TouchCounters: Designing Interactive Electronic Labels for Physical Containers

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ABSTRACT
We present TouchCounters, an integrated system of electronic modules, physical storage containers, and shelving surfaces for the support of collaborative physical work. Through physical sensors and local displays, TouchCounters record and display usage history information upon physical storage containers, thus allowing access to this information during the performance of real-world tasks. A distributed communications network allows this data to be exchanged with a server, such that users can access this information from remote locations as well.

Based upon prior work in ubiquitous computing and tangible interfaces, TouchCounters incorporate new techniques, including usage history tracking for physical objects and multi-display visualization. This paper describes the components, interactions, implementation, and conceptual approach of the TouchCounters system.

Keywords
Tangible interfaces, ubiquitous computing, distributed sensing, visualization

INTRODUCTION
For decades, research into computing technology has yielded steady improvements in processing power, network bandwidth and availability, and graphical realism. Despite this, objective measures indicate surprisingly minimal gains in productivity [2]. As we continue to invest in computers for schools, homes, and offices, we must face the question: will information systems really improve our ability to work together in the physical world?

Exchanges between people, information, and physical objects (the basic operations of work) are only partially accessible to digital processing and augmentation [Ken Cooper, personal communication]. While interpersonal communication is increasingly mediated by computers, the hundreds of daily exchanges between people and physical objects are largely unknown and unknowable to information systems. No mechanism exists for tracking the placement, movement, and usage of objects in the typical workplace.

In addition, computing systems are limited in their ability to deliver information in a working environment. Keyboards, mice, and GUI displays tether users to stationary boxes that require close attention to operate. Handheld computers, while mobile, also require direct manipulation that interrupts the flow of work. While these constraints are acceptable for some tasks, they limit the adoption of computer-supported collaboration to highly specialized environments.

Must every working environment be redesigned with computer clusters as focal points of activity? Will wall-sized, handheld, or wearable computers actually improve our ability to work together? In short, what kinds of interfaces will support collaboration in the physical world?

Our direction has been to employ the physical world itself as an interface [9]. By employing things that we can touch—objects, surfaces, and structures—as interface elements, we hope to enable seamless and natural interfacing of physical and digital environments. This vision has motivated the design of various "hybrid" objects that act as containers or controls for digital information, thus providing a means to record and access data through physical interaction.

In this paper, we present our efforts in developing an interface system to support physical-world collaborative work. We named this project "TouchCounters," as in some ways it is a physical analogue to the digital "hit counters" on web pages.

This paper begins with a brief description of our prototype system and the user interactions it supports. We then describe related research efforts and the defining characteristics of our approach. A more detailed discussion of the implementation follows, including reference to the design objectives that informed technical development. We conclude with our plans for further work and a summary of our contribution to HCI.

SYSTEM OVERVIEW: COMPONENTS

The TouchCounters system is comprised of electronic labels, physical storage containers, networked shelving surfaces, and a web server. Together, these components allow information to be gathered from and displayed upon physical objects distributed throughout a working environment.

The electronic labels are palm-sized electronic devices that attach to the front faces of plastic storage containers. The labels display bright, colored patterns on arrays of LED's. Each label module can sense physical motion, as well as the opening and closing of the container.

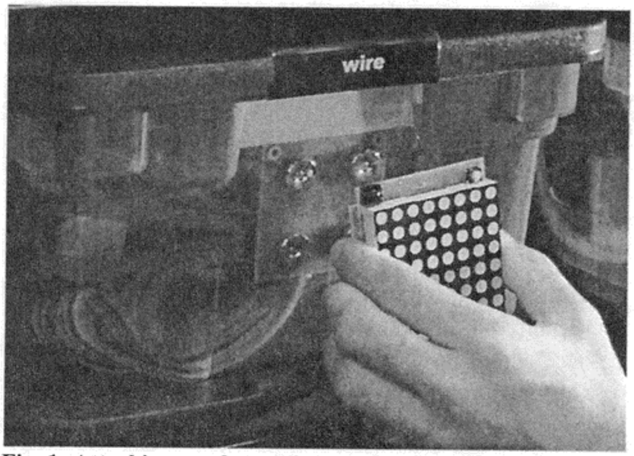

Fig. 1: Attaching an electronic label to a storage container

The containers are transparent plastic storage boxes with electrical connectors that attach instantly to the shelving surfaces. When a container is placed upon the shelf, it links its label to the server through a local data bus. Through this server, data can then be passed to other networks or to the Internet.

Fig. 2: Attaching a storage container to networked shelves

SYSTEM OVERVIEW: INTERACTIONS

We have implemented a variety of interactions using the above system of components. We present these here without discussion of the usage context; an explanation of the design objectives appears in the implementation section.

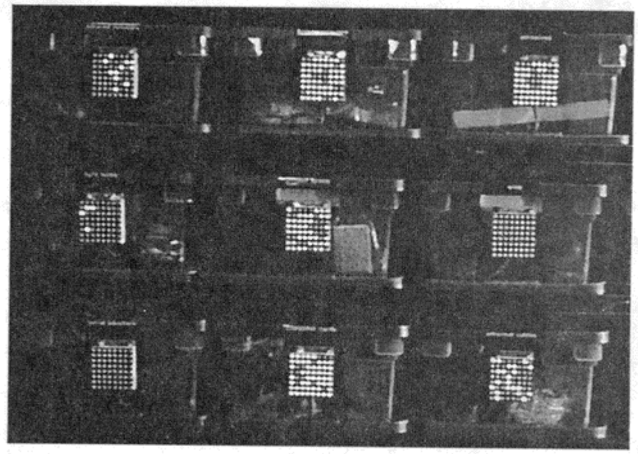

Fig. 3: Usage frequency distribution of multiple containers

Usage frequency visualization

The multiplicity of displays allows the visualization of usage information before even approaching the containers. The label on each box shows a dot pattern that indicates its recent frequency of use. (Each pixel represents a single use of the container during a given period. Just as hit counters display a count of accesses to a web page, these devices display a "count" of physical accesses. This led to the name "TouchCounters.")

When the entire set of containers is viewed from across a room, the aggregated independent displays comprise a spatial map of usage frequency. As one might expect, a small fraction of the containers are subject to much heavier use than the average; these "hot spots" can be used as starting points when searching for a commonly used item. In addition, the relative counts can be used to facilitate the manual task of optimizing box placement. For example, the most active ones can be placed at hand- or eye-level.

Usage correlation visualization

Frequently, *combinations* of particular boxes are used to accomplish a given task. Through analysis of the record of box accesses, the system determines the degree of usage correlation between all possible pairs of boxes. Once a single container is accessed, all of the others display patterns indicating their correlation to the first.

In this way, the search for a related item can often be accelerated by looking at the brightest displays in the area. This information can also be used to improve container placement, as paired boxes can be placed near each other.

Fig. 4: Correlation of usage of multiple containers (relative to container that has been removed)

Object labeling

In addition to displaying automatically recorded data, the system allows users to explicitly annotate the boxes with simple label information. By pointing an infrared remote control at the boxes, users can attach "glyphs" that indicate a common association between several containers.

Like the file "labeling" feature of the Macintosh ™ OS, these glyphs are generic symbols that can be associated with any categorization scheme desired by the user. For example, users indicate that certain boxes belong to a certain user to are related to a certain project. Alternately, a group of users could agree upon certain symbols as indications of the state of completion of a various prototypes.

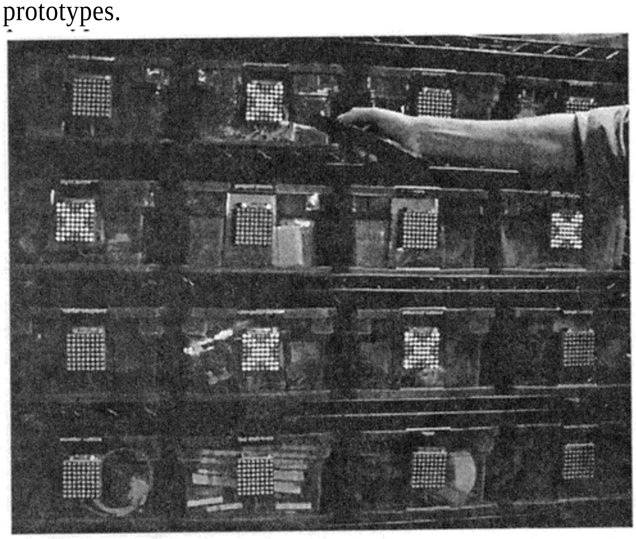

Fig. 5: Labeling multiple containers with an infrared remote control

Remote browsing

Finally, users can view and modify the entire system remotely. Since data from each label is transmitted to a server, the state of each label can be displayed through a Java-enabled browser. As a demonstration of the bidirectional interaction, users can also click on these web-based images; this triggers changes to the physical displays. In the future, this capability will allow physical object-based messaging and notification that integrates with traditional PC environments.

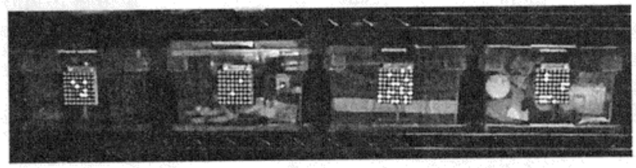

Fig. 6: Physical containers displaying frequency-of-use data.

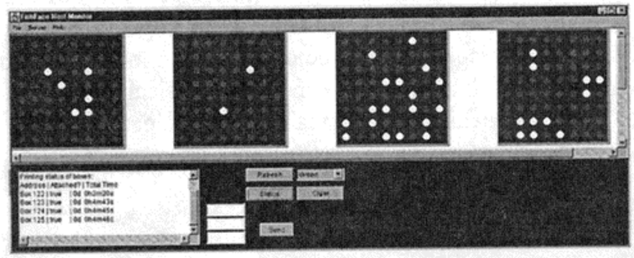

Fig. 7: Java applet displaying identical information on a web page

CONCEPTUAL APPROACH

We next consider the conceptual approach we employed applicable to the design of various physical interface devices. Here, we describe several significant elements of this approach.

First is the binding of *digital attributes with physical containers.* Containers are a means for categorizing physical objects, just as "folders" are a means for categorizing files. Placing a group of items in a box is thus akin to attaching a common attribute to each item. By recognizing the container (and not the individual items contained) as the unit of interest, we were able to link additional attribute information with an existing physical classification system. No modification of the objects themselves was necessary to achieve this.

Eventually, the automated association of attribute information (meta-data) will allow fundamentally digital operations to be performed on physical objects. Physical objects can be digitally indexed, searched, and even located *in situ* through simple physical actions. Clearly, centralized graphical interfaces can offer no comparable functionality.

Another key concept is the tracking of *physical usage frequency to support collaborative work.* Hill and Hollan have noted the effect of thumb smudges in well-worn repair manuals: as indicators of popular pages, these marks index the most useful sections of the book. [8] Of course, physical wear usually occurs too slowly to offer feedback for collaboration. (In addition, such wear is often associated with a loss in functionality or structural integrity.) A physical/digital interface, however, allows physical use to be displayed *without physical wear.*

Records of these interactions can then be used to improve resource allocation, ergonomics, and workflow.

As a visualization mechanism, the simultaneous use of *multiple displays in aggregate* represents a new paradigm for the information visualization community. Because all of the individual displays show the same type of data, they act in concert as a single, room-filling, "meta-display." This type of display allows a qualitatively different style of engagement from graphically complex handheld or wall-sized displays. If the mapping of information to display is persistent, the system can even recede into the "periphery" of awareness, noticed only when sudden changes occur [10].

Finally, the *object-centered interaction* physically situates information in its context of use, and makes unambiguous the association of object, information, and physical location. While general-purpose computers can also display this information visually, the complexity of accessing, configuring, and navigating these systems often renders them unsuitable for assisting physical tasks.

RELATED WORK

Our work draws from a variety of research in augmented reality [3], augmented environments [12], distributed sensing devices [11], information visualization [7], computational learning tools [13], and various interfaces based upon object manipulation [1], [5], [6], [9], [14], [15].

Ubiquitous computing

Ubiquitous Computing [16] anticipated the proliferation of various computational devices throughout the environment, all connected to a distributed network. Wall- and tablet-sized versions of such devices were demonstrated, in addition to a handheld version called the ParcTab.

Although our system fits well with the concept of ubiquitous computing, our approach differs substantially from that of handheld GUI devices like the ParcTab. While handheld devices support closely attended interaction with a single user, our distributed displays are equally well-suited for concurrent multi-user, multi-object interaction.

Spatially aware palmtops

The Chameleon prototype developed by George Fitzmaurice [4] is a handheld device that displayed "situated," or context-sensitive, information. The system's display acted as a window into a virtual workspace, responding dynamically to changes in its physical orientation and position.

Like the Chameleon, TouchCounters provide a spatial visualization of information, but eliminate the need for tilting, panning, and zooming. However, the possibility of integrating portable devices with augmented environments was a key inspiration. Fitzmaurice imagined a computer-augmented library with indicators beneath the shelves: "as we walk through the music section, books on the topic of interest as well as related material will be highlighted by indicator lights..." [4]

There are many issues involved in making such a system operational, and it was never implemented. However, our approach is very much in accordance with this concept.

History-enriched digital objects

Perhaps the most interesting related work connection is the concept of the "history-enriched digital object," or HEDO, by Hill and Hollan [8]. HEDOs are mechanisms for recording use history data onto digital objects. As described in *Edit Wear and Read Wear*, "object-centered interaction histories" allow records of use to be embedded within and displayed upon computational objects. For example the degree of editing or reading of different portions of a document can be indicated on "attribute-mapped scroll bars" accompanying images, documents, or email windows.

We too employ "object-centered interaction histories," but in our case the objects are physical containers. Our objects sense both physical and digital events, and portray them in glyphic form.

IMPLEMENTATION

Design approach

In addition to the TouchCounters system, we have developed several other interaction devices for the augmentation of working environments. Like the TouchCounters modules, each of these devices supports the visualization of a specific type of information. Although a detailed discussion is beyond the scope of this paper, we list some of these devices for reference: electric field sensing modules for non-contact, gestural input, electromagnet arrays with magneto-rheological fluid for tactile output [17], and tag reader interfaces for visualizing information on RFID (radio-frequency identification) tags.

To facilitate the development, deployment, and reconfiguration of these devices, we have emphasized modularity in all aspects of their design. This is evidenced by the electronic components, physical connectors, data protocol, and software used in the TouchCounters system.

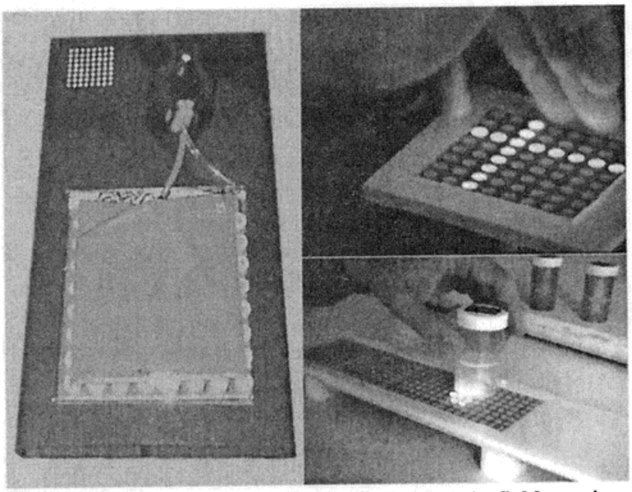

Fig. 8: (clockwise) Tactile output [17], electric field sensing, and RF tag reader interface devices

Electronic Labels

The TouchCounters modules are palm-sized (12x15x3cm) electronic devices. Each is essentially a simple computer equipped with sensing, display, processing, and communications capabilities.

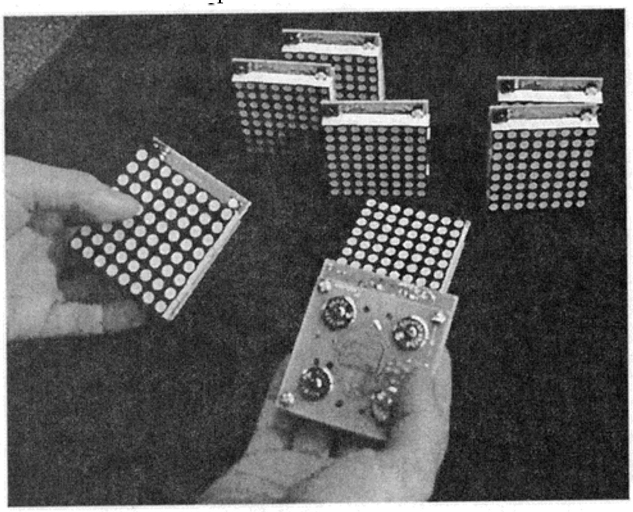

Fig. 9: TouchCounters electronic label modules; one is reversed to reveal the magnetic snap connectors

The sensing capabilities currently include magnetic and infrared detectors. Dual-axis accelerometers have been installed on some modules, but are not yet integrated with our working system. To detect the opening and closing of the container lids, permanent magnets were installed in the front edges of the lids. A magnetic reed switch on each module detects the proximity of this magnet to determine the status of the lid. Thus the system can count the number of container openings as discrete events.

The front of each module is covered by an 8x8 LED matrix display. Originally intended for use in outdoor electronic signs, these components can portray glyphic graphical patterns composed of bright red, green, and orange pixels. While these are not intended as a replacements for high-resolution monitors, they are well-suited for the dynamic display of simple quantitative information. Simple animations such as rotating lines or oscillating particles can also be rendered, but we felt that motion would be unnecessarily distracting and chose static graphics instead. Unlike liquid crystal displays, LED displays can be viewed easily at a large distance, a key characteristic for our intended use.

The inclusion of a Microchip PIC™ processor on each module greatly enhances the system's flexibility. As the processor is electrically erasable, new code can be rapidly uploaded through a five-pin programming port. To identify each module uniquely, the processor can read a 48-bit ID from a Dallas Semiconductor Silicon Serial Number™ chip. Higher-level identifications, such as descriptions of the container's contents, are addled at the server level.

The modules also support infrared and wired communications. Standard TV remote controls can be decoded through an IR receiver module, and IR can be transmitted through a small emitter. In the future, IRDA data transfer may be implemented to allow the direct annotation of information using a PDA.

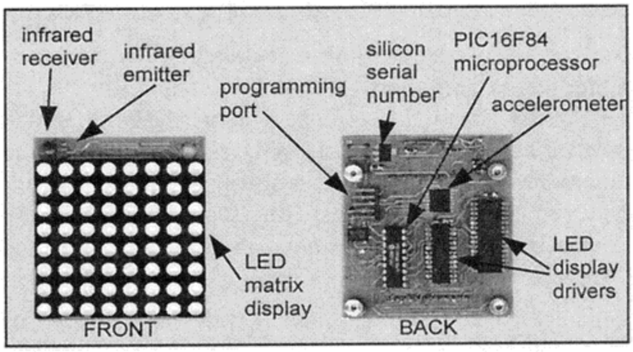

Fig. 10: Components used on the TouchCounters label modules

Containers and Shelves

Data is exchanged with the server through a series of connectors on the modules, storage containers, and shelves. The modules attach to objects using a set of four magnetic snaps located on their back sides; these allow rapid, robust, and single-handed attachment/detachment. As the snaps are electrically conductive, both power and data signals are activated through the act of placing the container upon the shelf. The receptacles on the shelves are hard-wired to a common bus connected to a central server. This architecture allows easy scaling of the number of containers or devices in the system.

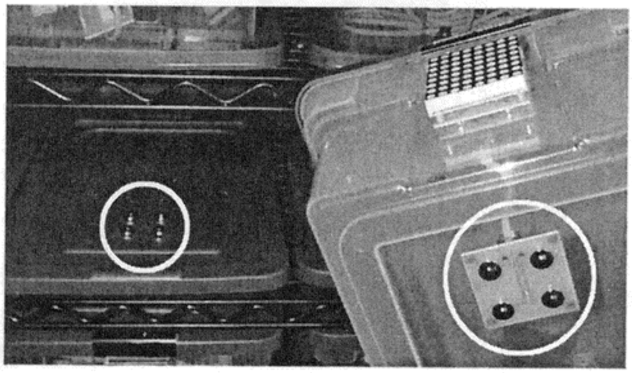

Fig. 11: Magnetic snap connectors connect storage containers to the shelves.

Web Server

The web server is a standard personal computer running Java™ code. Serial I/O classes enable the server to read data from the machine's serial port. To allow remote users to dynamically alter the code executed on this machine, Java's remote method invocation (RMI) routines were employed. All data is exchanged as ASCII text; this facilitated debugging of communications errors by humans.

Usage correlation is measured both through count information relayed from the labels, and by measuring the time that a box unit is *offline* and therefore removed from the shelf. Each access event is stored in a matrix of variables which is updated continually. Likewise frequency of use information is logged in a file available online.

A Java applet displays box status to remote users, and also allows data to be sent to the labels.

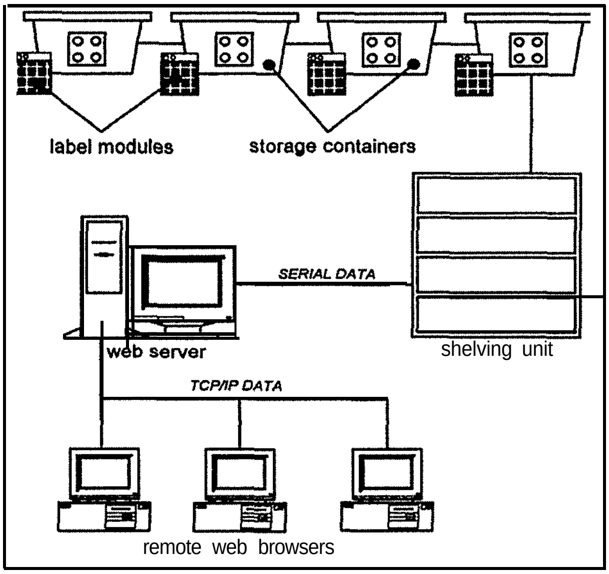

Fig. 12: Network topology of the TouchCounters system

PRELIMINARY OBSERVATIONS

In an effort to optimize its design, we have installed our prototype system in our own facilities for evaluation and integration with our everyday use. Though this is no substitute for controlled user studies, it has allowed us to obtain some qualitative feedback about this system.

This system was installed in a large room used by about a dozen researchers for prototyping and fabrication. Materials in this area, including supplies, materials, and tools, are stored in 50-60 plastic containers. Inevitably, the number of different users results in frequent changes in the positions of each box. The locating of any particular box is challenging, as the boxes span multiple shelving systems across a room. 16 containers were fitted with the labels and networking hardware; the remainder were left unchanged.

Users responded positively to the display graphics, and expressed interest in the complete implementation of the system. In particular, users liked the visual feedback that accompanied labeling with the remote control. It was noted that the electronic modules acted as both *labels* and as *indicators;* that is, they support both passive recording and direct annotation of data.

Some users asked how messages could be left on the containers themselves; for example, a note that an item had been borrowed from a box. Others asked whether the users of each box could be identified. We address these in Future Work section below.

Wire	Solder	Scissors	Velcro
Serial Cables	Ethernet	Serial Adapters	Foam
Fabric	Magnets	Abrasives	Adhesives
Paint	Markers	Tape	Monitor Cables

Figure 13: Sampling of items stored with TouchCounters system

FUTURE WORK

Our plans for further development include user studies, improvements to functionality and visualization, and the application of our approach to new environments.

While preliminary feedback has been encouraging, we plan to implement a complete system for testing under actual working conditions. To do this, we will have to determine which metrics will best quantify user performance and satisfaction, and to compose controlled experiments to test these aspects. This data will inform the refinement of our system's design.

Possible improvements to the system's functionality include PDA-based message annotation, user identification through wearable badges [13], and support for collaboration with geographically distant groups.

Additionally, we plan to implement more sophisticated indications of usage history on the matrix displays, indicating not only the number of accesses but also their temporal distribution. In its glyphic portrayal of temporal distribution such a system would closely parallel the spatial visualizations of TileBars [7].

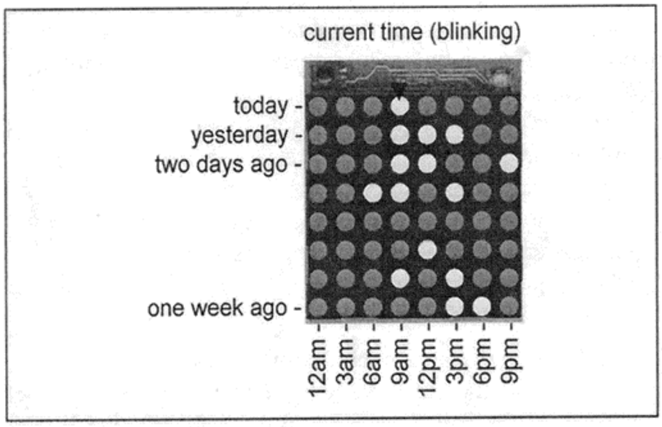

Fig. 14: Temporal distribution of frequency of use represented using glyphic display

Finally, we hope to investigate the extension of our system to accommodate objects which may allured have rich online associations-books, papers, compact disks, videotapes, etc. Recording history of use on such objects may involve very different technologies and visual representations. Nevertheless, we feel that the conceptual approach will be very similar.

CONCLUSION

In closing, we have noted the limitations of current computer interfaces in supporting collaboration, and have designed a lightweight information access system in response to this need. By recording and visualizing *in situ* the history of use of physical storage containers, we promote the use of real-world, distributed interaction systems for the support of physical work.

We have noted a number of parallels between objects in the physical and digital realms, and have enumerated the critical features of our approach towards physical design. In our discussion of technical implementation, we have demonstrated highly modular physical, electronic, and software design that supports easy integration with various devices and physical configurations.

Finally, we have indicated a number of promising directions for future work, including the further qualification and improvement of our system. We hope that our work will improve the collaboration of real people in the physical world by harnessing the power of computation.

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