Embodied Data Objects: Tangible Interfaces to Information Appliances

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ABSTRACT

This paper describes the idea of embodied data objects. Using this concept, everyday objects can be used to represent bits and bytes of active information. These data objects can be used to interact with information-appliance-like devices that provide specific services as dictated by the context of interaction. The inherent affordances of physical artifacts are leveraged to make the interaction with these service-oriented devices intuitive and natural. We describe the idea of embodied data objects, followed by the design and implementation of two such service-oriented devices: a presentation projector and a printer.

Categories and Subject Descriptors

H5.m. [**Information interfaces and presentation (e.g., HCI)**]: Miscellaneous.

General Terms

Design, Human Factors, Theory.

Keywords

Tangible Interfaces, Interaction Design, Embodied Interaction.

1. INTRODUCTION

Even though the age of the personal computer has brought computation closer to people, most users still stumble and struggle while trying to use computing devices [5]. Although computer interfaces have gone a long way toward trying to speak the user's language, they have only recently begun to break out of the rectangular frame of the display.

On the other hand, we see that everyday appliances have proven to be far less frustrating for non-expert users. Although most appliances are significantly less complex than computers, we believe that part of the reason for this difference in experience is because of the mental disconnect users face when dealing with abstract data on a computer.

One way to reduce user frustration, we believe, is by exploiting the familiarity users have with everyday objects, and in doing so, make their interaction with computers more natural and intuitive. Influenced by the idea of information appliances [6], we set out to create a family of computing devices that behave like any other ones we use in everyday life (e.g. toasters, television sets, etc.).

If these devices are one side of the story, the other side is the representation of data in physical form. In light of recent theories on embodiment and embodied interaction [2], we chose to design our data objects as embodied tangible representations of abstract computer data (e.g. presentation files, text documents, etc.). We call this *active information* – information that knows what to do with itself in certain physical contexts.

Bringing these ideas about information appliances and embodied representations for data together, our system lets users perform tasks such as printing and displaying presentations in a natural and intuitive way by simply placing a data object in a designated area on a printer device or projector device. Placing a data object on a device that can process it expresses intentionality on part of the user. The specific intention varies from one device to another – indeed, the information conducts an implicit dialog with the device which dictates the possibilities of use.

Radio Frequency Identification (RFID) technology is used to sense proximity and initiate appropriate action based on the unique identifier of the RFID tag which represents abstract computer data files. In the case of our two such service-oriented prototypes, the user's intention may be either to print a document, or to show a presentation, depending on whether we approach a printer or a projector. Our system captures this expression of intentionality to perform the intended action automatically, with minimal extraneous dialog between the user and the device.

2. RELATED WORK

The idea of bringing computation closer to the user and away from the computer has been around since the 1960s, when the first graphical environment was born. Since then, researchers have striven to develop interfaces that exploit humans' familiarity with the real world (through metaphors). More recently, considerable work has been done on Tangible Media at MIT by Hiroshi Ishii's Tangible Media Group [3, 9]. Ullmer and Ishii describe the Tangible User Interface, a platform that not only maps the user interface concepts into the physical world by providing graspable objects corresponding to GUI controls, but also exploits physical-space interaction beyond the GUI paradigm [9].

The theory of embodied interaction proposed by Dourish explains how interaction of humans with either tangible artifacts or with other people in a social setting is influenced by, and shaped by, the response received from the other end. To quote him, “designers of interactive systems have come to understand that interaction is intimately connected with the setting in which it occurs” [2]. We have not only created an active representation of data as a physical object, but also allow the attributes of this data to be manipulated via its physical representation. In a sense, our data objects embody the data itself and “contain” active information since the object may be used for interacting with information appliances.

Norman first suggested that the focus of computation should not be towards a physically-identifiable computer that occupies a desk, but towards a multitude of ‘information appliances’ each performing a very specialized function [6]. In our scenarios, we consider the printer, the projector and other such devices as appliances performing a specialized service for the user, which makes interacting with them as simple as walking up to everyday appliances such as television sets or toasters.

All of this brings us closer to Mark Weiser’s vision of ubiquitous computing [11] – embedding computation all around the user in an environment, such that it becomes virtually invisible, in that we stop noticing that we are, in fact, consumers of computing services. We should be able to use computing devices by interacting with them just like how we would with a physical artifact.

The idea of natural interaction with ubiquitous information appliances is the unifying thread behind all these related schools of thought – using computation without realizing that you are using it. What Weiser describes as doing to computation, we describe doing to data: we aim to place data everywhere in the environment and build a family of devices that know how to interact with this active information. This proliferation of data would also follow the principle of “being a calm technology”, in that, it would not require active thinking on part of the user to make it work: putting a data object on a printer to print, putting a data object on projector to give a presentation, just like one puts bread in a toaster to toast it.

Previous projects such as Durrell Bishop’s Marble Answering Machine and Natalie Jeremijenko’s LiveWire have influenced our thoughts about physical interfaces to data. The Marble Answering Machine represents voice messages as individual marbles, and supports such interactions as deleting, re-ordering, or delaying messages by simply re-ordering the marbles or placing them in a cup to instruct the machine to play the message corresponding to it.

In the past, other researchers have experimented with tagging physical objects. One such work used RFID tags to initiate actions such as navigating to web pages or loading certain applications [10]. A major drawback of this approach (that was also observed by others [7]) was that it failed to provide cues about the action associated with a particular tag until such action had been initiated. They mention an example where a book could be tagged with links to online reviews, booksellers, author's homepage, or any other website, thus making it difficult for the user to set her expectations before the tag is actually scanned. A second shortcoming was the dual role that the object performed: in the context of the system, objects initiated certain actions, whereas otherwise, they took on their natural roles.

An idea proposed by Barrett et al referred to such objects as 'Informative Things', and proposed using them as virtual floppy disks for ad-hoc file sharing [1]. Another such endeavor used tags for transferring digital data in a physical environment, but did not explore applications such as the role of tags in building information appliances [8]. Our design promotes a more solid view of embodiment (including actions other than simply copying passive data) and provides a visible interface to such data by means of appliances.

Perhaps the work that comes closest to ours is the Satchel system by Lamming et al. [4]. In their work, Lamming et al. have solved the partial problem of providing access to documents when one is away from one's desk. Our system is similar to Satchel in terms of the document appliance paradigm that they explored. Their system shares infrastructural features with our system; like theirs, we also use tokens to represent documents. However, their principal goal in designing the system was to provide access to documents remotely – exploring the interaction issues in this process was only a secondary concern. We share their goal of making universal document access easy and secure; we also have the additional goal of making the information contained in those documents, an active entity.

In Satchel, the information exists as logical tokens represented by labels and buttons in a Windows, Icons, Menus, and Pointing user interface (WIMP UI) on a Nokia Communicator (a personal portable device). This, therefore, requires the user to navigate through a PDA user interface to find the right token that represents the document to be printed and then “beam” it to a printer to print it. This introduces a level of complexity and the need for users to have a PDA. In our system, the physical implementation of these logical tokens is completely different. We represent the tokens as physical objects with individual shape and form embedded with inexpensive and reusable RFID tags. The information represented by each of these can be manipulated using our data manipulation devices. When these tokens are within the scope of an information appliance, they become active and "know" what they can do and are expected to do in that particular context. Instead of clicking on the appropriate interface elements or pushing the right buttons, the users of our system can simply walk up to a printer, place their token on a designated area, and press a single "Print" button. It is much like toasting sliced bread in an electronic toaster.

3. PROBLEM STATEMENT

For humans, handling of digital information is not transparent – the technology almost always gets in the way of performing the task [5]. An important observation during our investigation was that users struggled to carry their data with them in various incompatible formats that resulted in their data being tied down to a particular platform.

All the users we surveyed occupied the Computer Science building (but were not necessarily computer science majors) in our university. Almost everyone replied that although the building had an adequate infrastructure of computing platforms and peripherals, they lacked confidence that their data could be accessed flawlessly on any of the available devices. Sometimes, because of the unreliability or uncertainty of the available computing platforms, professors opted instead to carry their own laptop computers and projectors with known-good configurations (despite each lecture hall being equipped with adequate presentation hardware). Others often memorized arbitrary list of actions that need to be taken to get a particular configuration to work (“First set the laptop resolution to 1024x768, then connect the projector, then switch on the projector, and restart the laptop”). This inherent arbitrariness in interacting with computation devices is not only cumbersome, but also error-prone. For example, one professor in our department who we interviewed mentioned that connecting an Apple PowerBook laptop computer to a projector required a specific converter cable (Mini-DVI to SVGA) that was often forgotten or lost. This often resulted in a ten minute trek back to his office to fetch it.

3.1 Design Goals

Our investigation into the numerous problems people faced in our university while interacting with everyday computation devices such as printers and projectors motivated us to design a system that better supports a dynamic usage setting like a university and instills confidence in users. Another related issue was that current generation computing devices require unnecessary, and sometimes unintuitive, actions to set them up to work correctly. We identified that the general-purpose nature of computers contributed to this problem at least to some extent. Therefore we attempted to move away from the one-computer-does-everything paradigm to a service-oriented information appliance paradigm.

To clarify our design goals for this project, we present a short example of an appliance that is used daily by a lot of us: the pop-up toaster. The design of a toaster is self-descriptive: it shapes our interaction with itself by its form and the affordances it provides. We see slots that beckon us to put slices of bread into them and a handle that asks to be pulled down to initiate the toasting process. It performs exactly one function, and makes it extremely easy for even a novice user to operate. No instruction manual or warning stickers are needed; (burnt toast is, however, an unfortunate accident that occurs often).

3.1.1 User Interaction Goals

Users should be able to engage in easy and natural interaction with their data without being shackled by implementation trivialities such as file formats and operating systems. Solid and concrete pieces of embodied information should have a physical form that clearly directs people (by its appearance and affordances) to a natural style of interaction. All operations with active information in such a physical form – creation, modification, duplication, destruction – must be executed via physical manipulation of the objects themselves. Rehman et al [7] observed that invisible interfaces sometimes present unique difficulties for the user in forming a valid mental model. Our system addresses this concern elegantly because the system utilizes users' familiarity with everyday appliances. We set forth not only to develop devices to make ordinary interaction easier, but to document a framework that can be used to design an entire class of such devices. We believe that the best overall experience can only be achieved when such a paradigm is prevalent across device classes, not restricted to just a few peripherals.

3.1.2 Technological Goals

The technology should be resistant to noise and interference and, at the same time, not require high-precision actions from a user. Hence, an object that carries information should be able to interact with a reading/writing device from a short distance, but without necessarily direct physical contact. Data objects must be easily portable and must withstand the rigors of daily life. Users should be able to store data on them reliably and without fearing data loss.

4. SYSTEM DESCRIPTION

4.1 Usage Setting

This project serves the needs of people in organizations that have a large number of computers and peripheral devices for public use. Examples include universities, convention centers, libraries, Internet cafes, etc. The end users would be faculty members and students at universities, employees at work places and offices, and general population that accesses peripheral devices at these public places.

4.2 Usage Scenarios and the Role of Each Component

To demonstrate the use of one of our prototypes, consider the following scenario describing how a user can use a projector service device.

Jane is a graduate student in the Computer Science department at Lane University. She has been working on a desktop computer in her office and just finished creating a presentation on her latest research project. She is due to give a talk the next day in the department conference hall. She saves her presentation file and decides to find her advisor Prof. Smith to get some feedback. She right-clicks on the file which opens a context menu and selects the option “Embody this” (Figure 1). She is prompted to place an Embodied Data Object on the cup next to her computer. She picks a 1x1 inch photo frame cardboard cutout (to signify a presentation file) from a pile of various types of embodied data objects on her desk and places it in the special cup next to her desktop. She hears a beep and sees a dialog confirming the embodiment. She picks up the data object and goes looking for her advisor.

In the hallway, she runs into Tom, a fellow graduate student and collaborator. Jane informs him that she has just finished creating the presentation and Tom is excited. He asks her if he can see it. They both walk to Tom’s lab down the hall. Walking up to a printer (print service provider), they place the data object on a receptacle provided for this purpose. The RFID reader senses the tag, and reads the ID information from the tag, which refers to a uniform resource identifier (URI) of the file to be printed, in this case a MS PowerPoint presentation file. A file transfer module is invoked to fetch the file from a remote Infrastructure Server to the local device and an appropriate application is invoked to render the file and print it as a handout.

Jane and Tom look at the printout and discuss the points that need to be stressed in the talk. They both walk to Prof. Smith’s office and together the three of them go to the conference room for a rehearsal. Walking up to the projector (projection service provider) they place the data object on a receptacle provided for this purpose. Using the same process described above, the file is fetched and invoking the appropriate presentation software (MS

PowerPoint in this case), the file is projected onto the screen. After the talk, Jane removes the embodied data object and the system automatically shuts down, waiting for another data object to come into its proximity.

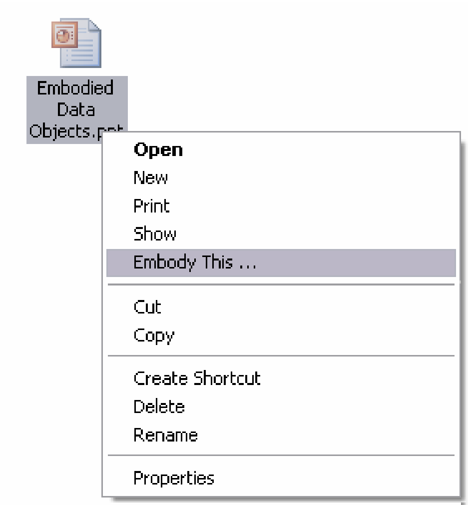

Figure 1: Embodying a presentation via the context menu on a desktop computer.

5. SYSTEM ARCHITECTURE

At an architectural level, there are three main parts to our system: service-oriented devices, data manipulation devices, and a network of infrastructure servers (Figure 2).

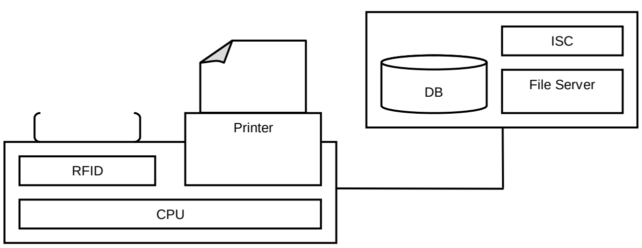

Figure 2: System Architecture Overview

5.1 Service Oriented Devices

Compared to its counterpart ordinary device, a service-oriented device has two more subsystems: a CPU and an RFID reader. When the RFID reader senses a data object in its vicinity (which is really an RFID tag), the device connects to an Infrastructure Server to request meta-information about the associated data. If it is equipped to provide a service for that particular type of data, it fetches data and proceeds to accomplish the task it was designed for.

There is an important distinction between types of functions and data formats: although a service-oriented device is built for a specific task, it is not restricted to a single type of information. A printer must be able to print various file formats such as documents, presentations, web-pages, filled forms, pictures, photographs, etc. A projector must be able to display presentations, slideshows of static images, or even movies (if the proper audio capability is also available).

In effect, we moved the burden of determining the right file format, hardware requirements, and other extraneous requirements such as connectors, device drivers, etc. from the user to the service providing device. In other words, each of these devices provides one service only, but that one service in a seamless and natural way.

5.2 Data Manipulation Devices

A data manipulation device consists internally of an RFID reader that can modify the data stored on a data object. Common operations involve copying a file onto the object, deleting a file, or packaging it for later retrieval. Copying is accomplished with the help of two sensitive surfaces: by placing the source object on the reader and a blank object on the writer, a copy of the source will be made onto the target with a single button press. Data can be introduced onto an object by dragging and dropping it onto a digital representation (i.e. a window) of the object on screen.

5.3 Infrastructure Servers

Service-oriented devices and data manipulation devices talk to a network of Infrastructure Servers. An Infrastructure Server is a decentralized repository of data – since the capacity of each individual tag is limited to a few bytes, the tag serves as an index into this larger database where the contents of the files are actually stored. We loosely follow the architecture employed by the Internet: each tag's address consists of two parts, an identifier for a network server, and an identifier for a data item on that server. An Inter-Server Communication Module forms part of the Infrastructure Server and manages the co-ordination and file transfer between individual servers.

Figure 3: A photograph showing the construction of our embodied printer device.

6. IMPLEMENTATION NOTES

Based on the system architecture described above, we implemented two working prototypes: a printing service and a projection service (Figure 3). The two prototypes shared the underlying framework consisting of a hidden laptop computer and RFID reader, which is consistent with our design goal of building a toolkit to make the design of such appliances easier. We used Texas Instruments' S-6350 (mid-range) RFID readers operating at 13.56 MHz which communicate with the host machine via a serial (RS-232) interface. We wrote an application-independent driver for the RFID reader to translate between high-level calls to read and write IDs and the actual bits on the wire. Whenever an ID was read, it raised an interrupt which was handled by the next higher layer, which was specific to our embodied devices.

Communication between the embodied devices and infrastructure servers was carried out via SOAP requests over HTTP. Files maintained on the server were delivered to clients via plain HTTP, so that such requests would not encounter trouble traversing firewalls.

6.1 Form Factor of Data Objects

In order to maximize the coupling between a physical artifact and its digital representation in the user's mind, we embedded tags in various shapes, such as a postage-stamp-sized cutouts, slides that were really old 35mm transparencies, and iconic representations of pictures such as a leaf (for nature photos) and a circular shape painted as a football (for photos of a recent football game). Other possibilities include business cards (with embedded digital contact information), a floppy-disk shaped piece (which can contain arbitrary data items). Eventually, users will be able to design their own personalized data objects by simply printing their choices and sticking them to a bare tag.

6.2 Choices of Sensing Technology

From a vast array of choices of technology such as bar-coded paper strips, magnetic stripe cards & readers, Bluetooth, and RFID-based systems we chose RFID for the purpose of this project.

Although barcodes encode (limited) information on physical artifacts easily and cheaply, duplication is too easy, giving rise to questions such as cloning, erasing or overwriting information. The delicate nature of paper and its susceptibility to environmental factors was a matter of concern in terms of reliability. Magnetic stripe technology was not viable because of the physical size requirement of the card itself. Bluetooth, with its short range and ad-hoc connection capabilities, appeared interesting, however the need for the embodied data artifacts to be actively powered all the time placed unreasonable demands on power requirements.

Using RFID (Radio Frequency Identification), data can be read over short distances, passive RFID tags do not require external power, and tags can be reprogrammed numerous times. The form factor of RFID tags is also favorable, almost equal to that of a postage stamp in width and height, and as flat as paper. They are also more durable than paper or magnetic stripes. Similarly RFID readers are also available in various form factors: interfacing with either PCs or handheld computing devices such as Personal Digital Assistants (PDAs).

6.3 System Constraints and Issues Encountered

6.3.1 Time delay

Since the file is not stored locally on a device, a delay occurs while the file is fetched from the nearest Infrastructure Server (IS) to the service-oriented device. If a file cannot be located on the nearest IS, the Inter-Server Communication (ISC) module needs to contact a remote IS to obtain the file. This exacerbates the effect of a delay.

6.3.2 Unintentional interaction due to proximity

Since the two service-oriented devices we built are in a prototype stage, we were not able to provide interaction controls on these devices. Currently any embodied data object (RFID tag) that comes into the immediate proximity of these devices (about 12 inches) is recognized and the associated data is processed for the corresponding service. This creates issues when an object is brought near a device unintentionally (for example, when a person with a data object embodying a text document walks by a print service provider, the document starts printing). Our future versions of this device will have interaction controls on the devices to address these issues.

7. CONTRIBUTIONS AND DISCUSSION

The primary contributions of our work include:

- Providing the user with the ability to embody computer data into real-world physical tokens or objects. This approach leverages the human ability to understand and process spatial and physical objects naturally, with minimal cognitive load.
- We have attempted to hide the complexity of devices, hardware and software applications from the user by incorporating these features into our service-providing appliances. This will help reduce user confusion and frustration as compared to the current standard way of accomplishing the same tasks.
- With information appliances, we have moved away from the one-computer-does-everything paradigm towards a specialized device infrastructure which handles service requests according to the context of interaction.

Neither of these contributions is novel in itself, however, we have successfully integrated them into a novel working system which provides for a calm user interface to everyday tasks such as printing and presenting. We hope that the synergistic integration of such diverse innovations in HCI research will lead to more and more novel designs than the individual application of any of these techniques.

8. EVALUATION

A question that much of the academic community has struggled with involves evaluation of interfaces intended to be used casually. Methods used for desktop interfaces (e.g. cognitive walkthroughs, think-aloud protocols etc.) are not very effective for ubicomp devices simply because the presence of another person sometimes affects the way people interact and the interaction is no longer natural. Instead of short-term laboratory testing, we are currently making the prototypes available to students using a computer lab on campus for about a month.

9. CONCLUSION

In this paper, we describe the idea of using tangible data objects to represent active information that can be used to naturally and intuitively interact with a special class of information-appliance-like devices. We use embodied data objects as physical interfaces to interact with information appliances that are easier and more natural to use than conventional computer peripherals. We describe the design and implementation of two such devices and an architectural framework for creating more such devices with maximum overlap of functionality using a toolkit approach.

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