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Tactual Interaction

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by

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Abstract of the Thesis

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By

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Professor Simon Penny, Chair

Modalities of interaction with computing systems are growing increasingly diverse. Throughout the last decade, several practitioners have gained a particular interest in integrating different aspects of our tangible nature as part of human-computer interaction. The shift towards *tangible interaction* brings about a significant change in our relationship with computing systems; it opens up the interactive space to the moving body and the variety of actions possible through *touch*. Although the screen often remains an important part of computing systems, the integration of the body and more specifically of touch requires that computing researchers gain a better understanding of everyday tactual perception and actions. Through the rich work of philosophers, psychologists and other cognitive scientists who have questioned human experiences with the tangible things that surround us, I present an account of the body and touch that span from the contact against the skin to the intentionality of actions. From this broad perspective, I observe the work of practitioners that, since the early days of computation, have

integrated the body and touch for interactive computing, and the commercial products that emerge from their work. Some factors arise from the observation of tangible computing systems, factors which are explored in *Parazoan*, an interactive installation that engages participants in unusual tangible and social interactions.

Introduction

Twenty years ago, I was faced with a minor dilemma that affected my daily engagement with the personal computer. The system was a Commodore 64 (C64). The games were numerous and diverse, piling heights of floppy black plastic. Physically, the design of the C64 was not far from the machine that sits on my desk today. A color screen that also served as a television, a stout keyboard that could absorb the force of a typewriter typist, and one of a few pointing devices. Although two models of computer mouse were available for the C64, I did not have one at my disposition, and my daily dilemma was to choose which of three different joysticks would best fit the game I wanted to play.

My three options were fairly different in so far as the range of joysticks of the late 80's go. One was a typical arcade joystick, with a heavy square plastic base, a slim metal stick and a hard red plastic sphere topped with a round push button. The second was clearly made by the same company as the first, wearing the same color, it had a similar base and an identical trigger button, but it was equipped with a narrow uniform red stick made of the same plastic. The third was significantly different. It was lighter, with four suction cups to hold it in place, a softer black plastic stick with indents for the fingers and a square trigger also on top. All three joysticks provided the same functionalities, identical number of buttons and similar directional sensitivity, so my choice depended on their design. The arcade joystick was sturdy, its hard plastic felt good in hand and it could sustain under the pressure of the most jerk-demanding games. Although the arcade joystick might have given the feeling of bringing the arcade into the home, my choices were purely based on the tactile experience and its relation to gameplay as I had yet to experience an arcade. The second joystick, also sturdy, was alien to me. I could never warm up to its shape and never found a game for which it would provide anything more than the other two. And the third, which was designed to look and feel like an airplane control stick, felt more fragile, its plastic of lower quality, but its shape made it a good fit for games that required more finesse.

From the start, my experience with computation was visual and auditory with the 256 colors and the 8-bit sound of the C64, but reminiscing brings back memories where the tactile aspect of the interaction played an important role. Not only did joysticks appropriate from social practices, like arcade gaming and airplane piloting, to provide players with an engaging interactive experience, but each offered a different physical feel in hand with their respective materials and shapes that affected the control I had on the game.

During the same period, researchers at the Xerox Palo Alto Research Center (PARC) laid down a vision of ubiquitous computing, of ”the computer for the 21st century”, a vision which never ceased to inspire several researchers in exploring the possibilities of human-computer interaction (Weiser, 1991; Weiser *et al.* , 1999). The goal of ubiquitous computing was audacious, to integrate computation ”into the fabric of everyday life” and render its use invisible to the user. The pervasive integration of computation envisioned by Weiser demanded a shift in the paradigm of interaction between people and computers. Computation needed to expand off of the desktop and infiltrate the physical objects and spaces that populate people’s environment as they go about their everyday life. At the time, researchers and artists were already designing interactive systems that departed from the desktop. The idea of ubiquitous computing was inevitably inspired by the work of practitioners in fields such as artificial intelligence and physical computing who were paying attention to the body and situatedness of people (or intelligent agents) in the world they inhabit. The vision of ubiquitous computing promised a future that guided research in several directions. Later, (Ishii & Ullmer, 1997) proposed "Tangible Bits", an approach that allows users to "grasp & manipulate" bits by coupling digital information with augmented physical objects. The goal of "Tangible Bits" is twofold; it seeks "to bridge the gaps between both cyberspace and the physical environment, as well as the foreground and background of human activities." As my experiences with the joysticks of the C64 indicate, computing was never completely independent from the tangible world that makes it possible. As one of many approaches following Weiser's vision, tangible computing not only drapes physical objects with computation, it allows the manipulation of digital information by grasping physical objects, and importantly, it facilitates the process of understanding by engaging people with familiar artifacts.

An interesting aspect of the shift away from the desktop computer has been the attention given to the body and its important role in human experience. Letting go of the mouse brought attention to the physical and social aspects of the interaction with computing systems, and emphasized the roles of the objects and people that populate our environments. Consequently, the integration of the body brought to the foreground the importance of movement through space and the perceptual system of touch as part of computing research. Touch is, to say the least, complex. Although the hands are often taken as the emblem of touch, a characteristic that differentiates it from the other senses is its distribution over the whole body, making it impossible to position it in one localized organ. In addition to being spread out over the body, touch involves more than the contact of objects against the skin. Physical objects are tactile and graspable, but also subject to manipulation in space; we must reach for them and often change their position to achieve our goals. Psychologically, Lakoff & Johnson (1999) argue that the way we experience and think about the world has been shaped by the structure of our brains and of ”our bodies, especially our sensorimotor apparatus, which enables us to perceive, move, and manipulate.” Linguistically, our embodiment affects how we share information as spatial and tactile metaphors populate our languages and ties this sense both to cognition, as I try to ”grasp the meaning of life, the universe and everything”, and emotions, as I am ”touched by Vogon poetry”. Arguably, touch might be the most socially molded sense. Socially constructed conventions and behaviors regulate tactile interactions with physical objects, without forgetting people. Most of the Western world is taught to not touch some type of food unless the interaction is mediated through another object, a fork, chopsticks, etc. Since Descartes postulated the separation between mind and body, vision has been the primary sense from which we are said to obtain reliable information from the real world around us, positioning the other senses as subordinate, undependable, subjective. An opposite view of human experience is the one of phenomenologists who situate the senses as part of the complex system of perception and affect that creates our individual human experience. Several areas of computing research have shown a growing interest in the phenomenological perspective, which situates us as active agents engaging with and creating the world we live in.

As computing systems continue to harness more aspects of the tangible nature of the world, it is important to question how such systems and their use relate to previous and current investigations of human experience. A critical look at the integration of the body, more specifically of tactility and movement, provides insights on the current state of tangible computing systems[1],

[1]Throughout this text, ”tangible computing system” is used to refer to any computing system that integrates and emphasizes the role of the body and touch as part of the interaction, inde-

pointing at factors that are compatible with and integrate what we understand of our embodiment in the world, and shedding light on underexplored aspects of tangible interaction. I present an account of the body and touch that span from the contact against the skin to the intentionality of actions through the rich work of philosophers, psychologists and other cognitive scientists who have questioned the tangibility of human experience. From this broad perspective, I observe the work of practitioners that, since the early days of computation, have exploited the possibilities offered by the body and touch, and the commercial products that emerge from their work. Additionally, I explore some factors that arise from the observation of these tangible computing systems in *Parazoan*, an interactive installation.

pendently from the field of practice where the system was developed (e.g. tangible computing, physical computing, wearable computing).

Chapter 1

Being Tangible

1.1 Embodied Interaction

The properties of the personal computer (PC) evolved significantly since its conception, but the machine as a whole only slightly breaks from its original design. It began in the 1950s with the SAGE network of computer systems, which had a large projection display that a commander would interact with using a light-pointer to identify its focus of attention. In the early 1970s, inspired by the previous decade of man-machine interaction, the researchers at PARC conceived of the Xerox Star Workstation, the PC as we know it, with its bitmap display, keyboard, mouse and what was to become the graphical user interface (GUI). In the decade that followed, the commercialization of the PC propelled its presence into a myriad of homes and offices. Over the years, the wide acceptance of the PC speaks for the value of the changes it brought to the practices and everyday activities it infiltrated and created. Today, screens are flatter, keyboards are quieter and mice are optical rather than mechanical, but they remain central to the interaction with the desktop computer. Although the continuous increase in computational power of the desktop computer allows us to execute ever more complex and simultaneous applications, the core modality of interaction remains the same.

However, the PC grew out of the job it was designed for. Originally destined for an office desk job, it now reaches heterogeneous spaces and takes part in increasingly diverse activities. The desktop computer still holds an emblematic position, but during the last two decades, we have seen a growing interest in the pervasive integration of computation. Hiroshi Ishii puts it bluntly when he writes that the "paradigm [of desktop computing] is reaching the end of its evolutionary potential," (Ishii & Ullmer, 1997) but in search for new interactive experiences, some trends in computing research have been exploring the interactive possibilities offered by computation detached from the desktop computer, designing physical and tangible modalities of interaction embedded in the world.

This research direction is part of an approach that Dourish (2001) identifies as "*embodied interaction*, the creation, manipulation, and sharing of meaning through engaged interaction with artifacts." Embodied interaction, Dourish argues, underlies different research directions in the field of Human-Computer Interaction (HCI), and "capitalize upon our familiarity with the everyday world, a world of social and physical interaction." Dourish brings together "tangible computing", which he defines as a general trend that "distributes computation across a variety of devices, which are spread throughout the physical environment and are sensitive to their location and their proximity", and "social computing", which applies the knowledge gained from sociological research to the design of interactive systems. He observes that social and tangible computing are two examples of research areas that are grounded by the same investigative goal of harnessing people's embodiment in the world for the design of human-computer interaction, an approach that, he posits, underlies different areas in the field of HCI.

Dourish's argument builds on the long history of embodiment in philosophy, especially in the phenomenology of Edmund Husserl, Martin Heidegger, Alfred Schutz and Maurice Merleau-Ponty, but also on theorists and practitioners who have been questioning the use of computation[1].

[1]Some of these theorists and practitioners are: Lucy Suchman (1987), Hubert Dreyfus (1992), Philip Agre (1997), Simon Penny (1995), David Rokeby (1998).

Phenomenology, which is central to the question of embodiment and human experience, has been increasingly studied in relation to different computing practices. Dreyfus (1992) brings to light the entanglement between philosophies of reason and the general approach towards digital computation, a relationship that defines how we perceive and interact with computing systems. Dreyfus' critique of artificial reason, and more specifically of the field of Artificial Intelligence (AI), first brought phenomenology to the attention of computing researchers. While it questioned the core beliefs and goals of AI, it also inspired a critical approach in diverse areas, including HCI. At the time, the field of AI concentrated on the implementation of disembodied "intelligent" agents, producing chess players and language translators that supposedly mastered the task they were designed for. It became apparent that the sustained promise of general purpose intelligent systems in the near future would require a type of intelligence beyond the detached reasoning of digital computer systems. Anticipating the failure of AI to attain the original goals of surpassing human intelligence, Dreyfus' argument emphasizes different aspects of our embodiment in the world that AI researchers have blatantly dismissed: the role of the body, enacted behavior and situations as function of human needs.

> If one thinks of the importance of the sensory-motor skills in the development of our ability to recognize and cope with objects, or of the role of needs and desires in structuring all social situations, or finally of the whole cultural background of human self-interpretation involved in our simply knowing how to pick out and use chairs, the idea that we can simply ignore this know-how while formalizing our intellectual understanding as a complex system of facts and rules is highly implausible. (Dreyfus, 1992)

In addition to opening computing research to the body of work of phenomenological theorists, Dreyfus's examination of AI, Dourish's framework of embodied interaction, and the work of several others who have questioned the use of computation in our tangible world, ground computation in a world that is both physical and social, pointing at the intricate and inseparable relationship that ties computation with our situated active human bodies.

1.2 Situated Active Human Bodies

> Our body is the ultimate instrument of all our external knowledge, whether intellectual or practical. In all our waking moments we are relying on our awareness of contacts of our body with things outside for attending to these things. (Polanyi, 1997, p.15)

The framework of embodied interaction invites us to take a step back from the user gazing at the visual display to broaden our attention to the human body in its entirety and its situatedness in the world. The special attention to the body in the interactive experience, especially in the experience of the everyday world of ubiquitous computing, is guiding researchers towards an integration of people's complex abilities for perception and action. The attention to human perception is far from new in HCI research. A dominant approach for the analysis and design of personal computing interaction has been, for a quarter of a century, the integration of perceptual, motor and cognitive factors to understand and improve people's relationship with the computer (Card *et al.* , 1983). The difference is set in the scope of the integration and its ties to the active body. The limitations set by the desktop computer means that the perceptual factors are often limited to visual perception, motor factors to the typing or clicking hands, and cognitive factors to the symbolic processes that make sense of the screen's visual content and manage hand-eye coordination, all in the user's mind. Although these human factors seem heavily restrained by the design of the desktop computer, the attempt at integrating them was ambitious and guided HCI research towards applied cognitive science. The attention to human factors improved several aspects of human-computer interaction, but as Bannon (1991) points out, it created a narrow portrait of the person "connoting a passive, fragmented, depersonalized, unmotivated individual." Bannon proposed a shift towards "human actors", connoting an active and controlling individual, which paved the way for embodied interaction in the field of HCI. With its particular attention to the situated body, embodied interaction signals that an approach that emphasizes the role of vision at the cost of the whole of human perceptual and motive abilities is not fit to support computing in the everyday lived world.

Merleau-Ponty regards humans' complex perceptual, motive and cognitive abilities in terms that break from the centrality of vision in applied cognitive science in the field of HCI. "Merleau-Ponty's account of vision is anti-Platonic. It inhabits a space which is tactile as well as visual, and is resistant to a unified, self-reflexive or panoptic viewpoint" (Vasseleu, 2002). Merleau-Ponty's approach positions vision as one part of the embodied experience, where the other senses —hearing, touch, smell and taste —play important roles that are not inherently subordinate to the sense of vision. As Vasseleu's (2002) study of the importance of light in Western thought shows, through the work of Luce Irigaray, Maurice Mearleau-Ponty and Emmanuel Levinas, vision is intimately tied to the tactile nature of our embodiment in the world. Therefore, following Merleau-Ponty's account of perception, the shift towards a framework of embodied interaction should analyze and design for the integration of the broad spectrum of human perceptual and motive abilities, understanding the strengths of vision, and refraining from attributing to it an unquestioned position on a podium of perception. As I will show in the next chapter, the work of several computer scientists, artists and game designers have been increasingly integrating the body, with its perceptual and motive abilities.

The perceptual nature of the body situated in a physical and tangible world is a central point of Merleau-Ponty's notion of embodiment. Broadly, tangibility refers to the material aspect of the world, to the things that are perceivable by the senses. Generally, tangible things refer to things that can be touched. Of our five senses, Aristotle observed that touch is the most primitive, that it is impossible for a living organism to exist without it (Nussbaum, 1992, p.227). The ancient relationship between touch and our existence in a tangible world inevitably affects how we experience and make meaning of the world. Although the five senses participate in human experience, touch tends to make us feel connected to the tangible, to the hard material world of atoms. In here, I use *tangible* to refer to the sensual nature of the material world in relation to what Gibson (1966) called the "perceptual systems" of the body. Gibson conceived of the external senses as perceptual systems, systems which are active rather than passive, interrelated rather than mutually exclusive, and participate in the formation of knowledge rather than acting as channels through which we access the tangible world. From this, an examination of the role of touch as part of our embodied interaction with computation requires that we look at the terminology that defines touch in more detail.

From this point on, I want to concentrate on the haptic, tactile and tactual aspects of computing systems, and the position of the active body in the framework of embodied interaction. I do not intend to elevate touch to the long standing position held by vision, but instead, I want to examine the use of our moving and tactile body for human-computer interaction, its perceptual as well as motive abilities and the culturally constructed behaviors that guide and constrain how we touch and manipulate things. It would be impossible to do this clearly without first untangling some of the necessary vocabulary.

1.3 Haptic, Tactile and Tactual

The complexity of touch is apparent in the way it infiltrates our languages. In English, we can touch, grasp, tap, stroke, feel, handle, finger, contact, pat, fondle and caress physical things, only to point at a subset of words relating to the different ways we can touch. In addition, the impact of touch and movement on our thought processes is found in the numerous expressions we use to refer to immaterial entities as things that we can physically grasp. I can stay calm and search a guide for ”hard” facts, and I might scratch my head until I ”put a finger” on the concept of consciousness. Coincidentally, the language we use to express feelings and emotions is full of metaphors of touch that appear as natural tools to approximately convey the essence of the immaterial. The sight of a sad robot might ”touch” me, or I might ”reach” a friend with uplifting words. This brief look at the presence of touch in the English language does not do justice to the complex ties that connect the body with language and thoughts, but others have studied the subject with startling conclusions. Lakoff & Johnson (1999) examine the relationship between embodiment and reason and suggest that

> our abilities to move in the ways we do and to track the motion of other things give motion a major role in our conceptual system.

> The fact that we have muscles and use them to apply force in certain ways leads to the structure of our system of causal concepts. What is important is not just that we have bodies and that thought is somehow embodied. What is important is that the peculiar nature of our bodies shapes our very possibilities for conceptualization and categorization.

Consequently, the predominance of touch and space metaphors is the inevitable result of the evolution of embodied thinking beings with bodies like ours. The human body allows for a wide spectrum of interaction, from delicate strokes to frantic jolts, which probably played different roles in the evolution of our complex thought processes. Touch is significantly more than the physical contact against the skin, reaching both inwards to our muscles, bones and brain, and outwards, to the physical and social space around us, while being inseparable from the motive abilities of the body.

Following the late J.J. Gibson's work, Schiff & Foulke (1982) remark that "tactual perception is considered as a set of problems concerned not only with energy detection and discrimination but also with how we obtain useful information about the world."

> The skin and deeper tissue can be stimulated without movement of joints or muscles... *cutaneous touch*. The skin and deeper joints can be stimulated together with movement of the joints... *haptic touch*. The skin and joints together can be stimulated in combination with muscular exertion... *dynamic touching*. The combination of skin stimulation along with vasodilation or vasoconstriction... *touch temperature*. And the combination of inputs from the vestibular receptors and the joints and the skin together... *oriented touch*, that

is, of objects in relation to gravity and the ground. (Gibson, 1966, p.109)

The complexity arises from the questioning of *how*, exactly, does the perceptual system of touch participate, actively, in our experience of the world. From the large vocabulary of the English language, three words are generally used to relate to perception through touch —haptic, tactile and tactual. In the history of the study of the perceptual body, researchers have analyzed the perceptual system of touch by separating its parts and questioning their role within a larger system. An aspect of touch that led to this separation is the impossibility to locate it into a single organ, a feature that stands out from the precise location of the other senses. Early on, this ”anomaly” pushed scientists to divide touch into analytically isolated elements, the skin, muscles and the joints of our body, while awarding the hand a special mention. Another view of the perceptual system of touch is from the perspective of the body as being both active and passive, able to touch and manipulate objects in its environment, and simultaneously being touched by it. Schiff & Foulke (1982) observe that, in history, the term ”haptic” is often used to refer to a touch that is active, exploratory and manipulative. Gibson (1966) defines the haptic system as ”an apparatus by which the individual gets information about both the environment and his body. He feels an object relative to the body and the body relative to an object.” Gibson’s perspective divides the perceptual systems of the body in terms of the type of information we pick up from the world around us. Although his view of the haptic system points at the importance of perceiving the human body as active, it comes in opposition with the phenomenological perspective that sees the world not as a entity waiting to be sensed, but as experienced through enaction. The term ”enaction” was introduced by Bruner *et al.* (1961) to refer to the active gain of knowledge through the interaction of perception and action with the environment, "knowing through doing". Varela *et al.* (1991) goes further and present enaction as not only a way to obtain knowledge, but as a form of interaction with the world where knowledge emerges from the dynamic coordination of action guided by perception, knowledge which is not predetermined by characteristics of either subject or environment. This fundamental difference in the understanding of our embodiment in the world surfaces when we question the interrelated roles of the our perceptual systems. Whereas Gibson mentions that "touch and vision in combination yield a redundant, doubly guaranteed input of information," information that specifies hard facts about the adjacent world, the phenomenological perspective sees the interaction of touch, vision and the other senses as "creating" the world around us, a world that differs with the perceptive and motive abilities at our disposition.

Marks (2002) mentions that the term haptic emerges in Deleuze and Guattari's description of "smooth space". For Deleuze & Guattari (1987), "[smooth space] is a space of affects, more than one of properties. It is haptic rather than optical perception." They point out that "'haptic' is a better word than 'tactile' since it does not establish an opposition between two sense organs but rather invites the assumption that the eye itself may fulfill this nonoptical function." Deleuze and Guattari state that they make free use of the notion of "close haptic-vision space" that first appeared in the writings of Aloïs Riegl in relation to his concepts of the *Kunstwollen*. Riegl's (1985) studies of the perception of roman decorative art creates a dialectical relation between the terms —the *haptic* and the *optical* —proposing an interplay between the "near" and the "distant." Although Riegl saw hapticality as a form of vision analogous to tacticality, placing vision as *the* means to experience the decorative art of his studies, his notion of haptic was an early start in questioning the role of touch, and by extension, of the body in the perception of artwork. From this view, the haptic evokes the intricate relationship between touch and vision that is present in the phenomenological notion of embodiment. Similarly, Merleau-Ponty employs the term 'praktognosia' to refer to that bodily experience of movement that provides us a way to access the tangible objects of the world that surrounds us, to connect the near and the distant (Merleau-Ponty, 1962). From these accounts of the body in the tangible world, and it is a term I will adhere to, *haptic* implies both perception and action, it involves direct contact, kinesthesis and proprioception, and it evokes the interplay of the senses that binds the body with the space that surrounds it.

It would be a difficult task to explore the integration of the body, and more specifically, of touch as part human-computer interaction armed with a single word —haptic —to refer to the complex system of touch. While the haptic integrates a touch that interrelates the body, objects and the physical environment, it brushes rapidly over the direct contact, the skin-object connection and some of the perceptive abilities of the hand. As Deleuze & Guattari (1987) observe, "tactile" refers to a touch perceived by a certain organ, which the haptic breaks away from, and which we generally attribute to the skin or the hand. This is not to say that a perception through touch is independent from the simultaneous perceptual experience of the other senses, quite the contrary, but we can still examine a subset of the haptic perceptual system, the tactile experience. Katz's (1925) pioneering work is a phenomenological investigation of touch concerned with the tactile, more specifically with texture and ground. Krueger (1982) observes that Katz emphasized the role of the active touch, which he defined as the moving hand on a surface, and the versatility of the hands, suggesting that the hand itself be considered the organ of touch. He understood the importance of the interplay of the senses and showed that vision affects the tactile experience of everyday life. Katz's complex examination comprises some interesting accounts of touch that I will come back to in more detail in the next chapter in relation to physical and tangible computing systems. From this, I use *tactile* to refer to the active touch that is part of the haptic perceptual system, the contact against the skin from which we perceive textures, the abilities of the hands to recognize and, to some extent, manipulate objects, and the intimate ties between tactility and the other senses.

The English language puts another term at our disposal. As I mentioned previously in the writing of Schiff & Foulke (1982), ”tactual” generally refers to a touch that is active. It suggests a touch that intentionally seeks information rather than a passive sense affected by the world. Although it is used less frequently in the discourse of touch, ”tactual” is sometimes presented in contrasts with passive tactile perception, or used to accentuate different aspects of the interrelated roles of touch and vision, as in ”the haptic-tactual system”.

An important aspect of touch remains outside of the definition of the haptic, tactile and tactual, terms that pay attention to part of the experience of the tangible world without explicitly referring to the intentionally and intersubjectivity of actions. In his argument for a framework of embodied interaction, Dourish points at a notion of embodiment that is about being both in a physical and social world. A complete account of touch as part of this framework must therefore pay attention to the aboutness of actions, to the experience of touching in presence of others, of touching people and how they touch us back, and to the socially and culturally constructed meanings and constraints that govern touch as we interact with the world. Interestingly, no word exists to differentiate between the touch of an object or of a person, between the tangible or the social aspects of a tactile experience. Dourish (2001) points out that, through the critical contribution of Schutz (1967), phenomenology extended beyond the individual to encompass the social world. It is possible that, like the phenomenological notion of embodiment, tactile, haptic and tactual experiences inevitably involves intentionality and intersubjectivity, and therefore, do not require a term to refer to the meaningfulness of our experiences of the world through touch. However, to help my investigation of touch in computing systems, I propose a use of *tactual* that explicitly refers to a touch affected by our intentional, and consequently, our socio-cultural nature. The flirtatious contact of elbows in a public space or the inappropriate use of the hands at the table are two experiences that I might refer to as being tactual. In their studies of routine in domestic life, Tolmie *et al.* (2002) present an interaction with the door artifact that exemplifies what I define as a tactual experience:

> Everyday features of the tangible world are being manipulated using mundane competencies people have for touching and moving surfaces. However, it is also clear that much of the significance of the use of these doors comes from what is done in the doing of actions with them. The knock on the door is not only the action of lifting ones hand and connecting it to the door artifact so as to make a sound audible to those on the other side of the door. Here it is also a means to coordinate actions and make others aware that you are ready to begin a routine. (Tolmie *et al.* , 2002)

This use of the term ″tactual″ builds from the ″haptic″, and integrates the intentional and socio-cultural nature of tactile behaviors with the complex system of perception and action of the human body.

1.4 Summary

At this point, it should be clear that these terms —tangible, haptic, tactile and tactual —do not define mutually exclusive categories under which we can classify experiences; they point at different, but interrelated aspects of active perceptual experiences involving the sense of touch. I am not suggesting that experiences might be tangible, or haptic, or tactile, or tactual, but instead that this terminology helps to accentuate the different aspects that form experiences.

> (1) *tangible* refers to the relationship between the body and the materiality of the world at large,
> (2) *haptic* points at the interplay between perception and action, and, through the interaction of the senses, connects the body with the surrounding physical environment,
> (3) *tactile* refers to the contact against the skin and the diverse abilities of the hands,
> (4) *tactual* emphasizes the intentionality and intersubjestivity of tangible actions.

I have presented the perspectives of computing researchers who have proposed approaches towards the use of computation that acknowledge and design for our embodiment in the world, and the work of phenomenologists, psychologists and cognitive scientists who have questioned human experience and embodiment before them. The fields of computing research which involve tangible interaction (e.g. tangible computing, physical computing, wearable computing) quickly adopted the terminology of touch I presented to refer to the novel forms of human-computer interaction involved in using the systems they create. As I have shown, touch is far more than the direct contact against the skin, it involves several inseparable elements that, as a whole, create our experience of the tangible world. Researchers have observed the role of the active touch in the perception of and interaction with the world, providing a different and arguably richer experience than passive touch. Although touch has often been studied independently from the other senses, some have examined the close relationship between them, especially between vision and touch. This relationship emerges principally in the work of researchers who have questioned and explored the haptic experience, but also in tactile perception, as the sight of objects transforms how the hands perceive them. Most importantly, we experience the world through actions that involve our tactile and haptic sense at different degree, these actions are intentional, about something, and intersubjective, as we share their meanings with others.

Following Ishii's (1997) presentation of tangible computing, the last decade saw fruitful developments that integrate touch and the tangible nature of the world in HCI research. However, artists have been exploring the possibilities of physical interaction since the late 50's and 60's, and it is interesting to examine the aspects of touch that these different systems integrate, the ones they dismiss, and the terminology they use in relation to previous accounts of human experience. In the next chapter, I present diverse computational systems that make interesting use of the body and touch as part of their interactive experience to elevate factors of interaction that deserve particular attention for the design of tangible interactions.

Chapter 2

Computing Touch

During the last decade, several computing systems and devices that harness certain aspects of our embodiment in the world were produced. The *Nintendo Wii*™ involves a form of gameplay that exploits part of the moving body in novel and interesting ways, transforming how players behave in front of the screen. *Microsoft Surface*™ redefines the table and how we might play and work on and around it. The projects that integrate aspects of the tangible world are numerous and diverse, differing in their purpose as much as their implementation, but they emerge from a history of practitioners that have been questioning the embodied nature of human-computer interaction since the late 50's and 60's. Because of the tendency of most work to orbit in the circles in which they originate, these projects are examined principally in relation to work produced within the same community. Although the increasing interest in interdisciplinary studies is transforming the critical approach of certain communities of practice, computing systems often remain studied within the boundaries of the artwork, game or application categories. Instead, it is possible to examine diverse projects by looking at how they exploit the embodiment of the people they engage, and more specifically, how they harness the tangible nature of the world. In the previous chapter, I presented an account of touch that goes far beyond the contact of the skin with objects. From this perspective, we can approach the examination of computing systems in terms of the interactive experience they engage people in: the integration of the body, the interaction with tangible artifacts, the tactility of the hands and skin, and the intentionality of actions. These are not mutually exclusive categories in which we can classify different projects; they are broad concepts brought forward in the study of tactual experience which can help us look at tangible computing systems from a viewpoint grounded in studies of human experience.

2.1 Integrating the Body

In the late 60s, artists were already exploiting computing technology to harness the body for interactive computing. A computer artist who delved into this technology is Myron W. Krueger. From the start, Krueger questioned the prevalent approach towards the design of technology which serves the sole purpose of solving problems, and pointed at a design approach which should be as much an aesthetic issue as an engineering one (Krueger, 1973, in Wardrip-Fruin 2003). In 1969, Krueger was involved in the development of *Glowflow*, a reactive room that responds to the footsteps of participants by affecting ambient sounds and lighting phosphorescent lights placed on the walls. Although the loose relationship between participants' actions and the environment's responses meant that *Glowflow* succeeded more as a kinetic sculpture than a responsive environment, it led Krueger to further explore interactivity. From this experiment, he moved on to develop *Metaplay*, an installation that emphasized the interaction between participants and a responsive environment. Briefly, the installation would create a real-time relationship between participants in a room and an artist situated in a remote location. One camera was aimed at the display screen of the computer controlled by the artist and projected on a wall of the room for participants to see. A second camera was placed to capture the participants in the space; its image would be composited with the image of the first camera and transmitted back to the artist. With this real-time connection, the artist could respond visually to the participants' movement in the space, who would react to the visuals, creating the interactive loop. *Metaplay* allowed participants and artist to construct visual and performative vocabularies as the interaction took place. *Metaplay* harnessed the ability of the computer to easily store and represent images and shapes as perceived by people, and it acknowledged the complexity of embodied interaction by allowing the relationship to evolve in situ. In (Krueger, 1973, in Wardrip-Fruin 2003), an interesting aspect of the relationship between artist and participant is left unmentioned. In *Metaplay*, were the participants aware that they were taking part in a mediated communication with a human artist and not interacting directly with an "intelligent" computer? It would be interesting to compare the interaction of participants who are made aware of this fact with others who are not, but the way Krueger plays with the concept of the machine having the same capability of interpretation as a human points to some of the limitations of the computer. The task of interpreting a participant's body movements into meaningful gestures was not accomplish by the machine, but remotely by the active artist. From a different perspective, Dreyfus (1992) observes similar limitations when examining the implementation of speech recognition techniques and points at three functions not as yet conceived in digital computer programs:

> (1) the inner horizon, that is, the partially indeterminate, predelineated anticipation of partially indeterminate data
> (2) the global character of this anticipation which determines the meaning of the details it assimilates and is determined by them
> (3) the transferability of this anticipation from one sense modality and one organ of action to another

Despite the fact that Krueger's artistic responsive environments and Dreyfus' questioning of speech recognition techniques emerged from drastically different areas of computing research, both point at the lack of body of the computer, which must "build up its recognition starting with determinate details" (Dreyfus, 1992). In terms of integrating the complexity of the human body and how we make use of it to interact with the world around us, interactive systems are limited by the data they perceive. Artists such as David Rokeby and Simon Penny tackle the problem by fabricating custom computer vision systems that provide more detailed information about the interacting body. In Rokeby's (1986) *Very Nervous System* (*VNS*), a camera captures a real-time image of the participant, who is invited to experience and discover the system, generating sound and/or music based on the motion of her body. An interesting aspect of *VNS* is its attention to details, from the wide swoop of an arm to the fine motion of the fingers, the system perceives the different levels of interaction to orchestrate the sonification. *Traces* proposes a similar interactive experience, but engages the participant in exploring the interaction between body motion and both visuals and sound in an immersive environment. "The movement of the user through the space leaves volumetric and spatial-acoustic residues of user movement that slowly decay" (Penny *et al.* , 1999). As a participant move about the space, her body appears to emit semi-autonomous agents in the form of dynamic particles leaving traces of their motion that slowly fade with time. A computer vision system constituted of multiple infrared cameras tracks the participant's body in a 3D space, providing a different set of data than systems which compress space into a single flat surface (e.g. *VNS*). On the one hand, the sensing technique used for *Traces* senses some properties of the interactive body that *VNS* is oblivious to (e.g. volume, position in 3D space); on the other, it loses some of the detailed information that creates the sensitive response of *VNS*. The perceptual limitations of computing systems and the complexity of human embodied interaction imply that the implementation of a system that integrates aspects of our embodiment must be intimately linked to the use and content of the system; an approach that goes against the all-purpose design of the desktop computer.

In the case of *VNS* and *Traces*, participants face abstract visual and auditory content that evolves as they explore the interactive possibilities of the systems. This form of interaction allows for flexible mappings between bodily interaction and content as the effects of gestures are discovered through exploration. Although a certain flexibility is possible with content due to the often unknown effect of the first interactive steps, the everyday use of our body and our detailed knowledge of its agility requires a fine-tuned fidelity between action and response. Arguably, all interactive computing systems involve a certain degree of exploration to determine the domain of interaction, but the purpose of some systems points participants in a certain direction. "With the notion of purpose we induce [the participant] to invent the machine we are talking about" (Maturana & Varela, 1980). The popular game *Dance Dance Revolution*^{TM} (*DDR*) uses a completely different approach to integrate the body with similar success. From the start, the title of the game and the physical apparatus that recreates a dance floor in the arcade make the purpose of the game clear; it is a dance simulator. In contrast with the complex computer vision systems of *VNS* and *Traces*, *DDR* uses eight pressure sensitive areas positioned on the floor (four per player), representing the forward, backward, left, and right directions. The engaging gameplay of *DDR* emerges from the balanced interplay between the precise steps that must hit the floorpad in synchrony with the scrolling dance sheet on the screen and the freedom of movement the game allows between each steps. Whereas debutants tend to approach the floorpad with care, a look at expert players reveals that the short moments between each step offers the space to create an individual experience, where players can use feet as well as hands to press the floorpad, jump from one side of the floorpad to the other, etc. A careful balance between what is perceived by the system and what is not is often more important than trying to sense every possible detail. *DDR*'s gameplay also relies on exploiting the social-cultural action of dancing and the dance floor artifact, but I will examine this aspect of the game later, when questioning the intentionality of tactual actions.

Another fundamental difference between systems that use computer vision (e.g. *VNS*, *Traces*) and others that require direct physical contact (e.g. *DDR*) is found in the way their interfaces define tactual actions. These two approaches are attempts at providing the computer, not with a body, but with the functionalities of independent organs. Whereas computer vision systems try to simulate the eyes (or often the eye), the more prevalent approach requires direct contact, limited by push buttons and pressure sensors that create a low resolution skin for the machine. This separation of the "organs" of the computer is reminiscent of the study of the human senses, which were divided and examined independently at first, only to be perceived as interacting systems later on (Gibson, 1966). This separation of the *seeing computer* and of the *touched computer* gives place to a form of touch unique to the interaction with the digital computer. In the case of systems relying on computer vision, people are often able to manipulate distant virtual artifacts without the possibility of ever touching them, incapable of physically connecting the near and the distant. This form of "touch" is present in the interactive experience taking place in *Traces*, where participants interact with virtual visual artifacts, and is addressed clearly in another interactive installation. In *Fugitive*, participants are invited to interact with a section of landscape is projected on the wall of a circular room (Penny & et al., 1997). The system, which uses the same computer vision technique as *Traces*, detects the participants' position and body movements to control the virtual landscape. However, if a participant approaches near the projected landscape, the projection rotates away from the participant, making it impossible to ever touch the landscape in sight.

With a similar approach, Camille Utterback is an artist who has been questioning the integration of our embodiment for the design of interactive computing systems. In *Untitled 5*, participants generate abstract painterly visuals by moving their body in front of a wall projection (Utterback, 2004). Utterback proposes a different view of the virtual "agents" generating the visuals of the piece:

> As a person moves through the space, a colored line maps his or her trajectory across the projection. When a person leaves the installation, their trajectory line is transformed by an overlay of tiny organic marks. These marks can now be pushed from their location by other people's movement in the space. (Utterback, 2004)

Whereas the graphical semi-autonomous agents of *Traces* emanate from the participant's body and slowly decay, the visuals of *Untitled 5* are created by the participants pushing invisible particles left in the space from previous interactions. In his study of touch, David Katz described three specific modes of touch —surface, film and volume —which extends touch beyond the direct experience of objects with defined surfaces (Krueger, 1982). For Katz, a *surface touch* is the experience of a solid substance having a continuous surface, *volume touch* is the feeling of solid objects through a soft material, and *film* *touch* is the immersed experience of a stream of a certain thickness —such as air or liquid. Participants interacting with *Untitled 5* are certainly not able to feel the contact of invisible particles filling the space against their skin, but a new mode of touch is found in the interplay between the moving body and the sight of responsive virtual artifacts. Although Katz's perspective does not always account for the interaction of the senses, it offers a different view for questioning the new form of distant touch offered by some interactive computing systems.

Since the early days of computation, artists and researchers have been experimenting with the integration of the body in interactive computing systems. I have presented the work of a few artists —Krueger (1973); Penny & et al. (1997); Penny *et al.* (1999); Utterback (2004) —who are part of a trend that emphasizes a form of interactivity that was appropriated by different practices. These artists share an approach towards interactivity that acknowledges the body as a whole, a body that wants to move freely, unburdened by input devices. More recently, this approach led to the development of video games that employ a digital camera and computer vision techniques —such as the *Playstation 2™ EyeToy™*. This technique allows players to use their body to control the elements of the game, a modality of play that moves away from the standard controller and the limited interaction of the fingers. Similarly, the last decade saw an increasing interest in the development of gesture-based interfaces. Some gesture interfaces, which were popularized in science-fiction movies including *Johnny Mnemonic* and *Minority Report*, engage users in a touchless interaction with content displayed on a transparent screen, (Wilson, 2004) while others require a direct contact with the surface (Dietz & Leigh, 2001). These two types of system are gesture-based, but as I observed in *Traces* (Penny *et al.* , 1999) and the *DDR* arcade game, their implementation limits the gestures each system is capable of perceiving. As Klemmer *et al.* (2006) remark, gestures are an important part of thinking and communication, and systems that constrain gestural abilities will impact on these processes. However, the limited perceptual abilities of computing systems inevitably requires certain constraints to render gestures visible to the system. The surface area of multi-touch screens, the space of touchless gestural interfaces, and the pressure points of a floorpad, define the gestural language people utilize to interact with the systems. Nevertheless, computing systems are not the only source of constrain on our actions. The physical and tangible world is full of constraints that define how we act and interact. Researchers have reached out and integrated the tangibility of objects as part of computing systems, objects which constrain and guide the movements and gestures of everyday actions.

2.2 Reaching Artifacts

As I observed in the previous chapter, the notion of the ”haptic” took form in the art studies of Aloïs Riegl and was appropriated by diverse fields of practice. The perception of our agile body, of our body in relation to its environment, and principally, the experience of seeing, reaching and manipulating the artifacts of the physical world define the domain of the haptic for Riegl and the psychologists who adopted the term to refer to the active touch. With the evolution of computation and interactive machines, the term ”haptic” was redefined to include all aspects of machine touch and human-machine touch interaction. The term emerges in disciplines including biomechanics, psychology, neurophysiology, engineering, and computer science to refer to the study of human touch and force feedback with the external environment (Eid *et al.* , 2007). However, the haptic's reference to the interactive relationships of the senses, and more specifically to the interplay between vision and touch, has been appropriated at different degrees by research areas developing and utilizing haptic technologies.

Generally, ”haptic technology” refers to interfaces that use force, vibration and motion feedback to augment the manipulation of remote physical or virtual objects, extending touch to the untouchable. Srinivasan & Basdogan (1997) define ”Computer Haptics” as a broad ”discipline concerned with generating and rendering haptic stimuli to the human user, just as computer graphics deals with generating and rendering visual images.” A decade ago, they pointed at applications of virtual reality and teleoperation for diverse domains including medicine, entertainment, education, industry and graphic arts that could (and do) benefit from haptic technology. These technologies have infiltrated the practices of telemedecine, surgical simulation, Computer-Aided Design (CAD), video gaming, to name only a few. Here, I do not intend to question the infiltration of operation rooms by ”smart” scalpels that might be repulsed by the touch of an artery (Nojima *et al.* , 2002), although it definitely deserves some thought, but instead, examine the different approaches of haptic research that use the interplay of the senses to connect the near and the distant.

The gaming industry rapidly adopted and pushed the development of haptic technologies. The design of the joysticks of my childhood are not far from the joysticks of today, but a significant change has been the integration of force feedback and vibration. Several joysticks and other specialized controllers (e.g. steering wheels) use haptic technologies to augment the player's experience. In addition, game consoles have widely adopted the use of vibration in controllers to create a more physical experience. Generally, these haptic devices attempt to simulate the kinesthetic feeling of manipulating an object or touching a surface by generating information that the player interprets in the context of the manipulation. A few successive vibrations combined with the sight of a pothole on the screen lead me to think that my vehicle rolled over something, without feeling anywhere near the experience of driving a real car on a real bumpy road. However, with the recent development of haptic technologies, some high-end controllers like the *Novint Falcon*^{TM} have infiltrated the consumer market with the promise of a more realist simulation of touch, allowing players to feel the shape, texture and dynamism of virtual objects. In the case of the *Novint Falcon*^{TM}, the user grabs a handle that moves in six directions (left, right, forward, backward, up and down) and is actuated by three motors applying force to simulate the surface of objects. Nevertheless, the hand and the eyes must inevitably maintain a separate focus; I imagine the touch of the object while I stare at the screen, or I perceive an invisible shape as I look at the hand guiding the haptic controller. This mode of simulated touch removes the need for the reach, for physically connecting the near and the distant, by placing the user's touch in continuous contact with the system.

A similar form of remote touch emerges in haptic technologies that discard or do not explicitly require the use of vision. These technologies are often, but not always, designed as aids for the blind, extending touch to the invisible. The *Enactive Torch* (*ET*) is a perceptual supplementation device that creates a similar form of mediated touch, allowing someone to feel remote physical things and properties of the environment through another object (Froese & Spiers, 2007). However, the approach of the *ET* is different in that it does not try to replicate the state of a remote object. Instead, "the *ET* provides the user with one continuous channel of vibro-tactile feedback, where the strength of the stimulation depends on the distance to the object which is currently pointed at" (Froese & Spiers, 2007). When using the *ET*, blind subjects can develop a new mode of perception that emerges from the combination of active motion and this new channel of information. Even with little practice, certain prominent features of the environment become recognizable, "corners and open doors take on a distinctive perceptual pattern which could be described as 'touching objects out there'" (Froese & Spiers, 2007). An interesting aspect of the interaction with the *ET* is the way it allows the user to create a new form of perception of the distant object or feature through enaction due to the lack of visual information. That is not to say that the combination of visuals and haptic feedback (e.g. video game controllers) creates a realistic experience without the active participation of the user, quite far from it, but that it is possible to create a meaningful haptic experience that does not attempt to simulate the visual properties of the object or environment the person interacts with.

A touch deprived of visual information is present in *inTouch*, a medium for haptic interpersonal communication that creates a connection between two remote physical objects (Brave & Dahley, 1997). Each object includes three rollers that are linked so that a force applied on the rollers of an object is replicated on the other. People physically manipulate the objects by moving the rollers and, through the object, render their presence tangible in a remote location. Through exploration of the interaction, a playful haptic communication might arise from the simultaneous manipulation of the objects, allowing for the mediated touch of a distant person. Whereas the touch of game controllers simulate distant virtual objects and the touch of the *ET* creates a perception of the environment through enaction, *inTouch* creates a link that is both perceptive and affective. With *inTouch*, actions affect the state of the remote object, but more importantly, they affect the distant person who physically responds to the invisible hand pushing the rollers. In this case, touch becomes more than the physical contact, more than connecting the near and the distant; it makes it possible to communicate and affect distant people through the touch of an object.

Given the abstracting nature of computation, the haptic came to refer principally to the touch of remote and virtual objects. However, originally, the notion of haptic was grounded in the tangible nature of the world, a perspective present in computing systems that integrate the world we can physically see and reach. Whereas computer haptics opened the doors to new modes of distant touch, touching virtual artifacts and remote physical things, certain tangible computing systems concentrate on augmenting the physical world at reach by engaging people in a direct haptic interaction with tangible objects. Broadly, tangible computing systems allow people to perceive or interact with virtual content through physical objects or environments. The fields of ”tangible computing” and ”computer haptics” are certainly not mutually exclusive as tangible computing systems often make use of haptic technologies, but their approaches differ in the way they create couplings between the virtual and the physical. Haptic devices generally attempt to simulate the touch of distant objects and surfaces, whereas tangible computing systems integrate physical objects as *representations* of virtual or remote entities.

The integration of tangible artifacts into computing systems opens up an interactive space by embracing the physical modalities of interaction that is central to our active human body. This expansion of computation into the objects that populate our environments necessitates that we question their everyday use in more detail, but already, during the last decade, researchers have developed diverse techniques that exploit the tangible nature of objects. For example, Tangible User Interfaces (TUI) allow users to control virtual artifacts through the manipulation of simple physical objects. Ullmer & Ishii (2000) point out that we already interact with analog TUIs every day and present the abacus as a prototypical example:

> The abacus makes no distinction between ”input” and ”output.” Instead, the beads, rods, and frame of the abacus serve as manipulable physical representations of abstract numerical values and operations. Simultaneously, these component artifacts also serve as physical controls for directly manipulating their underlying associations.

TUIs have been implemented to serve a variety of purposes including augmented maps (Ullmer & Ishii, 1997), urban planning simulation (Underkoffler & Ishii, 1999), and musical instrument (Patten *et al.* , 2002), but they generally recognize a similar set of properties: position, orientation and identity of augmented tangible objects. Users manipulate the objects, affecting their properties, changes which the system reflects on the virtual content. TUIs seek to harness the large set of behaviors people have learned through everyday interaction with the tangible world. Small cylindrical plastic pucks afford being picked up, slid and rotated on a smooth surface, and they can be coupled with virtual content in ways that are easily understood. Turning a knob to the left decreases a certain amount, while turning to the right increases it. Placing a magnifying glass on an an augmented map visually transforms the content below it. Until now, TUIs have integrated simple generic objects that are easily recognizable by the system and usable in different types of application. Early in the conceptualization of TUIs, Ullmer & Ishii (2000) pointed at the range of rich interface affordances that we have developed through the use and refinement of instruments, tools and everyday objects. However, one effect of the generalization of the objects integrated in TUIs has led to an exploitation of the hands as advanced pointing devices. In some situations, users' access to the simultaneous use of the hands is certainly an advantage over more constraining modalities of interaction like the mouse and keyboard, do TUIs fully exploit human dexterity and motive abilities?

The hands can perform complex bi-modal and asymmetric motion. In some cases, the organ of touch is not a single hand, but the two hands together, a phenomenon present especially for the blind (Krueger, 1982). "Entire professions, such as surgeons, sculptors, jewelers, musicians and puppeteers rely almost exclusively on their hands as the principle organ of expression, yet such capabilities are seldom exploited in computer systems" (Wilson, 1998, in Klemmer *et al.* 2006). In a sense, computing systems have exploited the fingers, and to some degree the hands, as some users become experts of the mouse and keyboard or using complex haptic devices. In terms of TUIs, the hands gain complexity by acknowledging the motive body, and consequently, the space that surrounds it. Surgeons execute tasks that require extreme precision and dexterity, but also reach for and exchange tools, interacting with the space and people that surrounds the main focus of the surgery. Norman (1988) points out the multiple modalities of the hands in interacting with everyday things. For example, when facing a sink with a single knob for temperature and pressure, people tend to instinctively rotate the knob with a free hand in the clockwise direction to increase the temperature, and counterclockwise to decrease it. However, in some cases, facing a sink with two knobs, the simultaneous use of the hands inverts how someone uses the right hand, expecting the right knob to increase pressure in the counterclockwise direction. This simple everyday interaction does not require a surgeon's dexterity, but the natural tendency of hands to act symmetrically is part of a larger set of behaviors that tangible computing systems should integrate in their design.

In terms of the ”haptic”, an account of the hand, and more broadly of physical actions, would be incomplete without acknowledging the tight relationship between touch and vision. The use of representative physical objects in tangible computing systems, and more specifically in TUIs, allows people to physically reach, touch and manipulate virtual artifacts through the objects. Although certain activities take place hidden from the view of others, actions performed in the physical world are inherently visible. Klemmer *et al.* (2006) examine how the visibility of actions in certain practices support collaboration and coordination. They point out that the visibility of actions in work practices allow for situated learning as active newcomers observe the experts at work in order to gain a better understanding of the practice. In addition, the visibility of actions manifests itself in the artifacts the practice creates, artifacts that become tools to coordinate with others. Work practices are not the only occasion for situated learning. At the arcade, amateur *DDR* players watch and learn while waiting for their turn in the audience that often forms around *DDR* performances. Situated learning is not restricted to the amateur-expect relationship; groups of amateurs, as well as groups of experts, can collaborate and learn by perceiving each other’s actions. This form of situated learning often takes place in art galleries where participants explore interactive work collaboratively (Hindmarsh *et al.* , 2005). This perspective extends the interactive space of tangible computing systems, a space that allows simultaneous and separate interactions. The visibility of actions often comes up in the questioning of tangible computing systems, but these discussions tend to separate the sight of users from the perceptual abilities of the system. At times, the extended interactive space leaves the system incapable of perceiving the rich range of ″visible″ actions, moments of interaction taking place out of the reach of the system. While some researchers are experimenting with extended tangible computing systems that integrate with physical objects and spaces (Rogers *et al.* , 2006), others are exploring the micro end, the direct contact, the tactile experience.

2.3 Tactile Contact

At this point, I have presented an account of diverse computing systems that harness two interrelated aspects of our tangible nature. It is possible to discern a trend that integrate the body, its agility, mobility, and its relationship to the surrounding space, and also, a trend that integrates tangible objects and the rich set of learned behavior that people have gained through everyday interaction in a tangible world. My intention is not to present a comprehensive account of computing systems that integrate the body and touch, but instead, point at some examples in order to question the different approaches taken for the design of interactive systems. Arguably, researchers' captivation with the integration of the body and with the graspability and use of tangible objects has fueled a significant portion of HCI research in the last decade, leading to important changes in the way we perceive and interact with computation. However, this attention to the large scope of bodily interaction has failed to integrate an important part of everyday interaction, tactile experiences. The integration of tangible objects in computing systems, and to some extent the integration of the body, produces interfaces that are often tactile as people come in direct contact with objects and other people, but these interfaces rarely harness the complexity of human tactility.

In the history of the study of tactile perception, Katz (1925) might have questioned human tactility with more depth than any other psychologists. Katz concentrated mainly on cutaneous sensitivity and used the notion of ”active touch” to refer to the identifying hand moving over a flat surface. In his studies, Katz proposed the hand as the unitary organ of touch, fitting with the general conception of the sense organ. For Katz, this approach brought a perspective on tactile perception that involved the complexity of our everyday interaction through touch, pushing beyond the energy sensitivity of the skin that had been at the center of attention of previous studies. As Krueger (1982) remarks, Katz was not alone in appreciating the power of the hands, and points at others who have paid attention to their complexity (Révész, 1950; Gibson, 1966; Kennedy, 1978). In everyday use, the hands are ”simultaneously and successively expressive, executive and perceptual” (Kennedy, 1978). Mentally, the perceptual prowess of the brain bridges the gaps of the fingers and of the fragmented strokes of the hands. The contact of a few fingers or sparse strokes of the hand over a surface evoke a mental image of the object in contact, an instance of the brain filling the gaps of the senses, similar to the blind spot of the retinas. Also, Katz noticed that the first touch of an object with the hand creates a memory image that gives a lasting perception of the object when successively placed in contact with less sensitive areas of the body (Krueger, 1982).

The dexterity that allows us to touch with different degrees of precision and the abilities of the hands to perceive various textures and shapes is far from a new subject in certain areas of computing research. In recent years, the hand freed from the grasp of the computer mouse has attracted interest, but the field of AI, more specifically of robotics, has examined the properties of our skin and hands since the early 70’s Nicholls & Lee (1989). observe that, in the early 80’s, roboticists started paying increasing attention to tactile sensing. At the time, the state of tactile sensors paled in comparison with the developments of machine vision, but the potential use of tactile sensing for different domains pushed researchers to develop the technology. The task was to design tactile sensing techniques that simulate certain aspects of our skin's perceptual abilities, providing a sense of contact, shape of an object, texture, temperature, hardness, moisture, etc. Sensors could then be deployed on certain regions of a robot's body to gain a limited form of tactility. In the development of tactile sensing technology, it is possible to distinguish two approaches to the analysis of tactile information, which replicate the path taken by researchers who have examined human tactile perception in history. On the one hand, several roboticists concentrated on the recognition of objects through the analysis of static tactile data, an approach that perceives touch as passive, limiting the information to the cutaneous receptors of the skin. On the other hand, some researchers were proponents of analyzing dynamic tactile information, approaching the problem with the notion of an active touch. The few possible contacts of the fingers or areas of skin on an object, which give the tactile modality of sensing its precision, simultaneously limit the perception of properties available at a near distance, making the task of forming a global image of the object arduous. The active tactile sensing approach bridges the gaps between the fingers (of the jaw grippers of robots), replicating the perceptual feat of the brain that had drawn Katz's (1925) attention. In the early stages of development of tactile sensing, the majority of research concentrated on creating new and improved tactile sensors and devising techniques for processing the sensed information. In the 1990s, the maturing field continued to develop diverse sensing techniques including soft materials, probes, whiskers and haptics, and moved on to focus on experiments integrating tactile sensors in systems performing a variety of tasks. As tactile sensing integrated the field of robotics, the interest in designing the transduction technology moved towards the engineering and use of sensors. Putting the sensors to use brought researchers to examine their fabrication, leading to advances in form, material, and the sensing of finer textures and properties such as softness. For a detailed review of tactile sensing in the field of robotics see (Nicholls & Lee, 1989) and (Lee & Nicholls, 1999).

Roboticists' goal of providing robots with ever more human qualities has led to important developments of tactile sensing technology, but the purpose of their systems tend to remove the human from the equation. Although robots might come in direct contact with humans, the majority of research has concentrated on robots' recognition and manipulation of tangible objects. In contrast, an area of computing research that centers around tactile interaction is found in the study and design of aid for the blind. An early example is the *Optacon*[1], a commercially available reading aid for the blind which was first marketed in 1970. The *Optacon* consists of a small hand-held camera that is moved over a surface, and senses a pattern of light and dark that is transfered to a 6-by-24 array of pins. While the user move the camera with one active hand, the other hand rests passively on the array of pins, feeling the vibrating pins that create a low-resolution tactile image of the visual content (Craig & Sherrick, 1982). The use of raised dot patterns to represent information for the blind is exemplified by the language proposed by Louis Braille in the early 19th century. Braille is a set of 64 distinct characters that are represented by patterns of six dots, each cell being a matrix of three rows and two columns. The primary difference between the *Optacon* and a braille text is the mode of representation they use to transfer visual information. A braille text consists of a series of characters separated by spaces to form words and

[1]The *Optacon* is one of many commercial products that followed Paul Bach-y-Rita's pioneering work on sensory substitution in the 60's (Bach-y Rita *et al.* , 1969).

grouped into paragraphs in a manner similar to most written languages.. Whereas a braille reader must learn the language to decipher the content of the text, an *Optacon* user might utilize previous knowledge to recognize the shape of, for example, roman characters, and of other visual artifacts present on a surface. Although it relieves readers from learning a new language, the *Optacon* fails to provide some important aspects of an interaction with a braille text. One significant feature of braille is its simplicity, which permits faster reading rates than systems which transfer the visual properties of characters (e.g. *Optacon*) (Foulke, 1982). However, in some situations, a blind person might prefer to have access to a wider range of visual information difficult to convey in words. Another important aspects of braille is that it allows a reader to use one or both active hands to perceive the information. It has been shown that beginner braille readers tend to use a single hand, whereas expert readers employ both hands, which leads to an increase of reading speed (Foulke, 1982). The interaction with the *Optacon* and the reading of printed braille text engage the hands in different ways. Whereas an expert braille reader might use both hands to scan different areas of a text, using the index finger of one hand to get a quick feel of the text and detect the position of the next line, while the index of the second hand fills in the details, the *Optacon* requires one hand to remains passive to feel the dynamic pins, while the other hand moves over the material.

Ramstein (1996) uses a similar technique for the design of a single cell braille display. This reading aid combines a single cell display with haptic technology to give the reader active control of the area to be perceived. A study of the system shows that the use of a passive finger on a dynamic cell physically separated from the active hand moving across a surface leads to faster reading rates than (1) the use of a single hand to read and move the device simultaneously and (2) the use of both hands to both read and move the cell attached to the movable arm of the device. However, both systems —*Optacon* and Ramstein's (1996) haptic single cell display —show reading rates far inferior than printed braille text. Despite this limitation, it is interesting to observe how the design of reading aids for the blind not only harnesses the notion of active touch, but integrates it in ways that create new modes of perception. Whereas a new sense that combines hand motion and haptic perception emerges from the use of the *Enactive Torch* (Froese & Spiers, 2007), some tactile displays give place to a new sense that combines the active motion of the hand with the passive cutaneous perception of the finger of the other hand. More recently, some researchers are exploring the possibilities of the active hands, trying to release them from the apparatus of previous designs (Kajimoto *et al.* , 2003, 2004).

Figure 2.1: Braille characters for the letter O and the letter K.

An interesting aspect of devices designed as reading aids for the blind is found in the interaction between people and kinetic objects. Devices such as the *Optacon* and braille displays transfer information onto a limited kinetic tactile surface. The approach that employs both hands, one passive and one active, in the perception of the information is a sensing technique that emerged as researchers experimented with this new relationship between the body and meaningfully kinetic objects. The single braille cell display is an example of a kinetic object for which changes are well understood. A change from a cell consisting of the two lower dots of the first column and the top dot of the second column to a cell made of the top and lower dot of the first column and the middle dot of the second indicates a reader that a shift from the letter O to the letter K occurred.2.1 The means for integrating motion into objects have changed considerably since the early days of tactile displays, and researchers are experimenting with more complex kinetic objects, creating a variety of interfaces that are part of a larger set of systems that Parkes *et al.* (2008) refer to as Kinetic Organic Interfaces (KOIs). A significant portion of these systems are designed as interactive kinetic sculptures (Poupyrev *et al.* , 2007), while others find refuge as educative toys in the hands of children (Raffle *et al.* , 2004). Despite the rich history of kinetic systems, KOIs have yet to integrate the domain of problem solving systems that TUIs have infiltrated over the last decade. Some researchers are already exploring the possibilities (Patten & Ishii, 2007), but the use of motion and physical transformation of interactive artifacts requires that we question the meaningfulness of actions and interactions with these new systems. Some people have learned to behave in the presence of interactive kinetic objects that attempt to replicate the living —such as an *AIBO*^{TM} (dog) and a *Pleo*^{TM} (dinosaur) —but creating systems that perform intentional actions requires an understanding of the languages of kinetic actions. In terms of tactility, a look back at fields of research that involve tactile interactions (e.g. robotics, design of aids for the blind) can bring insights to the design of these systems.

The majority of KOIs are fabricated using solid materials like wood, metal and plastic, but developments are taking place in the implementation of computing systems using soft and flexible materials including fabric, paper, foam, etc. This approach of ”soft computing” opens the doors to a new set of physical properties that a system can harness. *Sprout I/O* (Coelho & Maes, 2008) and *Surflex* (Coelho *et al.* , 2008) are two examples of soft computation that combine shape-memory alloys with flexible materials, harnessing their inherent property to bend when a force is applied and regain their shape when the same force is removed. In terms of a language of kinetic actions, we have learned to cohabit with kinetic objects in everyday life, objects which are generally fabricated with hard materials. In the past, the motion of flexible surfaces was left to the realm of the living, so the complex language of interaction between humans and other living entities will certainly affect how people interact with soft computing systems. Another important quality of soft computing systems is the range of textures they might integrate. Soft materials like fabric afford a refreshing language of interaction, moving away from the ubiquitous use of hard plastic, but the use of dynamic textures remains an underexplored area. The texture of tangible objects is a rich source of information in everyday life. At the grocery store, I base several choices on the texture of products; avocados must be soft enough, while apples must be firm. While writing this text, my hands are guided by the small elevations on the letter F and letter J of the keyboard. Most importantly, the feeling of the body, of our own and of others', provides complex information that we have learned to interpret, from the arousal of goose bumps to the problematic appearance of rashes. The control of the texture of tangible objects will surely become of interest as researchers develop and experiment with technologies that integrate this aspect of the tangible world.

2.4 Intentional Touch

> There is no way to talk about action independently of meaning —not simply how the action arises from conscious intent, but, more significantly, how intentionality arises from actions in the world. (Dourish, 2001)

Since its conception in the mid 40's, the digital computer has evolved into a pervasive multi-purpose machine. In the beginning, the military cradle of digital computers meant that users' actions were far from the mundane, routine use of most of today's computing systems. Nevertheless, from the calculations of early military computers to the quotidian reading and writing of emails, actions performed with computers are generally about something. Researchers typed at the teletype console to trigger a sequence of calculations in the computer, which helped in the creation of the first fusion bomb. At the arcade, I frantically press buttons while playing a game to overcome the *Invaders*, which might lead me to win the game. At home, I click a button that sends the final copy of this text to my advisors, taking me a step closer to obtaining a degree. Users perform actions *with* the computer (e.g. mathematical calculations, the killing of aliens, sending emails), and act *through* the machine to affect the lived world (e.g. building a fusion bomb, feeling the completion of a game, getting a degree[2]).

The majority of everday actions we perform with and through computers involve a certain form of touch. The design of the desktop computer requires us to type at the keyboard and click the buttons of a computer mouse, the designs of mobile phones and portable music players require us to push buttons or stroke a touchpad, etc. In contrast, I have presented several tangible computing systems that open the interactive space to a rich domain of tactual actions. That is not to say that the interaction with tangible computing systems are more meaningful than with the desktop computer, but instead, that an interface which integrates the body and a broad set of tactual actions offers new ways to perform meaningful actions. In the previous chapter, I presented a definition of the term "tactual" that refers to the intentionality of

[2]a discussion of the problematic relationship between a higher education degree and the lived world is beyond the scope of this thesis.

touch, and mentioned an example of tactual interaction where a person communicates with another by knocking on the door of a house. The action of knocking is more than the resulting sounds; through the door, it is an alert of someone's presence and, sometimes, communicates information about the situation. The type of surface, the force and the pattern are properties that can affect the interpretation of a knock. You might recognize the individual knock of close friends, or differentiate between the knock of party-goers and police officers. In contrast, the use of a digital doorbell might propagate the sound further away from the door, but it limits the range of possible tactual actions. It is still possible to ring a doorbell with different patterns, however, most people refrain from doing so because of the cacophony it might create. In some situations, the doorbell might be a more appropriate alert of someone's presence at the door, but the versatile use of the hand against a door allows for a richer set of meaningful actions. Through everyday interaction in the world, we have learned to interact tactually with doors in meaningful ways, and learned to use doorbells in the right situations. Similarly, by stepping away from restrictive input devices (e.g. mouse, keyboard), the approach of tangible computing systems can create interfaces that allow for a richer set of meaningful tactual actions.

The meaning of users' actions is shared at two different levels; users' actions are interpreted by the system and, in some cases, by people sharing the interactive space. Whether a user clicks the button of a computer mouse or interacts using gestures, computing systems always involve a certain amount of interpretation. However, the information present in gestures is often more complex than the click of a button, even though both are used to perform meaningful actions. Some researchers have experimented with an extended form of tactual interaction by augmenting a standard computer mouse. The

TouchMouse introduces capacitance sensors to detect the contact of the user's hand (Hinckley & Sinclair, 1999). Whereas a standard mouse detects the motion of the hand and the click of buttons, the *TouchMouse* also senses the user's touch when the hand is immobile. By using this touch-sensing technique, the computer interprets some of the user's tactual actions that are beyond the reach of a standard computer mouse. These actions might be implicit, when the user reach for or remove her hand from the mouse without realizing it, or explicit, when tapping, rolling and holding the scrolling wheel, or resting a finger on specific areas of the mouse. Context strongly affects how the computer should interpret these tactual actions. For example, when typing in a word editor, the user touches the mouse when she wants to access the toolbar, and releases it when she goes back to entering text. The computer might interpret the touch of the user as a change in the focus of attention, hiding or showing the toolbar accordingly to manage the limited screen space. A detailed examination of users' tactual actions with specific tangible computing systems should help better understand their respective interaction space and the valuable tools they provide, but I leave this endeavor for future research. However, some fields of research have studied the way people interact with the physical objects and people that populate their environments. Studies of distributed cognition, social psychology and non-verbal communication do not necessarily involve computing systems, but tactual actions are a significant aspect of the interactions they question.

Hutchins (1995) proposed the theory of distributed cognition with the basic principle that intelligent behavior emerges from the interplay of multiple elements, elements that are not only in the person's head, but "in the wild", where an activity takes place. Hollan *et al.* (2000) point out that three kinds of distribution of cognitive process become apparent in the observation of human activity ”in the wild”:

> (1) Cognitive processes may be distributed across the members of a social group.
> (2) Cognitive processes may involve coordination between internal and external (material or environmental) structure.
> (3) Processes may be distributed through time in such a way that the products of earlier events can transform the nature of later events.

In terms of tactual interaction with computing systems, the integration of external elements, of tangible objects, can facilitate users’ cognitive processes as part of certain activities. TUIs use the direct manipulation of tangible objects coupled with digital content and allow users to ”think through doing” (Klemmer *et al.* , 2006). Generally, the design of TUIs concentrate on the relative position and orientation of augmented objects, a form of direct manipulation appropriated from the interaction with the desktop computer. Through constraints and affordances, tangible objects provide information that can be directly perceived and employed by users, while simultaneously constructing the interaction space (Zhang & Norman, 1994). However, time is also an important factor in the interwoven processing of internal and external information. The solid-state objects integrated in TUIs become memory aids as a user departs from and returns to the system. Often, everyday human activities leave physical traces behind; whether they are notes left on a sheet of paper (Heath & Luff, 1996) or marks on a surface from the repeated use of a hard object, these physical artifacts form a visible history of interaction. Depending on the situation, people might make implicit or explicit use of these physical artifacts. Tangible computing systems should move beyond direct manipulation interfaces, and pay attention to the tactics people develop to exploit the physical properties of the environment (Hollan *et al.* , 2000). Tangible computing systems allow for these tactics to take place and facilitate meaningful actions without necessarily interpreting the complexity of a user's gestures and touch. Nevertheless, the visibility of actions performed when interacting with tangible computing systems often extends the interaction space to multiple people, who interpret each other's actions, directly or mediated by physical artifacts.

Computing systems are always situated within a physical and social space. The original design of the PC targeted work offices, which are locales of certain types of activities, and places where people share similar sets of goals. With the years, the desktop computer evolved with the office it infiltrated and, simultaneously, the office grew with the computer. The most visible change brought by computation might be the shift from analog to digital, which removes the need for certain physical artifacts, using digital files instead of sheets of paper, bits instead of atoms. However, a powerful aspect of computation is found in how it transforms the social spaces it is a part of. Similarly to physical environments, social spaces afford certain behaviors, and computing systems affect how we behave in those spaces. Previously, I presented the DDR arcade game as a physical computing system that successfully integrates the player's body. I observed that one reason for the engaging interaction of the game is due to the fine interplay between the control and freedom of players' gestures. In addition, another engaging aspect of the gameplay emerges from the social space the game creates. The DDR machine is large, colorful, loud and flashing; it includes a physical stage elevated from the floor and, to some extent, simulates the social space of the dance floor. The structure of this social space gives players permission to abandon their usual behavior in the arcade, and to fling their arms and legs about to dance to the music (Goffman *et al.* , 1997). However, a dance floor normally involves several people that act and interact in different ways, each taking part more or less actively in the space. By making the players' actions visible, DDR accomplishes a similar achievement; although I have never seen a group of people dancing around the players, a curious audience often forms around the performance. The social space of the game transforms the players' steps on the floorpad into dance movements, both for the players and the people present in the space. A similar phenomenon often takes place in art galleries where participants engage with interactive work; while some observe and learn the interactive possibilities, others prefer to watch passively (Williams *et al.* , 2005). Tangible computing systems create an interactive space that goes beyond the direct manipulation of the system, extending the interaction in space and time to reach other people sharing the space. How people collaboratively exploit the physical properties of the systems and of the environment to create meaningful actions is a subject that requires more examination.

2.5 Summary

I have presented tangible computing systems that integrate different aspects of the body and touch. Similarly to other modalities of interaction, the techniques used to implement tangible computing systems inevitably affect the behavior of people engaging with a system. Two discernible trends guide the implementation of these systems. On the one hand, some employ computer-vision sensing techniques that allow a detached and global sense of the body (e.g. *Traces*), and on the other, some use techniques that sense direct contacts, generating a more fragmented image (e.g. *DDR*). In both cases, a certain amount of interpretation is required to transform sensed information into meaningful actions, and this process requires a careful interplay between what is sensed and what is not to allow for engaging interactions.

In addition to integration the body, some systems harness aspects of everyday interaction with tangible objects. Haptic technologies allow users to touch virtual and remote objects, whereas TUIs integrate tangible objects as representations of digital content that users can manipulate directly. As studies of tactual perception have observed, the role of the active touch plays an important role in everyday actions. In addition to the tangibility of objects, some of these systems have integrated the active nature of touch as part of the interaction. For haptic technologies, the combination has lead to new modes of perception (e.g. *Enactive Torch*), and, in the case of TUIs, it opens the interactive space to the complexity of the hands, but also, exploits the visibility of actions in a tangible world. Despite tangible computing systems' emphasis on the use of the moving body and different forms of touch, the tactile abilities of the hands and the skin remain underexplored.

More recently, tangible computing researchers have been developing interactive systems that perform kinetic actions and change shape and texture (e.g. KOIs). However, roboticists and designers of aids for the blind have been experimenting with tactile interactions since the late 60's, and their research can provide insights for the design of tangible computing systems as researchers explore the complexity of human tactility.

From contacts against the skin to gestural movements, tactual actions are generally about something. Whether they are dance moves at the arcade (e.g. *DDR*), the handling of objects to navigate a map (Ullmer & Ishii, 1997), or gestures to explore the interactive space of an artwork (Penny *et al.* , 1999), tactual actions take place as part of larger activities. People can exploit the physical properties of the world to perform meaningful actions, actions which are visible and open for interpretation by others sharing the space. The integration of different aspects of the tangible and social world opens the doors of interactive computing to countless possibilities. Tangible computing systems must harness and built upon characteristics of the world that are relevant to the purpose of each system. However, the technologies available for computing systems often guide their development, an approach that might emphasize some aspects of the world while leaving some underexplored. In the next chapter, I present *Parazoan*, an interactive installation that involves participants in engaging and unusual tactual interactions.

Chapter 3

Parazoan

Digital information is not something we can easily put a finger on. We might grasp a device, a hard drive or a memory stick, but the nature of the information that these objects contain becomes apparent only once it is rendered perceivable in the physical world. The materialization of digital information can take several forms. This text is a file name in a text console, an icon in a graphical user interface, a formatted text in a word editor, the same text printed with black ink on white paper, etc. Since its conception, the computer screen has remained the prevailing tool for representing digital information and, over the years, its versatility has proven useful for the representation of multiple types of information. In addition, the screen's usual sidekicks, the keyboard and the mouse, allow us to interact with the information we perceive, to manipulate the digital content by extending a user's reach beyond her grasp. For the last two decades, researchers in the field of tangible computing have been exploring new possibilities to bridge the gaps between digital information and the physical world. From the early installations of Krueger (1973) to the ″Tangible Bits″ of Ishii & Ullmer (1997), these new approaches seek to exploit the well established relationships between people, objects and the spaces they inhabit. Tangible computing acknowledges that people are embodied in a physical and tangible world, therefore recognizing that the body plays an important role with its range of senses (sight, hearing, touch, taste and smell) and that people hold certain conventions and behaviors when they interact with the world. In turn, Dourish (2001) reminds us that people's engagement with the world is a social and situated affair, grounding our relationships with computing systems in a world that is both physical and social.

As de Certeau (1984) observed, ”our society is characterized by a cancerous growth of vision, measuring everything by its ability to show or be shown and transmuting communication into a visual journey.” People consume contemporary culture by reading, ”from TV to newspapers, from advertising to all sort of mercantile epiphanies”, and increasingly, from the computer screens that permeate everyday life. However, the computer comes with the promise of interactivity, with the possibility of ”touching” and transforming the information we consume. In the history of human-computer interaction, the prominent model of the user, as presented by Card *et al.* (1983), has emphasized the role of vision (and hearing to some degree), while constraining touch to the use of standardized input devices.

In addition to vision and hearing, tangible computing research seeks to integrate a broader and active view of touch to couple digital information with the physical world. Engaging with the physical world involves the sense of touch at different levels, which are inseparable and part of the complexity of human experience; our moving body makes distant objects reachable, we grasp and manipulate tangible objects, we feel the shape and texture of surfaces of all kinds, and we create meaning through tactual actions. Also, the simultaneity of the senses creates intimate bonds between them, especially between touch, vision and hearing. In addition, our social-cultural nature affects the way we act through touch in everyday life. Therefore, it is possible to examine human touch at different scales, but a better understanding of tactual interaction is found in the interplay between these fragmented views. Constraints, conventions and behaviors that people have learned through everyday interaction in the world define the way we touch. Tangible computing systems seek to exploit these factors to inform both how people manipulate information through augmented physical objects and spaces, and how they make meaning from the information they represent.

Tangible computing systems use strategies that differ greatly from one system to the next, but each exploits diverse aspects of people's and objects' embodiment in the world. A typical characteristic of these systems is their explicit use of the constraints of the physical world. Gravity causes physical objects to fall towards the ground, objects placed on flat surfaces tend to stay put, solid objects can not magically merge to occupy the same space, etc. For example, Tangible User Interfaces (TUI) concentrate on the manipulation of tangible objects that are computationally coupled to digital information (Ullmer & Ishii, 2000; Fitzmaurice *et al.* , 1995; Patten *et al.* , 2001, 2002). TUIs sense the spatial manipulation of objects and exploit physical constraints to provide intuitive mechanisms —such as limiting the distance between objects by using an artist's curve to set a physical boundary (Patten & Ishii, 2007). However, everyday interaction with the world goes far beyond our relationship with these physical constraints. Tangible computing systems harness the conventions and behaviors that people have learned through engagement with everyday objects in their environment. Shapes can provide certain affordances that guide the manipulation of an object in certain ways. These shapes might be generic, like the often used flat cylinders, which can exploit the clearly understood behaviors of knobs and the effects on the information they are coupled with. Rotating left turns the volume of my stereo down. Rotating right turns it up. In addition, the specific functionalities of some physical objects can be mapped to digital information. The shape of everyday objects —such as a magnifying glass —can help the user understand the relationship between the physical world and digital content by exploiting the user's learned conventions and behaviors for these objects (Ullmer & Ishii, 1997). Anyone who has used a magnifying glass knows that you should grab it by its sides or handle and look through the glass to see the transformed information. An augmented magnifying glass exploits these learned behaviors and applies similar transformations on the digital content it overlays. Quite often, people manipulate multiple objects as part of an activity and define relationships between these objects through the ongoing interaction. In the kitchen, a cook might use a set of tools and form relational conventions and behaviors between some of the objects. Someone might make the mistake once of using a metal utensil in a non-stick pan, scratching it's surface, and forming a relationship between plastic utensils and the pan that will guide future interactions. Although they might apply to specific objects in specific situations, conventions —such as the of use plastic utensils in non-stick pans —point to some interesting properties of the lived world and the way they govern our actions. Similarly, the use of different materials can guide people's interaction with physical objects, especially in the case of a tactile interaction. For example, the fragility of glass objects might afford a more careful manipulation than the use of plastic.

Generally, tangible computing systems provide functionalities to manipulate digital information through physical objects, but rarely affect the tangible properties of those objects. Nevertheless, some researchers are experimenting with connecting the digital and physical in both directions, allowing users to physically grasp content and, simultaneously, providing some control of the physical objects to the system. Tangible computing researchers are not the first to experiment with computer-controlled motion and shape transformation. For example, the design of aid for the blind has produced a variety of dynamic tactile displays, which provide tactile interfaces to ”read” diverse forms of information. While some tangible computing systems concentrate on directly reflecting the state of information on the physical objects, keeping a ”tight” link between digital and physical, others convey information by employing behaviors present in the everyday world. The behaviors of physical things can be transposed to an augmented tangible object to represent digital information. For example, the behaviors of living things are a valuable source often exploited by tangible computing systems. A blooming flower is intimately linked to the life, growth and health of a plant. The controlled blooming or wilting of a mechanical flower can exploit the plant's behavior and its capacity to convey information to represent the changing state of the digital information it is coupled with (Antifakos & Schiele, 2003). As Parkes *et al.* (2008) observed, the design of ”Kinetic Organic Interfaces” can find insights in the long history of the use of motion in computing systems, but also, gain from a better understanding of the everyday languages of kinetic actions.

Generally, tangible computing systems exploit broadly applicable aspects of people's and objects' embodiment. The primary functionality of a magnifying glass is independent from the type of information it is enlarging. The specific function of the magnifying glass and it's generality of use on any visual information facilitate its appropriation into different tangible computing systems. Clearly, people learn several conventions and behaviors that apply only to the manipulation of objects in certain situations. Inside or outside. Privately or publicly. It is interesting to think of the possible conventions and behaviors that not only differ for each person, but also change in relation to the situatedness of the interaction. An integration of more situated conventions and behaviors might get away from the general goal of tangible computing that seeks to create an interface that is intuitive to most people, towards the exploration of the non-uniform nature of people's engagement in the world as they adapt to each situation.

3.1 Description

Parazoan is an exploration of the interactive relationships between participants, a set of three augmented biomorphic physical objects (Fig. 3.1), and the digital content they are coupled with. From this point on, I use the term "*Parazoan*" to refer to the installation, and "parazoan" to refer to an augmented biomorphic object that is part of the installation. The parazoans are coupled with the digital content to generate visuals that reflect how participants manipulate them. Similarly to the painter's hand moving the brush, participants' gestures generate painterly graphics on a central display as they tilt, move, shake, squeeze and play with the parazoans, without the need for a direct contact with the screen. Each parazoan emits a particular color through its semi-transparent silicone skin and is coupled to a virtual "stroking agent" of the same color. The stroking agent generates a range of visuals based on the way a participant manipulates the object, from soft and detailed line drawings when handled with care to bold graphics when manipulated with intensity.

Figure 3.1: A parazoan.

In addition, the visuals reflect the co-located manipulation of the parazoans. When parazoans are handled in proximity or in direct contact with each other, the system visually represents the relationship on the screen by emitting particles that move between the stroking agents of the proximate parazoans. The exploration of the interactive possibilities of the installation can lead participants to generate visuals from minimal lines to complex intertwined strokes.

The unusual curvilinear shape of the parazoans evokes the features of a living creature, partly sexual, and yet similar to the shape of some typical game console controllers. The work of different artists has inspired the body of the parazoans; particularly, the cinematography of David Cronenberg and the sculptures of Matthew Barney have had a significant impact. The singular kinetic behavior of each parazoan is the vibration of its appendage, which, like a dog wagging its tail, might be perceived by participants as representing some type of situated information. A parazoan vibrates its appendage slowly as a participant picks it up and presses it gently, and vibrates frantically when approaching another parazoan, inviting the participant to explore further and engage in a proximate interaction. The soft texture of the silicone is not common to everyday objects, and sex toys might be the most common example of the use of this material. The installation seeks to engage participants with the unusual shape and material of the parazoans in a public space, exploiting some interesting learned conventions and behaviors that each participant brings to the interaction. How do people move and feel these biomorphic silicone objects? How does the interaction unroll in a public setting? How do participants cooperate to explore the details of the interactive space? In the end, the aesthetically pleasing visuals are traces of the history of tactual interactions with the system. Some participants might prefer to watch passively, while others reach, grab and actively engage with the visuals through the parazoans.

3.2 Hardware

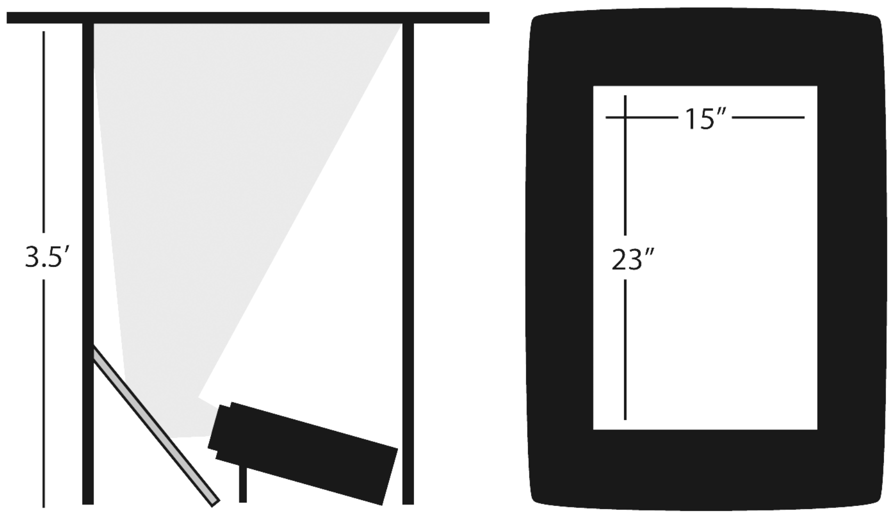

Figure 3.2: Diagram of custom table display.; (left) side view, (right) top view.

The installation consists of the set of three parazoans and a horizontal rear-projection display. A custom built wood table provides the inner space (15″ X 23″ X 3.5′) necessary to host a projector and a front-face mirror to create a sizable projection (Fig. 3.2). A first prototype of the table was constructed with a height of 4 feet, which only allowed very tall people to interact with the system. Some adjustments were made to the position and angle of the projector and mirror to create a projection that is large enough (15″ X 23″), but requiring a height of only 3.5 feet, which is acceptable for most people.

Rear-projection requires a mirror that reflects the image to gain the distance necessary to create a sizable projection. The first prototype used a common mirror, which was made of three layers: an opaque background, a reflective surface, and a layer of glass, in that order. However, the presence of the glass layer over the reflective surface produces a doubling of the image on the screen. A front-face mirror was required to produce the desired sharp image. A ready-made front-face mirror was not easily available at the time of construction, so to create the same effect, a layer of mat black paint was applied on the back of a one-way mirror (Fig. 3.3). Under the table, the projector lays horizontally on the floor and the mirror is placed at an angle to reflect the projection upwards. The image is projected on a piece of thin white cotton fabric (15″ X 23″) stretched over the hollow tabletop. Because the soft fabric tabletop is not strong enough to support heavy physical objects, a wide wood frame (6″) borders the projection, serving the dual purpose of framing the visuals and acting as a shelf on which the parazoans reside when not manipulated by participants.

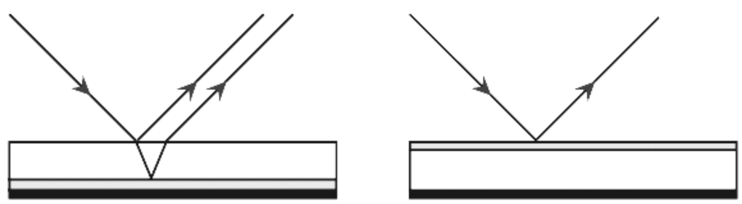

Figure 3.3: Light reflection of (left) standard mirror and (right) front-face mirror.

The parazoans are made of a custom built silicone casing covering an embedded microcontroller and a vibrating motor. The shape of the parazoans was sculpted out of clay, from which a negative silicone mold was created. A first prototype was inspired by the typical oval shape of a computer mouse, and it was created to easily fit in a single hand (Fig. 3.4). However, to facilitate two-handed interaction, and to allow more space for the embedded microcontroller, a shape that resembles a game controller was adopted (Fig. 3.1). The Mold Max^{TM} 15T silicone compound from Smooth-On was selected for its consistency, flexibility and ease of use. The microcontroller inside each parazoan is a Sun Microsystems Small Programmable Object Technology (SunSPOT). The SunSPOTs run on a 180 MHz 32 bit ARM920T core processor with 512K RAM/4M Flash. The installation only utilizes the SunSPOTs' 2G/6G 3-axis accelerometer, the 2.4 GHz IEEE 802.15.4 radio, two full spectrum LEDs, and one I/O pin connected to the vibrating motor residing in the tip of the appendage.

Figure 3.4: A clay prototype of the shape of a parazoan.

A projector and a SunSPOT base station are connected to the host computer residing under the table. The computer runs a custom Java application that parses the information the SunSPOT base station receives wirelessly from the parazoans, and generates the visuals.

3.3 Software

Parazoan utilizes two separate but interrelated pieces of software: one application runs on the microcontroller of each parazoan and another executes on the host computer. Each SunSPOT runs a Squawk Virtual Machine, which is a Java Virtual Machine (JVM) for embedded systems and small devices that is built in the device, and executes a custom Java application that manages the sensors, actuators and wireless communication of the parazoan. First, the application searches for the SunSPOT base station and establishes a connection to send and receive data from the host computer. Once the connection is made, the SunSPOT turns on two full spectrum LEDs to the specific color assigned to each parazoan; the application matches the unique id of each SunSPOT to a hardcoded color scheme. Then, at short intervals, the SunSPOT starts to read the values of the 3-axis accelerometer and sends the data to the host computer. Also, the SunSPOT establishes connections with the other active SunSPOTs (parazoans) and sends ping queries to determine the signal strength to and from each device. When changes occur in the signal strength of a nearby device, the SunSPOT sends the signal strength value to the host computer, which keeps an updated table of values. Furthermore, the SunSPOT activates the vibration of the appendage based on the values returned by different sensors; a change in acceleration after a period of rest triggers a light vibration, whereas sensing a strong signal strength from nearby parazoans creates a more intense and visible vibration. The SunSPOT of each parazoan executes identical copies of the application.

The application running on the host computer manages the data received from the parazoans and generates visuals reflecting how participants manipulate them. It controls the SunSPOT base station, which waits for the parazoans to connect. It parses the data it receives from the parazoans, and sends it to the graphical layer for rendering. To produce the visuals, the application controls three ”stroking agents” that are continuously present in the display space, but move in and out of visibility based on the interaction. A stroking agent is a color-coded particle that moves in a 3D space in response to the manipulation of a parazoan, leaving traces of its movement behind. It is possible to think of the ”stroking agent” as the contact point of a paintbrush against a surface. The brush moves parallel to a flat surface to leave traces of paint behind, but also moves closer and further away from the surface to create thicker or thinner strokes. Each parazoan is linked to its respective stroking agent, which leaves color traces matching the LEDs of the parazoan it is coupled with. As a participant tilts, shakes, squeezes and moves a parazoan, the manipulation is reflected in real-time on the display. By tilting a parazoan lightly, a participant controls the movement of its stroking agent with precision as it moves slowly in the tilted direction, allowing a participant to draw fine and detailed strokes. In contrast, a participant might hold a parazoan in one hand and execute a wide and brusque gesture, which would result in a bold and thick stroke following the path taken by the hand. As the tilt and acceleration of the parazoan are interpreted from the same sensed data, from the accelerometer, the interaction is an interplay between the close inspection of the parazoan and the use of broad gestures. In addition, the system records participants' gestures, which are defined as the motion taking place between two short moments of rest (<3 seconds), and replays them when the parazoan is resting on the table. Traces created by participants' interactions slowly fade away, while new ones take their place. This allows participants to generate interesting patterns and, in the absence of interaction, it creates continuous dynamic visuals for people to watch, which might entice them to interact. In addition, when a parazoan is held in proximity (<2") of another parazoan, its stroking agent generates colorful particles that are attracted by the agent of the proximate parazoan. These moving particles leave fine traces behind, which also slowly fade away.

3.4 Interaction Design

Parazoan was designed to engage participants in unusual tactual interactions, which reach from the direct tactile contact to the intentionality and intersubjectivity of tactual actions. Diverse features were integrated to address and involve different aspects of touch as part of embodied interaction with the system. Four interrelated aspects of the interaction were affected by design decisions: facilitating the use of the body, engaging participants with specific augmented objects tied to digital content, involving an interesting tactile experience, and creating a space for social interaction. These four aspects of the interaction are not sequential steps taken by participants, but instead, they are characteristics that intertwine to make the experience whole.

Harnessing the human body for interactivity is an important part of the design of any tangible computing system. The first contact that a participant has with *Parazoan* is visual. The installation is designed for art galleries, and a participant's first physical encounter with the piece takes place from a distance, as the participant navigates the gallery space. In contrast with users of problem-solving computing systems, who often interact with some particular tasks in mind, participants in an art gallery generally take a more exploratory approach. An early part of this exploration involve the participants moving freely from one artwork to the next to explore the interactive space. However, the participants do not move blindly, and the notion of the ″haptic″ that emerged in Riegl's (1985) studies refers to this interplay between vision and touch, to the connection of the ″near″ and the ″distant″. The use of continuous dynamic visuals in *Parazoan* is meant to entice this connection by attracting participants' gaze and attention, and inviting them near the installation. In addition, the dynamic visuals possibly communicate some of the history of interaction with the installation. Like the marks left by a sculptor's hands on some of the work studied by Riegl, the visuals of *Parazoan* can show the handiwork of past participants. Once they begin manipulating the augmented objects, participants might use the visuals they first encounter to guide the interaction. By providing visuals from the start, participants are made aware of what it is possible to create with the system, which might guide them in the exploration of the installation.

Another element that is central to the interaction with the installation is the design of the parazoans. The odd biomorphic shape is meant to visually and tactually engage participants. The organic and quasi-sexual shape of the objects grabs the attention of the participants, who might feel the need to touch and explore something familiar, and yet unknown. In addition, the softness of the material invites participants in a tactile discovery of the parazoan, which a solid surface does not afford, expressing the object's sensitivities to the quality of a participant's touch. Through the material, parazoans communicate a request for tactile manipulation. The combination of the shape, texture and the visuals generated by the manipulation of the parazoans creates a haptic experience through the participants' enacted behavior. As a participant picks up a parazoan, the system generates a visual and a tactile response; a colored halo appears around the "stroking agent" coupled with the parazoan, and simultaneously, its appendage vibrates. These interactive cues allow a participant to understand that tactile manipulation affects the system, and renders visible the visual area affected by the manipulation, which guide them to further explore the interactive possibilities. Once a participant perceives the connection between physical action and visual response, she might attempt to playfully manipulate the object in different ways: rubbing, bending, tilting, moving, shaking, etc. Participants perceive the diverse effects on the visuals as they try different manual actions with a parazoan. Through perception and action, participants explore and understand the interactive possibilities of the installation. Certain gestures become coupled with soft and detailed graphical strokes, while others are tied to thick and bold visuals. A language of interaction is formed by the interplay of physical actions and perception.

The installation is designed to allow multiple participants to simultaneously interact with the system. The use of the table-like display and of three wireless augmented objects is intended to facilitate collocated interaction. The medium size of the projection makes it possible for three participants to directly engage with the piece, while remaining in proximity with each other, and also allowing space for active viewers. Therefore, participants explore the interaction space by not only perceiving the effect of their own actions, but also, the system's responses to the actions of others. The unusual shape of the parazoans is meant to spark discussions between participants who can then collaborate to explore the installation. The proximity of participants interacting with the system might lead to discussion and collaboration, but it is possible to exploit aesthetics to guide and fuel the interaction. People engage with things that are more than functional; the strange, the ugly, the sexual and the beautiful are qualities by which we make meaning of the world. Tangible computing systems can exploit the subjective to entice and guide interaction and collaboration.

3.5 Exhibition

Parazoan was exhibited at the Beall Center for Art and Technology between June 9^{th} and June 13^{th} 2008. During this period, a few dozen people looked at and interacted with the installation, which was, for the most part, successful in engaging participants (Fig. 3.5). During the opening and closing day of the exhibition, participants were observed interacting with the piece, which brought out interesting aspects of the installation, some of which made the interaction engaging, and some pointing at areas that require improvement.

Figure 3.5: A participant (left) interacting with a parazoan and (right) observing the visuals.

The abstract characteristics of the installation, both in the visuals and in the form of the parazoans, enticed participants to approach and interact in different manners. Some quickly grabbed and started playing with the parazoans, trying to understand the effects of the manipulation on the visuals, while others preferred a slower approach, first watching the dynamic visuals, and successively engaging with an augmented object. As I mentioned earlier, the system records a participant's gestures when manipulating a parazoan, which are used to continue to draw once the participant deposits the parazoan on the table and stop interacting. With this feature, the installation is continuously dynamic, greeting participants with visuals generated from the gestures of past interactions. Although participants did not explicitly mention this, the dynamism of the visuals was meant to provide participants with an idea of what is interactively possible. An interesting feature that emerge from the use of dynamic visuals in the absence of participant is the cue it provides when people start interacting with the system. Often, the first steps of an interaction with a parazoan generate simple dots and lines as people try to make sense of the relationship between physical action and visual response. However, the dynamic history of interaction that participants leave behind quickly fills the display as it repeats itself over and over. The translation from one state to the other, from the repeated patterns of past interactions to the simple dots and lines of a new manipulation generated by a stroking agent, provides a visual cue that help the interaction unfold. Although a colored halo appears around the stroking agent of a parazoan when a participant starts interacting, participants seemed to notice and use the change of dynamism of the visuals to understand the effects of their first actions, often missing the colored halo, which would disappear after a few seconds. The change in motion was more easily perceived than the addition of a colored halo.

Tangible computing systems are often praised for allowing multiple people to interact simultaneously with shared content. For example, most TUIs consist of a horizontal display that users can view and approach from different directions, and multiple augmented objects that a single user can not easily have complete control over. Arguably, the large display and the dispersed parts of these systems afford collaboration (Hornecker & Buur, 2006). The

Figure 3.6: Close up of (left) participant interacting with a parazoan, and (right) parazoans interacting with each other after participants put them down.

physical properties of TUIs certainly help to facilitate interaction between users, but the nature of the visual content can also create power relations affecting the interaction. Although the content of a map placed on an horizontal surface is accessible from every direction, a person positioned so that the north points forward will have a significant advantage over others. In most cases, the observed interactions with *Parazoan* involved more than one participant. From the start, the participants shared comments about the unusual shape and texture of the parazoans, and explored the interactive space together by vocalizing their gestures and their understanding of the effects on the visuals. In addition, the abstract nature of the visuals allows participants to view and "read" the display from any directions, facilitating simultaneous interaction all around the installation. However, the system did not sense the position of participants, which lead to some confusion when trying to understand the relation between hand gestures and the orientation of the matching stroke on the visuals.

At first, the interaction with *Parazoan* is not completely obvious, and it was interesting to observe participants learning the relationships between tactual manipulation and the visual and tactile responses of the system. Despite the strangeness of the augmented objects and the ambiguity of the interaction, participants would progressively gain a certain control of the system. Often, new participants would perform short sequential actions and perceive the changes between the different responses of the system. Generally, after a short period, participants would seem to move on from this exploratory approach towards the performance of more specific actions based on what they learned through exploration. Participants seemed to use learned behaviors with the system to produce visuals with increasing accuracy, gaining some control of the system, but also producing unexpected results, which would lead to better understanding of the interaction. Each participant spent a different amount of time to understand the interaction, some spent more time learning individually while others prefered to initially share comments with others to gain control of the system. Generally, participants shared information to helped each other grasp the interaction. Participants shared information vocally, but also physically, by demonstrating gestures and pointing to the visuals they create.

In addition to the horizontal display and the multiple parazoans, two factors seem to have facilitated interaction between participants: the aesthetic of the parazoans and the large border of the display. The unusual look and feel of the parazoans makes it unlikely that any participants had come across an identical object. The strange ugliness of the parazoans provides a common ground that facilitated discussion between participants, who simultaneously attempt to understand the effects of their actions through exploration. Also, participants shared comments about the quasi-sexual shape, the soft silicone texture, and the vibration of the parazoans. The shape and texture afford a certain form of touch; participants were observed stroking and bending different areas of the objects, but also manipulating parazoans by placing them in direct contact with each other. (Fig. 3.6). The proximity and contact of parazoans was reflected on the display by generating different traces between the ”stroking agents” coupled with the manipulated parazoans. Although the installation was designed to exploit proximity of the objects, the rapidity and strength that participants demonstrated when pressing the parazoans against each other was unexpected. Due to the lack of tactile sensing, the installation failed to exploit the full richness of the tactile interactions between participants and parazoans, and also, between parazoans in direct contact with each other.

Another feature of the installation that facilitated social interaction is the large border of the horizontal display. The border is intended to simply host the parazoans when participants are not interacting with the system. Nevertheless, during the opening of the exhibit, the installation was appropriated by participants in interesting ways. Often, participants used the border to hold the drinks and food they were carrying. The flat surface provided participants with a useful space that allowed them to alternate between interacting with the installation and watching the visuals while drinking or eating snacks. This was also the case for other interactive artworks present in the gallery during the same period, although the pedestals and tables utilized by those artworks were not integrated into the pieces. In most cases, those installations involved one or many laptop computers resting on a piece of furniture. Although social interactions took place near those installations, *Parazoan* was at the center of the social space it created, physically and socially. Participants engaged with *Parazoan*, taking turns between interacting and watching, but also, they were observed discussing around the table even after everyone had stopped interacting with the system. At times, the installation became an aesthetically pleasing piece of furniture, until new participants arrived or the current ones decided to start interacting with the system.

Conclusion

During the last decade, we have seen an increasing interest in the development and use of tangible computing systems in diverse fields of practice. Commercial products including the *Playstation 2™ EyeToy™*, *Nintendo Wii™*, and *Microsoft Surface™* are examples that followed the work of diverse artists and researchers who have experimented with alternative modes of interaction for more than three decades. Interaction with tangible computing systems is no more physical, tangible or embodied than with other computing approaches, but these systems seek to integrate different aspects of everyday interaction with the tangible world. They harness some of the abilities of the human body and, in most cases, emphasize the perceptual and active role of touch. Tangible computing systems move away from the vision-centric approach of personal computing to acknowledge the importance of the situated active body which is at the center of human experience.

The rich work of phenomenologists and cognitive scientists who have studied and questioned the multiple facets of human experience can bring insights to the design of tangible computing systems. Some significant factors have emerged from the study of human embodiment in the world, factors which resurface in computing research that attempts to exploit tangible integration. An important aspect of human interaction with the world is the notion of active touch, which is understood to provide richer or more accurate information than passive cutaneous sensing. In their research, some psychologists —such as Katz (1925) and Gibson (1966) —asserted that this form of perception is far more than the passive sensing of external information, more than light touching our retinas, more than the cutaneous contact, etc. In developing reading aids for the blind, designers started by exposing the passive hand to dynamic dot patterns, only to later recognize the importance of the active and moving hands for perception. For tangible computing systems, releasing the hand and the body from the grip of the keyboard and the mouse certainly opens doors to more active forms of interaction. However, the integration of the active body is not the end goal, but only a means to carry out actions with computing systems. The development of tangible computing requires an examination of how people actively engage with their environment, and computing systems, as part of everyday activities. Researchers such as Hutchins (1995) and Norman (1988) have been questioning people's everyday situated actions and interactions, research that influences the development of computing systems in different ways (Suchman, 1987; Zhang & Norman, 1994). Others have observed people's behavior with interactive artwork in the art gallery (Hindmarsh *et al.* , 2005), an activity that, although part of everyday life, is governed by a specific set of rules where, as with the dance floor, people are invited to behave differently than in other private or public places. The situatedness of human behavior requires that we question the transferability of the knowledge gained from these examinations, but an approach that studies human activity "in the wild" is an important part of the design and development process of any technology and, especially, tangible computing systems that seek to integrate aspects of users' embodiment, which renders the user and its environment as one inseparable entity.

Designers of tangible computing systems have much to gain from the examination of previous and current work questioning human embodiment, but insights are also present in the study of use of these systems to inform our understanding of human experience and behavior in the world. Computing researchers often appropriate concepts from work that took place prior to the use of digital computers. For example, Norman (1990) adapted the concept of ”affordances” to the context of human-machine interaction from Gibson’s (1977) earlier work. Although the concept of affordances has helped researchers of interactive design, its application to computing systems requires that we question the physical and perceived affordances of system with capabilities that are largely hidden from view. For instance, it is possible that kinetic interfaces (Poupyrev *et al.* , 2007; Parkes *et al.* , 2008) create new forms of interaction that affect the way users perceive and act with objects integrating interactive kinetic behaviors. Examining how we relate with these entities situated between objects and animals can inform future designs, but also provide a new perspective to gain knowledge about human experience. Immersive interactive installations such as *Traces* (Penny *et al.* , 1999) can create an augmented sense of proprioception that, to some degree, approaches the sensation of swimming under water, but arguably offers a unique experience. Sensory substitution devices such as the *Enactive Torch* (Froese & Spiers, 2007) can provide new modes of perception that transform the users’ experience of the world and, consequently, the way they interact with it.

Parazoan is an interactive installation that was designed to engage participants in interactions that are uncommon for computing systems. The interplay between the use of silicon for the custom fabrication of the objects, their bizarre sexually suggestive shape and texture, the use of abstract visuals, and the table-like design of the display gave rise to some interesting interactions in the art gallery. Although *Parazoan* did not go as far as creating a new form of perception, it engaged participants in a novel form of tangible and social interaction. The observation of participants interacting with *Parazoan* pointed to some aspects of tangible interaction that will deserve more attention in the future.

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