tangible bits
designing seamless interface – between digital and physical

Hiroshi Ishii

Abstract

At the seashore, between the land of atoms and the sea of bits, we must reconcile our dual citizenships in the physical and digital worlds. Our windows to the digital world have been confined to flat rectangular screens and pixels – "painted bits". But while our visual senses are steeped in the sea of digital information, our bodies remain in the physical world. "Tangible Bits" give physical form to digital information, making bits directly manipulable and perceptible. Tangible bits pursues seamless coupling between these two very different worlds of bits and atoms, blurring the boundary between science-technology and arts-design.

1. At the Seashore

Where the sea meets the land, the coastline appears. It is unique in the landscape as a home to the living organisms of an inter-tidal zone. Here they engage in a fierce battle for survival between the tides, struggling in turn with heat and dryness followed by rough pounding waves. At the same time it is a fertile space where these organisms mix with light, water and air. Here at the border of sea and land they have blossomed into a myriad of unique forms. Many millions of years ago our ancestors also emerged from the ocean across this border.

We are now preparing to cross another coastline: the border between the land of the physical world and the sea of digital information. This will not be an easy transition. Our visual and auditory sense organs are steeped in the sea of digital information, but our bodies remain behind in the physical world. Beyond the countless screens which fracture our spatial experience, there extends a disjointed space composed of infinitely hyper-linked digital information. In

this space, one has no sense of one's own physical presence, nor the presence of those who have passed through it.

The "Tangible Bits" vision is to provide seamless coupling between bits and atoms. The core goal is to give physical form to digital information, allowing us to directly manipulate it with our hands, and to enable environmental recognition of digital information at the periphery of perception [5].

This paper introduces the conceptual framework of Tangible Bits and the some concrete interfaces designed by the members of the Tangible Media Group. These works were neither intended as purely aesthetic art pieces nor as technological demonstrations meant to solve well-defined problems. The goal of our research is to create new concepts.

The Tangible Bits vision is like a pair of eyeglasses intended to help people see what would otherwise remain invisible. Our hope is that these eyeglasses will help people see physical architectural spaces as interfaces with the digital world. A one-year exhibition of Tangible Bits started on Spetember 1st, 2001 at the Ars Electronica Center in Linz, Austria. We invite you to come to Linz and experience these conceptual eyeglasses by touching and feeling a variety of interfaces. In this exhibition, we invite you to experience a new and yet somehow familiar sense of what an interface can be, something that gestures to a new relation between information and ourselves.

2. Beyond Graphical User Interfaces, Towards Tangible User Interfaces

The basic concept behind today's standard human computer interface, the GUI (Graphical User Interface) has been in existence for more than thirty years. The GUI works by visualizing information on the screen as pixels or "painted bits." It began with the Xerox Star Workstation and, after some changes (some positive and some negative) and with the commercial success and dissemination of Microsoft Windows, the GUI has become the standard paradigm for Human-Computer Interaction (HCI) today. We believe this paradigm is reaching the end of its evolutionary potential.

The GUI, tied down as it is to the screen, windows, mouse and keyboard, is utterly divorced from the way interaction takes place in the physical world we inhabit. It makes no use of the skills we have learned through direct tactile contact with and manipulation of objects in our material world. Neither does it allow us to monitor ambient stimuli, such as changes in the weather and the passage of time. Today the interface which links cyberspace with the real world is the standard three-part set: screen, keyboard, and mouse. The GUI is designed on the assumption that we will sit directly in front of it and that it will be able to monopolize our vision and our foreground attention.

The objective of Tangible Bits is to provide concrete suggestions for how we might create a new interface paradigm that goes beyond the GUI paradigm.

Figure 1 illustrates the concept of "Foreground and Background" which serves as the foundation of the Tangible Bits design space. In this space the purpose is:

- to make bits directly manipulable in the foreground by combining information with graspable objects (as in the architectural models in "Urp"), and

- to be constantly aware of the information in the background (as in pinwheels) by infusing the environment with digital information using ambient media.
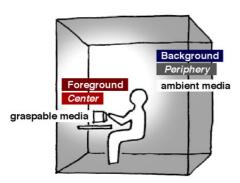

Figure 1: The relationship between the center and periphery of awareness in physical space, and graspable media and ambient media.

Caption: Human beings unconsciously take in and process a wide range of information from the periphery of their attention. Our research attempts to enable the smooth transition between this foreground and background information. This is achieved by combining graspable objects and ambient media. In this way, we attempt to refashion the very architectural spaces in which our bodies exist into interfaces between people and information.

3. Abacus – The Origin of Tangible Bits

The author met a highly successful computational device called the "abacus" when he was two years old. He could enjoy the touch and feel of the "digits" physically represented as arrays of beads. This simple abacus was not merely a digital computational device: because of its physical affordances, the abacus also became a musical instrument, an imaginary toy train, even a back-scratcher. He was captivated by the artifact's sound and its tactile properties.

This childhood abacus was also a medium for awareness. When his mother kept household accounts, he was aware of her activities by the sound of the abacus, knowing that he could not ask her to play while the abacus made its music.

This abacus revealed a new direction in Human-Computer Interaction (HCI) that we call Tangible User Interfaces (TUI).

First, the abacus makes no distinction between "input" and "output." Instead, its beads, rods, and frame all serve as physical representations of numerical information and computational mechanism. They serve as directly manipulable physical controls to compute on numbers.

Second, the simple and transparent mechanical structure of the abacus (without any digital black boxes made of silicon) provides rich physical affordances. Anyone can immediately understand what to do with this artifact without reading a manual. The TUI design challenge is to seamlessly extend physical affordances into the digital domain.

The Tangible User Interface (TUI) is significantly different from the GUI. The TUI gives physical form to digital information, serving as both a representation *and* a control. The TUI's physical embodiment makes digital information directly manipulable with our hands and naturally perceptible through our peripheral senses.

4. Sampler of Tangible User Interface Design

4.1 Pinwheels

Pinwheels is an example of ambient display that spins in a wind of digital information (bits). The spinning pinwheels allow people to feel the flow of bits representing human activities or happenings in the natural world in their peripheral vision while they concentrate on other activities (such as conversation) in the foreground [4].

An astronomer following the activities of a solar corona could install these pinwheels in his or her home in order to monitor solar winds in the background. Being peripherally aware of subtle changes in solar activity leading up to significant events could help the astronomer time periods of intensive observation. The basic concept is to make solar winds of ionized particles and all kinds of other information flows perceptible in architectural space as a "wind" driving old-fashioned pinwheels. Current graphical user interfaces display most of the information as pixels on a screen, requiring the user's conscious attention. As such they are foreground media. But our capacity to recognize and process information is exhausted when we are faced with too much data in the foreground, leading to information overload. Ambient displays, such as spinning pinwheels, help to solve this problem by representing continuous information flows as continuous physical phenomena in the background so the user can be aware of them peripherally.

http://tangible.media.mit.edu/projects/ICC_Exhibition/pinLarge.htm

4.2 inTouch

InTouch is a project that explores new forms of interpersonal communication through touch. InTouch uses force-feedback technology to create the illusion that people – separated by distance – are actually interacting with shared physical objects (Distributed Shared Physical Objects). The "shared" object is a haptic link between geographically distributed users, creating a channel for physical expression over distance [1].

Each of two identical InTouch devices use three freely rotating rollers. Force-feedback technology synchronizes each individual roller to the corresponding roller on the distant mechanism; when one InTouch roller is moved the corresponding roller on the other InTouch also moves. If the movement of one roller is resisted, the corresponding roller also feels resistance. They are, in a sense, connected by a stiff "digital spring." Two distant users can play through touch, moving rollers to feel the other's presence. InTouch demonstrates a unique interface that has no boundary between "input" and "output" (the wooden rollers are force displays as well as input devices). The sense of touch is playing critical role, and information can be sent and received simultaneously through one's hand.

Past communication media (such as video telephony) tried to reproduce the voice or the image of the human face as realistically as possible in order to create the illusion of "being there." InTouch takes the opposite approach by making users aware of the other person without explicitly embodying him or her. We think that InTouch creates a "ghostly presence." By seeing and feeling an object move in a human fashion on its own, we imagine a ghostly body. The concept of the ghostly presence provides us with a different approach to the conventional notion of telepresence.

http://tangible.media.mit.edu/projects/ICC_Exhibition/inLarge.htm

4.3 curlybot

curlybot is an educational toy that records and plays back physical motion. When the user takes hold of curlybot and moves it around on a flat surface it remembers how it has been moved. When it is then released, it replays the movement with all the intricacies of the original, including every pause, acceleration, and tremor of the user's hand. It was designed to help children develop geometrical thinking and as a medium for lyrical expression [2].

Phil Frei created the curlybot concept and completed the industrial and interaction design in late 1998. With the support of Victor Su for electronic circuit design and prototype construction, the first prototype was completed in the spring of 1999. The forced-feedback technology used for real-time simultaneous communication in inTouch is used in curlybot for the recording and playback of non-simultaneous gestures.

This project has significance in terms of both interface design and the use of computers for educational purposes. As a tangible interface it blurs the boundary between input and output (similar to inTouch): curlybot itself is both an input device to record gestures and a physical display device to re-enact them. By allowing users to teach curlybot gestures hand and body motions, curlybot enables a strong connection between body and mind not obtainable from anything expressed on a computer screen.

From an educational standpoint, curlybot opened new horizons as a toy that may help children acquire mathematical concepts. It is programmed not on the computer screen but simply by moving it around in physical space, demonstrating the power of "programming by gesture."

http://tangible.media.mit.edu/projects/ICC_Exhibition/curlyLarge.htm

4.4 Urp

Urp is a tangible urban-planning workbench based on the "I/O Bulb" concept originally developed by Dr. John Underkoffler in 1998. The "I/O bulb" creates high resolution, bi-directional light flows. It collects photons from physical surfaces, and uses knowledge about a particular domain, such as urban planning, to interpret the light patterns. It then responds with digitally-controlled light output, which is projected back onto the physical space.

In Urp, physical architectural models are placed on a table illuminated with "I/O bulbs" and shadows are cast according to a computer simulation. By adjusting the clock, it is possible to track the shadow movements and sun reflections. In addition, air currents around the buildings are rendered visible and a wind gauge can be used to measure the wind speed at any point. Using "I/O bulbs" to project real-time computer simulations onto physical models makes it possible to understand and directly manipulate digitally rendered urban spaces in a world that is contiguous with one's own body [6].

When designing tangible interfaces, it is important to consider which elements should be given physical form and which elements should be rendered as digital images. The key to a successful interface lies in hiding the boundary between the digital and physical worlds. The digital shadows (video projections) cast by the physical models in Urp represent one solution to this problem.

If we were to replace all of the hundreds and thousands of light bulbs in an architectural space with I/O bulbs, what kind of interaction design would be possible? The I/O bulb, as the core concept in this project, has demonstrated the potential for new digital interactions that occur not only on the tabletop, but within architectural space itself.

http://tangible.media.mit.edu/projects/ICC_Exhibition/luminLarge.htm

4.5 bottles

Through the seamless extension of physical affordances and the metaphor of bottles, this project explores interface transparency. Humans have used glass bottles for thousands of years. The basic concept uses glass bottles as both containers and minimalist interfaces to digital information. Just as we naturally open and close lids to access bottles' physical contents, in this project users open and close lids to access digital information. A wide variety of contents (including music, weather reports, and stories) have been developed to test the concept [3].

The "bottle-as-interface" concept began as a "weather forecast bottle," which Ishii envisioned as a present for his mother. Upon opening the weather bottle, she would be greeted by the sound of singing birds if the next day's weather was forecasted to be clear. On the other hand, the sound of rainfall would indicate impending rain. Such an interface would be consistent with her everyday interactions with her familiar, physical environment, such as opening a bottle of soy sauce. She never clicked a mouse or typed a URL in her life, but opened soy sauce bottles thousands of times.

In late 1998, Ishii and Rich Fletcher expanded this idea into "musicBottles" and began the project. They used sensor technology developed by Dr. Joe Paradiso and collaborated with different designers, engineers and artists to create a custom table and bottles with special electromagnetic tags. Three sets of bottles – each with different content: classical, jazz, and techno music – were designed and built. In June 2000, this project received the IDEA 2000 Silver Prize (International 2000 Industrial Design Excellence Awards competition).

We also developed custom wireless sensing technology for this project. An antenna coil attached to the underside of the table creates a magnetic field above the table. A custom electronic circuit detects disturbances in this magnetic field that are caused by the placement and opening of tagged bottles. The system then executes musical programs for each bottle (e.g. opening one bottle plays a piano) and controls the patterns of colored LED light projected onto the table.

This project uses a combination of artistic and technological techniques to support emotional interactions that are fundamentally different from conventional, function-centric interfaces.

http://tangible.media.mit.edu/projects/ICC_Exhibition/bottlesLarge.htm

5. Conclusion

This paper introduced our approach to take up these challenges based on the vision of "Tangible Bits" that gives physical form to digital information, making digital information directly manipulable and perceptible. Tangible bits pursues seamless integration between these two very different worlds of bits and atoms, blurring the boundary between digital and physical worlds.

Mark Weiser wrote in the first paragraph of his landmark paper "The Computer for the 21st Century" as follows [7]: "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

We continue our design research with strong hope that Tangible Bits will contribute to realize the ultimate invisible technologies that Mark envisioned.

6. Acknowledgement

http://tangible.media.mit.edu/projects/ICC_Exhibition/index.htm

7. References

- Brave, S., Ishii, H. and Dahley, A., Tangible Interfaces for Remote Collaboration and Communication , in Proceedings of CSCW '98, (Seattle, Washington USA, November 1998), ACM Press, pp. 169-178.
- Frei, P., Su, V., Mikhak, B., and Ishii, H., curlybot: Designing a New Class of Computational Toys, in Proceedings of Conference on Human Factors in Computing Systems (CHI '00) , (The Hague, The Netherlands, April 1-6, 2000), ACM Press, pp.129-136
- Ishii, H., Mazalek, A., Lee, J., Bottles as a Minimal Interface to Access Digital Information (short paper), in Extended Abstracts of Conference on Human Factors in Computing Systems (CHI '01), (Seattle, Washington, USA, March 31 - April 5, 2001), ACM Press, pp.187-188
- Ishii, H., Ren, S. and Frei, P., Pinwheels: Visualizing Information Flow in an Architectural Space (short paper), in Extended Abstracts of Conference on Human Factors in Computing Systems (CHI '01), (Seattle, Washington, USA, March 31 - April 5, 2001), ACM Press, pp.111-112
- Ishii, H. and Ullmer, B., Tangible Bits: Towards Seamless Interfaces between People, Bits and Atoms, in Proceedings of Conference on Human Factors in Computing Systems (CHI '97), (Atlanta, March 1997), ACM Press, pp. 234-241.
- Underkoffler, J., and Ishii, H., Urp: A Luminous-Tangible Workbench for Urban Planning and Design, in Proceedings of Conference on Human Factors in Computing Systems (CHI '99), (Pittsburgh, Pennsylvania USA, May 15-20, 1999), ACM Press, pp. 386-393.
- Weiser, M. The Computer for the 21st Century. Scientific American, 1991, 265 (3), pp. 94-104.