Slurp: Tangibility, Spatiality, and an Eyedropper

Jamie Zigelbaum
MIT Media Lab
20 Ames St.
Cambridge, Mass. 02139 USA
zig@media.mit.edu

Adam Kumpf
MIT Media Lab
20 Ames St.
Cambridge, Mass. 02139 USA
kumpf@media.mit.edu

Alejandro Vazquez
MIT
471 Memorial Dr.
Cambridge, Mass. 02139 USA
mc2@mit.edu

Hiroshi Ishii
MIT Media Lab
20 Ames St.
Cambridge, Mass. 02139 USA
ishii@media.mit.edu

Abstract

The value of tangibility for ubiquitous computing is in its simplicity–when faced with the question of how to grasp a digital object, why not just pick it up? But this is problematic; digital media is powerful due to its extreme mutability and is therefore resistant to the constraints of static physical form. We present Slurp, a tangible interface for locative media interactions in a ubiquitous computing environment. Based on the affordances of an eyedropper, Slurp provides haptic and visual feedback while extracting and injecting pointers to digital media between physical objects and displays.

Figure 1. Slurp, a digital eyedropper.

Keywords

Tangible user interface, TUI, ubiquitous computing, locative media, Slurp

ACM Classification Keywords

H.5.2 User Interfaces: Interaction Styles;

Introduction

As ubiquitous computing continues to spread, researchers have looked to the features of the world in which computation takes place in order to inform the creation of new interfaces [12]. Tangible user interface (TUI) [11] has emerged as a powerful concept for blending computation with the real world. Much of this power comes from the use of metaphor [5], affordances [4, 16], physical space [19], and physical syntax [18]. Nevertheless, we have not begun to throw out our laptops and cellphones. The very properties that make tangibles strong also limit them—solid forms embedded in persistent physical space are less mutable than pixel-based displays. Tangibles don't scale well, and although capable of manipulating abstract data [8, 23, 24], the use of indirect mappings reduces the benefit of physicalization, as shown in [5].

GUIs are strong where TUIs are weak. They scale well, they are great for manipulating abstract data, and they have high plasticity (capable of doing very different tasks through the same interface). How can we get the benefits of both paradigms in a seamless interaction design?

In this paper we present Slurp, a tangible interface for interactions with locative media, and discuss the design issues that arise when attempting to physicalize abstract digital information. Based on the affordances

Figure 2. Slurp, held for use. The bulb is full of data.

of an eyedropper, Slurp provides haptic and visual feedback to extract digital media from physical objects in everyday environments. Once extracted, media can be injected into displays such as computer monitors or speakers. Our goal is to explore a novel interaction technique for the future of ubiquitous computing and reflect on the ideas and challenges encountered along the way.

Locative Media Now and in the Future

As computation spreads further into the real world one can envision a future where every physical object is created with a digital object attached to it. For example, it would be nice to have a spec sheet for the light bulb you just bought incorporated directly into the light bulb itself, or to have media files showing the history of an antique couch come embedded in the couch rather than on external media. These media files could be modified or added on to; in the couch example the new owners could add their own experiences to the

couch's history. The information stored in the physical object could be a simple url, allowing for the participatory culture of the current Internet to extend into physical space and objects.

Currently RFID tagging can be used to achieve the above scenarios, but in the future other technologies may become more prevalent. Regardless of the technical details for how digital information will pervade the physical world we will have to develop new ways to interact with it. Imagine that every physical object in your living room is a container for digital information and you want to access the digital object attached to a mug on your table. One could quickly imagine a couple of ways to use a GUI for this task. A combobox or other list generating widget would work, but there could be hundreds of items in the list, or more, and if there were a few mugs on the table it might be difficult to know which list item corresponds to the correct mug. Another method would be to use a graphical map of the room and its contents with all of the physical objects correctly identified and located by the computer, this is an interesting possibility though it has some drawbacks.

Before detailing the issues with the second case imagine a third alternative, rather than using a GUI the user just points to the mug, loading the embedded digital media onto a nearby computer. This third option makes use of the existing spatial relationships that human beings are well suited to understand, and points to some of the problems with the graphical map solution. Even if the map were implemented perfectly the user would have to resolve the translation from 3D physical space to graphical space, relying on a virtual target that is not coincident with the physical object in

question—the mug. It is not too difficult to imagine using the graphical mapping interface, and in some cases it may be preferable, but why not go to the source when it's right in front of you?

Tangible Interfaces and Abstract Digital Media
A central question in this work is how to use physical affordances, metaphor, and spatiality to bridge the intermediary space between the graphical world and the physical world. This is not a new question. Ishii and Ullmer asked it when they presented their vision of Tangible Bits [11], as have many researchers since then. Terrenghi's work examining the affordances of gesture-based direct manipulation [21] points to relevant differences between interaction with the physical word and graphical displays. The widgets common to GUI desktop environments are not necessarily suitable for extension into physical space, nor are the metaphors that they rely on.

The use of metaphor in human-computer interaction (HCI) has been widely noted by researchers [2, 4, 5, 12, 16]. Functioning as something more than a literary trope, the use of metaphor in HCI is problematic—"Novel metaphorical UIs, despite their popularity, have seldom been natural or intuitive" [2]. When a designer employs metaphor to create an interface based on existing interactions, a third thing is born. The use of metaphor in HCI, though not necessarily intuitive, can serve to inform users by building on existing schemas (collections of generic properties of a concept or category) making "it easier for you to learn a new concept by tying it to a concept that you already know" [7].

Liquid Metaphor

The digital objects that we use on a day-to-day basis must be manipulated indirectly with specialized tools and, in practice, can never be touched. Humans have many sensory channels for interpreting the world; however, due to practical constraints GUIs have remained the dominant interaction technique. In confronting the problems of how to touch digital media we must chose methods to physicalize that media, this is particularly challenging when considering abstract digital objects. Haptics has proven an exciting field for this end [20] as has the use of tangible interaction and physical metaphor. One approach is to treat abstract digital media as water. Water, like some digital objects, is difficult to manipulate with bare hands. We can splash it around, but we need specialized tools to perform precise operations with it.

Abstract Digital Media

It has been easier to physicalize certain types of digital media in tangible interface design than others. Digital objects with spatial properties (such as building models in CAD software [25], molecules [6], or geographic maps [1]) lend themselves to physical form. Abstract digital media is difficult to embody tangibly and is therefore usually confined to screen-based interaction techniques, such as GUIs. More abstract digital objects (such as music, video, text, or data sets) can benefit from association with physical form through the use of *containers* and *tools* as defined in [8]. In the musicBottles interface [10], glass bottles are used to *contain* sound, in one scenario three bottles are used, each linked to a musician in a three-piece jazz ensemble. Open one bottle and you hear the drummer, open another and the pianist joins in. In the Tangible

Query Interface [24] wheels, pads, and racks are used as *tools* for parametric viewing of a data set.

A problem with physical interface treatments of abstract digital information is that the mappings between digital and physical objects lack the tight coupling and affordances found in the use of *phicons* or *tokens* [11]. We have tried to mitigate this issue by using haptic feedback in an active tool (Slurp) that treats abstract digital media like a fluid that can be slurped up and squirted out. Our approach is to embody abstract digital media in physical form, in the hopes of providing difficult-to-quantify benefits for users, such as enhanced feelings of ownership, improvisational support, and changes in user relationships with, and planning of, interactions. Some of these benefits have been studied already [22], and although not attempted here, we feel there is much value in future studies.
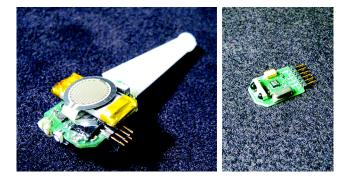
Related Work

David Merrill's invisible media project [12] does something very similar to the example mentioned earlier, where the user is gesturing at a mug. He used IR beacons, headsets, and pointing devices to enable users to access digital media that is associated with physical objects by pointing or gazing. There are a number of related projects that use RFID, graphical symbols, or other addresses to link to digital information [3, 26]. These systems allow users to access digital information from tags using cell phones or custom hardware such as Merrill's headset which plays audio content related to the object targeted.

There are other systems that allow the user to choose both the input and output for their media, such as

mediaBlocks [23] and Pick-and-drop [17]. In mediaBlocks small wooden blocks are associated with digital media and are used for transferring images or video from one device to another, or sequence slides in an editor. Users of Pick-and-drop can move files between touchscreen displays by tapping them with a stylus; this transfers the file across the network. TOOL DEVICE [9] is similar to Pick-and-drop in that they are used to move songs and other media files between touchscreens, they differ by providing local haptic feedback and using the affordances of a syringe, chopsticks, and a ladle.

Slurp

Slurp differs from existing work in a few ways. Slurp allows for the extraction of digital media from physical objects and the selection of an appropriate display device to access it from. It contains the digital information rather than working as a physicalized hyperlink. Slurp also provides local haptic and visual feedback removing the need for visible tags on accessible physical objects.[1]

Slurp combines the properties of *containers* and *tools* for manipulating digital objects. There are two parts to the system: Slurp (digital eyedropper) and the IR nodes [Figure 3]. Users hold Slurp in one hand with its bulb between the thumb and forefinger. They can *extract* (slurp up) media by touching Slurp to a screen, pointing it at a remote display or object and squeezing Slurp's bulb as if the user were sucking up a volume of water. After a digital object has been acquired by Slurp

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[1] Until digital augmentation of physical objects reaches a critical mass it is helpful to have visible cues as to what is accessible so one doesn't have to search around blindly.

Figure 3. Left: Slurp hardware before cast in silicone. Right: Infra red communications node (IR node).

via the extraction process users can *inject* (squirt out) the digital object by touching Slurp to a screen or pointing it at a remote display and again squeezing Slurp's bulb. A small pointer is passed between Slurp and the IR node; the related files are transferred in the background over the network.

Slurp, A Digital Eyedropper
Slurp has two parts, a stem and a bulb. The stem houses a tri-color LED to represent the state of targeted displays. The bulb contains the printed circuit board and batteries to run Slurp, a force sensitive resistor (FSR) to measure the pressure of squeezes, a vibrotactile actuator for haptic feedback, and a tri-color LED to represent digital objects extracted by Slurp. The physically rigid hardware (PCB, sensor, etc.) is fully encapsulated in a soft silicone rubber to afford squeezing and to mimic the experience of using a standard eyedropper with a rubber bulb.

IR Nodes
The IR nodes use infrared data communication (IrDA) to act as gateways between Slurp and the objects or devices with which it communicates. Each IR node is attached to an object or display (visual, auditory, or other) powered by a PC. Less expensive, self-contained IR nodes running from a microcontroller are also possible and could be attached to computationally passive unidirectional objects such as buildings, artwork, or trees for locative-media interactions.

Multisensory Feedback
The vibrotactile actuator is used to generate a *haptic narrative* that provides feedback on Slurp's state and mirrors targeted objects. Users can seek out digital signals in a given space; this interaction is similar to the beeping of a metal detector or the sounds from a Geiger counter to indicate the presence of objects invisible to the user. Once a digital object has been targeted, Slurp displays different feedback for discrete or continuous objects. Discrete objects generate a short burst of vibration and a static color in the stem. Continuous objects (such as video media) generate continuous feedback to mirror their current state. For a video playing on the screen, the color of each frame is averaged to a single pixel and displayed in Slurp's stem while the audio amplitude is converted to vibrations in the bulb. For playing audio objects (like a song on the radio) only continuous vibration feedback is generated in Slurp, the stem displays a static color.

When Slurp is empty and pointed towards an IR node Slurp's stem illuminates and mirrors the color of the target object in the same way that the stem of an eyedropper takes on the color of the liquid it is placed in. During extraction light moves from the stem to the bulb, staying in the bulb until injected. The silicone bulb acts as a diffuser for the LED; the light appears to fill the bulb. After informally testing Slurp with users we added a subtle flashing light in the stem for extra feedback, when Slurp is full and aimed at an IR node, the stem lights quiver as if the liquid inside is bubbling to get out. During injection, light moves from the bulb to the stem and then fades out. When Slurp is full, soft presses on the bulb injects the data object while retaining it in the bulb (which remains lit) for further injections. Hard presses inject and clear the data. This feedback is directly based on the use of an eyedropper; when it's full small presses release only some of the fluid.

Locative Media
As computers become more pervasive through the physical world, the spatial relationships between computational devices gain importance. Interfaces that make use of spatial relationships can reduce the ambiguity associated with navigating multiple devices through common GUI widgets.

Part of location-based or locative media is linking digital objects to locations in the physical world. This is often accomplished using cameraphones and 2D barcodes or text messaging. The barcodes act as pointers to locations on the web or a type of physical hyperlink. In the future (and perhaps in the present) rich media will be linked to all types of physical objects, locations, and people. Slurp can be used to aggregate these digital objects.

We attached IR nodes to objects in our lab space. Since the nodes project IR out into space the user can wave Slurp around and point it at various objects to remotely identify where digital objects are present in a physical version of exploratory search [27]. When Slurp is pointed at an object that is digitally active, in this case an image from a music video, Slurp reacts similarly to the previous scenario, by vibrating and lighting up. Then the user can extract the object and inject it into a container for later. This container could be a watch or cellphone with extended features for immediate viewing, but as proof-of-concept we used a PC.

Smart-Office
In developing Slurp we realized it could also be used similarly to a USB drive or Pick-and-drop [17] for moving files directly from one screen to another. In the smart-office scenario it is common for workers to use digital whiteboards, large shared displays, PDAs, smartphones, laptops, PCs, and audio systems collaboratively and concurrently. The problem of how to move and share data objects across these displays has been well studied [15, 17]. In a detailed study comparing techniques for multi-display reaching by Nacenta et al. [15] the authors found that systems with local feedback, 1-to-1 mapping between digital and

Figure 4. Slurp extracting a digital object from a sculpture.

Figure 5. Slurp injecting a digital object onto a screen.

physical space, accuracy, and remote operation were preferable to other systems.

We set up two desktop PCs and an audio system with IR nodes. We tested Slurp by moving video, audio, and files between the displays. A touchscreen display would be able to identify the position of Slurp against its screen, but since we didn't have any we simulated touchscreens by using the mouse and moving it to match Slurp's position. This allowed us to get a sense of screen-to-screen operations. By using Slurp's IR channel to tell the computer when to extract and inject the files along with the mouse position we could grab files directly off of one screen and deposit them onto the other. To provide graphical feedback we built a desktop in Adobe Flash. We created icon animations for extraction and injection of files as an additional notification of the system's state. These animations also enhanced the feeling that Slurp was pulling something out of the screen or depositing it into the screen, rather than just triggering a file transfer in the background.

In addition Slurp can work remotely with playing video and audio (in this case these media types filled the screen) by pointing in the direction of a display. Notably, Slurp works with non-visual displays (in this case speakers), a feature not implemented on many other multi-display reaching systems.

GUI—TUI Blending
A logical next step for Slurp would be to add it to existing tangible interfaces. Siftables [14] is a tangible sensor network platform based on multiple, small graphical displays. By adding Slurp to the Siftables system users could navigate large libraries of video media on a GUI and extract them directly from the monitor. Slurp could be used to move video between devices, leveraging the scalability of GUIs and the spatial, tangible properties of Siftables. We could also add Slurp to musicBottles, extending its capabilities in a similar fashion. We are currently exploring these options for future work.

Discussion
We presented Slurp at our lab's open house. Around 50 people used it informally during the 2-day event. Through this qualitative demonstration we received numerous suggestions and critiques. One user wasn't sure why someone would want a separate device just for accessing digital information from physical objects; he wondered why it wasn't part of a cell phone. It seems reasonable to think of adding similar functionality to a cell phone or camera, though there would be tradeoffs in doing so. Special purpose, limited-functionality devices have compelling benefits over convergence devices, but they can be less practical.

One could use a gestural interface, cell phone, or camera for locative media, though the presence of a single purpose, tangible tool simplifies the interaction. In Zhang, Fishbach, and Kruglanski's recent paper about multi-purpose devices [28] they showed that a pen that also functioned as a laser pointer was less likely to be used by participants than a pen that was just a pen. By adding additional functionality to a device it adds confusion. Gestural interaction requires remembering which gesture is used for which action, and the possibility of other gestures could confuse the user. The same could be said for multi-touch displays. Simple physical devices may be preferable to multi-

featured interfaces in an age of complex interactions. Rather than add additional functionality to Slurp, such as the ability to store multiple files, we feel that creating richer and clearer feedback would be the preferred next step.

Some users questioned the use of a liquid metaphor as the basis for Slurp's interaction design. The use of a liquid metaphor cannot account for all of the functionality found in the digital world. For instance, liquids are difficult to separate once mixed. On the other hand some users found the liquid metaphor to be magical, and gasped as Slurp spit out files directly onto a monitor. We have used the metaphorical or analogical use of liquid as a point of departure for touching abstract media; in practical use design tradeoffs must be made. Basing an interaction on existing physical models will always be problematic if the interface doesn't function exactly in the same way as its model. Nevertheless, as show in the recent work on Reality-Based Interaction [12], when thoughtfully applied, reliance on existing skills and knowledge in an interface design can provide benefit for users.

Conclusion
Digital objects come in many shapes, sizes, formats, packages, and levels of complexity; it is this very dynamism that makes digital technology so compelling. Abstract digital media resists being captured by physical form for good reason—the constraints of static physicality could overly constrict such media's use.

In this paper we have presented Slurp as an approach towards physicalizing abstract digital media. We did not design Slurp to be a more efficient method of accessing information then existing systems (although in a future where digital media is far more pervasive it may be very efficient). Our goal was to explore a novel interaction technique through prototyping, use, and reflection in order to better understand some of the current issues in tangible interface design.

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