User Experience of Physical-Digital Object Systems: Implications for Representation and Infrastructure

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Abstract. In this paper we articulate a design space for smart object systems. We describe two instances in this design space. The first instance, called the Palette, is a tangible user interface for giving multimedia slideshow presentations. The Palette research system became the CardGear product released by Fuji Xerox. The second is a design we are currently implementing to support workflow in a systems engineering organization. The ArticuulatedStickies research system uses a 'posti-it' style smart objects to provide easy manipulation and visibility of production tasks assigned to a group of engineers.

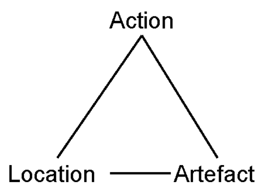
1 Introduction

Current designs for physical-digital systems largely focus on sensing as an input mechanism, where a set of physical manipulations affect a digital representation. Reflecting action based on computation back into the world (actuation or augmentation) is not as well explored. Within sensing systems, the digital representation is often an additional and secondary part of the user experience; for example:

- Physical objects may be used to model a larger scale physical process in which manipulations in a digital-physical model may be used to analyze the large scale system. This is a modeling strategy where the manipulations are part of an analytical task rather than a 'production' task. In the urban planning tool of Ulmer [6], actions taken on the artefacts are fairly simple (e.g., connecting pieces), the artefacts resemble the simple construction materials of the large scale model, and location sensing in the system is relative distance between interconnected pieces.
- Remotely sensed, tagged object can keep track of the flow of physical objects in a physical process (e.g., mail or parcels in transit) and report that in a digitally enhanced user experience. This provides a reporting capability where the sensed objects are not intentionally manipulated for their digital effect but are involved in a production or process task. In the parcel example, simple scanning actions are made upon discrete packages within a geographical frame of reference.
- Devices (e.g.., PDAs) may be instrumented to indicate intentional physical manipu-

lations that expand the range of expressiveness in using these devices [4]. This provides an expressive enhancement capability that is applied as a supplement of a digital experience. Actions are based on simple gestures or juxtapositions, taken on the computational objects.

We define a three-part framework for the design space of physical-digital object systems incorporating location, action, and artefact (Figure 1). These dimensions reflect a concern for what people are doing spatially and temporally with respect to other surrounding objects. For each attribute, we define a range of capabilities we order from simple or “dumb” to complex or “smart”. As a smart object system design evolves we would expect motion in this complexity range that is influenced by a number of factors (e.g., required capability, cost, performance).



Attribute	Simple Example	Complex Example
Action	Thrown switch	Negotiation
Location	Empty room	Smart space
Artefact	Static affordance	Self representing object

Figure 1. Design framework for Physical-Digital Object Systems.

The action dimension may incorporate actions along a dimension of increasing interactivity (e.g., multi-way exchange of information), changing approach (e.g., different implementations to achieve the original goal), and changing intent (e.g., objectives modified during the interaction). Hence, perhaps the simplest action is a switch, where a stimulus followed by a certain response, such as walking into a room and a simple trigger turns on the lights. Actions may require increasing degrees of attention; for example:

– Reordering a sequence of steps;
– Engaging in a transaction requiring a pin number or other supplemental information;
– Planning and re-assessing a complex transaction requiring many possible choices;
– Negotiating with others about how to achieve a mutually beneficial outcome;

Locations may be mainly non-technological, like an empty room or courtyard. The trend in ubiquitous computing is to start filling this space with communication capabilities with access to processing infrastructure, software services, and applications. For example, communication services such as wireless networking provide an infrastructure for locations and communication appliances provide new opportunities for location-based interaction such as digital community bulletin boards [2]) Sensors may be added to create active and interactive experiences with the devices that we bring in to the space such as tablet computers and laptops (e.g., [1]).

Artefacts may be simple objects with static affordances (e.g., a key inserts into a lock). We may complicate this with meta-data (e.g., the key provides a security identifier). Objects may exhibit change of state (e.g., an answering machine indicates a message is at hand). On the upper end of the complexity scale, objects may be self representing and self-explaining (e.g., Bluetooth devices identifying themselves and negotiating access).

But design decisions in these dimensions may interact with each other. Consider the situation of an proximity activated light switch. Such a design assumes that a simple user experience of a switch is where no intentional action is needed from the user. With an automated switch, the location (in terms of the location-action-object framework) is playing a role in the switching operation. Sensors are fallible and hence this simplicity breaks down when you walk into the room and the lights do not turn on, producing a set of actions: *discovery*, no lights turn on; *assessment*, need to find a switch; *recovery*, wave arms about to trigger the proximity sensor; *reevaluation*, waiting to see if lights are coming on or not. The complexity of the room design has been revealed to the user, requiring more complexity of action in this failure situation.

We compare this design space to a sort of mechanical ‘spring system’, where each particular design instance lies somewhere in the triangle between action, location, and artifact. Pulling the design towards one pole produces the need for design consideration in each of the other attributes.

2 Experiences with a Physical-Digital Object System

Our work in this area is on the use of sensed physical objects that combines all of these representational attributes above with the aim to create an easy flow between the physical and digital aspects of a user experience. Namely, in our previous Palette work [5], we investigated a tangible user interface for giving multimedia presentations. The Palette software formats and prints a paper card for each slide in a digital presentation. Barcodes on the cards are read when passed under a barcode reader, and this brings up the appropriate slide for display to an audience.

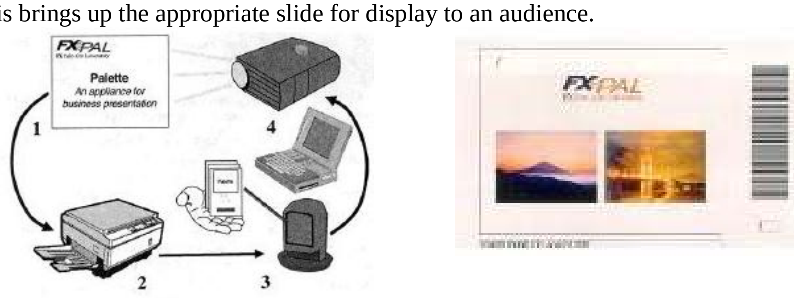


Figure 2. The Palette System and a Palette Card Object.

Figure 2 shows the information flow in the system and the format of the tagged presentation objects (Palette cards). The presentation process with a PowerPoint file (marked as 1). The Palette software formats, prints the cards, and copies all materials to the presentation computer (2). The presenter then may swipe any card under a barcode reader (3) to show the corresponding slide on the projection system. In this way the system takes up the burden of managing the digital content and creating the corresponding physical counterparts. The presenter is then able to arrange and annotate the cards to aid in the presentation actions of on-the-fly content selection and remembering things during or after the presentation.

In the Palette, we explored how a digital representation could be made responsive to corresponding physical manipulations (separating out a card and gesturing with it to control a display), where the physical objects are involved in the progress of a production task (sequencing the presentation flow), and provide additional capabilities in a physical digital environment (we explored ways to enhance the "Powerpoint" experience such as allowing multiple slides to be projected simultaneously, much as multiple transparencies arranged on an overhead projector). The Palette modifies the physical surrounding through augmentation, changing the appearance of the room through projection. This system was sold as the CardGear product, from Fuji Xerox.

The Palette was successfully used within an organization for giving over 400 presentations over the course of 3 years. In our subsequent assessment of this system as it was used over time [3], a number of issues were raised about the way users regard and use the physical and digital representations:

- The users do think of the identification of 'cards as slides', as was the design goal. However there were breakdowns in this conceptualization. For example, an important user practice of last minute editing of presentations before a talk was not well supported: the edit/generate cards/print cycle took 'too long'. Aside from the physical production process, there was a copying of files onto a presentation room computer requiring this regeneration of the tagged cards.
- The Palette's dependence on other technologies (e.g., networks, printer control, presentation applications) led to brittleness, thereby complicating the infrastructure in a manner mostly left invisible to users. This makes debugging (e.g., 'my cards did not print') complicated (e.g., more places for the system to break, and in places where users would not wish to know about or give attention such as print queues).

Along with the issues of representation in smart object systems, we must also provide designs that address process visibility and user feedback.

Looking at the Palette in the location-action-artefact framework shows a tradeoff in simplicity of object impacting the complexity of the location and its supporting infrastructure. Simplicity of card contributed to simplicity of action for the user. The location complexity becomes apparent to users under conditions of interrupted system flow.

Design Issues in a Physical-Digital Object Systems

The original set of physical objects in the Palette consisted of two kinds:

- Generated paper cards represent presentations slides.
- Pre-printed function cards are used to set the system into a certain state so that subsequent actions are modified (e.g, merge slides, control background).

This arrangement presents three sets of physical actions that affect the presentation:

- Show a slide gesture (i.e., swipe card to produce action).

– Set style gesture (i.e., swipe function card to change system settings)

– “Offline” actions, including annotating and reordering cards.

The offline actions were an important part of the user experience. In this case, the physical form of the cards were used to the advantage of the presenter, even when access to the computer was impractical (e.g., sitting in the audience waiting to present next).

The action of swiping the ‘slide’ cards proved to be of far greater relevance to users than the use of function cards. Feedback was immediate in terms of what slide was showing. Using the function cards were at most a curiosity to a subset of users.

The issue of feedback in this Physical-Digital Object System became most acute when the system did not perform (e.g., slide does not show), requiring debugging. And such debugging required knowledge of the multilayer implementation (e.g., what the barcode reader is doing, what Powerpoint is doing, how the file system on the presentation computer is set up, what other processes are running on the presentation computer that might interfere with operation, and so on).

Implications for design: a task awareness and coordination system based on “post-it” style physical interaction

Based on recent field work of production teams, we find that such teams that are engaged in collaborative work use online tools to coordinate their workflow. Activities appear as “To-Do” items within an overall plan for group activities and deliverables. The items in the plan are allocated to individuals or subgroups. In addition to such online To-Do lists (Figure 3), work rooms often have pubic space displays of the online workflow as a persistent physical, visual reminder of work activities and progress (Figures 4 and 5). Work tasks are noted on paper (e.g., Post-Its) and stuck to a markable surface (e.g., whiteboard) that has been segmented into work phases (e.g., software development lifecycle phase). This allows everyone in the office to get a sense of the flow of activity, be able to inspect, comment on, update, and otherwise follow up on the displayed status (e.g., taking or copying the notes for futher action).

Mapping the physical, public space representation to the online representation is error prone. We propose linking the online and offline representations using tags, sensors and instrumented physical poster boards to manage workflow more effectively.

We are currently designing a physical-digital object system, ArticulatedStickies, to support workflow processes, and these are aspects we would like to pursue in the workshop. Representations support local and remote creation, update, distribution of information about, and awareness of activities within said workflow process; namely how tasks are structured, who performs them, what their relative order is, how they are synchronized, how information flows to support the tasks and how tasks are tracked. Spatial arrangement and manipulation are sensed and interpreted as corresponding digital manipulations made accessible to a workflow support applications.

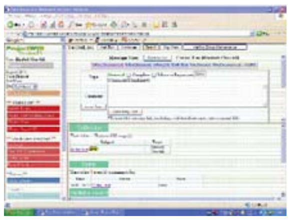


Figure 3: Online workflow management

Figure 4: Individual To-Do list items on coloured Post-its on a board

Figure 5: Columns on the board represent task groupings by project phases

We are investigating the use of the action-location-artefact framework to explore possible design possibilities for the workflow task (varying each attribute from simple to complex). One form of the work planning closely aligned with our observed practices with physical post-it notes uses the notes for artefacts, acting in the segmented location frame of posting board. Actions consist of creating, annotating, moving, and removing of the notes. By increasing or relaxing the complexity in each attribute we can explore new ideas in this domain of physical digital object systems.

This raises the following issues of object design:

- Triggering actions should be simple such as a card swipe, and result in a well defined action. In the workflow task, placing a post-it in a designated area should be reflected in the online system, preferable by a display located nearby, and designed to highlight the change of state of the system.
- Configuring actions should be physically visible throughout the duration of the configuration setting (e.g., post-it colour denotes a different status to the related workflow information.

This also raises the following issues of location infrastructure:

- The sensing layer for post-it notes requires immediate feedback for changes of state. In the event of sensing failure, resetting of the sensors by the users or replacing of the sensors by a repairperson should initiate a global check of all post-its in the system and updating of the digital application state. How much capability is needed in the objects or in the location where those objects is used?
- Loss of connection to the workflow application requires immediate feedback for change of state from the sensing system; e.g., an indication should result from the sensing data being processed or not by the workflow application. In the event of an application failure, resetting of the application by the users should initiate a global check of all post-its in the system and updating of the digital application state.

Conclusion

We are currently investigating the range of expressiveness appropriate for specific tasks embodied in tangible interactions. Are these to be appliances crafted to take advantage of straightforward physical affordances. Or will they exhibit complexities comparable to those in universal remote controls or office software applications? A transition to tangible interaction raises issues about the economic viability of installing infrastructures. If we build upon layers of existing architectures, how do we reduce the impact of dependencies better hid from users?

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