For a device whose fundamental properties have changed so radically over the past thirty years, the personal computer itself—the familiar beige box sitting by the desk—has changed remarkably little.

The personal computer (PC) as we currently know it has its origins in work carried out at Xerox's Palo Alto Research Center in the early 1970s. The forerunner of the modern PC was, arguably, the Alto workstation developed by researchers there; it pioneered such now-common features as bitmapped displays with overlapping windows, graphical interfaces with multiple fonts and pop-up menus, and computers linked together over local-area networks. Although underpowered by today's standards (it was clocked at 6 MHz rather than the many hundreds of today's PCs), it nonetheless set the stage for what was to come, and its basic feature set, built around “the three 'M's'”—millions of pixels, a megabyte of memory, and a million instructions per second—is still with us today.

On the other hand, an Alto in those days cost around $16,000 to build, scarcely affordable enough to put “a computer on every desk,” as Microsoft would later set out to do. A more affordable option in 1977 (by which time the PARC researchers were working on the Dorado, a considerably faster and more powerful machine) was the Apple II, the device which, arguably, kick-started the personal computer industry. The Apple II was powered by a 6502 8-bit processor running at 1.5 MHz. It had 8 kilobytes of semiconductor memory and stored programs on cassette tape; optional floppy disk drives stored around 150 kilobytes each. Compare that to the modern personal computer. The laptop computer on which I'm writing this is certainly not top-of-the-line; it wasn't even top-of-the-line when I bought it a year ago. It has a 166 MHz 32-bit
processor, 64 megabytes of memory, and a 13-inch color display and can store up to 6 Gb on an internal hard disk; and it cost under $4,000.¹

Imagine what it would be like if any other technology had undergone such rapid advances in price/performance. A car would cost a few dollars; airplanes would travel at hundreds of times the speed of sound; televisions would weigh a few ounces. More to the point, if cars, airplanes, and televisions had been so radically transformed, they would not be cars, airplanes, and televisions any more. They would have transformed themselves into something else altogether.

Computers, though, remain computers. As we enter the twenty-first century, today’s PC still looks remarkably similar to that of the late 1970s (and perhaps even more like the Alto of the earlier part of that decade; see figure 2.1). This is not simply a matter of packaging and

Figure 2.1
Xerox’s Alto (1974). This early personal computer is somewhat bulkier than today’s, but is otherwise very recognizable in form. Reprinted by permission of Xerox Palo Alto Research Center.

industrial design, although it is certainly the case that with a few notable exceptions, we seem to be firmly stuck in an age of beige boxes. My concern is not so much about the boxes themselves as about the relationship of the user to the box. Despite the fact that computers are so radically different from the computers of twenty years ago, and that their capabilities are so vastly different, we interact with them in just the same way; we sit at a desk, watching the screen and typing on the keyboard. If you were to look at a photograph of people using computers some time over the last twenty years, their clothes and hairstyle might give you a clue to the date when the picture was taken, but the style of interaction with the computer certainly would not.

Similarly, the style of interaction concerns not simply the set of physical devices (keyboards, screens, and mice) or the set of virtual devices (dialog boxes, scroll bars, and menus) through which we interact, but also the ways in which the computer fits into our environments and our lives. Interaction with screen and keyboard, for instance, tends to demand our direct attention; we have to look at the screen to see what we’re doing, which involves looking away from whatever other elements are in our environment, including other people. Interaction with the keyboard requires both of our hands. The computer sits by the desk and ties us to the desk, too. So, it is not simply the form of the computer that has changed remarkably little over the last thirty years; it is also the forms of computer-based activity and the roles that we imagine computers playing in our everyday lives.

Although this model of everyday computing might be conventional, it is not inevitable. The rise of the personal computer—and, more broadly, of personal computing—was an attempt to break away from the then-dominant paradigm of mainframe computing. Similarly, while personal computing may now be established as the dominant model, a variety of alternatives have been explored in the research community; departures from the world of the conventional PC as radical as the PC was from the world of the mainframe. In this chapter, I will take a brief tour through some of the research laboratories where these alternatives are being explored. In particular, I will focus on an approach that looks at the relationship between computers on the desktop and the world in which they (and we) operate. This is a model of interaction that I refer to as “tangible
computing." Although it is only lately that the tangible computing paradigm has become broadly established, its has emerged from a research program that stretches back over a decade.

Ubiquitous Computing

We begin the tour, ironically enough, in the Computer Science Lab at Xerox PARC—the same place that gave us the desktop PC. In the 1970s, Xerox had set up PARC to explore "the architecture of information," and the Computer Science Lab, under the guidance of former ARPA manager Bob Taylor, had delivered what was to become the basic elements of office information technology in the decades to follow—powerful personal workstations, laser printers, and shared servers, linked together on local area networks. Xerox, famously, had failed to recognize its own future in PARC's vision, so today's office technology generally doesn't carry a Xerox label (Smith and Alexander 1988).

By the start of the 1990s, the situation was different. PARC's vision of the architecture of information had, largely, come to pass; and, in the opinion of the new manager of the Computer Science Lab, Mark Weiser, it was time for a new and equally radical vision of the future of technology.

What Weiser proposed was a research program that he dubbed "Ubiquitous Computing." Weiser saw that the development and diffusion of general-purpose computers, and in particular PC's, had resulted in a focus on the computer rather than on the tasks that the computer was used to accomplish. He argued that ongoing technological developments, particularly in mobile and low-power devices, would transform the nature of computers and the way we interact with them. Why deal with a single, large, expensive computer when you could harness many tiny, low-cost devices spread throughout the environment? Instead of always taking work to the computer, why not put computation wherever it might be needed? Through the technical developments that supported this new model, he saw an opportunity to turn attention away from the dominating focus on the computer sitting on the desktop and back to the applications, and to the artifacts around which those applications were structured. Weiser's vision of "ubiquitous computing" was one of computationally enhanced walls, floors, pens, and desks, in which the power of computation could be seamlessly integrated into the objects and activities of everyday life.

One analogy that Weiser proposed as a way of understanding his vision for the new role of computation was that of solenoids, the electronically actuated switches that are part of the fabric of many everyday technologies. For example, he observed, a modern car has a vast number of solenoids, invisibly controlling everything from the air conditioning to the fuel intake. Solenoids are a critical component of modern technological design and are used in all sorts of settings. And yet, we don't deal directly with solenoids in the way we do with computers. We don't have to think about the design of the "human-solenoid interface"; we don't have programs on "solenoid literacy" in schools; you can't take a degree in "solenoid science," and nobody had to upgrade to "Solenoids 2000."

Why have computers and solenoids followed different paths? Various possibilities present themselves. Perhaps it is because of the nature of computers as multipurpose devices; or perhaps it is a historical accident, a feature of how computer technology was introduced into the home and work environments. And to be sure, there are all sorts of computer technologies surrounding us that are far more like solenoids than they are like PCs, such as the computer processors inside my television set, microwave oven, and car. The difference between my PC and those other devices is that those other devices are organized around human needs and functions.

Weiser's model of ubiquitous computing was also, paradoxically, one of invisible computers. He argued for a vision of computers in which the computer had become so ubiquitous that it had, essentially, disappeared. He proposed that the computer of the twenty-first century would have proceeded further along the path from the mainframe to the processor in my microwave oven, and that the intermediate step—the desktop PC—would be all but gone. However, in this world, although there might be no more computers as we understand them today, there would certainly be computation. In fact, there might be a great deal more computation than there is now. Computational devices would be embedded in all sorts of technologies, Weiser argued, creating a variety of specialized devices augmented with computational power. Computers would
disappear into the woodwork; computers would be nowhere to be seen, but computation would be everywhere.

Computation by the Inch, Foot, and Yard
In the Computer Science Lab at Xerox PARC, Weiser initiated a wide-ranging research program around his vision of Ubiquitous Computing, fostering the development of new computational technologies, the infrastructure necessary to support them, and new application models. PARC's ubiquitous computing strategy followed three tracks: they were known as computation by the inch, the foot and the yard (see figure 2.2).

"Computation by the inch" focused on the development of small devices, like electronic tags or computational "Post-It" notes. One focus of attention was the use of devices called "Active badges," originally developed at the Olivetti Research Centre in Cambridge, England (Want et al. 1992). Active badges are devices measuring roughly 1.5 inches square that are intended to be worn like normal identity badges. However, they house some simple electronics and emit a fixed, coded infrared signal every thirty seconds or so (or whenever a button on the badge is pressed). These signals are detected by a network of infrared receivers located in the environment, and which are connected to a computational server process. Because each badge emits an individual code, and because its signal will generally only be received by the closest detector, the server can maintain a map of the location of each badge within the sensor network, which in turn can locate the badge's wearer within the environment.

When people wear active badges, then applications can help make the environment responsive to their movements. The system can route telephone calls to the current location of the person being called, display relevant information on nearby monitors as they pass by, or customize the behavior of a computer system to the needs of the person sitting at it. In Weiser's model, badges or similar tags could also be attached to books and other artifacts, so that their location and mutual proximity could become a resource to computer-based applications.

If computation "by the inch" sought a model of computationally enhanced Post-It Notes, the computation "by the foot" was concerned with computationally enhanced pads of paper. The primary focus of this

Figure 2.2
Computing by the inch, the foot, and the yard: (a) an active badge, (b) the PARC Tab, (c) the PARC Pad, and (d) a meeting at the Liveboard. Reprinted by permission of Xerox Palo Alto Research Center.
area of work was the development and use of computational devices of about the size and power of recent laptop computers. Laptop computers were, of course, already widely available at this point, but they tended (as they still do) to function simply as scaled-down versions of their desktop cousins. In contrast, the goal of ubiquitous computing research was not simply on the size and packaging of the devices, but of how they would fit into a world of everyday activities and interaction. As a result, research concentrated on other concerns. Examples included stylus-based interaction, which could eliminate keyboards as the primary source of interaction, and which could support note-taking and sketching, and mobile operation, so that devices could be moved from place to place without interfering with their operation.

Finally, investigations into computation “by the yard” introduced the opportunity to consider much larger devices. In particular, attention focussed on wall-sized devices such as the LiveBoard. LiveBoard was a large-scale display (approximately five feet by three feet) supporting multiple pens, a sort of computationally enhanced whiteboard. Researchers observed how the very physical form of this device was an important component in structuring interactions with it. On the one hand, the use of pen input meant that collaborative activities (such as brainstorming in a meeting) would be implicitly structured by the fact that the board was large enough for everyone to see at once, but that two people could not stand in front of the same part of the board or write in the same area at the same time. On the other hand, the board’s large size also meant that new interaction techniques would have to be developed; using a scroll bar or pull-down menu on a board a board five feet wide could be, quite literally, a pain in the neck.

Discussing each of these components of PARC’s ubiquitous computing strategy independently can mask the critical integration of the various facets of the program. None of these devices was intended to operate on its own. The focus, after all, was on a form of computation more deeply integrated with the everyday environment, and the everyday environment is filled with a variety of objects and devices. So it was with the ubiquitous computing vision. A single user might have, at his or her disposal, tens or more of the inch-sized devices, just as we might have many Post-It notes dotted around, stuck to computer screens, walls, books, and sheets of paper; at the same time, they might also have three or four foot-sized devices, just as I might have a number of notebooks for different topics or projects; but just as I probably only have one or maybe two whiteboards in my office, there will be fewer of the devices at the larger scale. What is more, information is expected to be able to move around between the different devices. Notes that I have prepared on an electronic pad might be beamed onto the board for group consideration in a meeting; while action items might be migrated off into a hand-held device that stores my calendar and to-do list. In the everyday environment, information continually undergoes transformations and translations, and we should expect the same in a computationally enhanced version of that environment such as might be delivered to us by ubiquitous computing.

The Digital Desk

At much the same time as Weiser and his PARC colleagues were developing the ubiquitous computing program, related activity was going on in another Xerox lab, in Cambridge, England. EuroPARC had been set up as a European satellite laboratory of PARC. It was a much smaller lab (with a research complement of around twenty) with a focus on interdisciplinary research into Human-Computer Interaction and Computer-Supported Cooperative Work.

EuroPARC was home to a variety of technological developments, but the particular technology that concerns us here is the Digital Desk, designed and developed by Pierre Wellner (Wellner 1991; Newman and Wellner 1992). In common with many people, Wellner had observed that the “paperless office” envisioned by many in the 1970s and early 1980s had manifestly failed to develop. However, that was not to say that the development of personal computers, and increasingly networked personal computers, had not caused an massive increase in the number of digital or online documents that we all have to deal with everyday. Wellner was concerned with how we could work with both paper and electronic documents in a much more fluid and seamless way than is normally the case. The traditional approach to these problems was either to scan in the paper documents to bring them into the
electronic realm, or to print out the electronic documents to bring them into the physical realm. By moving across the boundary from online documents to paper documents and back again, users could take exploit the advantages of each; the digital malleability and computational power of electronic documents with the portability, readability, and informal interaction of paper ones. As many studies have attested, paper has many properties that are hard to reproduce in the electronic world (Sellen and Harper 1997; Henderson 1998), while, at the same time, electronic documents increasingly exploit features (such as animation, hyperlinks, or interactive elements) that paper documents cannot capture. So, the move back and forth between electronic and paper forms is not only inconvenient but also impoverished, since some features always remain behind. Taking his cue from Weiser’s ubiquitous computing work, Wellner wondered if there wasn’t a way to combine the two worlds more effectively by augmenting the physical world with computational properties.

Wellner’s Digital Desk (figure 2.3) combines elements of each. The Digital Desk was a physical desktop, much like any other, holding papers, pens, coffee cups, and other traditional office accoutrements. However, it was also augmented with some distinctly nontraditional components. Above the desk were placed a video projector and a video camera. Both of these were pointed down toward the desktop; the projector would project images onto the desk, over whatever objects were lying there, and the camera could watch what happened on the desktop. These devices were connected to a nearby computer. Image processing software running on the computer could analyze the signal from the video camera to read documents on the desk and watch the user’s activity. At the same time, the computer could also make images appear on the desk by displaying them via the video projector.

The result was a computationally enhanced desktop supporting interaction with both paper and electronic documents (Wellner 1993). Electronic documents could be projected onto the desktop by the video projector, but then could be moved around the (physical) desktop by hand (using the video camera to track the user’s hand movements and then “moving” the displayed document in coordination). Similarly, physical documents could be given computational abilities on the same
desktop. For example, a paper document containing a list of numbers could be used as input to a virtual calculator; the computer could use the camera to "read" the numbers off the printed page, and then project the result of a calculation over those figures.

Two features of the Digital Desk were critical to its design. The first was its support for manipulation. In Wellner’s first prototype, one moved objects around on the desk with one’s fingers; in contrast with the prevailing approach to interface design, this was really direct manipulation. What’s more, of course, while our computer systems typically have only one mouse, we have two hands and ten fingers. By tracking the position and movements of both hands or of multiple fingers, the Digital Desk could naturally support other behaviors that were more complicated in traditional systems, such as using both hands at once to express scaling or rotation of objects. The second critical design feature was the way in which electronic and physical worlds were integrated. A document on the digital desk could consist of both physical content (printed on a page) and electronic content (projected onto it), and printers and cameras allowed material to move from one domain to the other fluidly so that objects created on paper could be manipulated electronically. The Digital Desk offered developers and researchers an opportunity to think about the boundary between the physical and virtual worlds as a permeable one.

While the work on ubiquitous computing had shown how computation could be brought out of the “box on the desk” and into the everyday world, Wellner’s work on the digital desk expanded on this by considering how, once the real world was a site of computational activity, the real and electronic worlds could actually work together.

Virtual Reality and Augmented Reality

Weiser and Wellner shared the goal of creating computationally augmented reality. They both attempted to take computation and embed it in the everyday world. This follows in the trend, outlined earlier, to expand the range of human skills and abilities on which interaction can draw. In this case, the abilities to be exploited are those familiar ways in which we interact with the everyday world; drawing on whiteboards, moving around our environments, shuffling pieces of paper, and so on. One of the interesting feature of these approaches, at the time, was the way in which they developed in opposition to another major trend—immersive virtual reality.

Virtual reality (VR) is, at least in the popular consciousness, a technology of recent times; it became particularly prominent in the 1990s. Immersive VR as we know it today came about through the increase in computer power, and particularly graphics processing, that became available in the late 1980s, as well as some radical sensor developments that gave us data gloves and body suits. The technical developments supporting immersive VR became widespread at around the same time as William Gibson’s notion of “cyberspace”—a technically mediated consensual hallucination in which people and technology interacted—also entered the popular consciousness. Virtual reality has been around a good deal longer than that, however. Ivan Sutherland, the father of interactive computer graphics, went on to investigate what we now recognize as virtual reality technology back in the 1960s, and the use of digital technology to create environments such as flight training simulators is well-known. Howard Rheingold’s book Virtual Reality (1992) documents some of the early history of this seemingly recent technology.

Virtual reality immerses the user in a computationally generated reality. Users don head-mounted displays, which present slightly different computer-generated images to each eye, giving the illusion of a three-dimensional space. By monitoring the user’s head movements and adjusting the image appropriately, this three-dimensional space can be extended beyond the immediate field of view; the user can move his head around, and the image moves to match. With appropriating sensing technologies, the user can enter the virtual space and act within it. A “dataglove” is a glove augmented with sensors that report the position and orientation of the hand and fingers to a computer; the hand of the user wearing the glove is projected as a virtual hand into the same computer-generated three dimensional space that the virtual reality system generates, so that the user can pick up virtual objects, examine them, move them around, and act in the space.

The ubiquitous computing program was getting under way at about the point when virtual reality technology began to make its way out of
research laboratories and into newspaper articles. Both approaches to the future of computing are based on similarly science-fiction notions; immersion in a computer-generated reality, on the one hand, and computers in doorknobs and pens on the other. They embody, however, fundamentally different approaches to the relationship between computers, people and the world. In the virtual reality approach, interaction takes place in a fictional, computer-generated world; the user moves into that world, either through immersion or, more commonly these days, through a window onto the world on a computer screen. The world of interaction is the world of the computer. The ubiquitous computing approach to interaction—what Weiser dubbed “physical virtuality” and would become known as augmented reality—does just the opposite. It moves the computer into the real world. The site of interaction is the world of the user, not that of the system. That world, in the augmented reality vision, may be imbued with computation, but the computer itself takes a back seat.

The Reactive Room

The ubiquitous computing model distributes computation throughout the environment. All sorts of objects, from walls to pens, might have computational power embedded in them. For someone concerned with interaction, this raises one enormous question—how can all this computation be controlled?

At the University of Toronto, Jeremy Cooperstock and colleagues explored this question in an environment they called the Reactive Room (Cooperstock et al. 1995). The Reactive Room was a meeting room supporting a variety of physical and virtual encounters. It grew out of both the ubiquitous computing perspective and the “media space” tradition, an approach to supporting collaboration and interaction through a combination of audio, video, and computational technology (Bly, Harrison, and Irwin 1993). The room was designed to support not only normal, face-to-face meetings, but also meetings distributed in space (where some participants are in remote locations) and time (recording meeting activity to be viewed later by someone else). To that end, it also featured a shared computer display, for electronic presentations and application-based work; a variety of video and audio recorders; and audio and video units connected to a distributed analog A/V network that could be connected to similar “nodes” in people’s offices, so they could remotely “attend” meetings.

However, such a complex and highly configurable environment presented considerable challenges for control and management. To configure the room for any given situation (such as a presentation to be attended by remote participants), each device in the room would have to be configured independently, and adjusting the configuration to support the dynamics of the meeting was even more challenging. The design of the Reactive Room sought to use ubiquitous computing technology as a means to manage this problem. The critical move here was to see ubiquitous computing as a technology of context; where traditional interactive systems focus on what the user does, ubiquitous computing technologies allow the system to explore who the user is, when and where they are acting, and so on.

In the case of the reactive room, contextual information could be used to disambiguate the potential forms of action in which a user might engage. For example, by using an active badge or similar system, the room’s control software can be informed of who is in the room and can configure itself appropriately to them. Similarly, if the room “knows” that there is a meeting in progress, then it can take that information into account to generate an appropriate configuration. If a user presses the “meeting record” button on a VCR, to record a meeting in progress, the Reactive Room can determine whether or not there are any remote participants connected to the audio/video nodes and, if so, ensure that it adds those signals to the recording. When someone in the room makes use of the document camera or the projected computer display, the room software can detect these activities and automatically make the document camera view or the computer display available to those people attending the presentation, either locally or remotely.

In other words, the design of the Reactive Room attempts to exploit the fact that the people’s activities happen in a context, which can be made available to the software in order to disambiguate action. Clearly, of course, the sort of context that can be gathered with current technology is limited; the Reactive Room would make use of motion in
particular parts of the room, presence and activity as detected using active badges or pressure sensors, and so on. The other, perhaps most important, piece of context it made use of was the fact that it was the Reactive Room. That is, the room was designed for meetings and presentations, and so much activity in the room could be interpreted as being appropriate to meetings and presentations. The same sorts of inferences would probably be inappropriate in other settings, such as a private office, or a home. The “meeting” context, then, also serves to disambiguate the user’s goals.

The Reactive Room demonstrated the way that ubiquitous computing did not simply move out of the box on the desk and into the environment but, at the same time, also got involved in the relationship between the environment and the activities that took place there. The topic of “setting-ed” behavior will come back into focus in the next chapter; for the moment, however, we will continue to explore the development of tangible computing.

Design Trends

The systems that have been described—the vision of Ubiquitous Computing, and the Digital Desk and Reactive Room prototypes—have been firmly located in the domain of Computer Science research. However, “academic science” has by no means been the only contributor to the development of Tangible Computing. In fact, one striking aspect of the development of this line of investigation has been the contributions from the perspectives of art and design. Two pieces that have proved to be particularly inspirational to a number of researchers in this area were Durrell Bishop’s Marble Answering Machine, and Natalie Jeremijenko’s Live Wire.

The Marble Answering Machine was a design exercise undertaken by Bishop in the Computer-Related Design department at the Royal College of Art in London (Crampton-Smith 1995). It explored possible approaches to physical interaction for a telephone answering machine. Rather than the traditional array of lights and buttons, Bishop’s answering machine has a stock of marbles. Whenever a caller leaves a message on the answering machine, it associates that message with a marble from the stock, and the marble rolls down a track to the bottom, where it sits along with the marbles representing previous messages. When the owner of the machine comes home, a glance at the track shows, easily and distinctly, how many messages are waiting—the number of marbles arrayed at the bottom of the track. To play a message, the owner picks up one of the marbles and drops it in a depression at the top of the answering machine; because each marble is associated with a particular message, it knows which message to play. Once the message has been played, the owner can decide what to do; either return the marble to the common stock for reuse (so deleting the message), or returning it to the track (saving it to play again later).

The Marble Answering Machine uses physical reality to model the virtual or electronic world. In Bishop’s design, marbles act as physical proxies for digital audio messages. By introducing this equivalence, it also enriches the opportunities for interacting with the device. The problem of interacting with the virtual has been translated into interacting with the physical, and so we can rely on the natural structure of the everyday world and our casual familiarity with it. So, counting the number of messages is easy, because we can rapidly assess the visual scene; and operations such as playing messages out of order, deleting messages selectively, or storing them in a different sequence, all of which would require any number of buttons, dials, and controls on a normal digital answering machine, all become simple and straightforward because we can rely on the affordances of the everyday world.

Natalie Jeremijenko’s piece “Live Wire,” also sometimes known as “the Dangling String” and described by Weiser and Brown (1996), was developed and installed at Xerox PARC in 1994 and explored similar questions of the boundary between the virtual and physical worlds. Physically, Live Wire was a length of plastic “string” around eight feet long, hanging from the ceiling at the end of a corridor. Above the ceiling tiles, the wire was connected to a small stepper motor, which in turn was connected to a device on the local ethernet. Every time a data “packet” passed by on the ethernet, the stepper motor would move, and its movements would be passed on to the string. Ethernet, in its classic form, is a “shared medium” technology—all the traffic, no matter which machine sends it or which machine is to receive it, travels along the same cable.
The busier the network, the more data packets would pass by, and the more the stepper motor would move. The ethernet can carry thousands of packets per second, and so when the network was busy the motor would whirl and the string would spin around at high speed, its loose end whipping against the wall nearby.

Others have followed in the footsteps of Bishop and Jeremijenko and continued to explore the design “space” around these issues of the borders between physical and virtual worlds. Feather, Scent, and Shaker (Strong and Gaver 1996) are devices for “simple intimacy.” “Feather” features a feather that is gently lifted on a column of air, to indicate to its owner that, perhaps, a photograph of them has been picked up somewhere else; it is designed to convey a sense of fondness across distance. Scent, similarly, releases a pleasant, sweet smell in similar circumstances providing an awareness of distant action.

The topic of “awareness” is one that has concerned the developers of technologies for group working, who want their systems to be able to support the casual and passive awareness of group activity that coworkers achieve in a shared physical space. Strong and Gaver turn this around, though, and give us technologies for supporting shared intimacy rather than shared work. Their pieces are designed to be evocative and emotive rather than “efficient.” What is particularly interesting about this group of devices is that they originate not from a technical or scientific perspective, but from a design perspective. The result of this shift in perspective is that they reflect a very different set of concerns. It is not simply that they reflect an aesthetic component where the scientific developments are marked more by engineering concerns. That is certainly one part of it, of course; the design examples certainly do reflect a different set of principles at work. However, there is more than this.

First, the design examples discussed here reflect a concern with communication. What is important is not simply what they do, but what they convey, and how they convey it; and the communicative function that they carry is very much on the surface. There is an “at-a-glance readability” to these artifacts that stands in marked contrast to the “invisibility” of ubiquitous computing. Second, they reflect a holistic approach that takes full account of their physicality. The physical nature of these pieces is not simply a consequence of their design; it is fundamental to it. While it was a tenet of ubiquitous computing, for example, that the technology would move out into the world, the design pieces reflect a recognition that the technology is the world, and so its physicality and its presence is a deeply important part of its nature. Third, they reflect a different perspective on the role of computation, in which computation is integrated much more directly with the artifacts themselves. In the other examples, while they have aimed to distribute computation throughout the environment, there has always been a distinct “seam” between the computational and the physical worlds at the points where they meet. In these examples, however, the computational and physical worlds are much more directly connected.

The result is an approach to tangible computing that sees computation within a wider context. Ubiquitous Computing pioneers saw that, in order to support human activity, computation needs to move into the environment in which that activity unfolds. These design explorations take the next step of considering how computation is to be manifest when it moves into the physical environment, and recognizing that this move makes the physicality of computation central.

**Tangible Bits**

Most recently, perhaps the most prominent site for development of these ideas has been the Tangible Media group at the MIT Media Lab. A group of researchers led by Hiroshi Ishii has been exploring what they call “Tangible Bits,” a program of research that incorporates aspects of both the Ubiquitous Computing program and the design perspective explored by people like Jeremijenko.

The term “Tangible Bits” reveals a direct focus on the interface between the physical and virtual worlds. The rhetoric of the computer revolution has, pretty consistently, focused on a transition from physical (the world of atoms) to the virtual (the world of bits). We talk of the future in terms of “electronic cash” to replace the paper bills and coins we carry about with us, or we speak of the “paperless office” in which paper documents have disappeared in favor of electronic documents stored on servers and displayed on screens. We envision a world in which we communicate by electronic mail and video conferencing, in
gramme equivalent, are certainly the triumph of the virtual over the physical. They suggest that we will overcome the inherent limitations of the everyday world (such as the need to be in the same place to see each other, or that a thousand books actually take up real shelf space) by separating the “information content” from the physical form, distilling the digital essence and decanting it into a virtual world.

The MIT Media Lab, where Ishii and his colleagues are based, is one of the most prominent proponents of this vision, especially, perhaps, in the writings of its founding director, Nicholas Negroponte. His collection of essays Being Digital (Negroponte 1995), explores the relationship between atoms and bits and how the development and deployment of Internet technologies is changing that relationship.

The work on Tangible Bits provides some balance to the idea that a transition from atoms to bits is inevitable and uniformly positive. It is certainly not defined in opposition to the gradual and ongoing movement of traditionally physical forms into digital media. However, it observes that while digital and physical media might be informationally equivalent, they are not interactionally equivalent. By building information artifacts based on physical manipulation, the Tangible Bits programme attempts to reinvest these distilled digital essences with some of the physical features that support natural interaction in the real world.

**metaDESK, Phicons, and Tangible Geospace**

Let’s take an example from the work of the Tangible Bits group. The metaDESK (Ullmer and Ishii 1997) is a platform for tangible interaction. It consists of a horizontal back-projected surface that serves as the top of the physical desk itself; an “active lens,” which is a small flat-panel display mounted on an arm; a “passive lens,” which is transparent, also digitally instrumented; and a variety of physical objects called phicons (for “physical icons”). The metaDESK is shown in figure 2.4.

The functions of the various components of the metaDESK platform are best seen in terms of an application running on the desk. Tangible Geospace is a geographical information system augmented with tangible UI features and running on the metaDESK. It allows users to explore a visualization of a geographical space, such as the area of Cambridge, Massachusetts, around MIT.

The geographical information, in the form of a two-dimensional map, is back-projected onto the desk, so that the user seated at the desk can see it. The user can move and orient the map using phicons. One of the phicons represents MIT’s Great Dome, and when it is placed on the desk, the map is adjusted so that the position of the Great Dome corresponds to that of the phicon. As the user moves the phicon, the system adjusts the map to ensure that the phicon is always aligned with the point on the map that it represents. By moving the phicon around on the desk, the user can cause the map to move too, “scrolling” around in the geographical space. By rotating the phicon on the desk, the user can cause the map to rotate.

If a second phicon is added to the desk, say one representing the Media Lab building itself, then another degree of freedom can be constrained. The two icons, together, can be used to control the scale of the
map display. If the metaDESK always ensures that the virtual Great Dome always co-occurs with the Great Dome phicon, and the virtual Media Lab always co-occurs with the Media Lab phicon, then the user can control the scale of the map by moving these two phicons closer together or further apart.

The active and passive lenses can be used to provide access to other sorts of information. In the Tangible Geospace example, the active lens is used to view a three-dimensional model of the MIT Campus. The active lens is a computer display mounted on an arm over the desk. It is instrumented so that the metaDESK computer system can determine the position and orientation of the display. When this information is coordinated with the current position, scaling, and orientation of the map being displayed on the desk, the result is that the active lens can be used to control a “virtual camera” moving through the geographical space being displayed on the metaDESK. When this is combined with a three-dimensional model of the campus, then the active lens can be used to give a three-dimensional viewpoint on the two-dimensional map. The illusion is of “looking through” the lens and seeing a transformed view of the map underneath.

The passive lens works in a similar way, although it rests on the desk surface. The passive lens is simply a piece of transparent plastic. As it is moved around the desk, the computer system can track its current location. On the desk area directly underneath the lens, the metaDESK replaces the map with a view onto a photographic aerial record of the campus. As before, this is correlated with the current position, scaling, and orientation of the basic map, as well as the position of the lens. The effect is that it seems to the user that the lens reveals the photographic model underneath as it moves across the desk. This is similar to a user interface technique known as “magic lenses” (Bier et al. 1993), user interface components that selectively transform the content of interfaces as they are moved across the screen, although, of course, in the case of the metaDESK the lens has a physical manifestation.

**The Ambient Room**

Tangible interfaces such as the metaDESK explore interaction that is situated in the environment, rather than on a screen. This is even more clearly demonstrated by another of the MIT prototypes, called the Ambient Room (Wisneski et al. 1998).

The Ambient Room is a small office cubicle that has been augmented with a variety of “ambient displays,” designed to provide peripheral, background information to the occupant of the room without being overwhelming or distracting. Examples of ambient displays include projected light patterns, non-speech sounds, and objects that respond to changes in air flow.

The information that the Ambient Room conveys is typically information about activities in either physical or virtual space, such as the presence or activity of others, e-mail arriving, people logging in and out, and so forth. These can be mapped onto the displays available in the room. For instance, light patterns projected on the wall can respond to the activities of a networked computer system, conveying information about network traffic and hence activity in the virtual space; or movements in a shared project room can be mapped onto subtle sounds in the Ambient Room so that the occupant can be aware of comings and goings in the project space. Reminiscent of the Feather, Scent, and Shaker work of Strong and Gaver, these ambient displays can be used to project the actions in one space (either physical or virtual) into another; like the technologies of the Reactive Room, they can also respond to the activity of the room’s occupant, providing a display that is appropriate to the context in which they are working.

It is tempting to think of the metaDESK as exploring the potential for tangible media as input technologies, and the Ambient Room as exploring their potential for output. To do so, though, would be to miss an important point, which is that, in the everyday environment, “input” and “output” are fundamentally interconnected. This is a critical feature of the tangible media explorations. They should be characterized not in terms of “input” and “output,” but in terms of the coordination between phenomena; between activity in a space and the pattern of light on a wall, or between the movement of objects on the desk and the information presented there. This sort of coordination, or coupling, is fundamental to the explorations presented here; they depend upon it for the causal illusion they want to maintain.
Illuminating Light and Urp

Two other applications developed in the MIT group echo the Digital Desk in their creation of mixed physical/virtual environments for task-focused work. These are Illuminating Light and Urp, both developed principally by John Underkoffler (and illustrated in figure 2.5).

Illuminating Light (Underkoffler and Ishii 1998) is a simulation of an optics workbench, aimed particularly at students of laser holography. The interface is based on a combination of phicons and a camera/projector arrangement (which Underkoffler dubs the "I/O Bulb") similar to that of the Digital Desk. The application allows users to experiment with and explore configurations of equipment for laser holography. Real laser holography is a complex business, conducted using delicate and expensive instruments. Setting up and fine-tuning an experimental configuration can be extremely time-consuming, especially for novices. Illuminating Light allows holographers to simulate the effects of particular configurations and to explore them so as to develop a better intuitive sense for the interaction of their elements. Phicons represent physical elements such as lasers, lenses, mirrors, and beam-splitters, while the system provides a simulation of light paths through the experimental equipment, showing light emitted by the laser, redirected by mirrors, and so on. As the phicons are moved around a physical surface, the system continually updates its projection of the simulated light paths to reflect the moment-by-moment physical configuration. In addition to the simulated light beams, the system can also provide numerical descriptions of the configuration; incidence angles, distances, and so forth. In this way, users can rapidly explore a variety of configurations and develop an understanding of the consequences of different changes on the set-up.

Urp (Underkoffler and Ishii 1999) is an urban planning workbench in which physical models of buildings are combined with electronic simulations of features such as air flow, cast shadows, reflectance, and so forth. The underlying technology is similar to that of Illuminating Light but applied to a different domain. There are two sorts of phicons used in Urp. The first represent building structures. By placing these on the surface, the user can obtain a visualization of the shadows that the buildings will cast, or the wind patterns around them. Combining multiple structures allows urban planners and architects to explore the

Figure 2.5
Illuminating Light (a) and Urp (b) apply tangible interaction techniques to the domains of optics and urban planning. Reprinted by permission of The MIT Media Lab.
interactions of wind, reflection, and shadow effects in an urban landscape. As with Illuminating Light, real-time tracking of the position and orientation of these phicons allows the system to update the display continuously, so that users can move the buildings around or rotate them until they find a satisfactory arrangement. The second set of phicons acts as controls for the simulation. For example, a “wand” can be used to change the material of the buildings, so that the computed reflectance patterns will simulate buildings clad in brick or glass, another controls the direction of the simulated wind, while a “clock” has hands that can be moved to specify the time of day and hence the position of the sun for the shadow simulation. In this way, the simulator’s controls are introduced into the same space that is the focus of the system’s primary input and output.

Interacting with Tangible Computing

Tangible computing takes a wide range of forms. It might be used to address problems in highly focused and task-specific work, or in more passive awareness of activities in the real world or the electronic. It might attempt to take familiar objects and invest them with computation, or it might present us with entirely new artifacts that disclose something of the hidden world inside the software system. The bulk of this chapter has explored a range of tangible computing systems, but the survey has been far from comprehensive; indeed, I have said nothing about whole areas, such as wearable computing and context-based computing, that are clearly strongly related. My goal, however, was not to provide a catalogue of tangible computing technologies, but rather to introduce a sample of the systems that have been developed, and to begin to look for some common features of their design.

The first of these general issues that we see across a range of cases is that, in tangible computing, there is no single point of control or interaction. Traditional interactive systems have a single center of interaction, or at least a small number. Only one window has the “focus” at any given moment; the cursor is always in exactly one place, and that place defines where my actions will be carried out. Cursors and window focus insure that the system always maintains a distinguished component within the interface, which is the current locus of interaction. To do something else, one must move the focus elsewhere. When computation moves out into the environment, as in the tangible computing approach, this is lost. Not only is there not a single point of interaction, there is not even a single device that is the object of interaction. The same action might be distributed across multiple devices, or, more accurately, achieved through the coordinated use of those artifacts. Imagine sitting at your desk to write a note. The writing comes about through the coordinated use of pen, paper, and ink, not to mention the desk itself and the chair you sit in; you might write on the page with your dominant hand while your nondominant hand is used to orient the page appropriately. These are all brought together to achieve a task; you act at multiple points at once. In the same way, ubiquitous computing distributes computation through the environment, and, at one and the same time, distributes activity across many different computational devices, which have to be coordinated in order to achieve a unified effect.

A related issue is how tangible interaction transforms the sequential nature of interaction at the interface. The single point of control that traditional interfaces adopt leads naturally to a sequential organization for interaction—one thing at a time, with each step leading inevitably to the next. This ordering is used both to manage the interface and to simplify system development. For instance, “modal” dialog boxes—ones that will stubbornly refuse to let you do anything else until you click “okay,” “cancel,” or whatever they need—both structure your interaction with the computer, and save the programmer from the need to handle the complexity of worrying about other actions that might transform the system’s state while the dialog box is displayed. When we move from traditional models to tangible computing, sequential ordering does not hold. It is not simply that interaction with the physical world is “parallel” (a poor mapping of a computational metaphor onto real life), but that there is no way to tell quite what I might do next, because there are many different ways in which I might map my task onto the features of the environment.

These two issues are particularly challenging from a technical perspective, because they address the programming models we use to develop systems, embedded in software toolkits and applications.
third feature of tangible interaction may, however, provide some relief. This is the fact that, in tangible design, we use the physical properties of the interface to suggest its use. This is nothing new; arguably, it is what product design or other forms of physical design are all about. Kettles are designed so that we can tell how to safely pick them up; remote controls are designed to sit comfortably in the hand when oriented for correct use (at least when we’re lucky). What is more, this sort of design that recognizes the interaction between the physical configuration of the environment and the activities that take place within it can also be a way to manage the sequential issues raised earlier. For instance, Gaver (1991), in his discussion of “sequential affordances” (which will be presented in more detail in chapter 4), gives the example of a door handle, which, in its normal position, lends itself naturally to turning and then, in its turned position, lends itself naturally to pulling; the whole arrangement helps “guide” one through the sequential process of opening the door through careful management of the physical configuration of the artifact. Taking this approach, designers can create artifacts that lead users through the process of using them, with each stage leading naturally to the next through the ways in which the physical configuration at each moment suggests the appropriate action to take. The relationship between physical form and possible action can give designers some purchase on the problems of unbounded parallel action.

Interacting with tangible computing opens up a new set of challenges and a new set of design problems. Our understanding of the nature of these problems is, so far, quite limited, certainly in comparison to the more traditional interactional style that characterizes most interactive systems today. The theories that govern traditional interaction have only limited applicability to this new domain. At the same time, tangible computing has been explored, largely, as a practical exercise. Most prototypes have been developed opportunistically, driven as much by the availability of sensor technology and the emergence of new control devices as by a reasoned understanding of the role of physicality in interaction. We have various clues and pointers, but there is no theory of tangible interaction. Why does tangible interaction work? Which features are important, which are merely convenient and which are simply wrong? How does tangible computing mediate between the environment and the activity that unfolds in it?

This book is about developing answers to these questions. The interpretation that it will offer is one that is concerned not just with what kind of technology we use, or with what sorts of interactions we can engage in with that technology, but about what makes those interactions meaningful to us. From this perspective, the essence of tangible computing lies in the way in which it allows computation to be manifest for us in the everyday world; a world that is available for our interpretation, and one which is meaningful for us in the ways in which we can understand and act in it. That might seem to be quite far removed from looking at application prototypes, reactive rooms, and digital desks. The path from practice to theory will be easier to see after looking at the second aspect of embodied interaction—social computing.
Chapters 2 and 3 introduced tangible and social computing, two current research directions in Human-Computer Interaction. HCI, of course, encompasses much more than these two areas of research, but the goal was not to be comprehensive. The goal, instead, was to provide enough background to support an argument that, despite the fact that they are normally taken to be different research agendas, tangible and social computing are in fact two different aspects of the same program of investigation. This chapter sets out to show how.

Chapter 1 considered the development of HCI in terms of the human skills and abilities that interactive technologies draw upon. Understanding the relationship between tangible and social computing means finding the common skills and abilities they exploit.

One straightforward observation is that they both smooth interaction by exploiting a sense of “familiarity.” Tangible and social computing both capitalize upon our familiarity with the everyday world, a world of social and physical interactions. As physical beings, we are unavoidably enmeshed in a world of physical facts. We cannot escape the world of physical objects that we lift, sit on, and push around, nor the consequences of physical phenomena such as gravity, inertia, mass, and friction. But our daily experience is social as well as physical. We interact daily with other people, and we live in a world that is socially constructed. Elements of our daily experience—family, technology, highway, invention, child, store, politician—gain their meaning from the network of social interactions in which they figure. So, the social and the physical are intertwined and inescapable aspects of our everyday experiences. Tangible and social
computing are both attempts to capitalize on those experiences and our familiarity with them. They make interacting with the computer seem more like those arenas of everyday action with which we are more familiar and in which we are more skilled.

However, the idea of “familiarity” is a fairly shallow way to relate these concepts; I want to suggest a deeper connection. In exploring the relationship between tangible and social computing, my argument is based on the hypothesis that they are not just exploiting similar approaches, but are actually founded on the same idea.

The idea that underlies each of them is what I will call embodiment. Embodiment is the common way in which we encounter physical and social reality in the everyday world. Embodied phenomena are ones we encounter directly rather than abstractly. For the proponents of tangible and social computing, the key to their effectiveness is the fact that we, and our actions, are embodied elements of the everyday world.

The goal of this chapter is to introduce, explain, and explore the idea of embodiment, and to present it as a unifying principle for tangible and social computing. Mainly, this will mean exploring the emergence of the concept of embodiment from earlier work. Embodiment is not a new idea. It is a common theme running through a great deal of the philosophy of the last hundred years, and in particular the area of phenomenology. My argument here is that by looking to the phenomenological tradition, we can develop a position that serves to explain, to relate, and to develop the tangible and social computing programs.

**Embodiment**

We have already encountered embodiment, indirectly, as a phenomenon underlying the ideas of tangible and social computing. The goal of this chapter is to focus on embodiment directly, refining it by exploring its antecedents in phenomenology and related areas. As a starting point, though, we need a working definition. A naive definition would be one that emphasized physical presence:

**Embodiment 1.** *Embodiment means possessing and acting through a physical manifestation in the world.*

However, physical presence is a more restrictive definition than I have in mind here. Certainly, embodiment retains this notion of immanent “presence,” and of the fact that something occurs in the world; but it need not rest on a purely physical foundation. Embodiment extends to other phenomena that unfold directly in the world; conversations, mutually engaged actions, and so on. So we can start with a more elaborated definition:

**Embodiment 2.** *Embodied phenomena are those that by their very nature occur in real time and real space.*

This definition incorporates the sense of physical presence from the earlier one, but extends it to include a broader range of phenomena that may not be physical but are nonetheless occurrent in the world. Embodiment denotes a form of participative status.

This is much more than a concern with “making it like the real world.” We are familiar with “real-world-ness” in user interfaces through the use of metaphors of all sorts, from windows to desktops, buttons, and virtual worlds. However, embodiment strikes more deeply than simply the use of familiar models and metaphors in an interface. Some might serve to make this distinction clearer.

Imagine a 3-D computer game. It exploits my familiarity with the structure of the three-dimensional world by using perspective geometry to create a convincing and compelling setting for the game. It might rely on the fact that I understand that objects can be hidden from view by walls or other intervening objects, that if I can see you then you can see me, and other features of the everyday world. This could be further exploited by a version of the game designed for immersive virtual reality. It might use a head-mounted display to match the movement of the scene to the movement of my head, and so give me a stronger sense of being surrounded by the computer-generated imagery. Both of these approaches take advantage of my deep familiarity with the nature and structure of the everyday world.

However, there is a considerable difference between using the real world as a metaphor for interaction and using it as a medium for interaction. As in this game, real-world metaphors can be used to suggest and guide action, and to help us understand information systems and how to
use them. Even in an immersive virtual-reality environment, users are disconnected observers of a world they do not inhabit directly. They peer out at it, figure out what’s going on, decide on some course of action, and enact it through the narrow interface of the keyboard or the data-glove, carefully monitoring the result to see if it turns out the way they expected. Our experience in the everyday world is not of that sort. There is no homunculus sitting inside our heads, staring out at the world through our eyes, enacting some plan of action by manipulating our hands, and checking carefully to make sure we don’t overshoot when reaching for the coffee cup. We inhabit our bodies and they in turn inhabit the world, with seamless connections back and forth.

Similarly, “conversational” computational systems, which use natural language-processing techniques and attempt to incorporate the rules of conversational interaction, may well make it easier and more natural to interact with computer systems in as much as they can exploit familiar patterns of everyday human action. However, encoding conversational rules about turn-taking and anaphoric reference is a world away from responding to the way in which those conversational rules arise out of a world of human social action, conducted through the coordinated media of spoken language, gaze, and posture. We inhabit conversations as embodied phenomena in the everyday world.

Distinguishing between inhabited interaction in the world on one hand, and disconnected observation and control on the other, is at the heart of the embodied interaction proposal. First, though, we should ask: If we are all embodied, and our actions are all embodied, then isn’t the term embodied interaction in danger of being meaningless? How, after all, could there be any sort of interaction that was not embodied? What I am claiming for “embodied interaction” is not simply that it is a form of interaction that is embodied, but rather that it is an approach to the design and analysis of interaction that takes embodiment to be central to, even constitutive of, the whole phenomenon. This is certainly a departure from traditional approaches to HCI design.

Tangible and social computing both reflect this central concern with embodiment. The tangible computing work attempts to capitalize on our physical skills and our familiarity with real world objects. It also tries to make computation manifest to us in the world in the same way as we encounter other phenomena, both as a way of making computation fit more naturally with the everyday world and as a way of enriching our experiences with the physical. It attempts to move computation and interaction out of the world of abstract cognitive processes and into the same phenomenal world as our other sorts of interactions. The trends in social computing are also built upon a notion of embodiment. The use of sociological approaches in the design of interactive technology has, however, been driven primarily by concerns with the interaction of computation and “the workday world” (Moran and Anderson 1990). The paradigmatic perspective on social action motivating this approach is the “situated” perspective (e.g., Suchman 1987; Clancey 1997), which is grounded in the relationship between social action and the settings in which it unfolds, the relationship of embodiment.

The best way to see how the same form of embodiment underwrites both of these areas is to consider the origin of the concept as it has developed in the phenomenological tradition of the past hundred years or so.

The Phenomenological Backdrop

Although it is not generally incorporated into HCI design approaches, embodiment is not a new idea. It has been explored perhaps most extensively within phenomenology, a branch of philosophy that is principally concerned with the elements of human experience. In contrast to philosophical positions that look for a “truth” independent of our own experience, phenomenology holds that the phenomena of experience are central to questions of ontology (the study of the nature of being and categories of existence) and epistemology (the study of knowledge).

Originating in the latter part of the nineteenth century, phenomenology has gone through a number of transitions in the past hundred years and has separated into a number of distinct intellectual positions. However, the behavior of embodied actors going about their business in the world has been central to all of them. What follows briefly outlines aspects of the work of four phenomenological theorists—Edmund Husserl, Martin Heidegger, Alfred Schutz, and Maurice Merleau-Ponty—whose thought and writings have been particularly relevant to questions of embodiment and interaction.
Husserl's Transcendental Phenomenology

In this way, Hilbert discovered the solid foundation of mathematics in the consistency of its formal system: mathematics does not have to be "true" as long as it is "consistent" and as long as that is the case, there is no need for further foundation.

—Kojin Karatani, "Natural Numbers"

Edmund Husserl (1859–1938) was the founder of the phenomenological tradition. For Husserl, phenomenology was a method for exploring the nature of human experience and perception.

Husserl had originally trained as a mathematician. However, he was unhappy with the direction that mathematics and science were taking during his lifetime. This was a critical time for science, when foundational issues about the relationship of science to the world were in question. The advent of non-Euclidian geometries, and the explorations of formalists like Hilbert and Frege, had begun to question the idea of mathematics as an objective formalization of the world. Husserl was frustrated by the idea that science and mathematics were increasingly conducted on an abstract plane that was disconnected from human experience and human understanding, independently of questions of truth and applicability. He felt that the sciences increasingly dealt with idealized entities and internal abstractions a world apart from the concrete phenomena of daily life. In his later work, he pointed particularly to the work of Galileo¹ as a turning point in the development of this abstract, idealized reasoning:

For Platonism, the real had a more or less perfect methexis in the ideal. This afforded ancient geometry possibilities of a primitive application to reality. [But] through Galileo's mathematization of nature, nature itself is idealized under the new mathematics. Nature itself becomes—to express it a modern way—a mathematical manifold. (Husserl 1936:23)

Husserl's primary criticism of this idealized scientific conception of the world was that it had distanced science and mathematics from the everyday world and everyday practical concerns, and in doing so, had distanced it from the live experience of people acting in the world. Galileo was responsible for a surreptitious substitution of the mathematically substructed world of idealities for the only real world, the one that is actually given through perception, that is ever experienced and experienceable—our everyday life-world. (Husserl 1936:48–49)

Husserl wanted to redress this balance and envisioned a science that was firmly grounded on the phenomena of experience, which in turn meant developing the philosophy of experience as a rigorous science. This had also been Descartes's intent; Husserl saw his program as a Cartesianism for the twentieth century.

Descartes had attempted to uncover how a subjective consciousness could know with any certainty about external reality. Franz Brentano, under whom Husserl studied, had further developed this into a theory of "intentionality," which described the way that mental states could refer to elements of external reality. Intentionality describes the relationship between the tree outside my window and my thinking about it; for Brentano, all mental states have this property of being about something. Husserl elaborated Brentano's ideas further, and proposed phenomenology as a method for examining the nature of intentionality.

Phenomenology aims to uncover the relationship between the objects of consciousness—the objects of intentionality, which Husserl terms noema—and our mental experiences of those objects, our consciousness of them, which he terms noesis. Making this separation allows the phenomenologist to begin to analyze how we perceive and experience the phenomena of the everyday world: how noema and noesis are related and how they feature as parts of our experience of the world. However, in order to examine these questions rigorously, the phenomenologist must suspend the "natural attitude" to the world that assumes the existence of the perceived objects on the basis of perception. Phenomenology's objective is to explore how the natural attitude comes about in the first place.

What Husserl posits is a parallelism between the objects of perception and the acts of perception. When I see a rabbit, I have not only to recognize that what I'm seeing is a rabbit, but also that what I'm doing is seeing it (as opposed to imagining or remembering it). There is a parallelism between these two domains, and mental acts can themselves become phenomena of experience as I recall or reflect upon them.

The separation that Husserl proposes between the objects of perception and the perceptions themselves is mirrored by a second separation between the elements of the world and their "essences" or essential characteristics. In recognizing that what I'm seeing is a rabbit, I move from the world of immediate everyday affairs—this particular set of
sense-impressions—to the world of the formal, the essential. He argues that the objects of intentionality are always “essences.”

These ideas and the phenomenological method were developed initially in Logical Investigations (1900) and Ideas: General Introduction to a Pure Phenomenology (1913). In his last major work, The Crisis of European Sciences and Transcendental Phenomenology (1936), Husserl further elaborated his principles (partly in response to criticisms from some such as Heidegger, below) and introduced the concept of the life-world, or lebenwelt. The life-world is the intersubjective, mundane world of background understandings and experiences of the world. It is the world of the natural attitude and of everyday experience. Although the life-world is the background from which any scientific understanding of the world emerges, Husserl argued, it had gone largely unexplored in earlier accounts of meaning, knowledge, and understanding. Incorporating the idea of the life-world into phenomenology served to direct its attention to the role of these unconscious, “sedimented” understandings in our dealings with everyday reality.

Phenomenology, then, was a significant departure from previous philosophical positions. Most importantly, it rejected abstract and formalized reasoning, looking instead at the pretheoretical, prerational world of everyday experience. Although (as we will see) many people later moved away from a pure Husserlian position, Husserl’s work has had considerable influence in turning attention, first, to everyday experience rather than formalized knowledge, and second, to that experience as a phenomenon to be studied in its own right.

Heidegger's Hermeneutic Phenomenology
Although Husserl had first articulated the phenomenological position, it was one of his students who would most profoundly influence the development of phenomenological thought. That student was Martin Heidegger (1889–1976). Heidegger’s magnum opus, Being and Time (1927 [tr. 1961]), took Husserl’s work as a starting point but developed it in radically new ways by showing how mental life and everyday experience were fundamentally intertwined.

Heidegger followed Husserl in attempting to uncover the intentionality of experience. However, where Heidegger broke with Husserl was in rejecting the mentalistic attitude that Husserl had adopted. By “mentalistic,” I mean a focus in Husserl’s phenomenology on cognitive, mental phenomena separated from the physical phenomena of mundane existence.

This was a perspective that Husserl had inherited from Descartes. Descartes’ famous dictum, “cogito ergo sum”—I think, therefore I am—had reflected a doctrine that we “occupy” two different and separate worlds, the world of physical reality and the world of mental experience. This doctrine, called Cartesian dualism, holds that mind and body are quite different; thinking and being are two different sets of phenomena. In common with most philosophers, Husserl had adopted this dualism and had devoted his attention to mental life and cognition, to how we could know about the world “out there.”

Heidegger argued that Husserl and others had focused on mental phenomena, on the cogito, at the expense of being, or the sum. However, he proposed, clearly one needed to be in order to think. Being comes first; thinking is derived from being. So, it would make no sense to explore intentionality independently of the nature of being that supports it. The nature of being—how we exist in the world—shapes the way that we understand the world, because our understanding of the world is essentially an understanding of how we are in it. So Heidegger rejected the dualism of mind and body altogether. He argued that thinking and being are fundamentally intertwined. Essentially, Heidegger transformed the problem of phenomenology from an epistemological question, a question about knowledge, to an ontological question, a question about forms and categories of existence. Instead of asking, “How can we know about the world?” Heidegger asked, “How does the world reveal itself to us through our encounters with it?”

This was a radical transformation of the traditional point of view. Most philosophers since Descartes had taken the position that the mind is the seat of reason and meaning. The mind observes the world, gives it meaning by relating it to abstract understandings of an idealized reality and, on the basis of that meaning, formulates a plan of action. Heidegger turned that around. From his perspective, the meaningfulness of everyday experience lies not in the head, but in the world. It is a consequence of our mode of being, of the way in which we exist in the world.

Where traditional philosophical approaches argued that we proceed
from perception to meaning to action, Heidegger stressed the way that we ordinarily act in a world that is *already organized* in terms of meaning. The world has meaning for us in the ways in which we encounter it and the ways that it makes itself available to us.

The most important aspect of the way in which we encounter the world is that we encounter it *practically*. We encounter the world as a place in which we act. It is the way in which we act—the practical tasks in which we are engaged, and how they are accommodated into the world—that makes the world meaningful for us. Heidegger rejected the very kinds of intentionality that Husserl and others had pursued—an abstract, disconnected intentionality, the intentionality of a Cartesian homunculus peering out at the world and seeing what’s there. Instead, he argued for intentionality as an aspect of practical affairs:

The kind of dealing which is closest to us is as we have shown, not a bare perceptual cognition, but rather that kind of concern which manipulates things and puts them to use. (Heidegger 1927:95)

*Meaning inheres in the world as we find it.* The central element of our existence is to interpret that meaning through the ways in which we encounter the world. The interpretive nature of understanding is the basis for Heidegger's phenomenology, a hermeneutic phenomenology.

At the center of Heidegger’s work is the concept of *Dasein*, which is the essence of being human. Dasein is usually translated as “being-in-the-world,” emphasizing the way in which *being is inseparable from the world in which it occurs*. It follows, then, that one of the central questions concerns how *Dasein* is oriented toward the world. As noted earlier, the orientation is a fundamentally practical one; it is purposeful and active. The world, however, is not simply the object of Dasein’s action, but also, at times, the medium through which that action is accomplished. In other words, one of the ways that Dasein encounters the world is to be able to use what it finds in order to accomplish its goals. Heidegger uses the term *it* to refer to elements in the world turned into tools for our use. There are two important ideas captured by the term equipment. The first is that it refers not simply to the tool, but to the tool as a tool and for some task. “Equipment,” Heidegger comments, “is essentially ‘something in-order-to’” (1927:99). The second is that equipment does not stand alone. Equipment is linked to other equipment in the way that it relies upon, works with, suggests, is similar or dissimilar to, or is otherwise related to other equipment.

This aspect of Heidegger’s phenomenology is already known in HCI. It was one of the elements on which Winograd and Flores (1986) based their analysis of computational theories of cognition. In particular, they were concerned with Heidegger’s distinction between “ready-to-hand” (*zuhanden*) and “present-at-hand” (*vorhanden*). These are ways, Heidegger explains, that we encounter the world and act through it. As an example, consider the mouse connected to my computer. Much of the time, I act through the mouse; the mouse is an extension of my hand as I select objects, operate menus, and so forth. The mouse is, in Heidegger’s terms, *ready-to-hand*. Sometimes, however, such as when I reach the edge of the mousepad and cannot move the mouse further, my orientation toward the mouse changes. Now, I become conscious of the mouse mediating my action, precisely because of the fact that it has been interrupted. The mouse becomes the object of my attention as I pick it up and move it back to the center of the mousepad. When I act on the mouse in this way, *being mindful of it as an object* of my activity, the mouse is *present-at-hand*.

Heidegger does more than point out that we have different ways of orienting toward objects; his observation is more radical. He argues that the mouse exists for us as an entity only because of the way in which it can become present-at-hand, and becomes equipment only through the way in which it can be ready-to-hand. And in being ready-to-hand, it disappears from view—or “withdraws”—as an independent entity:

*The ready-to-hand is not grasped theoretically at all... The peculiarity of what is proximally ready-to-hand is that, in its readiness-to-hand, it must, as it were, withdraw in order to be ready-to-hand quite authentically. That with which our everyday dealings proximally dwell is not the tools themselves. On the contrary, that with which we concern ourselves primarily is the work.* (1927:99)

In other words, as we act through technology that has become ready-to-hand, the technology itself disappears from our immediate concerns. We are caught up in the performance of the work; our mode of being is one of “absorbed coping.” The equipment fades into the background. This unspoken background against which our actions are played out is at the heart of Heidegger’s view of being-in-the-world. So, in fact, although I
suggested earlier that Heidegger had transformed the question of meaning from an epistemological question to an ontological question, the form of his answer is really "ontological." By preontological, I mean that it is outside of and prior to our focused attention. The way in which the world occurs as an unconscious but accessible background to our activity is essential to our mode of being.

We can see that although Heidegger had taken Husserl's work as his starting point, he soon departed from it radically. Our mundane experience of the world was central to his work, just as it had been to Husserl's; but for Heidegger, our engaged participation in the world came to play a central role in the questions of being and meaning. Where Husserl had turned his (and our) attention to the primacy of actual experience rather than abstract reasoning, Heidegger had moved the site of that experience into the world. Dasein is embodied being; it is not simply embedded in the world, but inseparable from it such that it makes no sense to talk of it having an existence independent of that world.

Although it has been extremely influential, Heidegger's was not the only elaboration of Husserl's work. Husserl's phenomenology was developed in different directions by others. One of these was Alfred Schutz, whose work is a key bridge from the concerns of Husserl and Heidegger to those of Harold Garfinkel and other sociologists.

Schutz's Phenomenology of the Social World

Husserl and Heidegger had developed phenomenology in different directions, but they had nonetheless both concentrated on the individual experience of the world. The critical contribution of Alfred Schutz (1899–1959) was to extend phenomenology beyond the individual to encompass the social world.

Schutz was Austrian, and lived for the first part of his life in Vienna. He published his first major work, The Phenomenology of the Social World, in 1932 [tr. 1967]. After working briefly with Husserl at Freiburg, he moved to the United States, where he spent the rest of his life, further developing his ideas about a phenomenological approach to the problems of sociology.

In particular, Schutz's program centered on the problem of intersubjectivity. At its most basic, the problem is this: given that our experiences of the world are fundamentally our own, how can we achieve, between different individuals, a common experience of the world, and a shared framework for meaning? If I don't know what you experience of the world, or what you experience when I talk to you, how can we ever understand each other or come to any understanding of the world around us? How can the relationship between two people's subjective experience be maintained?

The problem of intersubjectivity is a crucial one for sociology. Social order is mutually constituted by its members; it arises out of the collective action of us all. Collective action, however, depends on intersubjectivity. It depends absolutely on our intersubjective understandings of the world and of our actions in it. Unsurprisingly, then, the early sociologists had turned their attention to these foundational questions.

Schutz's starting point was the work of Max Weber. Weber was one of the founding figures of modern sociology. He held that the goal of sociology was the interpretive understanding of subjectively meaningful social acts. By interpretive understanding, Weber meant that sociology's goal was to study action in order to uncover the orderliness that lay behind it, an orderliness that could be expressed in terms of general rules. The objective reality of these laws and social facts was the unquestioned position of traditional sociology. Weber and other sociological theorists argued that society and the stability of social facts are a given, existing independently of their application or interpretation by social actors.

However, Schutz rejected this view. In particular, he was concerned with Weber's treatment of the problem of intersubjectivity. Schutz felt that Weber had passed over the issues of how those "subjectively meaningful social acts" that Weber wanted to explicate actually became meaningful to people, and could be recognized and understood by others as being meaningful. Clearly, the whole edifice of Weber's sociology turned on this issue. In contrast with the traditional approach, Schutz argued that the meaningfulness of social action had to emerge within the context of the actor's own experience of the world. Drawing on the phenomenological tradition and its concerns with everyday experience, he saw intersubjectivity not as some universal law, but rather as a mundane, practical problem, routinely solved by social actors in the course of their action and interaction.
Chapter 4

In other words, Schutz identifies the source of intersubjectivity as Husserl’s \textit{lebenswelt}. This is the life-world that Husserl had introduced in his later writings, the “mundane world of lived experience already existing as a product of the unreflecting cognitions of ordinary actors” (Heritage 1984:44). For Schutz, this world of lived experience incorporates our social understandings, too—understandings of how our actions look to others and how others’ look to us.

Essentially, Schutz argues that the actions of others seem to us to be the actions of reasonable social actors because we assume them, in the first instance, to be so. \textit{Intersubjectivity is achieved}, as a practical concern, as a consequence of these assumptions; that we share a common reality, that we act rationally within that reality, and so forth. This assumption of rationality is part of the “natural attitude.” We work under the assumption that others are rational as we are, and that others’ experience is like our own:

A man in the natural attitude, then, understands the world by interpreting his own lived experiences of it, whether these experiences be of inanimate things, or of his fellow human beings. (Schutz 1932:108)

All genuine understanding of the other person must start out from acts of explanation performed by the observer on his own lived experience. (Schutz 1932:13)

So, in Schutz’s model, intersubjectivity is the outcome of these assumptions in the natural attitude. Intersubjectivity results only and entirely from the fact that people do it. It is a practical achievement of social actors, a response to the practical problems of engaging with each other in concerted social action.

Schutz recognized that this assumption of rationality could not be simply an instantaneous achievement. To interpret actions as rational requires that we can see them emerge within a pattern of goals, causes, requirements, and motivations. To this end, Schutz developed a model of the social world that reflected its orientation toward past events and future intentions as a feature of the practical achievement of intersubjective meaning.

The interpretive model of intersubjectivity that Schutz proposed applies not only to explicit acts of communication, but also to simple observable behavior. Following Weber, he used the example of watching a woodcutter chopping wood. One understands the woodcutter’s actions by projecting oneself into the place of the woodcutter, imagining oneself to be carrying out his actions, and so interpreting the actions of the woodcutter from the point of view of one’s own life-world and experience. This relies on the assumption that the woodcutter is, broadly, motivated by the concerns that would motivate us in that situation, attentive to the same sort of issues that we would be, and so forth. Now, more or less other information—observable information related to lived experiences—may or may not be available to be told more, such as whether the woodcutter is cutting wood to earn a living or for exercise. But, regardless, the assumption of rationality provides a starting point for the development of further understanding. This is one important aspect of the characterisation of the problem of intersubjectivity as a practical, mundane problem—that the solution need only be “good enough” for the matters at hand.

Schutz’s approach brought phenomenological reasoning to the problems of sociology. In doing so, he opened up a new set of concerns for sociologist, by turning the life-world into a site of social scientific inquiry:

For Schutz, the \textit{lebenswelt} is a world of mundane events and institutions which the ordinary members of society constitute and reconstitute without even being aware of the fact. This mundane world is both the unnoticed ground on which social science is founded, and, in many cases, its unnoticed object of investigation. (Heritage 1984: 44).

Taking the life-world as a focus recasts the problems of sociology. It means turning away from the idea of general laws that operate outside the immediate purview of the actors whose behavior they regulate. Instead, it characterizes sociological problems as practical, mundane ones routinely encountered—and solved—by social actors in the course of their day-to-day activities. Social actors are, in effect, practical sociologists, solving the problems of sociology for themselves every day. This reorientation of sociology toward a new set of questions and a new method of inquiry was one of the critical motivations for Garfinkel’s development of ethnomethodology, as introduced in the previous chapter and explored in more detail shortly. For the moment, however, I will address one further aspect of the development of phenomenology.

Merleau-Ponty and the Phenomenology of Perception
Of the various phenomenological thinkers presented here, the one for whom the notion of “embodiment” was most central was the French
Cultural world in which we are embedded. Each of these aspects, simultaneously, contributes to and conditions the actions of the individual, both in terms of how they understand their own embodiment (the “phenomenological body”) and how it is understood by others (the “objective body”).

Given the central place of “embodiment” in Merleau-Ponty’s work, and his concern with the body and bodily experience, this may be an appropriate moment to say something more about the use I want to make here of the term embodied. I am using the term largely to capture a sense of “phenomenological presence,” the way that a variety of interactive phenomena arise from a direct and engaged participation in the world. As I outlined earlier, this includes both physically realized and socially situated phenomena, and the chapters that follow will explore both the dimensions and the consequences of this approach. However, in Merleau-Ponty’s work, the idea of “embodiment” is used to draw particular attention to the role of the body. This concern with the body is echoed in much current work in Critical Theory, and particularly in explorations into the relationship between questions of self and technology, such as the “cyborg” work initiated by Donna Haraway (1991), Sandy Stone’s (1991) comments on virtual presence, or (more distantly) Don Ihde’s (1991) investigations of the mediating role of technology in science. I am sympathetic to their perspectives, but my concerns here are not those of Haraway and her colleagues, nor should my use of the term embodied be confused with the issues that they wish to identify. Indeed, the lessons I want to draw from the phenomenological perspective will be broader (and less specific) than those that primarily occupied Merleau-Ponty.

Although his influence in HCI has been much less significant than that of Heidegger or even Schutz, Merleau-Ponty has nonetheless made an appearance. Robertson (1997) uses Merleau-Ponty’s work as the basis of a taxonomy of embodied actions for the analysis of group activity. For instance, Merleau-Ponty’s emphasis on the “reversibility” of perception—how, in our bodily presence and through our bodily experience, we can apprehend aspects of the perceptions of ourselves that we engender in others—provides her with the tools to explore how groups manage their mutual orientations, both to each other and to external artifacts, in
face-to-face and in virtual settings. Robertson’s investigations show the relevance of embodied accounts of phenomenological perception in understanding how technology mediates interpersonal communication. While the communicative role of technology is quite clear in Robertson’s work—she was, after all studying the use of video-communication technologies—I will argue that this same communicative role can be ascribed to a much broader range of technologies, and that phenomenological perspectives can be similarly enlightening.

**Summary: Phenomenology and Being-in-the-World**

It should be clear by this stage that embodiment is not a new idea—far from it. Instead, it has been central to a particular thread of philosophical thought since the late nineteenth century. However, for each of the phenomenological positions that have been outlined here, embodiment has played a different role. Husserl was concerned with how the life-world was based in everyday embodied experience rather than abstract reasoning; Schutz recognized that this conception of the life-world could be extended to address problems in social interaction. For Heidegger, embodied action was essential to our mode of being and to the ways in which we encountered the world, while Merleau-Ponty emphasized the critical role of the body in mediating between internal and external experience. Throughout these accounts, the idea of a world that we encounter directly rather than abstractly is of central concern.

What the phenomenologists have explored is the relationship between embodied action and meaning. For them, the source of meaning (and meaningfulness) is not a collection of abstract, idealized entities; instead, it is to be found in the world in which we act, and which acts upon us. This world is already filled with meaning. Its meaning is to be found in the way in which it reveals itself to us as being available for our actions. It is only through those actions, and the possibility for actions that the world affords us, that we can come to find the world, in both its physical and social manifestations, meaningful.

It should also be more clear, in light of this introduction, why embodiment and phenomenology are relevant to tangible and social computing. The relationship between tangible and social computing is not simply that they both exploit familiar metaphors for interaction. Instead, they both build on an account of the relationship between action and meaning that phenomenology has explored. They both place action and interaction prior to “theory” and abstract understanding. So, the phenomenological perspective offers a starting point for a foundational understanding of embodied interaction, one that the rest of the book will attempt to set out.

Before moving on, though, I want to spend some time discussing other approaches and show how they relate to the work discussed so far. Up to this point, I have primarily addressed the phenomenological tradition, but it is only one approach concerned with the relationship between cognition and action. In the rest of this chapter, I will introduce some other perspectives. These other approaches serve two roles here. First, they flesh out the picture of embodiment as an aspect of twentieth century thought; and second, they can provide us with further insights into the nature of being-in-the-world, both physical and social.

**Being in the Physical World**

A number of theorists, working in different domains and bringing different perspectives to bear, have recognized the importance of our physical embodiment in the world as a central aspect of how we act and react.

In HCL, the work of the psychologist J. J. Gibson is perhaps the most familiar, especially as explored in the writings of Donald Norman. Throughout his career, Gibson was principally concerned with visual perception; with how living creatures can see, can recognize what they see, and can act on it. Although psychologists had long studied the topic, Gibson became frustrated with conventional approaches. His frustration stemmed from the fact that they separated seeing from acting, while he regarded the two as being deeply connected.

Gibson’s starting point was to consider visual perception not as a link between optics and neural activity, but as a point of contact between the creature and its environment, an environment in which the creature moves around and within which it acts:

One sees the environment not just with the eyes but with the eyes in the head on the shoulders of a body that gets about. We look at details with the eyes, but we also look around with the mobile head, and we go-and-look with the mobile body. (Gibson 1979:222)
Gibson placed visual perception within a frame of being and acting, and in doing so laid the foundations for what he and others came to call "ecological psychology." In contrast to approaches such as cognitive psychology, which tended to restrict their focus to mental processing and were defined by the boundaries of the head, ecological psychology was concerned with the organism living and acting in the world. From the ecological perspective, "cognition" was not purely a neural phenomenon, but was located within (and throughout) a complex involving the organism, action and the environment. Ecological psychology studies "knowledge in the world" rather than "knowledge in the head."

One central construct of Gibson's approach, which has had a particularly telling impact on the development of HCI, was the concept of "affordance." Technically, an affordance is a property of the environment that affords action to appropriately equipped organisms. For example, the glass of my window affords looking to me, because I have eyes that operate in that part of the electromagnetic spectrum to which the glass is transparent. The atmosphere at sea level affords comfortable breathing to me, for the oxygen content of the air provides my body with adequate sustenance; but at an altitude of 35,000 feet, the atmosphere no longer affords breathing to me, although it might afford it to some other creature with lower oxygen requirements. My office chair affords sitting to me, because its seat matches the length of my legs. My office chair does not afford sitting to a horse or a rabbit; they are not "appropriately equipped" individuals. Similarly, I am not appropriately equipped to be able to breathe underwater or see in pitch darkness, although other creatures are, and so these environments afford different kinds of actions to them than they do to me.

In other words, an affordance is a three-way relationship between the environment, the organism, and an activity. This three-way relationship is at the heart of ecological psychology, and the challenge of ecological psychology lies in just how it is centered on the notion of an organism acting in an environment: being in the world.

As noted, ideas from ecological psychology have made their way into the world of HCI. Donald Norman (1988, 1993) has made considerable use of Gibson's analytic framework, and particularly the concept of affordance, in his work on design and interaction in both the everyday physical world and the world of computer interfaces. Norman uses the concept of affordance to explore the relationship between form and function in design and to show how good design can make the appropriate use of a device clear and obvious to a user. Although Norman uses many examples drawn from the physical environment and physical product design, the same ideas also apply to the design of user interfaces, where the functionality (or the "opportunity for action") that a system offers can be made more or less obvious in its visual appearance.

Subsequently, William Gaver took affordances as a starting point for a model of interactive system design (Gaver 1991), as well as for the analysis of cooperative technologies (Gaver 1992). Gaver's goal was not simply to use the ecological approach to analyze interfaces, but also to build it into a systematic basis for interactive system design. For example, taking his cues from Gibson's discussion of the "eyes in the head on the shoulders of a body," Gaver argued that one failing of video-communication technologies was that they offer no means for visual exploration of the remote scene. Typical arrangements of cameras and monitors provide only a fixed view of the remote location, and that view is outside the control of the observer. By contrast, in the everyday world, our field of view is related to the way we are moving through the environment, and we have the opportunity to stop, look around, and so build up a better picture of what is around us by exploration. On this basis, Gaver and colleagues developed a prototype video-communication system (called the Virtual Window) that allowed users to explore a remote scene through head movements analogous to those by which we might look around us in the everyday world (Gaver, Smets, and Overbeeke 1995).

The idea of physical embodiment as an aspect of understanding the world was also one explored by Michael Polanyi. His book The Tacit Dimension (Polanyi 1966) explored the idea of "tacit knowledge": those things that we know, but unconsciously and inexpressibly. One source of examples of tacit knowledge is we might call "embodied skills," such as juggling or riding a bike. These are "tacit" skills in the sense that, while we might able to describe them, we cannot explain exactly what we do when we go about these tasks. We just do them. The understanding of "what" and the understanding of "how" are different kinds of knowledge.

Explicit integration cannot replace its tacit counterpart. The skill of a driver cannot be replaced by a thorough schooling in the theory of the motorcar; the
knowledge; I have of my own body differs altogether from the knowledge of its physiology; and the roles of rhyming and prosody do not tell me what a poem told me, without any knowledge of its rules. (Polanyi 1966:20)

Embodied skills depend on a tight coupling between perception and action. Polanyi distinguishes between what he calls proximal and distal phenomena. Loosely, proximal means “close by” or “at hand,” while distal means “at a distance.” He argues that, in cases of tacit skills, our focus is on the distal phenomena, while the proximal phenomena are those through which the distal is achieved. Take the example of using a stick to feel your way in the dark. You have the sense of exploring the ground in front of you (distal) while, in fact, what you are experiencing is a set of sensory impressions at the hand holding the stick (proximal).

So, although your actual experience might be proximal, your attention is transferred to the distal phenomenon. Just as the environmental movement urged us to “think globally, act locally,” so Polanyi observes that we think distally but act proximally. He notes that this transfer of attention, from proximal to distal, is associated with a semantic shift. The meaning we associate with proximal phenomena is actually that of their distal correlates. In the stick example, the pressure on our hands is interpreted to mean the presence of a barrier on the ground. Or again, on a boat, we interpret the subtle shifts in our balance in terms of the movement of the deck beneath our feet without even being aware that we are making the transition from proximal to distal phenomena. Polanyi sees this as a general phenomenon:

All meaning tends to be displaced away from ourselves, and that is in fact my justification for using the terms “proximal” and “distal” to describe the first and second terms of tacit knowing. (1966:13).

Even though bicycle riding and juggling seem to pop up as the quintessential examples of tacit knowledge, Polanyi’s interests are broader than simply physical skills. His idea of tacit knowledge applies generally to situations in which we understand “what to do” without being able to express “how to do it.” In The Tacit Dimension, what he actually has in his sights is not riding bicycles, but rather the question of how science is conducted and theory uncovered. A scientist before he turned to philosophy, Polanyi set out to address the observation that although science appears to progress through a thoroughly rational and regimented sequence of hypothesis, experimentation, observation, and analysis, it is equally dependent on such “irrational” phenomena as insights, hunches, and intuitions about results that do or do not “ring true.” He makes the case that the relationship between proximal and distal phenomena is akin to that between a hidden reality and observable fact, and that it is through the scientist’s relationship to this hidden reality that science progresses.

The progress of science is not of immediate concern here (except in as much as we might be able to contribute to it). What is significant, though, is the way that Polanyi sees the relationship between proximal and distal in semantic terms, that is, in terms of the meaning they convey. This is strongly reminiscent of the concerns of the phenomenologists with the relationship between meaning and action, but we can see it, too, in the way that embodiment arises from these other perspectives.

**Being in the Social World**

The directness of embodiment is not only a phenomenon of the physical world. It is also crucial to a stance on the social world that has underpinned a good deal of the influence of sociological thinking on HCI in recent years.

We have already encountered one major trend in the role of embodiment in sociology, particularly with respect to issues of Human-Computer Interaction. That trend is the one represented by “situated” perspective, associated particularly with Suchman, but also with others such as Clancey (1997) or Lave (1988). And, as I have suggested earlier, Suchman’s work can be related directly to the work of the phenomenologists, in that Suchman works in the ethnmethodological tradition established by Harold Garfinkel, who himself drew extensively on the work of Alfred Schutz.

We encountered these perspectives in the previous chapter, but let me briefly summarize in order to draw attention to the threads relating their positions. Suchman’s critique of the prevailing cognitivist model in Artificial Intelligence and interaction design drew attention to the fact that the sequential organization of action is not formulaic outcome of abstract planning, but rather is an improvised, ad hoc accomplishment, a moment-by-moment response to immediate needs and the setting in which it takes
place. The organization of action emerges within the frame of the action itself. Suchman demonstrated how a number of problems with interactive technology lay in the imbalance between the situated organization of practical action and the regimented models that systems embody. In coming to this conclusion, Suchman drew extensively on the ethnomethodological perspective that Garfinkel had pioneered. Whereas conventional sociological approaches take the position that we act in response to an objectively given social world, ethnomethodology claims that everyday social practice creates and sustains that social world by rendering it publicly available and intelligible. Members’ methods for making action accountable are means through which the phenomenon of objective social reality is achieved.

As should be clear, Garfinkel’s ethnomethodological approach is heavily influenced by Schutz and his work. Schutz had emphasized that intersubjectivity is the achievement of social actors in the course of their activity, and drew upon Husserl’s formulation of the lebenswelt, the life-world of mundane experience, in claiming intersubjectivity as an achievement or outcome of the natural attitude. This approach is echoed in Garfinkel’s concept of accountability, his concern with practical rationality and commonsense understandings, and his exploration of members’ methods for rendering their actions meaningful to each other. Indeed, Garfinkel repeatedly observes that Schutz, almost alone among social scientists of his generation, had begun to uncover the ways in which social reality is the ongoing achievement of social actors. Subsequently, as discussed in chapter 3, Garfinkel elaborated Schutz’s orientation toward the life-world and used it to initiate a radical reconsideration of the problems, topics, and methods of sociology.

So, the link that Suchman forged between HCI and sociology also connected it to a broader tradition that was, from the outside, oriented toward questions of embodiment. Ethnomethodology adopted a concern for these issues from Schutz’s phenomenology. Garfinkel drew from other sources as well, however, and at least one other important basis for Garfinkel’s work addressed questions of embodiment, albeit from a different angle. This was the ordinary language philosophy of Ludwig Wittgenstein.

Wittgenstein and the Meaning of Language
Like Elvis Presley, Ludwig Wittgenstein (1889–1951) had a professional career that fell into two distinct phases.

The first phase is his work up until his initial withdrawal from philosophy in 1919, and encompasses his investigations into the philosophy of logic and mathematics with Russell and Moore at Cambridge. The major work of this period was his dissertation, Tractatus Logico-Philosophicus, which he completed while a prisoner of war. Published in 1921, the Tractatus is organized as a series of terse, numbered propositions, arranged into seven sets and accompanied by some commentary. Proceeding from the first proposition, “The world is the totality of facts,” to the last, “Whereof we cannot speak, thereof we must remain silent,” the Tractatus attempts to explore the nature of facts and propositions. One of the best-known elements of this work is the “picture theory” of meaning, according to which language represents (or pictures) the relationships between entities in the world.

After 1919, Wittgenstein "retired" from philosophy and taught in an elementary school in rural Austria. Finding it hard to keep away, though, he returned to Cambridge in 1929 to take up his philosophical studies again. In this second phase of his career, though, he departed radically from the principles that guided his earlier work.

The major work of Wittgenstein’s second career is the Philosophical Investigations, which appeared posthumously in 1953. Once again, the topic is meaning, but now Wittgenstein took a very different perspective. In this later work, Wittgenstein rejected the positivist view of language and meaning that had characterized the Tractatus. He no longer held the view that words simply signify states of the world. He now saw meaning as embedded not in language or linguistic expressions themselves, but rather in the practice or use of language.

Wittgenstein reoriented his view of language from a logical construction of facts and truth statements to a set of loosely connected “language games,” socially shared linguistic practices “consisting of language and the actions into which it is woven.” Language games reflect a common orientation toward action and experience that provides a context for determining meaning. Using language, he argued, is a human activity, and its effective meaning must be sought in the activity that it accomplishes, or in what Wittgenstein called the “form of life” that surrounds specific linguistic practice. It is on this basis that, in Philosophical Investigations (§43), he famously wrote, “the meaning of a word is its use in the language.”
The "language games" perspective emphasizes that language is not simply an external expression of inner mental states, but rather is a form of action. It is something that people do. So, the utterance cannot be separated from the speaker, or from the systems of meaning in which speaker and hearer are enmeshed. From this perspective, the questions that he had struggled with in his early career were rendered meaningless. The "truth" of a statement was no longer a sensible topic; now, his attention was turned to the "appropriateness" of an utterance, that is, to what made it the right thing to say in such-and-such a circumstance, and what might make it meaningful to hearers. The question is how language is organized into systems of meaning or language games. Language games are the embodied practices of communities, and the context of the language game arises from the experience, needs, capacities, and so forth of those who are engaged in it. "To imagine a language," Wittgenstein observed, "is to imagine a form of life" (§19). In other words, the setting in which language is used contributes to the apprehension of its meaning, where "setting" is not just the local occasion of its use, but the very way in which the speakers of that language exist in the world.

So, embodiment is as central to Wittgenstein's approach to language as it is to Heidegger's view of Being. He argues that language and meaning are inseparable from the practices of language users. Meaning resides not in disembodied representations, but in practical occasions of language use. Although Wittgenstein was not working directly in the phenomenological tradition, his approach clearly resonates much of that line of thought, and indeed, his exploration of meaning and rule-following figure as strongly as the influence of Schutz in Garfinkel's ethnomet hodology.

Summary

This chapter has taken something of a whirlwind tour through the work of many people who have addressed the issue of embodiment in one way or another.

It began with the phenomenologists. I outlined Husserl's attempts to recast the Cartesian program around the phenomena of experience; Heidegger's reconstruction of phenomenology around the primacy of being-in-the-world; Schutz's expansion of the phenomenological program to account for problems of social interaction; and Merleau-Ponty's elaboration of the role of the body in perception and understanding.

I also explored the work of others who, although outside the phenomenological tradition, followed similar paths. So, we saw how Gibson had initiated an approach to psychology that recognized the importance of the interaction between an organism and its environment, and how his work has subsequently come to be adopted in HCI. Similarly, I explored the ways that Suchman's program, introduced in chapter 3, traces its intellectual lineage to Schutz, through Garfinkel. Finally, I introduced Wittgenstein's work on ordinary language philosophy, another of the major influences on Garfinkel's work.

It has not been my goal to spin these all these threads into a uniform theoretical fabric; that would be a monumental and potentially misguided task. Instead, my goal is to take these related approaches and find some common patterns that might shed light on the relationship between tangible and social computing. There are three notable common elements to the approaches outlined in this chapter.

First, they all take embodiment as central. "Embodiment" does not simply mean "physical manifestation." Rather, it means being grounded in and emerging out of everyday, mundane experience. The claim of the approaches outlined here is that embodiment is a foundational property, out of which meaning, theory, and action arise. They all place the source of action and meaning in the world. Embodiment is a participative status, a way of being, rather than a physical property.

Second, the approaches focus on practice: everyday engagement with the world directed toward the accomplishment of practical tasks. They all take action in the world to be fundamental to our understandings of the world and our relationship with it. So, their perspective is not simply that we are embodied in the world, but also that the world is the site and setting of all activity. It shapes and is shaped by the activities of embodied agents.

Third, they point to embodied practical action as the source of meaning. We find the world meaningful primarily with respect to the ways in which we act within it. Whether this is through Gibson's affordances of the environment or Heidegger's concern with objects manifesting themselves
through coming to be present-at-hand, the approaches outlined in this chapter see embodiment as a source for intentionality, rather than as the object of it.

Early in this chapter, I laid out some working definitions for embodiment and embodied interaction. After exploring how the idea has been used and developed by other schools of thought, we are, perhaps, now in a position to lay out some better ones.

The starting point was:

*Embodied phenomena are those which by their very nature occur in real time and real space.*

In light of the elements brought together in this chapter, we now have a better understanding of embodiment, and its consequences. We can now say:

*Embodiment is the property of our engagement with the world that allows us to make it meaningful.*

Similarly, then, we can say:

*Embodied Interaction is the creation, manipulation, and sharing of meaning through engaged interaction with artifacts.*

The major lesson that I draw from the phenomenological work is that embodiment is about the relationship between action and meaning. We have already spent some time, in considering social perspectives, talking about action. What we need to explore in more detail is just what is implied by “meaning.”

5

**Foundations**

The backdrop is now complete. Chapters 2 and 3 detailed the emergence of tangible and social computing, presented examples of work in those areas, and discussed some of the issues they raise. Chapter 4 made a case for the idea of embodiment as a central aspect of both the tangible and social approaches, and showed how various theorists, particularly phenomenological philosophers, have addressed embodied action in their work. It is now time to develop a deeper understanding of the themes that have emerged so far, and to consider their consequences for the design of interactive software systems.

The major theme that arose in chapter 4 was the relationship between embodiment and meaning. In contrast with Cartesian approaches, phenomenology describes a much more intimate relationship between our inner experience and the mundane world that we occupy. Cartesians claim that meaning is an internal phenomenon, which we assign to sense-data. Phenomenologists point out that the world is already filled with meaning, arising from the way in which the world is organized relative to our needs and actions, not just physically, but also socially and historically. So from the phenomenological perspective, we encounter, interpret, and sustain meaning through our embodied interactions with the world and with each other.

Tangible and social computing each adopt aspects of this perspective. Tangible computing encourages users to explore, adopt, and adapt interactive technology, incorporating it into their world and into everyday practice. It allows users to create and communicate the meaning of the actions they perform, rather than struggle with rigid meanings encoded in