information have to be accessed directly?

5.2.4 How

How is the actual information source to be sensed? How will that data be interpreted, or manipulated? How will that information be mapped and displayed within the environment? The raw data could be directly mapped to a device, as with the pinwheels, or the data could be further interpreted as with the dynaLux. Several different data inputs could be combined and output through a single output using a even more complex artificial intelligent agent. Should the output method be movement , light, sound, smell, or some combination?

5.2.5 Where

Where is the display going to be located? What is its environmental context? Are there many other displays? What is the activity level, or chaos level of the space? What are the acceptable thresholds of the space? Will the display be overwhelming in the environmental context or not strong enough.

6 conclusion

6.1 summary

In this thesis I have introduced the notion of kinetic objects for digital information display. I have examined how kinetic physical objects in an architectural space could be used to convey information. I have attempted to develop new types of displays that can allow the creation of environments that can keep us connected to information in a more aesthetically pleasing and humane way than is afforded by current model of on screen information display.

I approached these issues through several exploratory design studies. I have demonstrated the development of ideas about kinetic information through these design studies. In the ambientROOM, I explored how an architectural space could be used to convey information to a user and have that information smoothly transition from the user's center of attention when needed and fade into the periphery when not in use. Through the ambient fixtures I brought these ambient displays out of the personal context of the ambientROOM into group workspace, creating a displays for use by several people simultaneously. The ambient fixtures also started to push the physicality and persistence of display devices. The spline brought about notions of more expressive and abstract displays. The wobble lamp pushed further on the notion of expressive and qualitative displays. The dynaLux, evolving from the wobble lamp moved from an expressive display to a display with character or personality, with a sense of social interaction with the display mechanism.

Through this series of design studies I was able to develop a geography for the design space of kinetic objects as digital information displays. This design space can be used in the development of future kinetic displays. When new kinetic forms of displays are assimilated into future environments, appliances of all kinds may likely change. The function of many common appliances may be extended to connecting people with information they otherwise would not be easily perceived, or accessed practically with current methods of interaction with information displays.

6.2 future directions

In introducing early explorations of new research themes new directions in the display of information within our physical environment, this thesis has only begun to develop many issues which seem to suggest promising and provocative future research. In order to expand the notion of a display device this thesis has focused mainly on the development of kinetic display objects themselves rather than a focus in the information to be displayed. While I have found this approach to be fruitful and still allows space for a great deal more development of kinetic objects, I believe the reverse approach starting from an information source would also be an extremely worthwhile endeavor.

Several other avenues for research also come to mind as this point in the process. The development of a information mapping taxonomy for kinetic display devices would also be very valuable. User testing for the effectiveness of kinetic displays in relation to more conventional display methods could help to show the tradeoffs of each. The inTouch just begins to scratch the surface with respect to the idea of haptic communication as well as the powerful notion of a multi-locational object.

The concept of expressive kinetic displays is one that is extremely interesting to me. I am extremely fascinated by the way people see emotion, or feelings in extremely basic and abstract forms and motions. I will continue this exploration with the dynaLux as well as the development of new expressive kinetic objects.

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