Origami Desk

INTEGRATING TECHNOLOGICAL INNOVATION AND HUMAN-CENTRIC DESIGN

In this paper, we present a case study of an interaction design exhibit, Origami Desk. This system integrates multi-modal interaction technologies and techniques in new ways to instruct users in folding origami paper into boxes and cranes. Origami Desk uses projected video clips to show users how folds should be made, projected animations to directly map instructions onto the users' paper, electric field sensing to detect touch inputs on the desk surface, and swept-frequency sensors to detect the papers folds. More importantly, the Origami Desk project incorporated numerous aspects of design—hardware design, installation design, interface design, graphic design, sensor design, software design, content design—into an interactive experience aimed at making the user forget about the technology altogether. This foray into teaching users physical and spatial activities led us to rethink the physical layout of the computer, and to invent inputs that were more spatial and implicitly, rather than verbal or graphical and explicit. The multidisciplinary process, human-centric design considerations and technical implementation details described in this case study may greatly inform future interactive environment applications where physical and digital worlds must be integrated to assist users in creative spatial tasks. In addition, the experience of deploying the exhibit into actual public spaces led us to examine issues of design for assembly and on-going maintenance in the context of interactive environments.

KEYWORDS

design innovation, interaction design, interactive projection, luminous interface, tangible interface, radio-frequency, electric field sensing

INTRODUCTION

This paper presents a case study of an interactive conference exhibit to illustrate how to resolve a technology-inspired design approach with human-centric interaction principles. Origami Desk is an interactive installation that guides users through the process of folding squares of paper into simple boxes and cranes. As an exhibit, it was designed to showcase several technologies currently under development at the MIT Media Lab that

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enable new modes of human-computer interaction.

Although many argue that technology motivated design approaches are inherently flawed, such processes are inevitable when invention is occurring in the realm of the barely possible. The design process for technological prototypes should thus be measured by different criteria than that for commercial products; their success depends upon their ability to creatively use the technologies at hand and their ability to communicate the larger purpose of such designs. It is worthwhile to consider what methodologies guide designers of inventive concept applications to couple technological innovation and experimentation with sound human-centric design, so that the end-product feels like a compelling rationale for these innovations, rather than a rationalization.

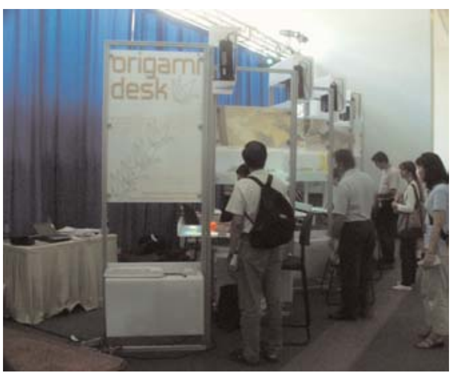

Figure 1: The Origami Desk exhibit at SIGGRAPH 2001

Figure 2: Different user roles and their relation to the exhibit

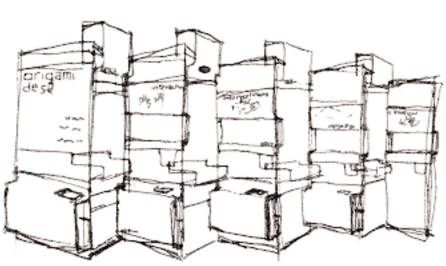

Figure 3: Sketch of Origami Desk installation design.

We begin by describing the background to the design of Origami Desk, to establish the context of this project in a progression of interactive environment designs. Next, we delve into various aspects of the Origami Desk design process in detail, noting high-level principles developed along the way that aided us in maintaining a user-centric perspective our technology-inspired interaction design efforts. We proceed to evaluate the design and design process used in creating Origami Desk

We conclude by drawing on this design experience to provide perspective on the role of new technologies in the realm of human-centric design.

BACKGROUND

Origami Desk is an interactive installation that guides users through the creation of origami boxes and cranes. Its purpose is two-fold: to engage users in the pleasant task of learning origami, and, on a deeper level, to illustrate how developing technologies might transform our future workspaces to make humans more capable.

The Origami Desk project was a six-month project undertaken by students at the MIT Media Lab to integrate several related threads of inquiry in the realm of interactive environments. The multi-disciplinary design team included members who specialize in interaction design, hardware design, software design, and architecture. The project was first exhibited in a conference setting at SIGGRAPH 2001 in the Los Angeles Convention Center from August 12th –17th [1].

INTERACTIVE ENVIRONMENTS

Origami Desk was inspired by a number of research projects in the area of interactive environments. Jeremy Cooperstock, et al.'s investigation into Reactive Environments introduced the notion of considering human factors in the design of such systems to promote invisibility, enable user control, and provide appropriate feedback to users. [2] The focus of their application, however, was in enabling automation of video conferencing systems, and the human factors considerations were largely geared at allowing humans to overcome the systems shortcomings.

Pierre Wellner's Digital Desk investigated the role that physical tools such as paper, pencils and erasers played in the environment when these objects were imbued with digital capabilities through the use of projection displays and computer vision [3]. Wellner's work addressed the issue of human-centric computing from the perspective that humans are better equipped to interact in the tactile domain, and so interactive environments allow them to explicitly manipulate digital data more naturally.

John Underkoffler and Hiroshi Ishii's work on Urp, a interactive workbench for urban planning, built upon Wellner's work by stretching the realm of interactive environments beyond standard office applications [4]. This design work required a more detailed consideration of the application-specific concerns of the users, and utilized the tools of the trade, the architectural models to enable tangible control of projected digital information.

ACTIVE WORKSPACES

Active Workspaces differ slightly from these previously mentioned interactive environment applications in that Active Workspaces are geared to teach people how to perform physical tasks. Rather than using tangible devices to manipulate digital information, Active Workspaces use digital information to help people produce a tangible product. The first Active Workspace design, for example, was an interactive kitchen counter that guided people through recipes. CounterActive used digital video clips, cheerful music, and verbal instructions to teach and motivate novice cooks [5].

A major challenge in Active Workspace design lies in the fact that physical instruction is demands that the computer works in the user's space. In addition, the interaction is affected by the requirement that the computer not unnecessarily distract the user from the task at hand. Finally, because Active Workspaces are meant to be instructional tools, the designer must presume a novice user who is unfamiliar with the tools in the environment. Thus, the design principles suggested by Cooperstock, et al. in their design Reactive Environments need to be amended. Rather than being invisible, for example, the Active Workspace needs to have variable visibility; some tools and interactions need to be invisible, to allow the user to focus on the task, and others need to be visible to clearly communicate to the user how they are to be used. Users need to be provided with explicit control, but the interactive system also needs to take into account some of the user's physical actions as implicit commands. And the need for feedback is even greater, for the Active Workspace needs not only to convey to the user what it is doing or what it thinks the user wants, but it also needs to provide real-time feedback to the user about his or her performance of the task at hand. The need for adaptability for different environmental conditions or different types of users becomes critical.

Our approach in the creation of new Active Workspace applications is to analyze the application to form a model of what user should be seeing, thinking or doing at any time during the course of the interaction and design the technology and content design suit the situation.

INTERACTION TECHNOLOGIES

At the heart of many of these interactive environments are new interaction technologies that free the computer from the traditional CRT-mouse-keyboard paradigm by allowing computers to interface with users on more physical terms. New developments in non-contact sensing, embedded computing, wireless networking, and ubiquitous projection have enabled the computer to become completely plastic in form, and allow designers to better adapt computer technologies to new application areas.

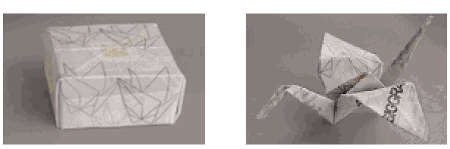

Figure 4: Origami Desk users choose between creating a box (left) or a crane (right)

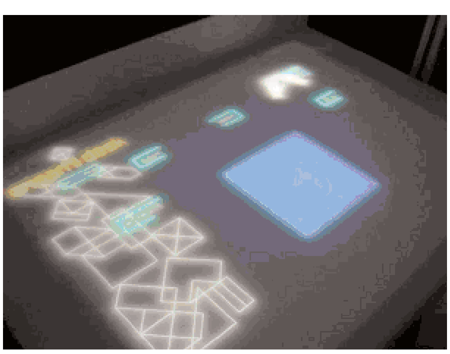

Figure 5: Photo of Origami Desk interface projected on worksurface.

In developing the idea for Origami Desk, we sought to further the capabilities of two new tools for human-computer interaction: electric field sensing and radio-frequency tag reading. Some degree of knowledge with regard to each of these technologies was already available. The electric field sensors we used, nicknamed tauFish arrays, were previously developed for an installation of interaction furniture for the Un-Private House exhibit at the Museum of Modern Art in 2000, to allow a computer to track hand gestures and touch inputs on a generic table surface [6]. Roy Want of Xerox Parc used electronic tags to help computers track physical objects [7]. We highlighted these technologies because they enable the user to communicate with the computer unencumbered by the traditional mouse and keyboard; coupled with projected interface, these technologies allow interactions to transpire in the user's space, eliminating the need for the metaphoric mapping between the digital world and our physical one, and increase the plasticity of the computers' form.

DESIGN PROCESS

It is certainly possible to design innovative applications in the realm of interactive environments using off-the-shelf technologies. With a little creativity and some flexibility, many tractable ideas can be prototyped with no hardware design whatsoever. However, it is somewhat naïve to believe that one can just merely observe users and blue-sky some needed solution and subsequently find the appropriate hardware to make that possible. True leaps of invention require an intimate working knowledge of what is technologically possible. That said, a technology-initiated design need not be mutually exclusive with the human-centric approach.

The Origami concept

The inspiration to use origami as an Active Workspace application came from Richard Fletcher and Neil Gershenfeld's research in determining how the resonant frequency of electromagnetic coils varies with changes in geometry [8]. We speculated that these variations in resonant frequency might enable us to sense folds in coils; quick prototyping with copper foil adhered to paper proved this concept to be possible.

Heartened by this event, we fleshed out other aspects of origami folding that made it a suitable application for a demonstration. Folding paper is an inherently spatial task, but it was relatively planar, making it easy to use with 2D projection displays. The process of folding paper structures was relatively short. People had heard of origami, could relate to the trials of attempting the folds, and the joys of succeeding. The task was not so easy that everyone could do it on their own, but not so hard that most people couldn't be taught in five minutes or so, especially with proper feedback. The demo came with its own souvenir. It was a good idea. We just had to know if we could pull it off.

Hardware design

The Origami Desk project was only possible because much of the hardware needed to make the project work was already designed and tested, and only needed to be modified somewhat for the idea at hand.

Of the two interaction technologies we showcased in the Origami Desk project, one, the tauFish field sensing array, was well-understood. It had been used by various team members in a number of prior applications, and was thus a low-risk way to create a touch interface on the Origami Desk surface.

The other, the swept-frequency tag-reading sensor, had also been used before, but in a very different way. Traditionally, radio frequency tags are created at set resonant frequencies determined by their geometry; using different frequencies of these inexpensive tags of differing frequencies, it is possible to distinguish different objects in the tag-reading sensor's read range. However, instead of using tags with static frequency settings, Origami Desk sought to use these tags in a dynamic fashion to detect changes in geometric shape.

By using existing tag-reading hardware, we were able to come up with numerous possible designs for the fold-sensing tags to create something really original to truly suit the application and the timescale of the project. However, we also anticipated the scenario where the tags just didn't work, and resolved to design the interface so that such a failure would not strongly impact the overall exhibit experience.

The important distinction in methodology here is even though we begin with the technological tools at hand, we view these tools with an open mind. Those who wield a hammer need not see everything as nails. They might look at the hammer, and ask, "Does it fit under the door? Can I use it as a weight? If I separate the wood handle from the metal, can I do something really new with it?"

BENCHMARKING

To follow up on the concept of teaching origami, we began to study various means of teaching origami and analyzing the user interaction issues with each method.

Traditional diagrams and coaching
We conducted informal user tests of origami instructions on colleagues and acquaintances. We had numerous people fold patterns from traditional origami diagrams in books to characterize for how long various patterns took to fold, which folds were toughest to decipher, and what common hang-ups existed from user to user. We were surprised to find that many users were completely baffled trying to map their work to even fairly simple diagrams, would grew frustrated and were inclined to quit mid-process if there was no other resource to clarify the instructions.

Figure 6. Origami Desk draws crowds at SIGGRAPH 2001

Figure 7. Participants enjoying the Origami Desk

These observations caused us to resolve to form multiple streams of instructions to give the user more basis to infer the instructions from.

We also tried teaching users origami by example, folding step-by-step alongside them. One of the challenges in this approach was getting the users to see how their folds mapped to those of the coach. Another challenge in this domain was finding the appropriate granularity of instruction: too much information and the users could not follow, too little and they felt impatient.

Multimedia origami tutorials

We also studied numerous online and CD-ROM origami tutorial applications (Casey Reas' Iogami [9] is one particularly graceful example). We found that the issues of mapping and granularity of instruction continued to be an issue in these tutorials. We also observed that the tenor of the folding experience was highly affected by the visual style of the tutorial.

One program, Hypergami, took an interesting approach to resolving the difficulty in mapping the diagrams on the screen to the paper. Hypergami, an educational software application designed to guide children through the design and construction of mathematical models, generates flat patterns that are printed out with construction line where all the folds lie [10]. This inspired us to think about way to project construction lines onto the Origami Desk interface to help users map instructions to their paper.

We also found that earlier projects had attempted to pair digital origami instruction with the user's physical space. The Origami Electronic Performance Support System at the equipped users with a head mounted display over one eye to provide just-in-time information about their folds [11]. The researchers found that people generally preferred using traditional diagrams from a book to the wearable computer interface. In our analysis, it seemed that users objected to the cumbersome apparatus and not the instructions per-se.

Interaction design

At the outset of our design, we only considered the participant who was actively engaged in folding origami at the desk. We contemplated whether the participant would want to stand or sit, how long they would be willing to fold for, what sort of physical context we needed to create for the appropriate tone. Our basic idea was that the user could select an easy or hard pattern to fold by directly touching the written options projected on the desktop. A digital video clip in the corner of the screen would indicate what the user should do, and a projected animation mapped onto the paper would illustrate where the folds should lie at each step.

However, as we began to consider the whole of the user interaction experience, from the moment they first lay eyes on our exhibit, we realized that there were several user roles, and we needed to explicitly design the way our installation would interact with each of them. The passerby, for example, might not stop at our exhibit, but we still wanted to convey some idea of what was going on in the booth to those who were afar. The bystander, too, might want to be able to watch others fold origami even if he or she is not engaged in folding. These considerations led us to try to design the physical system to afford more people the ability to see what participants were doing.

Also, because this exhibit was also supposed to be educational, we were wanted to develop a design to allow curious parties to see the sensors, computers and projectors that made Origami Desk system work. This presented an interesting problem, for the very workings we wanted to hide from the participant needed to be obvious to the technologists passing by.

Exhibit design

As in every exhibit design, the physical structure of the Origami Desk installation has a complex program. The design goals for the structure are multi-fold: to integrate the display and sensing technologies into one structure, to provide a peaceful and meditative environment for the user to work in, to allow people to walk around back to see the technologies that make the interaction possible, to catch the attention of passersby from a distance, and to help communicate the ideas of Origami Desk from afar.

Visual metaphors

To help reconcile the Origami folding theme and the folded coils sensors than enable this application, the physical exhibit combines visual elements from a Japanese folding screen and coiled fold of translucent Plexiglas "paper." The nine rectangular aluminum frames arranged in an accordion fold pattern to form four folding stations. scheme combines visual elements from a Japanese folding screen and the coiled pattern of the tags in the origami paper. The structure's open sections made it easier for others to look on as users folded, and allowed us to lean over the interface from behind to provide assistance as needed. A front panel was added to allow signage to let users know the name of the exhibit, and sepia-tone photos printed on transparent media were applied to the shelving areas to help the exhibit communicate its purpose to passersby.

The choice of materials was also driven by pragmatic concerns. The aluminum frames were selected because they were lightweight and easy to ship but were strong enough to support the ten-pound projectors overhead. The Plexiglas panels were selected in part because they are non-metallic and do not harbor moisture, qualities essential for the electromagnetic field sensing used in the hand detection and fold recognition.

Interactive Tutorial Design

Our informal benchmarking tests led us to select a box and a crane pattern for people to fold at the Origami Desk. The boxes' symmetry and simplicity made it easy to fold and also made it an ideal pattern for our folding sensing technology. The crane was selected because it is more traditional and more challenging to fold.

Interface design

The interface was the site of many of compromises between what we wanted and what we could pragmatically accomplish technologically in the time allotted. For instance, the interaction designers would have liked to be able to place the origami paper anywhere on the table and have the desk sense it and lay the screen elements out accordingly. The hardware designers would have liked to have the users work in a non-sensing area, and then to "check" each step out after they were done by placing it on a designated check-pad. Instead, we used the graphical interface to suggest that the user place the paper over the spot where the tag-sensing hardware coincidentally happened to live, and performed real-time sensing of the paper as the folding occurred. As we will see later, these decisions had profound implications on the system integration.

Origami Desk employs three different instructional resources for the user to determine what to do on each step. The demonstration clips to illustrate what to do with one's hands, the animations projected on the paper show where the folds lie, and the fold sensing to provide users positive feedback when they have successfully completed a step. This redundancy is intended to appeal to people's different manners of learning, and also to compensate for shortcomings in any individual technology. The fold sensing was not able to identify all the things a user could do wrong, but we hypothesized that it would be helpful and reassuring even to know when things were done correctly.

We designed numerous iterations of interfaces to determined a soothing visual style, suitable colors to provide visual contrast, proper size and layout of various buttons and graphic elements, appropriate pacing of video and animation and, of course, the perfect font.

System integration

The "ubiquitous" nature of interactive environment design usually requires many components, which in turn requires significant efforts to be spent on integrating all the pieces of the system. System integration does not occur last; it occurs all throughout the design process. Clear and explicit communication between team members working on various aspects of the design is essential to avoiding conflicts and enabling optimizations between system components.

For example, one critical aspect of the Origami Desk design is how these components are located physically with respect to one another. The projector displays the interface directly onto the user's workspace, and the field sensing array and the swept-frequency sensor are mounted immediately underneath; the projected interface guides users to fold their paper over the fold sensing hardware, or to touch "buttons" dynamically assigned to various spots on the work surface, so the mapping must be exact.

Because users are interacting directly with the work surface they are looking at and folding on, we had to overlap the read coil of the tag reader with the active space of the electric field sensing array, and fit both boards and their accompanying network converters within the desk area, which in turn affected the visual layout of the interface.

We had to verify that harmonics of the electric field sensing electric fields did not interfere with the swept-frequency tag reader, and had to filter out coupled noise on the network lines that was broadcast on the electrodes of the electric field sensing array. The electric field sensing was aligned to the left of the display area, making room for the tag reader hardware and networking hardware on the left. This created a "no button zone" of about 3.5 inches on the right side of the screen; concerned that this left-ward bias on the interface might seem awkward, the architect mounted the computer CPUs to the participants' right, so that the interface seemed once again to be centered where the user would normally stand.

EVALUATION

Origami Desk has been exhibited in multiple locations, to a variety of audiences. In this section, we characterize the differing types of Origami Desk participants at a conference, at a university lab and at a science museum, and reflect upon general affect and performance of participants in each location. With each showing, we have learned more about what was missing in our initial designs and developed subsequent improvements; we discuss both changes in the design and possibilities for future improvements.

Conference Exhibit

Origami Desk was received with great enthusiasm at the Emerging Technologies exhibits at SIGGRAPH 2001. We estimate that over 2000 people visited the Origami Desk installation, which was set up with four origami folding stations set desk heights between 25 to 46 inches. The audience members at SIGGRAPH are generally conference attendees, computer-savvy adults with a penchant for computer animation, although we did have a few people who professed to have little computer experience, as well as several children. Although most of the conference attendees were from Northern America, we had numerous visitors from other countries. We particularly attracted a lot of attention from the Japanese visitors.

We were gratified to find that roughly 90% of the users completed the box or crane programs in their entirety, which indicated both that the system was functional enough to guide someone through the whole process and that it was interesting enough to keep users engaged to the finish.

Although it took users about four minutes on average to finish the box program, and ten minutes to finish the crane program, almost all were willing to work with it to get all the way through the process. Users were usually thrilled to finish the program, and usually commented both on the difficulty of the task ("That was actually pretty hard!") and their pride on having created something "by themselves." Comments of the second variety indicated to us that the Origami Desk succeeded in its goal of preserving the agency of the users (no one felt that the computer had made the origami, which can be an issue in human-computer systems), and reaffirmed the idea that the challenge of creation improves people's self-esteem.

The preponderance of Origami Desk participants were primarily motivated to fold origami, although a number of the participants were interested in learning about the technologies behind the desk as they waited for a turn at the desk or waited for a colleague to finish folding. We changed one station to a show-and-tell station where we showed live sensor data so users could see how the peak patterns changed with the different folds. People were generally interested in how the technology worked, although only one or two a day would ask how they might replicate the equipment.

We found that we did not allocate enough time during the onsite setup of our exhibit to properly calibrate the tag-reading sensors with the high-noise environment of the SIGGRAPH exhibit floor. Fortunately, we had made several backup plans to cover eventualities such as this one. The redundancy in the tutorial interface allowed the origami instruction to work smoothly even in the absence of the tag-reading. We merely disabled the tag sensing on the origami tutorial to prevent the bugs from interfering with the paper folding experience.

We found that our "empirical user test" within the conference environment taught us a great deal about the limitations of design foresight. For example, some patrons had larger girths than the student population we had tested our designs on; their abdomens that would rest up on the edge of the desk and throw off the capacitance readings for the field sensing arrays. A similar problem would occur if people rested their arms on the desktop.

Naturally, in any design enterprise there are always a number of things that in hindsight could have been done better. We traced our inability to show the functionality of the fold sensors back to the fact that setup and calibration of the exhibit took much longer than we thought it would; in retrospect, we realize that designing for setup and assembly is a very critical part of any design, but particularly for exhibit design. Because of designs had anticipated fold sensing as a potential failure mode, our interface worked without it and this problem did not negatively impact the audience's experience. Nevertheless, we were very disappointed in not being able to show this technology to full advantage.

In-Laboratory Demonstration

We also demonstrated the Origami Desk at a Media Lab corporate sponsor function in October 2001. We ran the demonstrations on only one station, for several hours over the course of two days. The participants at these functions are largely adults with varying degrees of experience with computers, although several visitors were fellow graduate and undergraduate students. The fold-sensing technology was operational during these demonstrations. The reception was generally positive, although many users seemed distracted and less engaged than those at SIGGRAPH.

In this setting, only about half of the users were interested in folding the origami forms, although most did try a few steps to get a feel for the technology. Many users, however, asked detailed questions about the technology and other potential uses for such a design. The students were far more likely to wish to fold the origami for the sake of folding; these participants had more origami experience than the conference visitors. It took participants roughly three minutes to finish the box program, and eight to finish the crane. The false triggering of sensors due to body girth or arm resting did not occur, possibly due to the standing height of the folding platform.

Museum Exhibit

Origami Desk was exhibited for a week at the Museum of Science in Boston in March 2002. The Museum of Science participants were by and large schoolchildren, often accompanied by adults. We exhibited two stations set at a low height. For most of the week we did not use the fold sensing paper, due to the fact that the tags make the tags harder for children to fold.

The museum setting was the best test of our application, for almost all of the museum participants were interested solely in folding origami, and asked few questions about the underlying technologies. We saw many use patterns we had not anticipated. There were many instances of multi-user interaction: children would stand shoulder to shoulder and follow instructions together, parents would stand behind their children and press buttons for them, multiple kids would work on a box together, correcting one another's mistakes. Because of this usage, it was necessary to redesign the sensor and interface layout so that the multitude of arms and hands on the table top would not affect the sensor functionality.

We found that both children and adults were very enthused about folding origami, enough to follow the instructions even though it took them nine minutes on average to complete the box and over fifteen minutes to complete the crane. Over 80 percent of the visitors completed the origami patterns, but they required far more help from those of us staffing the exhibits. Museum-goers had great difficulty surmising what three-dimensional folds were being suggested by the two-dimensional animations and by the small low-resolution video clips. Also, we found that children generally pay attention to the video instructions over the written instructions or animated instructions.

Redesign issues

During the course of our exhibitions, we changed much about the layout and operation of Origami Desk. However, we also have some changes which we would like to implement in the future. On the technological side, we would like to develop better normalization and calibration procedures so that our sensing can better deal with multiple hands, variable background noise and fluctuations in temperature. On the user interface side, we feel that we could redesign the tagged paper so that it is easier to fold, and so that it provides feedback throughout the entire box-folding process. And on the exhibition front, we would like to focus more on redesigning the exhibit for quick setup and tear down.

DESIGN PROCESS RETROSPECTIVE

As we finished the Origami Desk project, we took some time to evaluate the design process that we used. Overall, we felt that this was an exceptional project in its integration of technological invention to the application space. Our sentiments after talking to a wide range of participants is that people genuinely liked folding origami with the system, and those who were technologically oriented were struck by the notion that future computers could be physically interactive and teach them to do things rather than do things for them.

At the conference and museum exhibits, we felt that setup and calibration took far longer than we anticipated, and so the technology worked far less well than it did in the laboratory environment. In retrospect, we realize that we had not designed for assembly of the exhibit, and this led to our often not being able to demonstrate the full functionality of our designs. It is important to write up setup procedures for the hardware, install programs for the software, and to write calibration programs to aid in adjusting aspects which are environmentally dependant.

This oversight stems from a larger problem where we failed to consider ourselves—the exhibit designers and attendants—as users in our design scheme. A better design would not only be set up more easily, but require far less maintenance and explanation on our behalf.

We felt that the following design principles were important additions to Cooperstock, et al.'s Reactive Environment principles, particularly for Active Workspace design:

Coherency- strive to make all the aspects of the project work together. Maintain a balanced perspective as to whether that tools is really appropriate to create tight couplings between user actions and system reactions.

Translucency- carefully consider which aspects of your system you want to be visible and invisible, at what times, and to whom.

Comprehensiveness- do not forget to consider all the possible users and use scenarios.

We feel that Origami Desk succeeded in both enticing people to learn origami and in communicating the possibilities offered by Active Workspaces. Smaller computers, lighter networks, new substrate materials that enable printed circuits or inexpensive display media and the ever growing realm of new sensors will give designers greater reign in finding solutions to help users learn to create things on their own. Follow-on applications should further investigations into using augmented materials and tools to monitor people for performance feedback, and might also investigate scenarios where the computer's ability to store data and gauge long-term trends are employed.

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