ADAPTIVE INTERACTION TECHNIQUES FOR SHARING AND REUSING DESIGN RESOURCES

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Brian Andrew Lee

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

(Scott R. Klemmer) Principal Adviser

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

(Terry A. Winograd)

I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

(Andreas Paepcke)

Approved for the University Committee on Graduate Studies.

Abstract

Today's designers generate content both on paper and online. Designers spread their work over physical and digital media, each of which has powerful—but distinct—sets of affordances. Recent work suggests that augmented paper interfaces can marry the ubiquity of paper interactions with the ease of search, annotation, and presentation afforded by digital representation. This dissertation examines novel ways to support and augment the practice of design through sharing and reappropriation of digitally captured design content.

The thesis of this dissertation is that an *ecology* for design that integrates *augmented physical and digital tools* can facilitate *collaboration* between designers and improve the *visibility* of design practice through the *sharing* and *proactive presentation* of design content. Our contributions are twofold: we study actual use of augmented tools for capture and access of visual design content, and we describe an approach for proactive display of example design materials that uses design dimensions as facets in selection and presentation algorithms.

To investigate the potential value of augmented tools for design, we developed the *iDeas design ecology*, which integrates physical notebooks with a digital faceted metadata browser that offers explicit annotation and sharing mechanisms, and conducted four studies with student design teams. Our findings indicate that, while there are clear benefits to tool use, such as increased excerpting and sharing of design material, users perceive high costs of maintenance and access control issues when using explicit capture and sharing tools.

The findings from these studies motivated our second tool, *Adaptive Ideas*, which explores the use of implicit mechanisms to improve visibility of example design resources. We describe a facet-based approach to selecting, presenting, and browsing design material adaptively, using decision-theoretic selection and end-user preference as inputs. Results from a laboratory study of an example-based web page builder indicate that proactive presentation of examples is useful in helping designers explore and understand spaces of design alternatives.

Acknowledgements

A dissertation, like all epic quests, is the culmination of many small miracles, or perhaps one big one. Certainly no quest this epic is completed without the support, encouragement, and inspiration of colleagues, friends, and family.

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To my sister Sharon, and my parents Gary and Lorna: Words cannot express the depth of my gratitude for a lifetime of love and support. Thank you.

To my parents,

Gary and Lorna Lee

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1 Introduction

Modern designers use a toolbelt [70] of digital devices, from desktop computers and laptops to mobile phones, digital cameras, and portable music players, for documenting their activities. Yet despite the ubiquity of these digital tools, many still depend primarily on physical artifacts for tasks both complex and mundane; in the so-called digital age, the use of paper has increased [67] (see FIGURE 1.1). Previous work has introduced augmented paper interfaces to bridge this divide between the physical and digital realms. How best to integrate the two worlds in the service of design practice, however, remains an open question.

We propose that the emergence of augmented interfaces for integrating physical and digital interactions, combined with the search, annotation, and presentation mechanisms afforded by digital content, reveals new ways to support and augment design practice through the transformation of cognitive design artifacts into *social artifacts*. This dissertation examines the implications of such a transition.

1.1 Thesis Statement

The thesis of this dissertation is:

> *Augmented paper and digital tools can facilitate collaboration between designers and improve visibility of design practice through the sharing and proactive presentation of design content.*

To evaluate this thesis, we will examine the following supporting hypotheses:

- H1 Lightweight digital capture can decrease the effort needed to share and annotate content generated during design activity.
- H2 Adaptive interfaces that leverage the automatically captured and user-generated metadata afforded by the use of augmented tools can ease the task of accessing design content of interest.
- H3 Proactive and reactive mechanisms for browsing and sharing content collections can increase exposure to and awareness of inspirational design materials without imposing significant additional user burden.

These hypotheses correspond to desirable user experience goals. The first two hypotheses suggest that augmented tools can *encourage rich design documentation and collaboration* (H1) and *enhance retrieval, review, and reuse of design content* (H2). The third hypothesis suggests that augmented tools designed with the above goals in mind can *provide design inspiration* and *improve awareness of design activity* through intelligent selection and presentation of example design resources (H3).

1.2 Thesis Contributions

This dissertation offers contributions in two areas:

- I Implementation of a system that uses augmented tools for capture and access of design materials
  - A Lightweight hybrid mechanisms for supporting design *documentation* and *annotation*
  - B Designs for facilitating *collaboration* through explicit sharing of design artifacts
  - C *Implementation* of these techniques in a functional system comprising physical notebooks and other design artifacts
  - D Longitudinal *deployment* and *evaluation* of the system's effects on design practice
  - E Design *guidelines* for integrating physical and digital interactions in creative work

2 Facet-based algorithmic approach for presenting example design materials proactively in order to promote shared awareness and design inspiration
   - A Approach for increasing *visibility* through proactive presentation and facet-based browsing of design artifacts
   - B Technical *analysis* of the feasibility of the approach
   - C *Evaluation* of utility through a first-use study of example reuse

1.3 Solution Overview

In this section, we outline how this dissertation addresses the thesis contributions and evaluates the supporting hypotheses.

1.3.1 Augmented tools for capture and access of design artifacts

To investigate the potential value of augmented tools for early-phase design, we developed the *iDeas design ecology*, which integrates physical notebooks with a digital browser that offers annotation and sharing mechanisms. We provide an augmented *ensemble* of design tools which facilitate collaboration and awareness among a community of designers. Unlike previous systems for design ideation and documentation, the iDeas tools support both the physical aspects and digital aspects of designers' existing work practices, from need-finding and brainstorming to presentation and reflection, through augmented tools for capture and access.

The iDeas tools harness the handwriting capture features of Anoto digital pens [1]. When used with an Anoto digital notebook, the pens record a vector-graphics representation of each stroke, along with the page, date, and time. We extend the Anoto pen system by combining captured writing data with digital images and other media, and offering advanced browsing, annotation, and sharing functionality not available in existing software.

Designers interact with captured content through the iDeas browser, an extended version of ButterflyNet [80] which integrates digitally captured notes, photographs, and other media into a *faceted metadata browser*. Content is automatically annotated with timestamps, and users may add tags and Post-It-style annotations to individual items. Users may browse notes linearly as with a physical notebook, or search for specific pages via available metadata. A context panel automatically presents data related to the pages in focus, such as notes or images from around the time the content was created, while a timeline visualization allows users to jump to content by date.

The iDeas system provides three major sharing mechanisms. First, designers can get a *direct view* of fellow designers' notebooks through the browser. Second, they can

FIGURE 1.1 Design practice *in situ*. Designers work with a variety of physical and digital artifacts during activities throughout the process, from brainstorming and fieldwork to presentation and reflection. This dissertation presents techniques for supporting and augmenting the practice of design through the use of augmented physical and digital tools, and algorithms for proactive presentation of design resources.

export snapshots of notebook pages as graphics to other programs or upload images to Flickr [78], allowing them to paste sketches into documents or emails without the burden of scanning. Third, designers can place important content into *group notebooks*, shared virtual repositories similar to text-based Wikis but incorporating sketches and other media.

We conducted four ten-week deployments of iDeas to students enrolled in design classes at Stanford University. In each study, participants were given Anoto digital pens and notebooks and the iDeas browser. Data was collected through five methods: *observations* and videotapes of class and group meetings; *interaction logs* of activities within the iDeas system; *analysis* of students' design notebooks, associated coursework, and performance metrics; *interviews* of students who used the system extensively; and *pre- and post-experience questionnaires*.

In the context of design practice, this set of studies is the first longitudinal evaluation of augmented paper interfaces in the literature. While ethnographic work has shown the centrality of paper in work practices (*e.g.*, [29, 67]), and previous research has used ethnographic work and short-term usability studies to inform the design of augmented paper systems (*e.g.*, [38, 49, 80]), to date the literature has lacked an ecologically valid understanding of the design of augmented paper systems and their effects on actual practice.

Participants cited the ability to fluidly excerpt and share notebook content as a standout feature of the iDeas toolset. We found corroborating evidence of this in students' class assignments: several groups inserted sketches from their design notebooks into project reports as samples of their ideation, a practice not prevalent in previous offerings of the courses. In general, the lightweight import and export of content offered by the iDeas tools appeared to encourage higher levels of documentation and collaboration, supporting hypotheses H1 and H2.

However, other models of sharing offered by iDeas were anecdotally found to have significant shortcomings. Automatic sharing of personal notebook content introduced privacy concerns regarding sharing and permissions, even among close-knit groups. The group notebook feature was used sparingly, and was generally perceived as requiring too much effort to use relative to the benefits provided. We note that careful consideration and presentation of perceived costs and benefits is important when introducing features not already part of current practice, and suggest that fitting into existing physical and digital practices is essential to the success of augmented systems.

1.3.2 Adaptive algorithms for presentation of design artifacts

These results motivated our second tool, *Adaptive Ideas*, which explores the use of implicit sharing mechanisms to improve the visibility of example design resources. We use the term *implicit sharing mechanisms* to denote a class of interfaces which require little to no user intervention in order to share resources, *i.e.*, information is provided proactively by the system. One goal in designing implicit sharing mechanisms is to lower the perceived barriers to adoption found in the studies above.

This dissertation describes an optimization-based approach to selecting, presenting, and browsing design material adaptively, using decision-theoretic selection and end-user preference as inputs. The core of our approach is a *subset selection algorithm* which chooses examples from a corpus to display so as to "maximize" estimated design value. Using distance metrics calculated along facets of the available designs, we define two criteria of interest to the presentation of design materials: *similarity* and *variety*. Interface layouts are generated automatically by assigning utility values to visual elements and searching the space of valid interface layouts for an optimal solution, using dynamic programming and branch-and-bound methods to boost performance. We built several prototypes demonstrating the Adaptive Ideas approach, including an awareness sidebar, showing relevant materials in the iDeas browser; public awareness displays, designed for viewing on a digital whiteboard, providing awareness of group activity; and personalized awareness displays designed for viewing in a desktop web browser.

To evaluate the benefits of this approach in a specific, concrete design task, we created the *Adaptive Ideas web page builder*, an HTML-based interface that seeks to assist web page designers by displaying examples of existing web pages and allowing designers to copy desired elements. Example web pages are automatically displayed next to a WYSIWYG web page editor. Users may search for examples either by requesting items similar to a given example for a given design attribute, or by requesting items representing a variety of values for a given design attribute. Elements may be copied from an example web page to the web page being constructed.

We conducted a comparative first-use study of the Adaptive Ideas web page builder. Results indicate that the selection and presentation algorithms aid users in the web design task by *facilitating discovery and exploration of design alternatives*, in support of hypotheses H2 and H3.

1.4 Dissertation Roadmap

CHAPTER 2 covers related work, beginning with research that sparked our interest in cognitive artifacts (§ 2.1) and encouraged our social approach to these artifacts (§ 2.2). It next discusses inspirational work on augmenting physical practices, including augmented paper interfaces (§ 2.3) and other systems for capture and access (§ 2.4). It concludes by presenting work that inspired our algorithmic approach to interaction design, specifically in the realms of document scoring (§ 2.5) and automatic layout of interfaces, images, and information (§ 2.6).

1.4.1 Explicit sharing through the iDeas design ecology

In Chapters 3 and 4, we describe the motivation, design, and evaluation of the iDeas design ecology, which integrates physical and digital tools in support of early-stage design practice. Chapter 3 begins with a description of current practice (§ 3.1) and scenario of envisioned tool use (§ 3.2). It then outlines the augmented capture tools (§ 3.3), and augmented access tools (§ 3.4) in the iDeas ensemble. Next, it discusses sharing mechanisms offered by the system (§ 3.5). The chapter closes with a summary of practical design challenges along with our current implementation (§ 3.6).

Chapter 4 discusses evaluation of the iDeas ecology from four multiple-month deployments. It first presents our study methodology (§ 4.2) and continues with high-level results from the studies (§ 4.3). The chapter concludes with implications for design of augmented tools and longitudinal deployments (§ 4.4).

1.4.2 Implicit sharing through Adaptive Ideas

In Chapters 5 and 6, we describe the motivation, design, and evaluation of Adaptive Ideas, which uses proactive presentation and facet-based browsing to improve the visibility of example design resources. Chapter 5 opens with a scenario of envisioned tool use (§ 5.2). It next introduces basic concepts and algorithms for example selection (§ 5.3) and automatic interface layout (§ 5.4), followed by an analysis of required layout calculations (§ 5.5). The chapter closes with a detailed description of our current implementation (§ 5.6).

Chapter 6 discusses evaluation of Adaptive Ideas from a comparative laboratory study. It begins by presenting our study methodology (§ 6.1), continues with qualitative and quantitative study results (§ 6.2), and closes with design implications for augmenting design tools with examples (§ 6.3).

Chapter 7 concludes the dissertation with a summary of contributions and research directions for further exploring the space of augmented tools in design.

2 Related Work

This section describes how prior work has influenced and inspired this dissertation, and outlines the contributions that this dissertation offers beyond existing research.

The first two sections of this chapter provide background on the design philosophies underlying this dissertation. SECTION 2.1 introduces the design notebook, highlighting benefits and limitations of current paper instantiations. SECTION 2.2 motivates the social approach to cognitive design artifacts used in this work.

The next two sections address the integration of augmented paper and digital interactions. SECTION 2.3 presents a summary of seminal and current research on augmented paper interactions. SECTION 2.4 reviews systems for capture and access of both physical and digital content.

The final two sections address issues of information selection and presentation. SECTION 2.5 presents previous research on document ranking and scoring. The chapter closes with SECTION 2.6, which describes prior work on systems for automatic and adaptive layout of information.

2.1 Introduction

Most designers maintain a paper journal called a *design notebook*, also known as a *logbook* or *idea log*, to capture and structure personal notes [39, 50]. Design notebooks provide an individual space for ideation and documentation; they can be used to take notes, record meetings, sketch ideas, document design rationale [54], and write down field observations [52] (see FIGURE 2.1).

The paper notebook offers several benefits for designers. Paper is a robust, lightweight resource: its “display” has infinite battery life, it requires no maintenance beyond keeping it reasonably protected from the elements, and use of paper requires a no more specialized tool than a pen. Paper is also an exceptionally fluid and expressive medium; in contrast to the typical computer with its mouse and keyboard, paper is an excellent tool for sketching and drawing. Lastly, paper is both familiar and ubiquitous: everyone knows how to use paper, and it can be found almost anywhere.

However, there are drawbacks to paper-based practices. For example, while design is usually done in groups, real design teams are not always co-located. When design activity is distributed, paper content cannot be shared directly; instead, either the desired content must be imported into a digital format and delivered electronically, or the paper itself must be physically mailed. While early phases of design often involve a

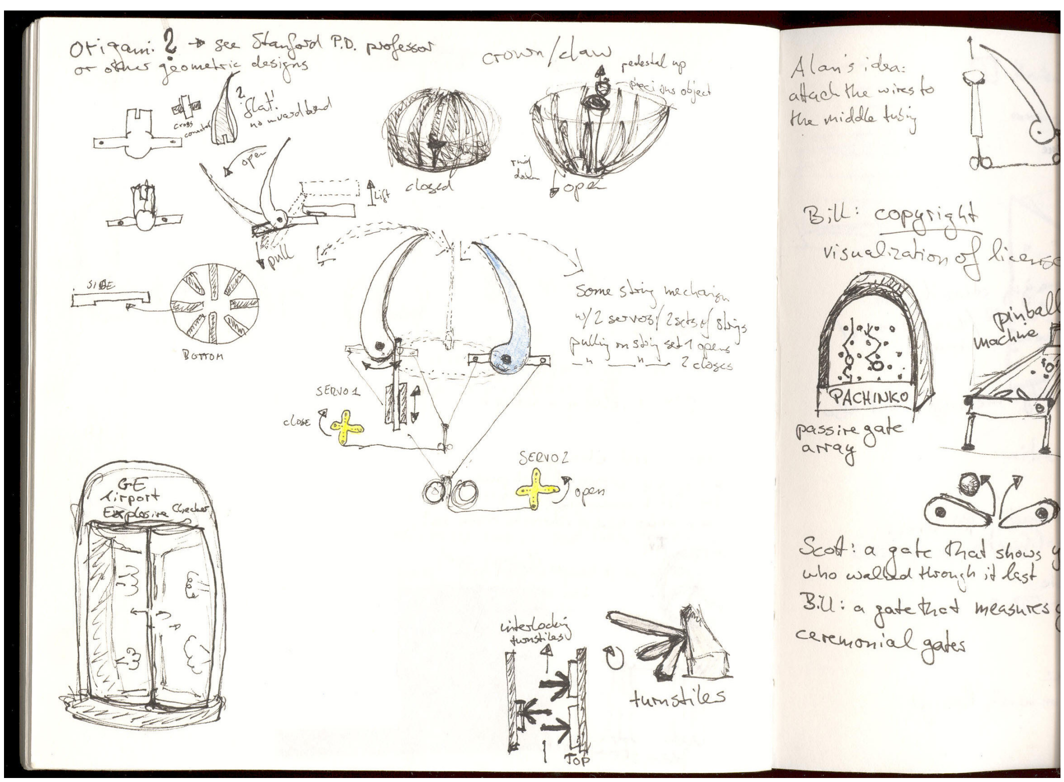


FIGURE 2.1 Design notebook entry from a student enrolled in the human-computer interaction studio course at Stanford University.

significant amount of brainstorming and sketching on paper, significant portions of later stage design activity take place in the digital domain [4]. Electronic media now exist alongside physical media for individual ideation and documentation: laptops, cell phones, and digital cameras are ubiquitous. Interactive prototypes and written documents are created on the computer, often based on notes taken earlier. Transitioning between paper-centric design stages and pixel-centric design stages can be highly problematic [38, 75]; while devices exist to convert paper content into digital form (*e.g.*, scanners), these tools are generally heavyweight and cumbersome, at odds with the fluid, freewheeling nature of creative work.

Previous research has observed that design is a social process in which communication plays a critical role. *Cognitive artifacts* [59] such as sketches and prototypes play a key role in structuring communication, allowing designers to explore new ideas and domains, share design visions with users, collaborate with other designers, and defend designs to stakeholders and organizations [19, 62]. This dissertation examines new ways to support design activity through the *digital capture, presentation, and sharing* of designers' cognitive artifacts.

2.2 Motivating a Social Approach to Cognitive Design Artifacts

The main theoretical lens for this work is *distributed cognition* [33]. Distributed cognition advances the theory that cognition is not confined to the individual, but is distributed over both people and artifacts. These cognitive artifacts can act as memory aids, serve as inspirational tools, or offer alternative ways to structure problems.

Interaction designers have observed and applied these theories in the design of computer systems. One body of work that has particularly inspired the sociotechnological aspects of this dissertation is Erickson's research on information management. In his personal reflections on electronic notebook usage [18], Erickson notes a "synergy between note making and messaging," an early observation of the power of sharing notes and the higher quality of notes and reflections that results from the practice. Later, in work on designing socially translucent systems [20], Erickson and Kellogg discuss the idea of making activity more visible within knowledge communities, using abstract proxy artifacts that signal others' activities. These insights regarding the power of sharing and displaying cognitive artifacts, later espoused by Notepals and other systems (*e.g.*, [15, 31]), forms the basis of this dissertation's social approach to the cognitive artifacts of design.

2.2.1 Analogical cognition

In *The Analogical Mind: Perspectives from Cognitive Science* [26], Gentner argues that analogy plays an important cognitive role in reasoning and problem solving. One illustration of analogical cognition can be found in the use and reuse of examples, where people draw from one example of a subject to gain insight or information on another. Viewing examples of previous work is an established technique in many design disciplines: compendiums such as *The Big Book of Logos* [10] serve as highly regarded resources for inspiration.

Digital information technologies have significantly improved users' ability to access a wealth of information; designers seeking to find examples of other designers' visual work need only open their web browsers. However, locating and accessing examples that are useful (representative, interesting, different, *etc.*) in a vast ocean of digital design resources is currently a nontrivial task. This dissertation proposes novel mechanisms for displaying sets of analogous design resources using design facets as the basis for selection algorithms. It then proposes displaying selected resources in design interfaces automatically, allowing designers to draw inspiration or gain insight on the task at hand without explicitly requesting additional information.

2.2.2 *Ecology approach*

At a larger scale, this dissertation takes an *ecology* approach to understanding the experiences involved in the use of our proposed technologies. An ecology may be thought of as "an open, complex adaptive system comprising elements that are dynamic and interdependent" [7]. The term ecology originates from biology, describing the scientific study of relationships between organisms and their environment. Conceiving of a general system as an ecology draws attention to the complex relationships between entities in the system.

Researchers have applied ecological frameworks in several human-computer interaction contexts. In *Information Ecologies: Using Technology with Heart* [56], Nardi and O'Day use the concept of *information ecology* to advocate a focus on better understanding how people and information technologies are interrelated. Barron [2] and Brown [7] coin the term *learning ecology* to describe how the presence of overlapping communities of interest can lead to powerful feedback loops of knowledge production and transfer. Recent work by Forlizzi [22] uses the term *product ecology* to

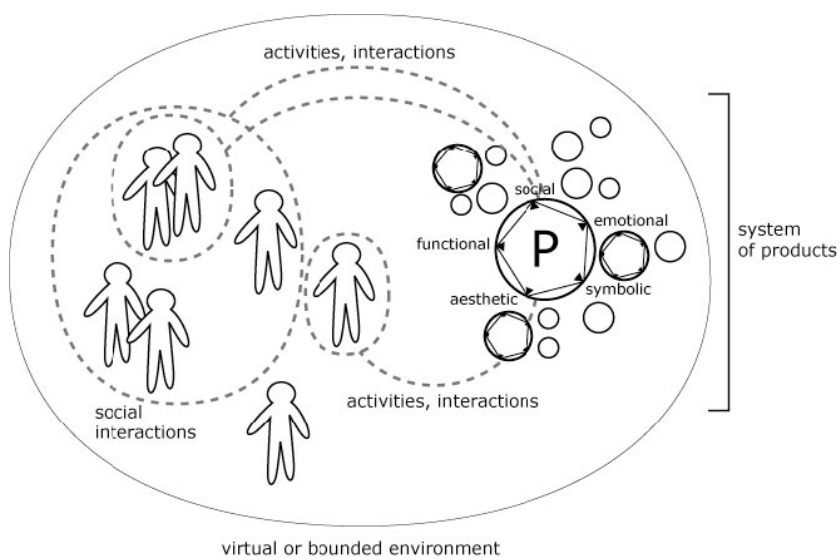


FIGURE 2.2 Forlizzi's product ecology [22]. Ecology frameworks emphasize the social context of technology use, placing technologies in a larger system that includes people, activities, environments, and social and cultural contexts.

describe the social experience surrounding the use of a product, foregrounding how the use of a product changes both its users and its contexts of use (see FIGURE 2.2).

For purposes of this dissertation, we define a *design ecology* as the larger system of people, tools, activities, environments, and contexts surrounding design practice. Within this ecology, the iDeas system provides an augmented *device ensemble*: a diverse collection of tools and content, used by a community of designers, which facilitates collaboration and visibility of design practice. The iDeas design ecology incorporates both physical and digital artifacts in support of designers' work activities, with the goal of forming a whole greater than the sum of its parts. The ecological philosophy espoused by the researchers above—that of understanding how technologies themselves become catalysts for change, and designing with such effects in mind—motivates both the system development and the longitudinal studies undertaken in this dissertation.

2.3 Augmented Paper Interfaces

We now turn our attentions to a growing body of research on integrating physical and digital interactions, and in particular on augmented paper interfaces.

2.3.1 Importance of paper-based practices

One influential study on the role of paper in computer-supported collaborative work is Mackay's work with air traffic controllers [47, 48]. Controllers use paper flight strips to track and modify information about aircraft and flight plans (see FIGURE 2.3). While the existing paper-based practices were extremely safe, increases in air travel were encouraging airports to further modernize and automate the control systems, which had remained substantially unchanged for four decades.

Mackay found that controllers were strongly attached to the familiar, easy-to-use paper flight strips, both as tools for *information management* and as cognitive artifacts facilitating *social coordination* between controllers. Attempts to replace the physical strips with more computerized controls were ultimately rejected by the controllers. However, Mackay found that further automation did not have to involve getting rid of the paper strips. Instead, "alternative input and output devices, including paper itself, can provide user interfaces to computer systems that are both familiar to controllers and still provide the benefits of a computer… Paper need not be an old-fashioned technology to be tossed away, but rather a new form of computer interface that is truly under the control of its users." [47, p. 337] Mackay's research highlights the importance of understanding the nuanced ways that physical tools contribute to work practice [16, 37], and supports the idea of augmenting paper as a method of introducing digital functionality while respecting paper-based practices.

2.3.2 *Integrating paper and digital media*

NotePals [15] first introduced the idea of shared electronic repositories for digital note-taking. The NotePals system captured notes and related documents for a workgroup and provided a central electronic repository for the information, allowing users to access all the notes taken from a given context. Researchers found that shared notes were more

FIGURE 2.3 Air traffic controllers collaborating with paper flight strips.

valuable when retrieved using task-specific interfaces that group and display notes with related information, such as class notes and lecture slides (see FIGURE 2.4). However, this early digital notes interface was limited in that users could only search notes for recognized text and very basic metadata (timestamp and author). Handwritten notes and associated task-specific information were also the only media supported in NotePals.

Several other projects have explored the ability of augmented paper to provide lightweight integration with digital media (see FIGURE 2.5). Stifelman's Audio Notebook [68] introduced a paper notebook augmented with audio feedback; tapping on a portion of a handwritten page retrieved audio recorded at the time those notes were written, an early example of using augmented paper as a tool for querying digital data. Books with Voices [36] demonstrated a similar concept, using paper transcripts as an interface for browsing corresponding video.

The Designers' Outpost [38] augmented existing paper-based work practices by directly integrating physical and digital interactions through computer vision and tracking. Its combination of a design-time capture tool and a timeline-based browser for

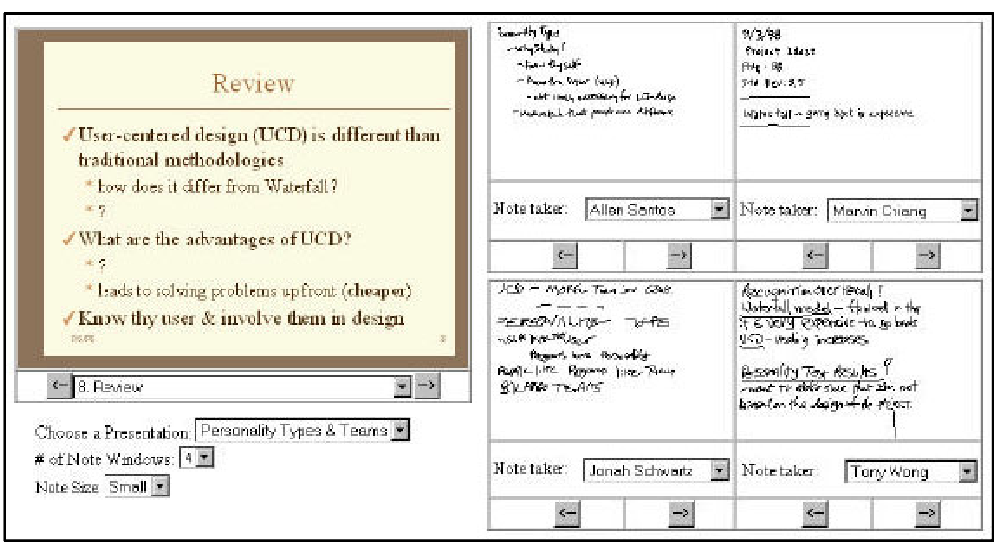
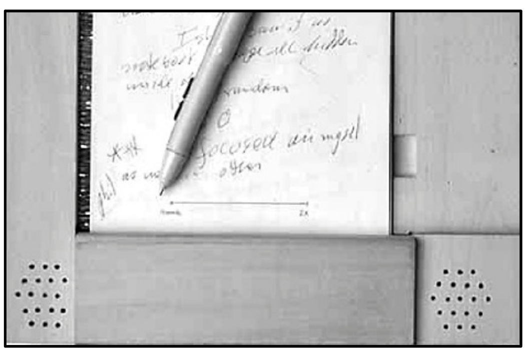


FIGURE 2.4 Davis *et al.*'s Notepals [15].

retrieval of design history inspired this dissertation's work on rich interfaces for browsing early-stage design content.

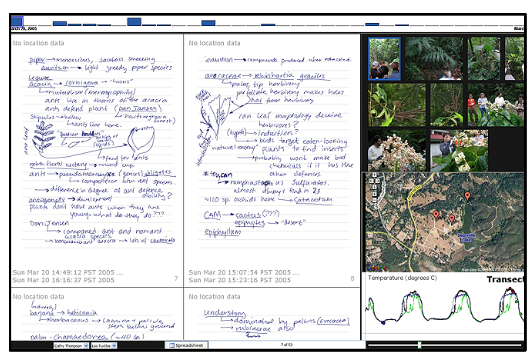
Rasa [53] uses paper in a distinctly different setting—military command posts—as a robust, failure-safe component within an augmented multimodal environment. Paper in the Rasa system was augmented with sensors to recognize speech and handwritten symbols, offering many benefits of digital activity capture while introducing minimal overhead. This tight integration worked well for the highly structured and disciplined work practices of military personnel. As design activity is often more creative and freeform, the work in this dissertation takes a less invasive approach to augmenting design tools. Our approach is more similar to that of Paper PDA [30] and PADD [27], which use paper as a passive input device at capture time and allow users to take advantage of electronic capabilities via synchronization.



Stifelman's Audio Notebook [68].

Klemmer *et al.*'s Designers' Outpost [38].

McGee *et al.*'s Rasa [53].



Yeh *et al.*'s ButterflyNet [80].

FIGURE 2.5 Four inspiring applications that offer rich content browsing through the integration of paper and digital media.

Mackay's A-book [49] and Yeh's ButterflyNet [80] integrated paper notes into broader capture and access systems in support of biologists, using the digital capture of biologists' notebooks to enable rich transformation and correlation with digital media sources. This dissertation extends the ButterflyNet media browser to serve as the browser component of the iDeas system.

Overall, this research extends the above work on augmented paper interfaces in two key ways. First, this dissertation offers a richer user interface for browsing and sharing captured content. This work integrates augmented paper and digital images into a unified capture and access system for design ideation and documentation. It uses automatically captured and user-generated metadata to facilitate sorting, searching, sharing, and automatic presentation of design content. Second, unlike the above systems, this dissertation evaluates augmented paper tools in *multiple month deployments*, offering research insights and design considerations from long-term deployment and use.

2.4 Capture and Access Systems

A number of systems have looked at the use of device ensembles for capture and access, including Audio Notebook [68], ButterflyNet [80], and Books with Voices [36].

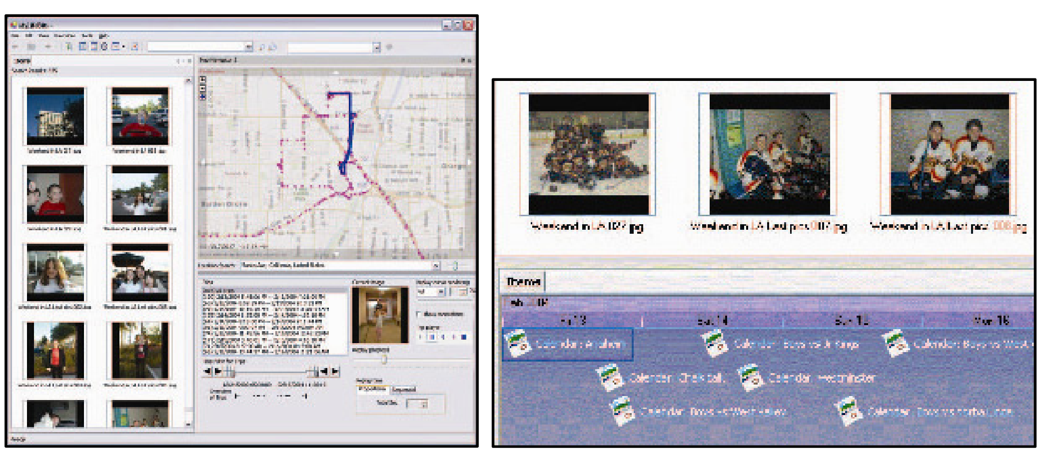


FIGURE 2.6 Gemmell *et al.*'s MyLifeBits [25].

Another platform, MyLifeBits [25], attempts to both capture and provide access to all of a person's information. MyLifeBits shares many similar architectural features with the augmented tools described in this dissertation: both systems integrate physical and digital content (using scanners in the case of MyLifeBits) and keep track of extensive metadata on captured content; both use SQL databases to store metadata and allow the user to query the system based on pivots and correlations (see FIGURE 2.6). This dissertation explores these ideas further by attempting to proactively present related materials, both while explicitly browsing and in ambient displays, thus creating more useful and serendipitous encounters with captured content.

2.5 Document Scoring

This dissertation draws on information foraging theory [63] to improve access to design content. Our browsing interfaces seek to improve the "information scent" of interfaces; more precisely, the goal of our adaptive algorithms is to provide "scents" of potentially valuable information in addition to specific information requested. The use of small steps observed by Teevan *et al.* in their study of orienteering behavior [72] points to the value of providing scent via contextual information.

2.5.1 Faceted metadata

The information model in this work on adaptive interfaces draws on the idea of *faceted metadata*. In [79], Yee and Hearst observe that metadata can be categorized into conceptually distinct facets, or types, such as time, tags, location, or media type; they develop a system that allows users to browse a database of images using these facets (see FIGURE 2.7). Recent research on lightweight techniques for labeling photographs with rich metadata [14, 55], and the use of rich metadata in information retrieval, has been equally instructive for our approach. While we employ the same ontological mechanisms, the contribution lies in the use of this schema to improve browsing, sharing, and automatic display of design materials.

2.5.2 *Information management*

As the quantity of information we work with increases [46], and metadata becomes ever more prevalent [5], improved techniques for sorting this information are required. Adaptive user interface techniques have proven particularly useful in managing our personal information. Rhodes' Remembrance Agent [65] demonstrated the use of richer types of metadata—most notably location—as a means for retrieving information. Haystack [34] takes a highly flexible, semi-structured approach to faceted data presentation and user interaction that could easily integrate adaptive techniques to increase visibility (see FIGURE 2.8). Perhaps most similar to this project is Horvitz *et al.*'s email ranking system [66], which employs decision-theoretic techniques to prioritize and rank emails that are likely to contain higher value information or be more urgent. This work was inspirational in framing our approach to adaptive display.

2.6 Automatic Layout

The software architecture of our automatic presentation work is largely inspired by prior work on model-based techniques. The area of model-based user interfaces (*e.g.*,

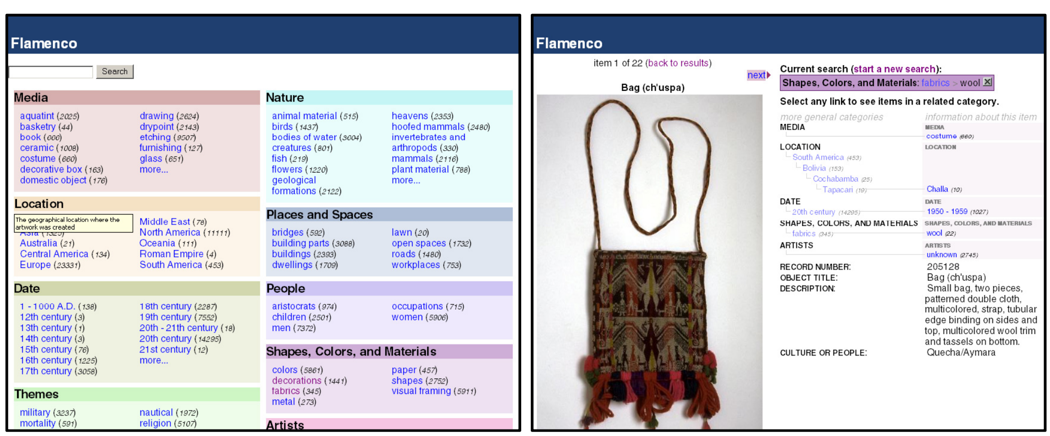


FIGURE 2.7 Yee *et al.*'s faceted metadata browser [79].

[60, 64]) began with the interest of creating tools for specifying interfaces declaratively, through high-level semantics, rather than imperatively, by the pixel-level details of the implementation. Szekely [71] provides a retrospective overview of this field. After the initial string of successes that Szekely identified, this field slowed down in the early 1990s, primarily because the single desktop PC experience did not provide sufficient diversity to mandate a higher-level representation: the value of abstraction is derived from the lower margin costs of repurposing—with one platform, there was no amortization to be had. Lately, however, model-based techniques have seen a resurgence, as interaction designers become more interested in creating interfaces that automatically adapt to different contexts of use.

2.6.1 *Interface layout*

In his early survey of adaptive software, Norcio [58] identifies four domains of understanding needed by general adaptive interfaces: knowledge of the interaction scheme; knowledge of the problem task or domain; knowledge of the underlying system; and knowledge of the current user, or user modeling (*e.g.*, [21]). This

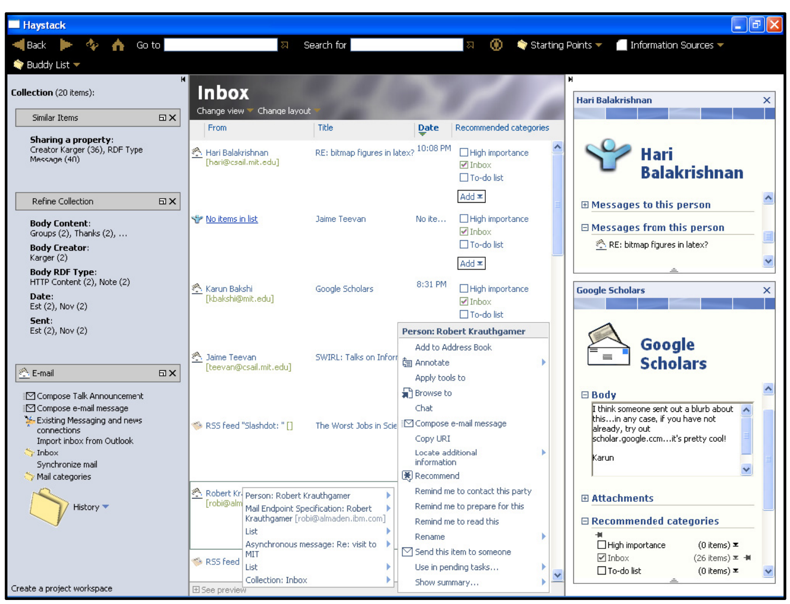
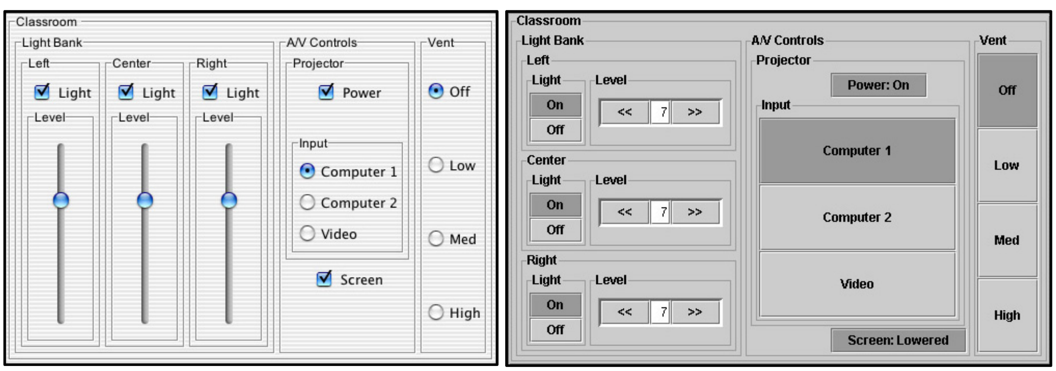


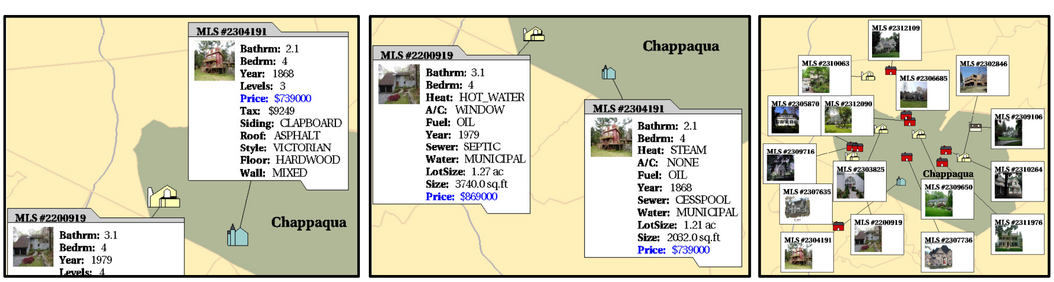
FIGURE 2.8 Karger *et al.*'s Haystack [34].

dissertation proposes a new method for adaptive systems to "understand" the domain of design, through the use of faceted metadata to describe design attributes.

Many projects have explored the automatic construction and layout of interfaces for specific contexts. Probably the most closely related systems in the literature are SUPPLE [24] and RIA [81], which examined constraint-based optimization approaches to interface adaptation (see FIGURE 2.9). We apply a decision-theoretic strategy similar to that of SUPPLE and RIA, but with significantly different constraints. The Adaptive Ideas work addresses both user interface elements and visual information sources, supporting a mix of information selection, adaptive interface generation, and designer specification. It also has an additional burden of rendering layouts interactively during the browsing process, potentially introducing interesting tradeoffs between optimality and performance. Finally, the RIA system dealt with highly structured, heavily faceted metadata; its algorithms depended on an intricate understanding of the dimensions and



Gajos *et al.*'s SUPPLE [24].



Zhou *et al.*'s RIA [81].

FIGURE 2.9 Two inspiring systems that construct and layout interfaces in an automatic and adaptive fashion.

their relationships. Adaptive Ideas uses design properties as metadata inputs; in general, these dimensions have less inherent structure and are more loosely related.

2.6.2 *Image layout*

Image browsing research has proposed many novel methods of dealing with the problem of laying out large sets of data. PhotoMesa [3] (see FIGURE 2.10), a zoomable image browser which encouraged browsing serendipity by presenting images in a 2D space-filling layout, inspired several design choices in our implementation of Adaptive Ideas (*e.g.*, quantum elements). Saliency-based cropping methods, such as those presented by Suh *et al.* [69], are another innovation that could be applied to our adaptive browser, posing questions regarding how to weigh semantically cropped materials in display utility functions. Our work on adaptive presentation extends this body of work by applying these techniques in the context of large sets of design resources, using domain-specific features to sort and display elements in an adaptive fashion.

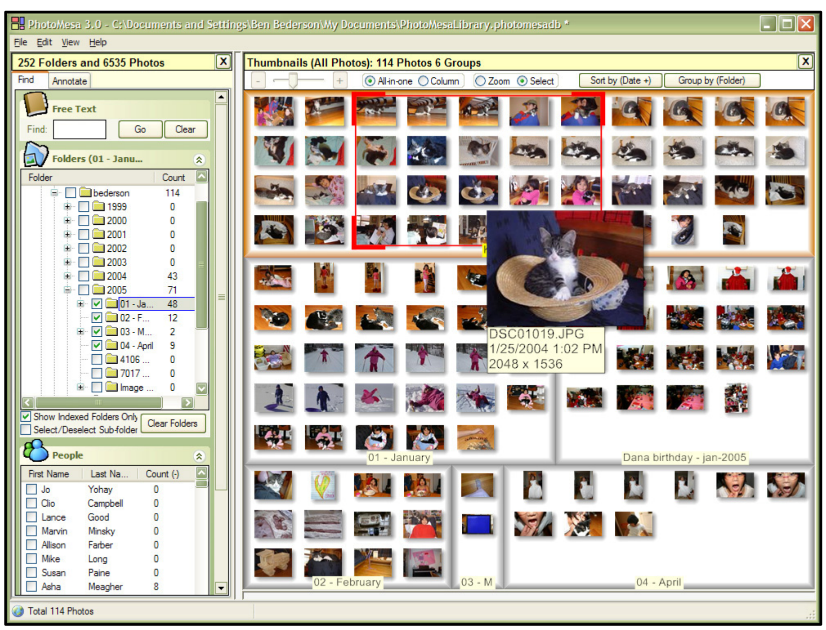


FIGURE 2.10 Bederson *et al.*'s PhotoMesa [3].

2.6.3 *Information layout*

The selection of what information is visible and its arrangement for the user has significant implications for cognitive activities that are ready-at-hand [35], and the effective presentation of personal information has been the subject of considerable activity. One early system in this area, Furnas's fisheye calendar [23], introduced the idea of a *focus+context* visualization: the calendar item in focus was displayed largely and with local detail, while non-focus items would correspondingly shrink. More generally, this example demonstrated how constraints can be effectively used to manage screen layout globally; this research continues in that vein. Other research has explored book-like metaphors for information collections [9], and facet-based approaches to personal information management and search [17] (see FIGURE 2.11; also see § 2.5.1). In this dissertation, we make no particular ideological commitment to maintaining the navigation affordances of prior technologies, though certainly the existing "user base" of paper books would make a compelling case for doing so. Our approach is more similar to that of faceted search, with the exception that the displayed information is not

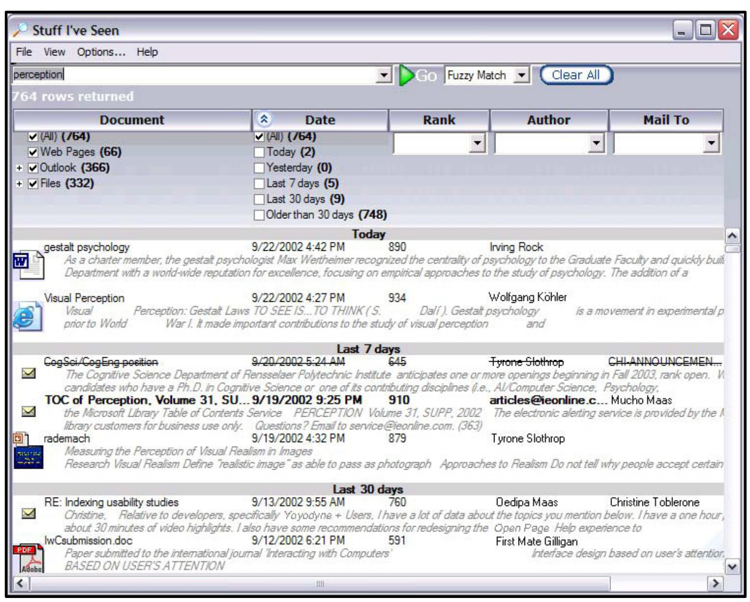


FIGURE 2.11 Dumais *et al.*'s Stuff I've Seen [17].

constrained to be *only* that requested—elements with relationships or similarities to requested information may also be displayed, as a means of providing serendipity in search and browsing.

Ambient displays have explored the use of spaces and surfaces for automatic, proactive presentation of information [74, 77]. Prior work by Hsieh has attempted to facilitate serendipitous generation of ideas by peripherally displaying notes [32], but only focusing on basic selection heuristics (recency and user-flagged importance). We follow up on Hsieh's work by exploring the use of both general metadata and design-oriented faceted metadata to select interesting and inspirational examples for display. In particular, this thesis explores the targeted presentation of cognitive artifacts to encourage exploration and increase visibility of work practice.

3 iDeas Design Ecology

To address and embrace the plurality of artifacts within early-stage design practice, we developed the *iDeas design ecology*, which integrates augmented physical notebooks with digital tools that offer advanced browsing, annotation, and sharing mechanisms not available in existing tools. Designers take notes using the Anoto digital pen, which automatically records handwriting data. Later, designers interact with captured design content through a *faceted metadata browser*, which integrates digital notes, photographs, and other media. The iDeas browser offers three mechanisms for sharing: *direct view* of fellow designers' notebooks; *export of snapshots* of notebook pages as graphics to other programs; and *group notebooks*, shared virtual repositories for group project data.

One notable challenge in the design and implementation of the iDeas tools was constructing a system *robust* enough to support actual real-world use, yet *powerful* enough to support the existing and novel practices that we sought to study. Where possible, we leverage off-the-shelf components to provide stable implementations of desired functionality. Our research software integrates these disparate components into an ensemble which supports current practice while enabling new interactions with content. The robustness of this system allows us to study how augmented technologies support and alter design practice through *longitudinal deployments* (see CHAPTER 4).

Portions of this chapter were originally published by the author, Heidy Maldonado, Isabelle Kim, Paz Hilfinger-Pardo, and Scott R. Klemmer in [41], and by Ron B. Yeh, Chunyuan Liao, Scott R. Klemmer, François Guimbretière, the author, Boyko Kakaradov, Jeannie Stamberger, and Andreas Paepcke in [80].

3.1 Introduction

This dissertation presents the iDeas design ecology, which supports the *paper-based content generation* of early-phase design while simultaneously enabling the *digital capture, browsing, and sharing* of design content. In the iDeas system, designers maintain the same fundamental paper-based practices, sketching and taking notes in notebooks as usual—the paper notebooks that they currently use are not replaced, but rather augmented. Augmented paper combines the familiar, nuanced interactions available with paper artifacts with the flexibility offered by digital representation [47, 67]. The iDeas tool ensemble supports the automatic transformation of paper-captured design artifacts into digital form, while also integrating other typical digital capture tools such as digital cameras; thus, the majority of design content is digitally captured. We suggest that this approach enables new mechanisms for digitally browsing, annotating, and sharing design content. In particular, this dissertation proposes that digital *metadata* can enhance the way that designers find, encounter, and share design content of interest.

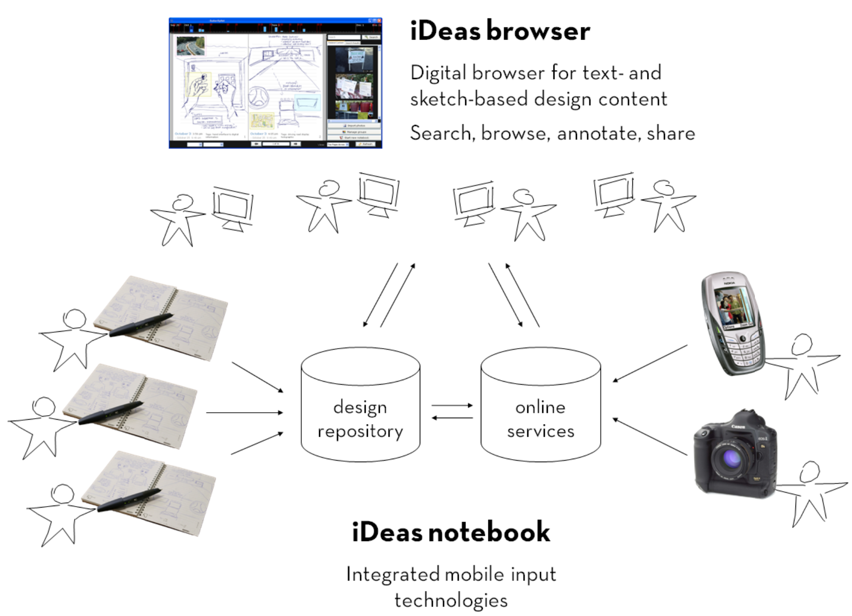


FIGURE 3.1 High-level sketch of the iDeas design ecology.

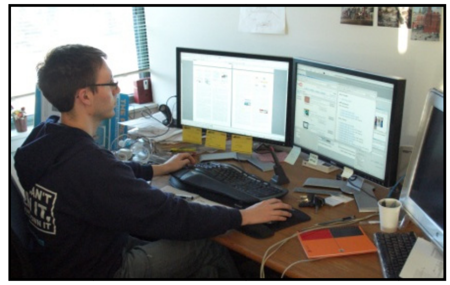
We define two broad classes of artifacts in the ecology (see FIGURE 3.1): the *iDeas notebook* encompasses capture devices, including augmented paper notebooks and digital devices such as digital cameras, while the *iDeas browser* provides access to heterogeneous design content through faceted browsing, search, annotation, and sharing.

The rest of this chapter is organized as follows. SECTION 3.2 presents a scenario envisioning how augmented tools such as the iDeas ensemble might be used in design practice. SECTION 3.3 discusses the augmented capture tools integrated into the system (iDeas notebook). SECTION 3.4 describes the augmented access tools for browsing and annotating design content (iDeas browser). SECTION 3.5 introduces the sharing mechanisms available in the iDeas tools. SECTION 3.6 offers a detailed description of the system architecture and implementation. CHAPTER 4 describes our longitudinal evaluations of the ecology's impact on design practice.

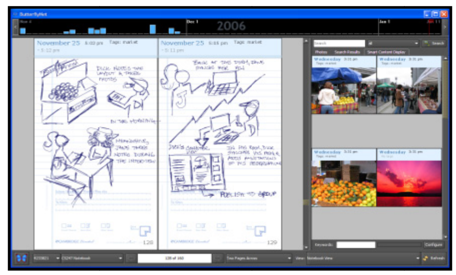
3.2 Scenario

We begin with a scenario of envisioned use for augmented design tools.

A group of designers is investigating augmented technologies for merchant farmers. For the past few weeks, they have headed into the field for need-finding sessions at the weekly local farmer's market. Toting augmented paper notebooks and digital cameras, they wander through the farmers' stalls, observing customers browsing and buying, interviewing farmers about their business practices, taking snapshots of interesting displays and interactions.

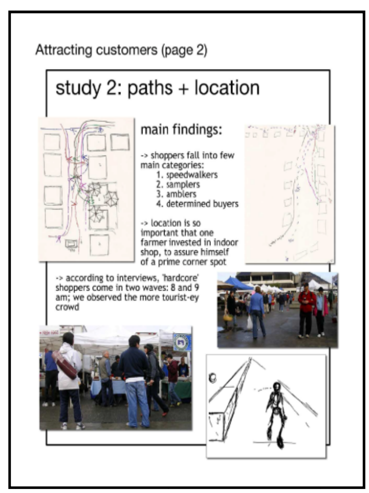


After returning from the last field observation, one of the designers, Dan, sits down at his desk and places his digital pen into a cradle. Notes from his design notebook upload to his computer. Once the synchronization is finished, his design browser opens automatically.



Dan's tasks for the afternoon are to prepare a report on results from the field observations, and to start some group brainstorms on possible augmented tools. He begins by reviewing his notes from the morning's fieldwork, tagging a few of the more interesting ideas and pictures for further iteration. His paper design notebook sits beside the keyboard; occasionally, he jots down stray thoughts and quick drawings of design ideas.

Next, Dan opens up some of his co-workers' notebooks in the digital browser to examine their publicly shared field notes. He sees a particular brilliant depiction of a tasting session in his co-worker Connie's notebook. Highlighting it with a virtual Post-It, he adds a comment ("Nice sketch!") and tags it for future reference as well.



He opens up his word processor and creates a new document titled "Fieldwork Report." As he browses the group's notes, Dan selects some salient sketches and pictures for export and pastes them into the report, to better illustrate some of the observed interactions between farmers and customers.

The last thing Dan does before heading home for the day is compose an email to the group. "I think there are opportunities for augmenting farmers' fruit stands. How could we do it?" he writes. "For instance, are there ways for us to provide auditory or olfactory feedback automatically?" He does a quick search for "fruit stand" in the digital browser, grabs a picture of a giant orange and lemon display that he had tagged earlier, and sends it off with the email.

3.3 Augmented Capture: iDeas Notebook

Designers use the Anoto digital pen system [1] to capture handwritten notebook content. (For our study deployments, we use the Nokia SU-1B [57] and Logitech io2 [45] pen models.) When used with an Anoto digital notebook (see FIGURE 3.2), the pens record a vector-graphics representation of each stroke, along with the page, date, and time. Designers can upload and view their digitized notes by synchronizing with a PC. Unlike purely digital systems such as Tablet PCs, the Anoto digital pens also act as normal ballpoint pens: should the pen digitizer fail (*e.g.*, if the pen runs out of battery power), users may continue taking notes and sketching as if they were writing with

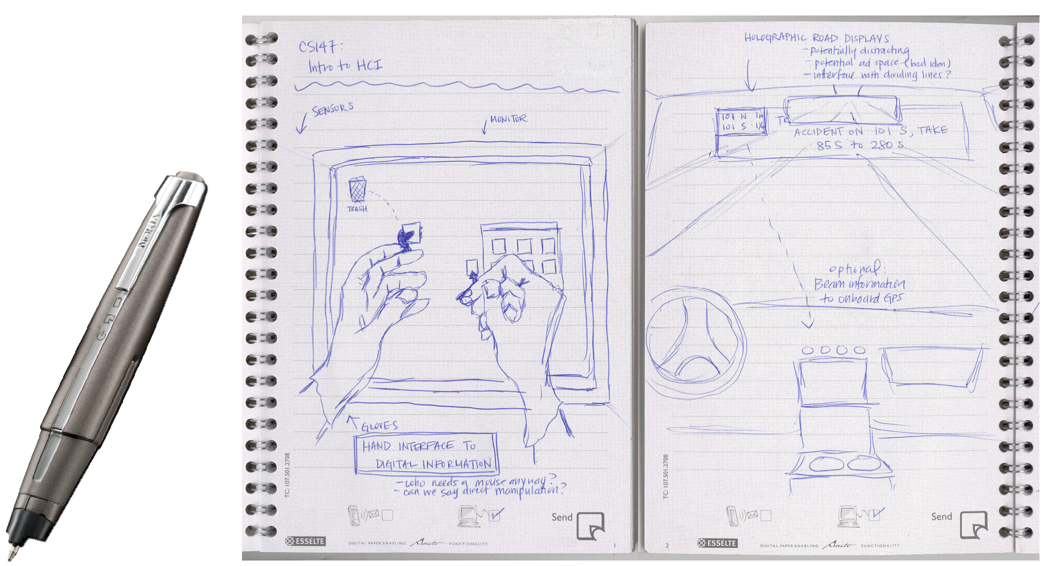


FIGURE 3.2 iDeas notebook. The Anoto digital pen and notebook are the primary input mechanisms for handwritten content.

normal pen and paper. Likewise, if the physical notebook is lost or unavailable for any reason, users may refer to the electronic version of their notes.

The iDeas system does not specify a particular interface or tool for capturing digital images; any image may be directly imported into the iDeas design tools. Designers may document fieldwork using digital cameras, take quick snapshots using camera phones, or find inspiration in material downloaded from the web. Captured content is indexed and archived, with notes held in a central design repository, and images stored online on the Flickr photo sharing service [78], which is directly integrated into iDeas. (See SECTION 3.6 for more details on system architecture.) In addition to digitally capturing the content itself, these tools capture *metadata*, such as timestamp, location, and other contextual properties not accessible from traditional physical tools.

3.4 Augmented Access: iDeas Browser

Users interact with captured content through the iDeas browser (see FIGURE 3.3), which integrates digitally captured paper notes with photographs and other media through a *faceted metadata browser*. The iDeas browser is originally based on code from ButterflyNet [80]. Content items currently in focus (digital notes by default) are displayed in the *content panel* on the left; the browser offers the ability to view more or fewer pages at a time via a drop-down menu. The *context panel* on the right automatically presents data related to the content in focus, such as content captured around the same time the focus content was created.

IDeas extends the original ButterflyNet work in three ways: time-based visualizations, content search and annotation, and group-oriented collaboration. At the top of the browser, a *timeline visualization* allows users to jump to content by date. The height of each bar represents the amount of content written on that date. Flags representing important events (*e.g.*, course milestones), indexed by date, provide links to further information while simultaneously providing a visual aid for users searching for content related to a given milestone. Individual notebook pages can also be replayed: designers can view an animation that shows how the drawings on a given page were formed, from first stroke to the last.

The digitization of design content in the ecology enables rich search via metadata annotation. Ubiquitous digital capture enables easy indexing of content by creation time, as embodied in the timeline visualization. Captured content can be highlighted using *annotations*, or virtual Post-It notes, each associated with an area of a page or image. In the iDeas system, designers may also annotate content with keywords to form a folksonomy [73] of design content. Notebook pages and photographs may be labeled with a *tag* (classification keyword) to create a set of information; these sets may then be searched or shared. Tags and annotations offer a simple yet powerful mechanism for finding, documenting, and understanding content belonging to oneself or others.

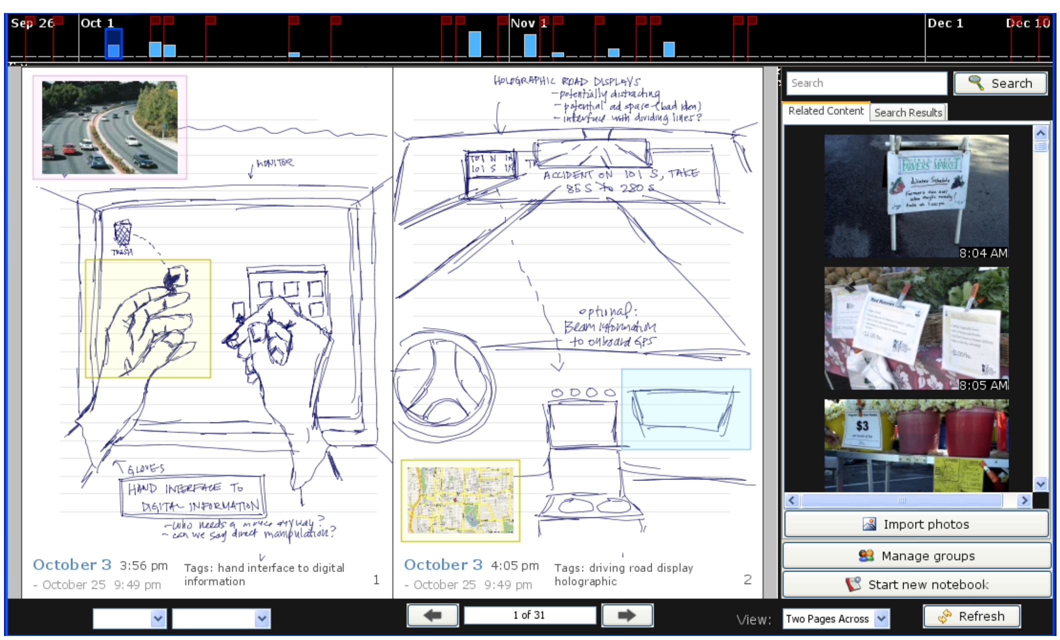


FIGURE 3.3 iDeas browser. Notebook pages and annotations are shown in the left content panel; related images are shown in the right context panel. A timeline shows the quantity of notes collected on days throughout the quarter, augmented with class milestones.

Lastly, the iDeas system offers several networked collaboration features. Users can create and join *groups* in the system. Group members have access to several additional integrated sharing mechanisms described in SECTION 3.5, including the ability to comment on and highlight one another's work by annotating interesting pages. The iDeas system also supports the concept of *staff members*, or managers; these privileged users have access to aggregate views of the entire user populace, as well as the ability to view and annotate any notebook.

3.5 Sharing Mechanisms

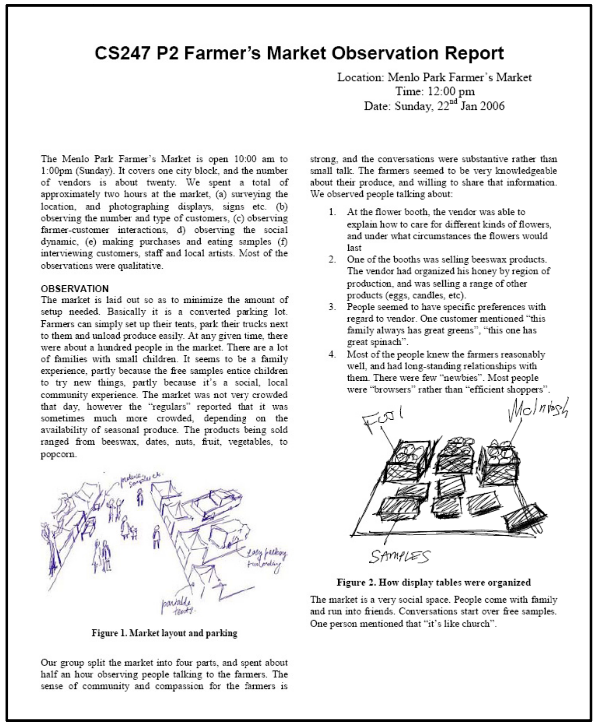
In schools, in design firms, and elsewhere in the "real world," design work is usually done in teams. Design projects feature strong interplay between times of individual ideation and reflection, and times of group presentation, discussion, and brainstorming.

Our observations of designers have suggested two potentially fruitful directions for research into collaboration: group practice and reflective activity. While personal practices are well-supported by traditional technologies, the physical/digital divide is more problematic for group activity, which is often conducted remotely. The realities of work practices and space limitations imply that design teams often work in personal spaces and collaborate both remotely and asynchronously, even if they come together regularly for team meetings. Reflection suffers from a similar media break: while reflective artifacts such as project reports and portfolios are usually composed electronically, early content in the design process is often created on paper.

The augmented paper and digital tools of the iDeas ensemble are well-suited to filling both of these needs. In response to these issues, we have implemented three sharing mechanisms in the iDeas browser: *export of snapshots* of notebook pages as graphics to other programs; *direct view* of fellow designers' notebooks; and *group notebooks*, shared digital repositories for group project data.

3.5.1 *Export features*

The most basic sharing mechanism in the iDeas system is the ability to export captured data into other productivity applications, such as email clients and word processors (see FIGURE 3.4). The iDeas browser allows copy and paste of entire notebook pages or selected excerpts via the system clipboard. This allows designers to complete common tasks such as pasting sketches into documents or sharing their design content without the burden of scanning. Images are pasted as vector format if supported by the target application, or bitmap (JPEG/PNG) otherwise.



CS247 P2 Farmer's Market Observation Report

Location: Menlo Park Farmer's Market
Time: 12:00 pm
Date: Sunday, 22nd Jan 2006

The Menlo Park Farmer's Market is open 10:00 am to 1:00pm (Sunday). It covers one city block, and the number of vendors is about twenty. We spent a total of approximately two hours at the market, (a) surveying the location, and photographing displays, signs etc. (b) observing the number and type of customers, (c) observing farmer-customer interactions, d) observing the social dynamic, (e) making purchases and eating samples (f) interviewing customers, staff and local artists. Most of the observations were qualitative.

OBSERVATION
The market is laid out so as to minimize the amount of setup needed. Basically it is a converted parking lot. Farmers can simply set up their tents, park their trucks next to them and unload produce easily. At any given time, there were about a hundred people in the market. There are a lot of families with small children. It seems to be a family experience, partly because the free samples entice children to try new things, partly because it's a social, local community experience. The market was not very crowded that day, however the "regulars" reported that it was sometimes much more crowded, depending on the availability of seasonal produce. The products being sold ranged from beeswax, dates, nuts, fruit, vegetables, to popcorn.

Figure 1. Market layout and parking

Our group split the market into four parts, and spent about half an hour observing people talking to the farmers. The sense of community and compassion for the farmers is strong, and the conversations were substantive rather than small talk. The farmers seemed to be very knowledgeable about their produce, and willing to share that information. We observed people talking about:

1. At the flower booth, the vendor was able to explain how to care for different kinds of flowers, and under what circumstances the flowers would last
2. One of the booths was selling beeswax products. The vendor had organized his honey by region of production, and was selling a range of other products (eggs, candles, etc).
3. People seemed to have specific preferences with regard to vendor. One customer mentioned "this family always has great greens", "this one has great spinach".
4. Most of the people knew the farmers reasonably well, and had long-standing relationships with them. There were few "newbies". Most people were "browsers" rather than "efficient shoppers".

Figure 2. How display tables were organized

The market is a very social space. People come with family and run into friends. Conversations start over free samples. One person mentioned that "it's like church".

FIGURE 3.4 Observation report produced in Microsoft Word, using notebook material excerpted from the iDeas browser.

Notebook images may also be exported as PNG images directly to Flickr, or output to PDF files for archiving.

3.5.2 *Direct notebook view*

Augmented paper and digital tools also enable methods of sharing not feasible or possible in current practice. In the iDeas system, members of a group can directly view the contents of each other's notebooks using the iDeas browser. Users select another group member and notebook using drop-down boxes in the browser interface. Group members can comment on and highlight one another's work by using the tag and annotation features, and search across group members' notebooks and photos in the same fashion they search their own content.

3.5.3 *Group notebooks*

When collaborating, designers often need a place to put group content. Today, design teams use a variety of systems to create a group-accessible space, such as group Gmail accounts, networked file systems, and shared blogs. Other teams elect to maintain separate data stores; group members then email requested resources to the larger group as needed. Although all of these get the job done, none of these ad hoc solutions is completely satisfactory. We believe that augmented physical and digital tools open up new possibilities for providing a shared storage space and persistent common ground for design collaborations.

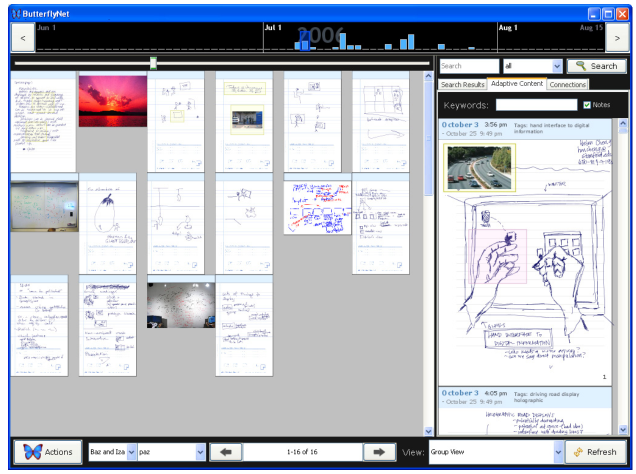


FIGURE 3.5 Group notebook. Designers explicitly select and contribute material to this shared set of content, which can be viewed and searched in the iDeas browser.

As one method for addressing this need, the iDeas tools offer a *group notebook*, which provides persistent content sharing among team members (see FIGURE 3.5). Conceptually, a group notebook is a shared digital repository for design content, similar to text-based blogs but incorporating sketches and other digital media. Formally, a group notebook is a set of shared design content, explicitly selected for and contributed to the set by members of the group. Designers can place content from their personal notebooks, digital photographs, or any other sources (*e.g.*, links, text, documents) into the shared space. Users paste content into the group notebook by digitally selecting it in the iDeas browser. Later, group members may review the contents of the group notebook through the browser. The digital nature of the notebook allows users to view content in a variety of ways: sorting or filtering by date, by contributor, by tags, *etc.* Users may also create custom orderings of shared content to suit their own perspectives or mental models.

By offering multiple views of key group data, group notebooks support both formal and informal presentations of content. Group notebooks can be used to share design content with group members and project managers, to preserve important data for later retrieval, and to produce rich yet lightweight documentation of team activities. This documentation, in turn, can facilitate the creation of status updates, project reports, and portfolios by highlighting vital content gathered over the course of a collaboration.

3.6 Current Implementation

In developing the iDeas ecology, we were faced with the challenge of constructing a system robust enough to support real-world use: informed by the ecology approach described in SECTION 2.2.2, we wanted to study how augmented tools actually change designers' practices. At the same time, the ecology tools had to be advanced enough—and thus, complex enough—to support the existing and novel practices that this dissertation sought to study.

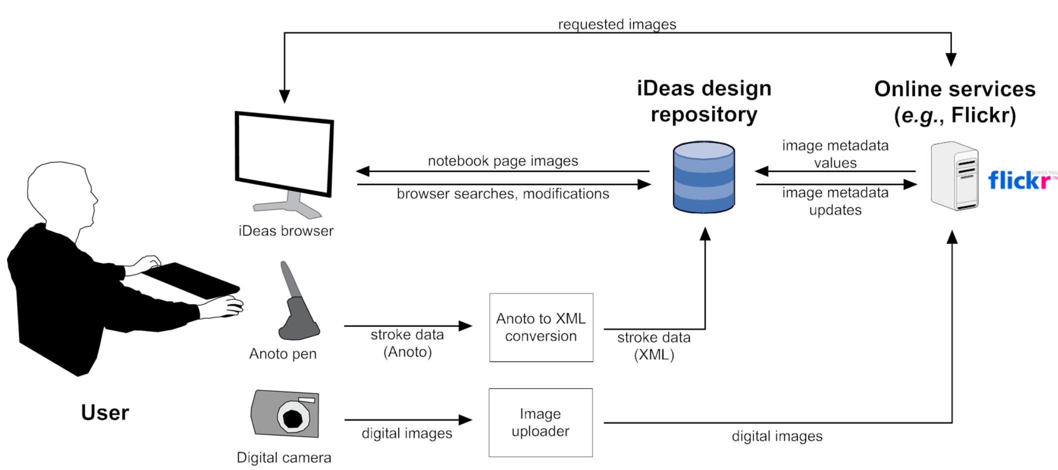


FIGURE 3.6 Architecture of the iDeas design ecology.

We leverage several *off-the-shelf components* to provide stable implementations of desired functionality (see FIGURE 3.6). The Anoto digital pen system [1] provides augmented paper services, including pen hardware, digital notebooks, and Windows synchronization software; the iDeas system uses C# and the Anoto SDK to download and convert proprietary stroke data into easily understood XML. Digital images are uploaded to the online photo sharing service Flickr [78] through a free upload client.

Our research software integrates these components into a unified capture and access system, using a client-server architecture. To provide networked collaboration features, we use Subversion [12] as a distributed file system. The *iDeas design repository* is a Subversion server accessed over secure HTTP. Content state is shared among distributed clients through updates of files on the Subversion server. All files are locally cached, with edits and changes committed back to the Subversion server immediately; a client updates its cache when the iDeas browser is first opened and refreshes its cache later upon user request. Pen data in XML format, tags and annotations of notebook pages, group notebook contents, and group member information are stored in the repository.

Support for digital image storage and metadata is fully provided by Flickr. The iDeas software uses the Flickr API to read and/or modify image contents, tags, and other metadata.

The iDeas browser and its various extensions, including group notebooks, have been primarily implemented in Java using the Java SE 6 API, leveraging an HSQLDB embedded database for efficient access to content metadata. An Apache web server and HTML/Java GUI interfaces provide group management functionality. Users authenticate by entering a login name and password when opening the iDeas browser, allowing the system to pre-fetch data from other group members.

From the end user's perspective, the iDeas browser provides single-point browsing and sharing of personal and group design content, transparently connecting the various services together to provide a seamless augmented access experience.

3.7 Summary

This chapter presented the iDeas design ecology, which provides an augmented paper and digital tool ensemble for design practice. The ecology includes two broad classes of artifacts: the iDeas notebook, Anoto digital pen, which automatically records handwriting data; and the iDeas browser, which integrates digital notes, photographs, and other media into a faceted metadata browser. The iDeas browser offers three mechanisms for sharing: direct view of fellow designers' notebooks; export of snapshots of notebook pages as graphics to other programs; and group notebooks, shared virtual repositories for group project data.

The iDeas system was constructed to be both robust enough to support actual use by designers over a period of months and powerful enough to support the existing and novel practices that we sought to study. It leverages off-the-shelf components to provide stable implementations of desired functionality. Our research software integrates these components into a unified system which supports designers' current practices while simultaneously enabling digital annotation, search, and sharing of generated design content.

We have validated our design through several *longitudinal studies* spanning multiple months. Results from these studies are described in CHAPTER 4.

4 iDeas Design Ecology Evaluation

We conducted four ten-week-long deployments of the ecology to students enrolled in design classes at Stanford University. In these studies, we collected data through five primary methods: *observations* and videotapes of class lectures, discussion sections, group meetings, and field trips; *interaction logs* of activities within the iDeas tools and some electronic exchanges across groups; *pre- and post-experience questionnaires* given to all participants, with follow-up *interviews* of students that extensively used the iDeas system; and *content analysis* of participants' design notebooks, project coursework, and performance metrics.

Analyses found that the lightweight import and export of content offered by the iDeas system appeared to encourage richer documentation and collaboration practice, by supporting fluid incorporation of paper content into digital workflows. There were, however, significant barriers to adoption in our research instantiation, including pen ergonomics and maintenance, and shortcomings in the design of other sharing mechanisms, which were used sparingly. We note that careful consideration and presentation of perceived costs and benefits is important when introducing features not already part of current practice, and suggest that fitting into existing practices, both physical and digital, is essential to the success of augmented systems.

Portions of this chapter were originally published by Heidy Maldonado, the author, Scott R. Klemmer, and Roy Pea in [51], and by the author, Heidy Maldonado, Isabelle Kim, Paz Hilfinger-Pardo, and Scott R. Klemmer in [41].

4.1 Introduction

To date, the literature has lacked an ecologically valid understanding of the design of augmented paper systems and their effects on practice. Achieving ecological validity in CSCW and ubiquitous computing is generally difficult [11]: with a few notable exceptions (*e.g.*, [6, 61]), there has been a dearth of longitudinal evaluation. From a methodological perspective, longitudinal use is the missing piece of the puzzle: *how does integrating physical and digital interactions change users' practices, and what implications does this have for the design of augmented paper systems?*

We chose to study student designers for two reasons. First, it was more practical to conduct evaluations in local design classes than to secure permission for long-term deployment in a professional design firm or other external environment. Second, we were also interested in how the ecology tools might support and augment design learning education. The studies presented in this chapter were carried out jointly with Heidy Maldonado, a Ph.D. candidate in the School of Education studying the effects of technology on learning processes. (For details on some of the learning and educational impacts of augmented tools, please see [51].)

4.2 Method

We primarily deployed the iDeas design ecology in two Human-Computer Interaction (HCI) courses at Stanford University: CS147, Introduction to Human-Computer Interaction Design [76]; and CS247, Interaction Design Studio [39]. Student participants in CS147 were from generally diverse academic backgrounds, while CS247 participants had predominantly Engineering backgrounds. Between September 2005 and March 2007, we evaluated use of the iDeas system with more than 100 student designers in studies covering four ten-week academic quarters:

- In Fall of 2005, one discussion section of CS147 was randomly selected to participate in a study of the iDeas ecology. All 18 students in the section consented to participate.
- In Spring of 2006, all of the students enrolled in CS247 were asked to participate in a second evaluation of the iDeas ecology. Of these, 38 (10 female, 28 male) consented to use the technology, while ten did not; eight of the latter students participated in surveys but did not use the iDeas tools.
- In Fall of 2006, students enrolled in one discussion section of CS147 were asked to participate in a study of the iDeas ecology; five students consented. Also during this quarter, two student teams comprising eight students in ME310 (Design Entrepreneurship) [42] consented to use the iDeas system in a parallel study.
- In Winter of 2007, all of the students enrolled in CS247 were asked to participate in a evaluation of the iDeas ecology. Of these, 38 students consented.

Study participants were provided with Anoto digital pens and notebooks, as well as the iDeas browser and related software. As part of the evolution of the iDeas tools, we evaluated and deployed different commercially available Anoto notebooks. Early study participants received A5 (148mm×210mm) or 5" × 8" notebooks, which provided a portable form factor but had thin plastic covers, which were not well-liked. Later study participants received 11-3/4" × 8-1/4" casebound notebooks, which were larger but provided a better, harder writing surface. Similarly, we took an iterative approach to the design of the iDeas browser: results from earlier studies informed the redesign and revision of ecology tools subsequently deployed.

We attempted to minimize extra factors that may have affected usage data wherever possible. While participants' design notebooks were graded for these courses, no explicit remuneration—whether monetary or in terms of grades—was given to encourage the use of the iDeas system. The authors were not involved with grading at any time, and students were free to use the technology as much or as little as they desired. Electronic versions of a student's notebook were not used to grade the student's work unless the students specifically requested it from the course teaching assistants.

4.2.1 Data collection

Data was collected through five primary methods. First, we *observed* students in class lectures, discussion sections, group meetings, and out in the field (see FIGURE 4.1). We also videotaped meeting sessions to document some of the interplay between personal tools, such as notebooks and laptops, and collaborative tools, such as whiteboards.

FIGURE 4.1 Observations of student design teams: in class, discussion sections, group meetings (using different tools), on class field trips.

In order to measure how often various sharing mechanisms were used by participants, we instrumented the iDeas browser to *log interactions*. Every action taken in the iDeas browser (*e.g.*, opening a notebook, making an annotation, copying an item for export) was logged to a file which was then synchronized to the research server. This allowed us to track how often the digital browser was used, and which augmented tool functions were most and least used.

All study participants received pre- and post-experience *questionnaires*. Survey questions asked about technological proficiency, assessment of the iDeas tools, prior group work experiences, and experience in maintaining logbooks, including design notebooks, blogs, and journals. Questions drawn from earlier studies' findings about collaboration, feelings of belonging to a group, interpersonal closeness, friendships among teammates, satisfaction with project outcomes, group interactions, and other behaviors of interest were included as well. (See APPENDIX A for a sample questionnaire from the study.)

At the conclusion of each study, we *interviewed* selected study participants to obtain a deeper understanding of how designers used the iDeas tools, as well as how the augmented tools affected their work practices from a user perspective.

Finally, we *analyzed design content* captured over the course of a study. In addition to the digital notebook pages, digital photographs, and associated metadata captured by the iDeas system, we also had access to students' physical design notebooks, course assignment submissions, and performance evaluations. Over the four studies, the iDeas system digitally captured more than 6,500 pages of design notebook content; in the same period, students and staff members contributed more than 1,500 tagged digital images to Flickr.

4.3 Results

This section presents results from our studies. SECTION 4.3.1 begins by summarizing how early users perceived the value of augmented physical and digital tools. Subsequent sections detail high-level findings across all four studies. SECTION 4.3.2 notes the power of exporting design content to other tools. SECTION 4.3.3 discusses the importance of fitting into current digital practices. SECTION 4.3.4 presents observations on how physical and digital media coexist in design practice. SECTION 4.3.5 details our measurements of participants' tool adoption patterns. SECTION 4.3.6 concludes with shortcomings of the research software and hardware.

4.3.1 Value proposition of augmented tools

Participants in the first study rated the iDeas system as significantly useful, easy to understand, and easy to learn (median 4, 5-point Likert scale). For exporting and sharing design content, these students preferred using the augmented paper tools to traditional means such as copiers and scanners (median 6, 7-point scale).

Student designers also resonated with the broad value proposition of digital tools, responding in questionnaires that, "I like the idea of having a digital copy of my notes, and the ability to annotate them," that "It was easy to import and export images, from and into other programs," and that "I like the idea of seeing/copying/sending notes. Tagging, importing pics, *etc.* is also great." Other participants responded that they found value in "the ability to import pictures to view with notes" and "sharing data across remote locations."

We interviewed prolific users of iDeas, who repeatedly mentioned the significance of being able to quickly share information among teammates. The perceived benefit was twofold: the ease of sharing visual ideas electronically outside of face-to-face situations; and the lessened need to document the same materials as teammates, particularly during meetings. Course staff also found the server-stored digital capture of notebooks useful, as staff members could peruse student content and provide feedback without taking design notebooks away from students.

Some participants in the early studies requested more direct integration of sharing into iDeas (as the concept of groups did not exist in early deployments of the iDeas ecology). In response, we developed the group-oriented sharing mechanisms described in § 3.5.2 and § 3.5.3.

4.3.2 Export to broader ecology of tools

The iDeas design ecology lowers barriers to excerpting content from notebooks into other productivity tools relative to current practice, encouraging sharing and reuse in documents and messages.

Participants in all four studies cited the ability to quickly find and insert excerpts from paper notebooks into digital documents and communications as a standout feature. As expected, the augmented paper technology made the process of digitally capturing handwriting more fluid than traditional tools (scanners). We observed that the iDeas browser's search and annotation features made it easier to locate and flag relevant materials, and digital export enabled migration of visual content to the larger ecology of productivity tools, such as email clients and word processors.

Though we did not have direct comparisons to prior editions of the courses, two data points suggest sharing and reuse increased as a result of the iDeas ecology. The first was self-reported use of browsing, copying, and pasting mechanisms. This was corroborated by our observations and logs of browser activity, which indicated that search and export were easily the most popular features, used regularly by those that adopted the iDeas technologies.

The second source of evidence was students' course assignments. While inserting digital images into project reports was common practice before the iDeas tools were introduced, during the studies, several design teams inserted sketches and diagrams from their notebooks into reports as samples of their ideation, a behavior that, in our experiences as past instructors and teaching assistants, was not prevalent in previous offerings of the courses (see FIGURE 4.2). In later studies, participants also used the iDeas tools to create electronic portfolios [8], another common reflective practice in design.

4.3.3 *Fitting into existing digital practices*

Typically, designers keep their images either in personal hard drives or on photo sharing web sites such as Flickr [78]. Early versions of iDeas required users to import photos into the iDeas design repository (§ 3.6), meaning that users had the additional burden of maintaining two or more distinct image repositories. In response, we redesigned the system architecture to integrate Flickr directly into the iDeas system. Digital images are stored on the Flickr servers; images and metadata are accessed through the Flickr API and displayed in the iDeas browser.

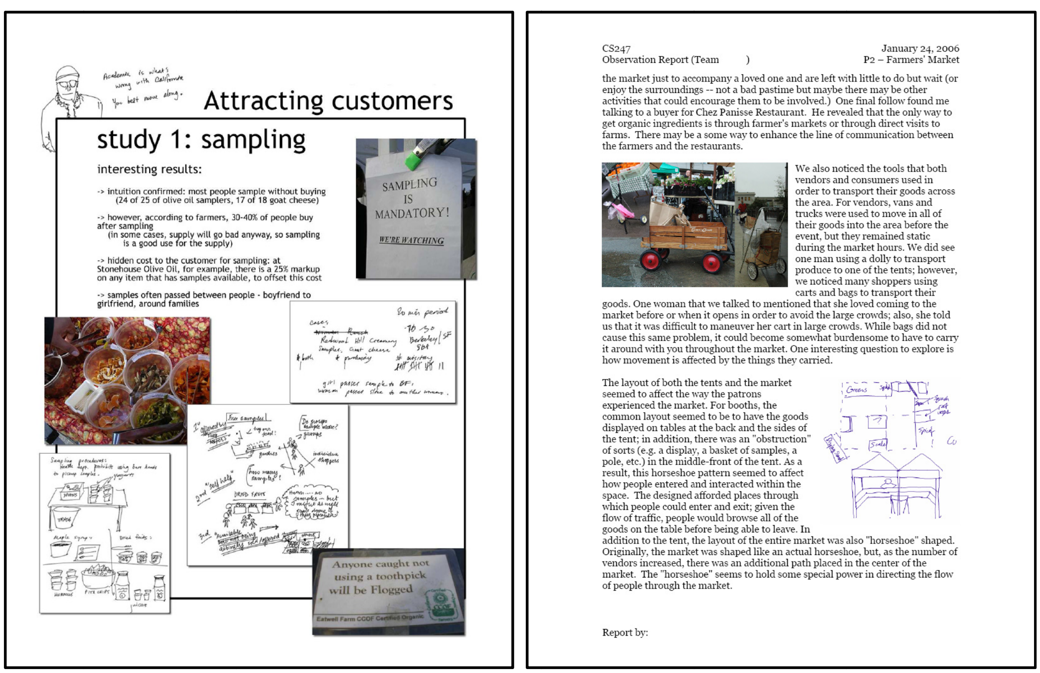


FIGURE 4.2 Sample course submissions from the design class studied in Winter of 2006. Inserting hand-drawn diagrams and sketches as samples of ideation and documentation was not common practice in previous editions of the course.

We believe this reflects a broader principle: augmented tools should be designed to *fit into existing digital practices* as well as physical practices where practical [16, 37]. The fluid transition of physical content into electronic form opens new possibilities for integration into digital toolsets. Where an off-the-shelf solution exists and offers services which users already find usable and valuable, it may be advantageous to use it directly, as duplicating existing functionality can actually detract from the user experience. More generally, there exists a tradeoff space between the utility and flexibility harnessed by leveraging existing tools and practices, and the potential benefits gained by introducing new tools and practices. In the case of image storage, an off-the-shelf service (Flickr) had been previously adopted by many users and provided all of the envisioned functionality, meaning that there was no reason not to augment users' current digital practices.

4.3.4 Coexistence of paper and digital

Pasting inspirational images or relevant materials into design notebooks is common practice for designers (see FIGURE 4.3). The use of Anoto technology in the iDeas system implies that content written with traditional pens or physically pasted into the notebook does not transfer into the digital domain. Similarly, digital annotations and photos linked to the digital pages are not made available in the physical notebook.

Analysis of the notebooks from studied courses found cases of asymmetry, where students pasted in *different* images to their digital and physical notebooks, creating two slightly distinct versions: one with digital "extras" and the other with physical extras. This asymmetry in storage was also found in between digital repositories, with images pasted directly into the digital versions on notebooks and other images stored as tagged photographs on Flickr.

The coexistence of asymmetric representations, with physical materials pasted into the physical notebook while digital references are inserted into the virtual, points towards another question: which, if any, is the “real” notebook? We expect that both the physical and digital representations will continue to serve *complementary* roles in design. In our studies, students appeared to maintain multiple distinct repositories of design content, moving media between them as the need arose. Augmented tools such as those found in the iDeas design ecology lower the threshold for these transitions, thereby encouraging more mixing of media from different sources.

4.3.5 Adoption measures

The augmented capture tools in the iDeas ecology have significant value as an instrument for studying students’ design practices, allowing us to gather extensive data on design activity and tool usage. FIGURE 4.4 shows usage patterns from the Winter 2006 study using server-logged timestamp data. Sparklines show the number of pages

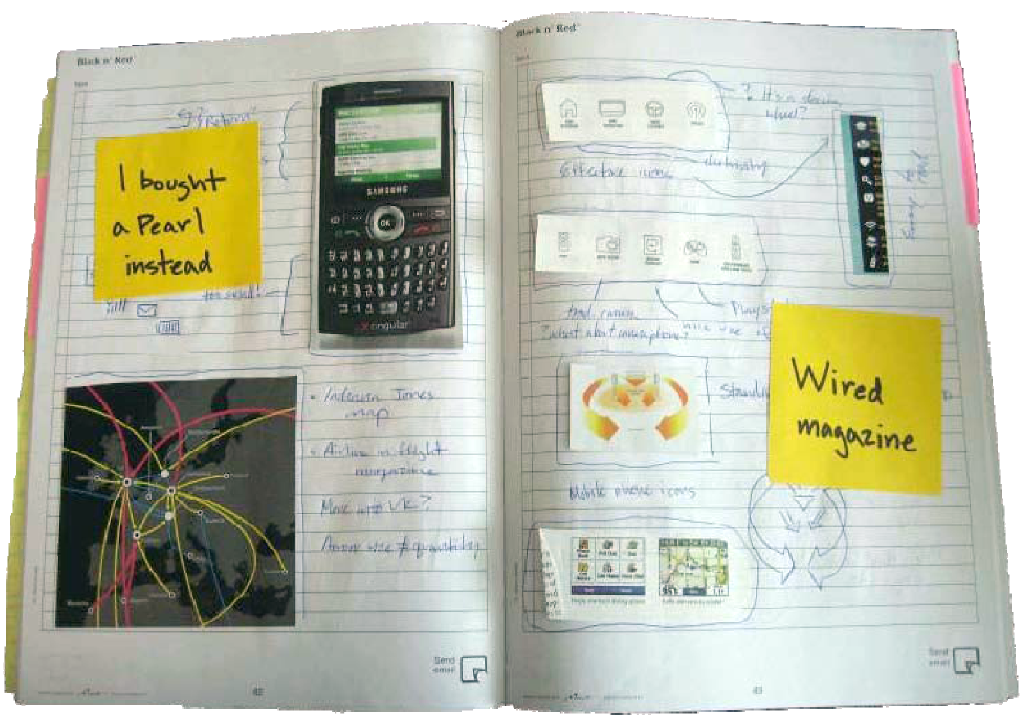


FIGURE 4.3 An Anoto digital notebook annotated with physical media. Though augmented tools offer an additional bridge between the physical and digital realms, physical and digital media still coexist in ad hoc fashions throughout the practice of design.

each of these 38 students wrote daily with the Anoto pens. Students varied greatly in the frequency and amount of content created, falling broadly into three categories: those that quickly adopted and used the technology *continuously* throughout the study (11 students); those who used the system during early projects which focused on *ideation*, but mostly abandoned it later when programming demands took over (15 students); and those that only gave the technology an *early try* (12 students).

Interviews indicated that the usage falloff for the second group in FIGURE 4.4 occurred partially because the notebooks and pens were more relevant for the ideation and iteration that characterize the early parts of the course; later weeks focused on implementation and evaluation tasks, where note-taking was not seen as

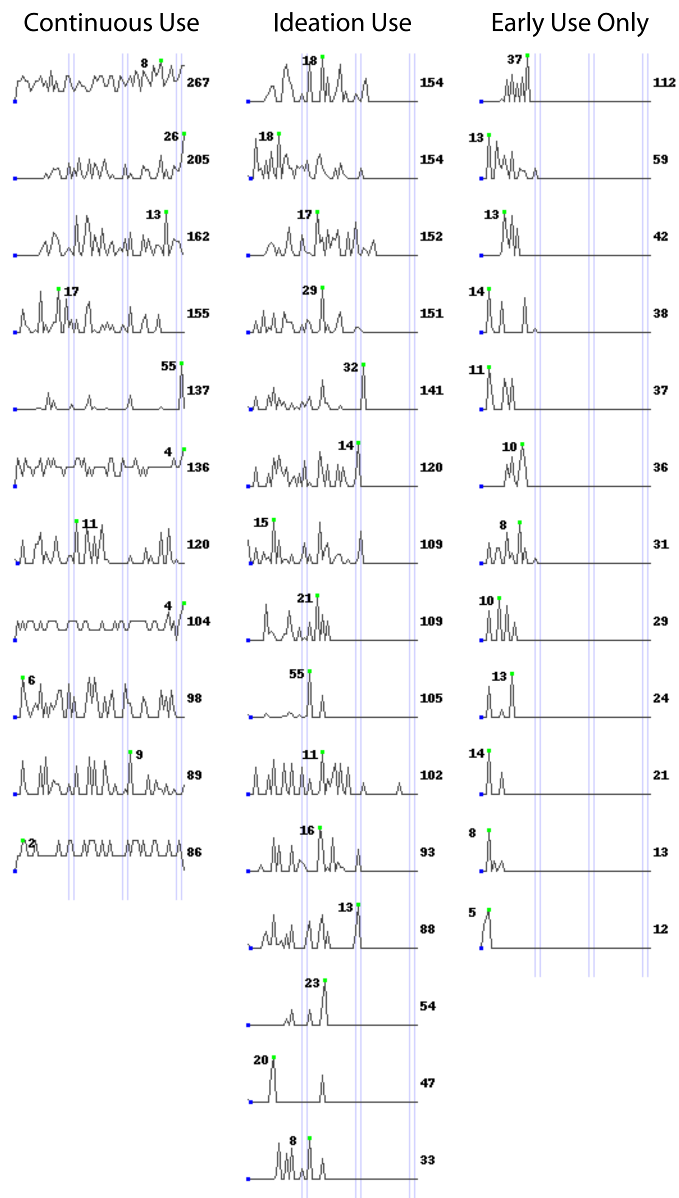


FIGURE 4.4 Sparkline graphs showing the number of pages each student completed each day during the Winter 2006 study, with the total number of pages filled throughout the quarter displayed at right. Visualization by Heidy Maldonado. Reprinted from [51].

important. However, many users used the iDeas tool for the duration of the study, while still others did not use the system much at all. In subsequent analyses, we sought to understand other reasons why users did or did not adopt the iDeas technologies.

4.3.6 Adoption challenges

The studies identified two adoption challenges for the iDeas system. The first was the augmented paper hardware and software: many participants noted the poor *ergonomics* of the digital pen as the primary reason for their lack of continued use. The Anoto digital pens were variously described as big, clunky, and awkward, discouraging users from carrying them. Users cited *battery life* as an issue; having to remember to charge the pens every day was a maintenance cost for participants. The *physical notebooks*, of lower quality than many typical design notebooks, drew some complaints, and interviews with students and teaching staff suggest that the lined Anoto paper discouraged freeform content in favor of textual content. Finally, several users cited difficulties with *software installation*. In the study implementation, users were forced to install pen service components from several manufacturers in addition to the iDeas browser software, resulting in a complicated package with several potential points of failure.

The second challenge concerned *sharing and permissions* of captured content. We found that two of the explicit sharing models introduced into the iDeas system, though providing value to designers, had significant perceived shortcomings regarding access control for captured content.

Direct notebook viewing (§ 3.5.2) erred on the side of *inclusivity*: content was automatically visible to any group member. This feature, first introduced in the Winter 2006 study, pleased some teams with its ease of sharing group-oriented notes. Other participants were uncomfortable with the possibility of private writings being revealed to other group members, even in close-knit groups; the iDeas system provided no way for users to keep certain content from being shared. In retrospect, this is not surprising—physical notebooks of all sorts are generally perceived as personal artifacts, with corresponding social protocols governing when it is permissible to "peek" at someone else's notebook.

Group notebooks (§ 3.5.3), introduced for the Winter 2007 study, erred instead on the side of *exclusivity*: content had to be explicitly contributed to the group space. However, we observed that the extra overhead of going back and explicitly adding items at a later date deterred most participants from using this unfamiliar feature. Also, the granularity of contributions—users could only add entire pages or images—may not have matched users' needs as well as did the export features, which allowed designers to highlight specific portions of a page for copying and pasting.

We believe that these findings highlight an important design distinction for sharing in ubiquitous computing systems, particularly those which integrate physical and digital activities. Tacit social protocols govern the sharing of physical artifacts. In traditional computer systems, rigid location and permissions formalisms define which files are accessible by whom. Information appliances, on the other hand, generally lack "directories" or formal storage structures. Offering users access controls can address this issue, yet explicit controls have their own drawback: they often go unused in ubiquitous computing situations, meaning that settings are left at defaults indefinitely, which may not be desirable from a social or work practice perspective.

4.3.7 Study limitations

While long-term deployments to design practitioners offers a richness of data unavailable from traditional laboratory studies, there are several limitations to the particular methods we adopted. One notable caveat is that the dissertation author's advisor was one of the instructors for CS247 in both studies of that course, which may have artificially inflated rates of adoption. Where possible, we tried to minimize undue influences, as described in SECTION 4.2. Another caveat is that we chose to study design students, many of whom were learning how to be designers during the study. Student designers' practices may differ significantly from those of more experienced design practitioners, limiting how our results might generalize to other situations and domains. SECTION 7.3 presents a discussion of the overall limitations of our approach and how the specifics of our study methodologies may have influenced results.

4.4 Design Implications

The adoption challenges described above, while not intrinsic to the technological approach, point to a key concern for longitudinal deployments of ubiquitous computing tools such as iDeas: *technologies are only adopted to the extent that the perceived benefits outweigh perceived and actual adoption costs*.

Neither digital excerpting nor sharing were impossible before the iDeas system—tools for importing physical content into the digital realm already existed in the form of scanners and other devices—yet we observed these behaviors more frequently with augmented tools. We therefore believe that the success of these features is due in no small part to the fact that the benefits of easy content search and export into other programs, such as email and word processors, are already well-understood among designers today. These finding support our hypothesis that augmented paper and digital tools can decrease the effort needed to share and annotate design content (H1; see § 1.1), which in turn can ease the task of accessing interesting content (H2) as a result of searchable metadata and increased sharing.

However, the other two explicit sharing mechanisms introduced in iDeas were not as successful. Anecdotally, we found that group notebooks were not successful due to the perceived costs of explicitly adding items to an unfamiliar tool, while even the simple viewing of other group members' notebooks introduced perceived drawbacks for some users with regards to privacy and permissions. We found it encouraging that designers who bought into the value propositions went ahead and used the iDeas tools anyway. Nevertheless, we suggest that future instantiations of augmented tools should carefully consider these issues, striving to illustrate the *benefits* of novel features (possibly by analogy with, or direct improvements to, current tools and practices) while minimizing the *costs* of adopting them.

Lastly, problems with pen ergonomics and maintenance requirements made the overall system less appealing to some study participants, even though those issues were irrelevant to the research topics we sought to study. Though it seems likely that future versions of augmented paper technology will overcome the limitations of early instantiations, such issues must be taken seriously for development and longitudinal deployment of current technology hybrids. Consider, by analogy, the challenges of conducting a longitudinal study with the brick-sized smartphones circa 1999—while mobile email and other applications have since demonstrated their value, before the technology matured, this finding was confounded by ergonomic and technical limitations of early systems. The difficulties in longitudinal evaluation of emerging ubiquitous computing platforms remains an issue for continued investigation [11].

4.5 Summary

This chapter presented results from four ten-week-long deployments of the iDeas design ecology to students enrolled in design classes at Stanford University. Data was collected through observations of designers, interaction logs of activities within the tools, pre- and post-experience questionnaires, interviews of students that extensively used the iDeas system; and content analysis of design notebooks and associated coursework.

Broadly, we found that the lightweight import and export of content offered by the iDeas ecology appeared to encourage richer documentation and collaboration by enabling digital behaviors such as search, annotation, and sharing. There were also significant barriers to adoption, however. In particular, explicit sharing mechanisms offered by the ecology were found to have significant perceived costs, and newly introduced sharing features not closely linked to current practice were used sparingly by many participants. The findings from these studies motivated us to investigate the use of *implicit* mechanisms to improve visibility of design resources, as discussed in CHAPTER 5.

5 Adaptive Interfaces for Supporting Design by Example

The second half of this dissertation examines how digital design tools can support the design-by-example paradigm through *proactive presentation and facet-based browsing of example design artifacts*. Motivated in part by our studies of the iDeas tools, we explore the use of implicit mechanisms to improve visibility of example designs while reducing need for explicit user action. We describe an optimization-based approach to selecting, presenting, and browsing design material adaptively. The core of our approach is a facet-centered subset selection algorithm, which chooses examples to display so as to "maximize" estimated design value. This approach defines two criteria of interest to example presentation: similarity and variety. Interfaces are generated automatically by assigning utility values to visual elements and finding an optimal layout. The approach is manifested in the *Adaptive Ideas web page builder*, an HTML-based interface that seeks to assist web page designers by displaying examples of existing web pages and allowing designers to copy desired elements. Example web pages are automatically displayed next to a WYSIWYG web page editor; users may search for examples similar to a given example, or request a variety of elements for a given design attribute. Results from a first-use study of the example-augmented builder are discussed in CHAPTER 6.

Portions of this chapter were originally published by the author, Scott R. Klemmer, Savil Srivastava, and Ronen Brafman in [40].

5.1 Introduction

Analogy plays an important role in reasoning and problem solving [26] (§ 2.2.1). One illustration of analogical cognition can be found in the use and reuse of examples: viewing examples of previous work is an established technique for inspiration and learning in many design disciplines. While research has looked at example reuse in other domains, such as programming [28], the task of finding related or inspiring example designs is not directly supported in most current design tools (*e.g.*, FIGURE 5.1, left). Instead, designers have to explicitly search for example material using general-purpose tools such as search engines, which have no semantic understanding of dimensions that the designer might find interesting.

We propose a novel approach to supporting the design-by-example model through *proactive presentation and facet-based browsing of examples* in design tools (see FIGURE 5.1, right). The design of such a system raises several issues: How does the system choose what examples to show? How does one browse the chosen examples? How are examples

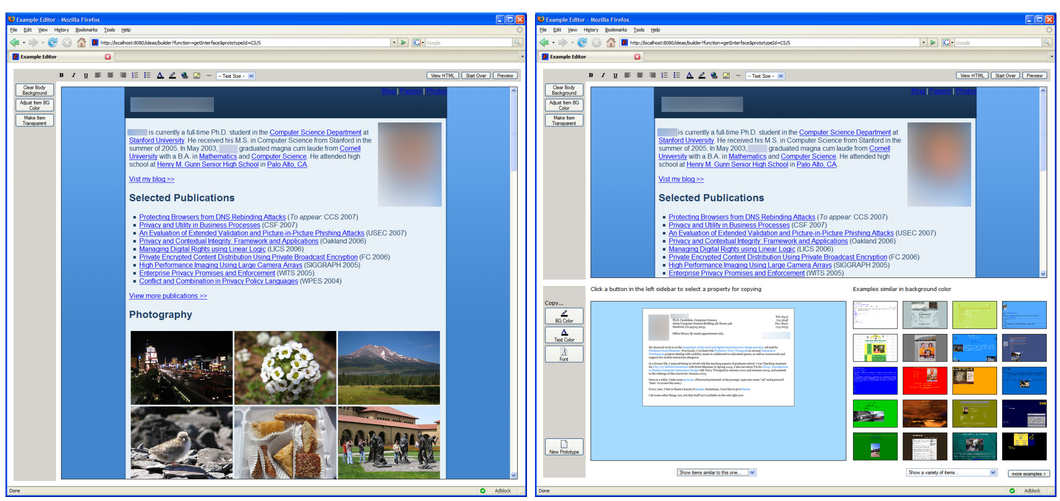


FIGURE 5.1 Web page editing with example augmentation. *Left:* Screenshot of a basic WYSIWYG web page builder, with controls solely focused on the task of web page editing. *Right:* Screenshot of an example-augmented web page building interface. The traditional web page editor occupies the top half of the screen, while example designs are automatically displayed along the bottom half.

provided to the system in the first place? How does one copy and/or modify features of existing examples in order to integrate them into one's own work?

Our research focuses on the first two questions: how to find, present, and browse interesting sets of examples in ways which are felicitous with design practice. In addition to developing methods for choosing interesting examples, we also examine how to manage the dynamics of the user's attentional focus [12], as the proactive display of information introduces additional potential for distraction and error.

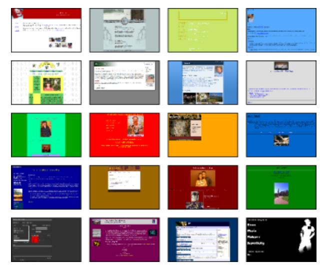
This dissertation contributes decision-theoretic techniques for dynamically selecting example design materials and generating example-augmented interfaces. Our original vision was to use this approach to produce *awareness displays*, drawing content from the iDeas system to proactively present relevant or inspirational examples of design sketches and other media. To ground these techniques in a more concrete design task, we created the *Adaptive Ideas web page builder*, an HTML-based system which leverages content metadata to automatically generate example-augmented displays relevant to the task of web page design. The dataset in the Adaptive Ideas web page builder prototype is drawn from real homepages posted on the World Wide Web.

The remainder of this chapter is organized as follows. SECTION 5.2 presents a scenario detailing how a user might design a web page with an example-augmented interface. SECTION 5.3 introduces basic concepts and algorithms for example selection. SECTION 5.4 introduces basic concepts for automatic interface layout, while SECTION 5.5 describes how layouts are calculated. SECTION 5.6 offers a detailed description of our current implementation. CHAPTER 6 describes our evaluation of Adaptive Ideas in the context of web page design.

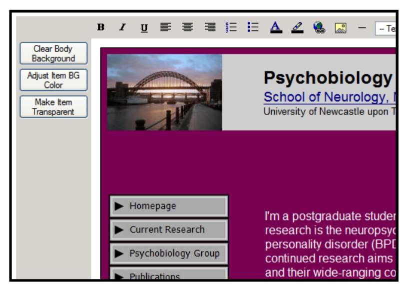
5.2 Scenario

We illustrate the envisioned use of the Adaptive Ideas approach with an example scenario: building a web page.

Elaine is a 21-year-old economics student, starting her senior year. Studious and reserved, Elaine spends much of her time outside the classroom serving as vice president of the Alpha Beta Gamma honor society and volunteering as a tutor at a local high school. Elaine wants to make a homepage that details her undergraduate activities, including class projects, research papers, and leadership positions. Her vision for the page includes a mature, sophisticated design and a slightly conservative feel.

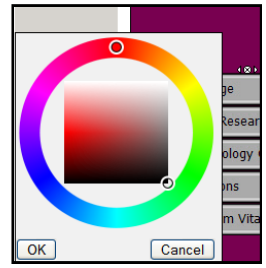


She opens the Adaptive Ideas web page builder and is presented with a variety of possible starting points for her website. She browses through them, looking for a design that she thinks is appropriate. Elaine chooses a two-column design with a purple background.

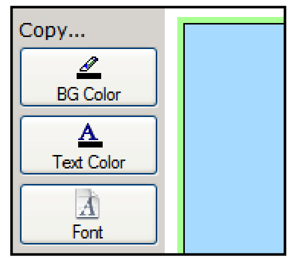


The interface displays her selection in the editing area. Links and buttons indicate features that the user can copy and where to paste them. A text note reminds Elaine that she can browse more examples and copy elements from each of them to her prototype, or she can edit things manually using the controls along the top of the interface.

Elaine decides that the background color isn't exactly what she would want, so she selects "Show a variety of background colors;" the interface presents several examples spanning different hues, saturations, and brightnesses. Elaine selects one of the blue examples and then clicks "Show examples similar to this one"; a set of blue and purple examples is displayed. She sees an example with a tasteful light blue background that she fancies. She clicks on "background color", clicks on the blue of the example, and clicks a third time on the prototype to replace the purple background with the new blue.



Elaine still isn't completely satisfied with the background color, so she clicks on the color widget at the top of the interface, and selects the background of the prototype. A color wheel pops up, allowing her to tweak the blue slightly, making it a touch lighter. She then clicks on the text of the prototype web page, replacing the example's name with hers, and filling in some of the page navigation with her categories.



She continues to browse examples looking for inspiration. A page that uses the Georgia font catches Elaine's eye; after some consideration, she switches the prototype to Georgia, both for readability and style, and alters the font size using the manual controls. She adds a head-and-shoulders picture of herself to the top-left corner of the page. Next to the picture, she places a prominent link to her resume. Satisfied, she uploads the page to a server.

5.3 Example Selection

The Adaptive Ideas web page builder seeks to assist users by displaying examples of existing pages. At its core is a subset algorithm that chooses examples from a pre-existing corpus to display to users so as to "maximize" estimated design value.

Design value is operationalized through two proxy measures: the *usefulness* of example content to the user's current task or request, and the *value* associated with the size of display elements in the overall interface. In this section, we elaborate on how content is selected for display.

5.3.1 Content elements

Content elements are example media that together comprise the dataset from which the adaptive algorithm selects. In Adaptive Ideas, they are existing homepages harvested from the web. Content elements have *attributes*, which are facets [79] of design properties that can be flat or hierarchical.

Our research focuses on using *visual properties* as attributes, including background color, text color, primary font, column layout, and visual density. In this research, we manually assigned values for each page attribute; we believe that a production implementation could tractably assign them automatically.

5.3.2 Distance

To sort examples along different design dimensions, the Adaptive Ideas algorithm uses the concept of *distance*, a metric that models the difference between attribute values, or points in a design space (see FIGURE 5.2a). The distance between two attribute values is a real number whose value depends on the properties of the attribute. For example, the distance function for background colors is calculated by mapping the colors into a three-dimensional space (biconic HSB) and calculating the Euclidean distance between the respective points in the color space. In contrast, the distance function used for fonts is a simple ternary function: 0 if the fonts are the same, 1 if they are both serif or both sans serif fonts, 2 if the fonts do not share serif characteristics. We use Euclidean distance and serif comparisons because they are simple calculations: as we are not seeking optimality, approximations for distances that are meaningful to designers in some way are all that is necessary.

Distance functions use two criteria to compute subsets of interest for example display: *similarity* and *variety*.

5.3.3 Similarity

The goal of the similarity subset algorithm is to find a set of n objects most similar to a given object for a given attribute. We hypothesized that showing examples similar to a given example would be useful for designers who may have an exemplar in mind which is close to ideal, and are looking for subtle design variations.

Adaptive Ideas uses a simple algorithm to derive similarity subsets: it calculates the distance of all objects from the given object and sort them in ascending order of distance, taking the first n items (see FIGURE 5.2b). These types of relevance algorithms are commonly found in search engines and other applications.

5.3.4 Variety

The goal of the variety subset algorithm is to find a set of n objects that represent a "diverse" subset of objects along a given attribute axis. We hypothesized that showing a well-selected variety of examples along a given attribute would give designers a better feel for the overall attribute space and thus provide better inspiration.

This raises the question of what defines a "well-selected" variety: one that shows off all possible values of the given attribute, one that represents the distribution of the underlying dataset, or one following some other formula. For example, the majority of websites have a background color of white. An algorithm that chooses examples randomly, or tries to represent the distribution of actual elements, would return a set containing mostly white web pages (clustered as in FIGURE 5.2c). Here, an algorithm that focuses on displaying a variety of possible values may be more desirable, allowing users to see the full design space (FIGURE 5.2d). On the other hand, such an algorithm may emphasize outliers or unusual points in the design space.

The Adaptive Ideas framework takes a *spaced stochastic approach* to selecting a representative variety. First, the system picks a random example from the dataset as a starting point. Next, a random example is selected from the remaining elements in the dataset which are at least ε distance away from all of the elements selected thus far, where ε is a spacing function defined on a per-attribute basis. Similar approaches are used in graphics for point sampling [13] and in biochemical research for finding dissimilar subsets of compound databases.

The choice of ε has significant influence on the behavior of the spaced stochastic algorithm. When ε is zero or small relative to the design space, this algorithm degenerates to the completely random case (FIGURE 5.2C). As ε gets larger relative to the space, the algorithm has fewer elements from which to choose, and thus risks not filling

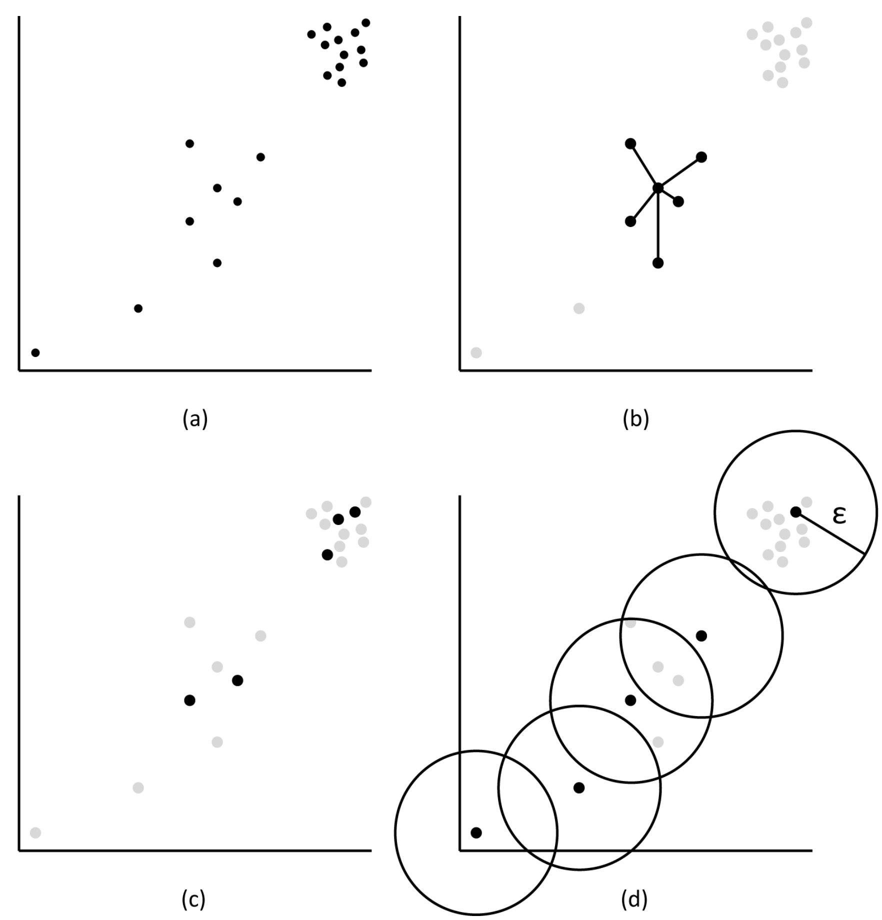


FIGURE 5.2 Illustration of Adaptive Ideas subset selection algorithms. (a) Two-dimensional representation of examples laid out in a hypothetical attribute design space. Note that the space is "chunky," that is, a large fraction of the examples can be found in one area. (b) Similarity algorithm, which chooses the *n* closest examples to the given example. (c) Naïve variety algorithm, which randomly chooses *n* elements from the design space. Note that large areas of the design space are not represented by any chosen examples. (d) Adaptive Ideas variety algorithm, which chooses examples at least ε distance away from other chosen elements. Although the underlying distribution is partially hidden, users are shown a larger portion of the valid design space.

up the space. We select a large ε, such that the theoretical maximum number of elements chosen is slightly larger than n.

The algorithm continues picking elements until either n elements have been selected or there are no legal elements remaining, *i.e.*, every remaining unselected element is less than ε distance away from an element in the selected subset. If more elements are needed, the algorithm selects elements at random from the full set of remaining elements until n have been chosen. On balance, the spacing guarantees that distinctly different values for the given attribute will be represented in the variety set, while filling out remaining elements randomly implies that some of the underlying distribution of values will be reflected. A variant would be to iterate over successively smaller values of ε until enough legal elements are found; this would further emphasize the breadth of the design space.

5.4 Interface Layout

The Adaptive Ideas system recognizes two categories of display elements: *content* elements—examples—and *interactive* elements. Interactive elements are interface units which provide some function or expose a service. In the Adaptive Ideas web page builder, there are three interactive elements: the web editor, the focus pane, and the example pane. (See SECTION 5.6 for a complete description of these interactive elements.)

The Adaptive Ideas system uses a combination of designer specification and adaptive techniques to perform interface layout. The tool interface designer creates an XML-based *template* to partially specify the appearance and behavior of an example display. Similar to Damask [43], templates allow interface designers to specify grouping and layout of interactive elements in a device-independent fashion. In the Adaptive

Ideas implementation, all elements are allocated rectangular regions, and region sizes are determined dynamically by the system.

The layout algorithm decides how to visually present the display elements by selecting a *layout style*. The layout style is a function of the output display D and template T, and is specified as a set of tuples of content elements, positions, and sizes:

$$\langle e, x, y, w, h \rangle$$

where e is an element, x and y are the element's position in this layout, and w and h are the width and height in pixels of the element.

The example pane is an instance of a special region called an *adaptive information grid*. The template dictates where these grids should be rendered, but sizes of contained elements are dynamically chosen in the same fashion as other elements.

5.4.1 Presentation value

A key consideration when choosing a layout is deciding the size at which to render display elements. Larger items are generally easier to read and select, and therefore correspond to higher attentional value than smaller items. However, increased space for

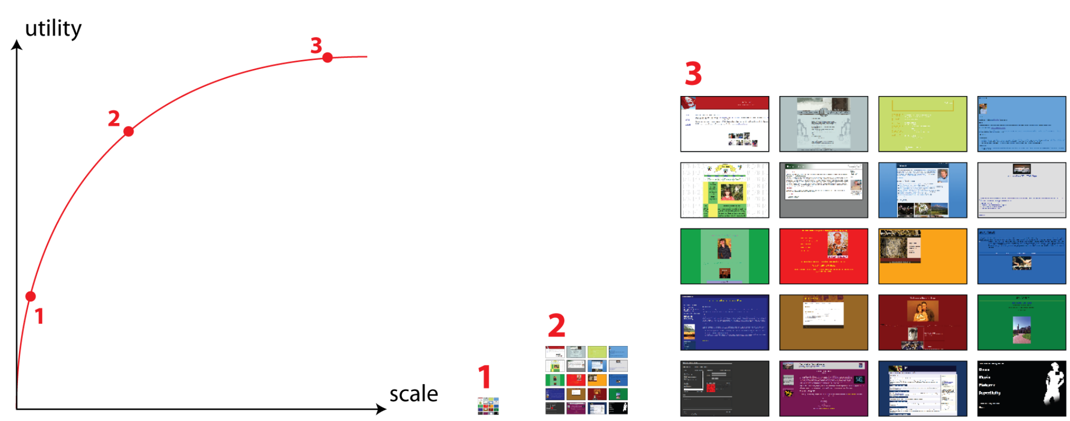


FIGURE 5.3 The Adaptive Ideas system assigns presentation value functions for content elements. Left: Graph of sample presentation values for example images. Right: A grid shown at very small (1), small (2), and large (3) sizes. Note that the images are readable when larger, still understandable when smaller, but not generally useful at the smallest sizes, modeled by the significant drop in presentation values at the latter.

one element necessarily implies less space for another. We encode this tradeoff in a *presentation value function*: $p(e,w,h,D)$. This function estimates the utility of presenting a display element e at a given size (w, h) in a given display D.

In general, larger sizes receive higher presentation scores and smaller sizes receive lower scores. However, the relationship between size and value is non-linear, and varies by element type. (One could extend the Adaptive Ideas architecture so that this relationship is defined on a per-instance basis, perhaps using metrics similar to those of Suh *et al.* [69].) Figure 5.3 shows an example of how content presentation scores are calculated.

We derived the presentation value functions for the current Adaptive Ideas system by assessing utility of the various element types (text, images, interactive widgets) at different sizes, then hand-tuning the functions and their parameters. One special case is the adaptive information grid, which has a presentation function equal to the sum of the presentation values of the content elements it contains.

5.4.2 Relevance

Another important piece of the Adaptive Ideas layout algorithm is *relevance*, which models the value of an interactive element in a given situation.

Relevance is determined with respect to a user's *focus*. In the Adaptive Ideas web page builder, users can focus on an example for closer inspection. This focus can be specified or cleared implicitly when selecting content to view or edit, or explicitly by requesting a similarity or variety subset. By using focus as an input, we try to ensure that the system displays only elements relevant to the user's current activities, so as to minimally distract her from the task at hand.

To estimate the usefulness of seeing an interactive element d given the current focus F, the Adaptive Ideas system uses a *display relevance function*: $r(d,F)$. Elements which are not needed in the current interaction state are assigned an r score of zero. For example, when there is no focus element, the focus pane (§ 5.6) is given an *r* score of zero, as the interactive element is not needed in the current interface. These relevance functions are defined by hand on a per-element basis, but may be configured by designers or adapted through use.

5.5 Adaptive Calculations

The Adaptive Ideas algorithm receives the following inputs from the system and the environment: content elements, interactive elements, output display, and a design template. The algorithm searches the space of possible layouts and selects the layout with the maximum estimated utility for the given output display.

5.5.1 *Estimated value of display elements*

For displays of content elements in information grids, we use a simple algorithm for indicating order: a *row-major ordering* (left-to-right, top-to-bottom) where the starting item is at the top left. For similarity subsets, the most similar items are presented first; for variety subsets, the items are ordered along the requested variety dimension.

In this formulation, an element's absolute location has no effect on its estimated value. A more complex model would assign different values if an element appeared in the center or the side, near the top or near the bottom of the interface.

Given a focus F, the estimated value of an interactive element at a given size is a multiplicative function of its relevance to the given focus and its presentation value at the given size:

$$s(e,w,h,F) = p(e,w,h) \times r(e,F)$$

A low *presentation* or *relevance* value will result in a low score, even when the other input value is high: a highly relevant item is of little value if it is unrecognizable, and a prominently displayed item is not valuable if it is not relevant to the user's current task or state.

5.5.2 *Estimated value of a layout*

Given a focus *F*, the estimated value of a layout is the sum of the estimated values of all elements displayed in the presentation:

$$s(F, L) = \sum_{e \in L} s(e, w, h, F)$$

where w and h are the width and height of element e in layout L.

This function presumes that the contributions of a given element are independent of the presence or absence of other elements. Though we account for some of this in our selection algorithms, we recognize that this assumption may not be valid for all situations: there may be interactions between different elements that may either increase (*e.g.*, due to synergies) or decrease (*e.g.*, due to clutter or overlap) the estimated value of a presentation. Computing such relationships has been researched in other domains with highly structured metadata [81] but is nontrivial when dealing with freeform and less structured data.

5.5.3 *Finding the optimal interface layout*

Assuming no additional constraints beyond the requirement to fit all selected items on the screen, and using the current model of presentation scores, this problem can be viewed as a two-dimensional variant of the knapsack problem, which is a difficult and active area of research [44].

We use dynamic programming (caching the results of subproblems; in this case, partial layouts) and branch-and-bound methods to conduct the search. To boost performance, we also perform *discrete calculations* for layout: instead of evaluating every possible integer width and height, we iterate through possible dimension values in five-pixel increments.

Optimizing layout is simplified when laying out content elements in a grid. As fractional displays of content elements are useless, the algorithm needs only to search through a small range of discrete size settings, specifically sizes that result in an exact integer number of elements either across or down for a given size. Finding the best set of content items to display at a given size then becomes a greedy search, linear in the number of elements.

Intuitively, the information presentation problem is a tradeoff between showing a smaller number of items at larger sizes and showing a larger number of items at smaller sizes. The Adaptive Ideas framework quantifies this tradeoff neatly and succinctly, enabling quick and efficient evaluation of candidate interfaces.

5.6 Current Implementation

We have implemented these algorithms in the form of an example-based application for web page design. The *Adaptive Ideas web page builder* generates HTML interfaces using Java Servlets and AJAX for additional interactivity. Our testbed implementation leverages a collection of approximately 250 homepages harvested from the web. For each

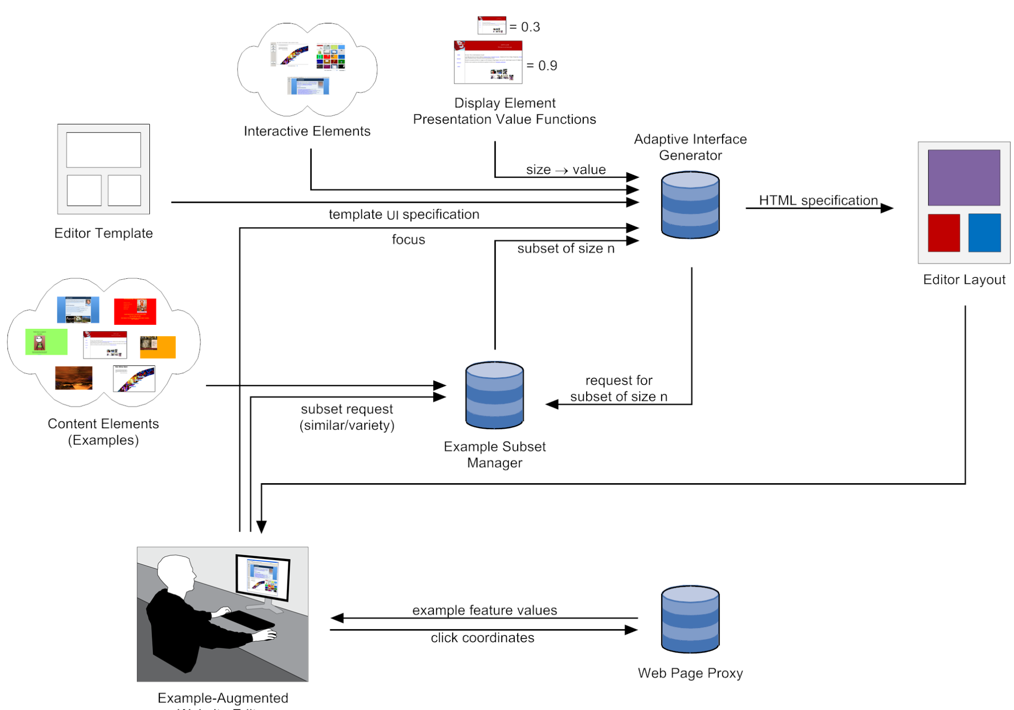
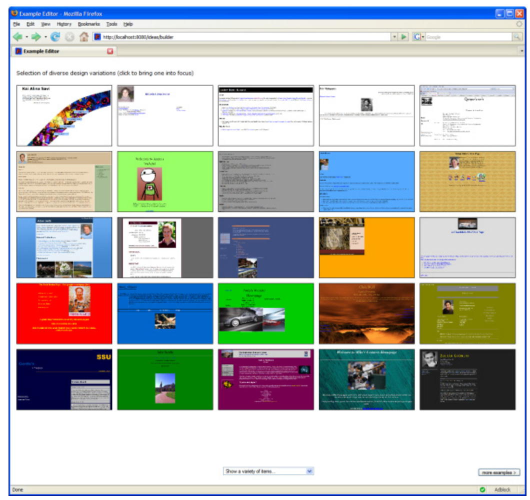


FIGURE 5.4 Architecture of the Adaptive Ideas web page builder.

example web page, a researcher estimated values for each design facet by hand; these values were then indexed in an HSQLDB embedded database for quick access. On current hardware, the Adaptive Ideas system generates interfaces in user-interactive timeframes, taking an average of less than 100 milliseconds to perform necessary calculations for subset selection and interface layout.

Internally, three components drive Adaptive Ideas (see FIGURE 5.4). The *subset manager* takes a content request (similarity or variety, number of items), reads metadata from the Adaptive Ideas database, and returns an appropriate subset of the elements. The *adaptive interface generator* takes as input a set of content elements, a display template, and a set of output properties, and returns an



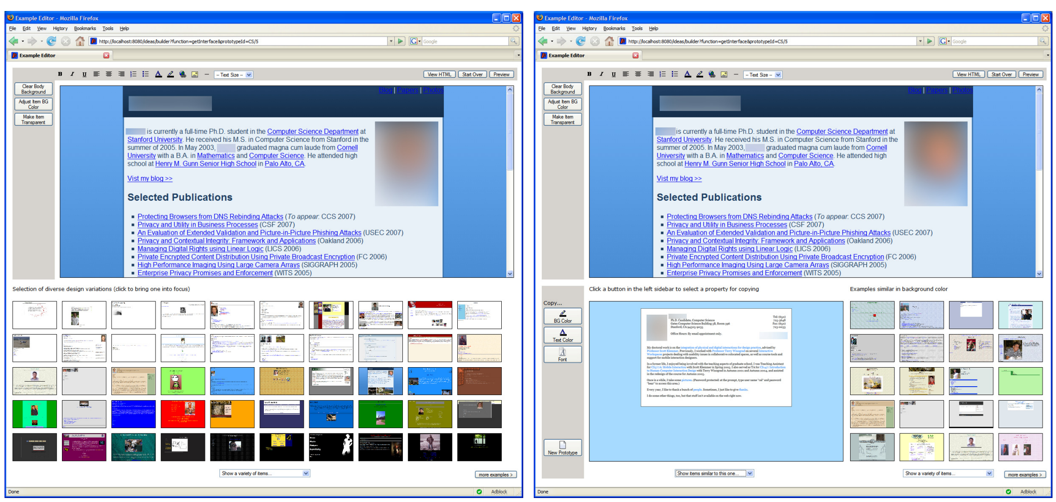


FIGURE 5.5 Screenshots of the Adaptive Ideas web page builder. *Top:* Initial grid of examples. As the user has not yet selected an example to modify, the editor and focus panes have zero *r* values, so those components are hidden. *Bottom left:* Interface after the user has selected an example to modify; the selected example is loaded into the web editor, with more examples along the bottom of the screen. *Bottom right:* Interface after the user has selected an object on which to focus (light blue image, bottom left) and requested to see similar items (grid of pastels, bottom right).

HTML layout. The *web page proxy* identifies the properties of example websites in the focus pane, taking a click coordinate and returning the requested style feature at that point.

From a user perspective, the Adaptive Ideas website editor interface contains three interactive components: the web editor, the example pane, and the focus pane.

The *example pane* is an adaptive information grid which displays a set of examples. When the interface is first started, only the example pane is shown (see FIGURE 5.5, top). To begin, the user is presented with examples representing a variety of background colors. The user navigates through the examples by clicking *next* and *previous* buttons at the bottom right and bottom left. The user may also request to see a variety of elements along a different dimension by clicking a drop-down box at the bottom of the component.

The user selects an example to modify by clicking on an example on the initial screen. This brings up the example page in the *web editor* (see FIGURE 5.5, bottom left) at the top of the page. The web editor is a WYSIWYG HTML editor, implemented using Mozilla Firefox's design mode, which allows the user to manually edit the page.

Once the user has selected an example to edit, clicking on another example in the example pane brings that example page into view in the *focus pane* (see FIGURE 5.5, bottom right). From the focus pane, the user may copy features from the example to their prototype by selecting a feature, clicking on a point on the example to copy the feature from that point, and clicking on a point in the prototype to paste the feature at that point. The user may also request to see examples similar to the example in focus by clicking a drop-down box at the bottom of the component.

5.7 Summary

This chapter presented Adaptive Ideas, a system for supporting design by example through proactive presentation and facet-based browsing of example design artifacts.

Our system takes an optimization-based approach to selecting, presenting, and browsing design material adaptively. We describe a facet-based subset selection algorithm which chooses subsets of interesting examples based on estimates of similarity and variety along design dimensions. To evaluate the benefits of this approach, we created the Adaptive Ideas web page builder, which seeks to assist web page designers by displaying examples of existing web pages and allowing designers to borrow desired elements. Chapter 6 describes a comparative laboratory study of this example-augmented tool.

6 Adaptive Ideas Evaluation

This chapter describes a first-use study of the Adaptive Ideas web page builder. The goal was to assess the usefulness of example-augmented interfaces for design practice. It found that novices appreciated the automatic display of examples as well as the ability to browse these examples in a design-oriented fashion. Expert opinions, meanwhile, were mixed, describing a tradeoff between the lost screen space due to unrequested example display and the added utility of seeing and browsing selected examples upfront. We also observed that users browsed *significantly less* when using the facet-oriented variety and similarity algorithms for browsing examples than when browsing random sets of examples. Based on these findings, we conclude that proactive presentation and facet-oriented browsing of examples can aid designers by *facilitating discovery and exploration of design alternatives*.

6.1 Method

We conducted a first-use study of Adaptive Ideas to assess the usefulness of our example-based interfaces for design practice. The study group comprised nine participants. Participants had the following educational backgrounds: three from Computer Science, four from Engineering, and two from Humanities disciplines. Participants' ages ranged from 24 to 30; six were male, three female. All of the participants were frequent web users. Two of the participants self-rated as experienced

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Portions of this chapter were originally published by the author, Scott R. Klemmer, Savil Srivastava, and Ronen Brafman in [40].

or expert web designers, having personally created more than three web pages with more than one type of design tool; the remainder self-reported as novices with little to no experience designing websites, having created two or fewer web pages, usually with template-based tools.

Participants were seated at a workstation with the Adaptive Ideas web page builder. Sessions began with a demonstration of the capabilities of the web page builder. Participants were then asked to create websites for two different personas (see FIGURE 6.1), using a different variation of the builder interface for each. The *adaptive features* variant offered the full set of controls described in the Implementation section. The

> Elaine Marsh is a 21-year-old economics student, starting her senior year at Stanford University. Studious and reserved by nature, Elaine spends much of her time outside the classroom serving as vice president of the Alpha Beta Gamma honor society and volunteering as a tutor at a local high school. Elaine wants to make a homepage that details her undergraduate activities, including class projects, research papers, and leadership positions. Her vision for the page includes a mature, sophisticated design and a slightly conservative feel.
>
> *Your task is to design a website for Elaine, including layout, colors, fonts, and content, by selecting and modifying one of the examples provided.*

> Dan Simmons is a 20-year-old junior pursuing a degree in political science at San Diego State University. An avid fan of hip hop and an aspiring drummer, Dan is famous among his friends for his love of cheesy ’80s bands and off-key karaoke renditions of their songs, complete with air guitar. On weekends, he and his buddies enjoy getting together to eat pizza and watch college football. Dan is looking to create a webpage to share some of his personal interests, and would like the page to be fun and energetic, with something of an edgy feel to it.
>
> *Your task is to design a website for Dan, including layout, colors, fonts, and content, by selecting and modifying one of the examples provided.*

FIGURE 6.1 Persona cards for the Adaptive Ideas user study.

standard features variant disabled the similarity and variety features and sorted the examples randomly: users could view all examples, but could only browse them using the next and previous page controls. We assume that the random example sorting models the approach a user of a normal web page builder interface would take if interested in finding examples of others' web pages: while such a user could easily open up a search engine and find some examples, these examples would not be sorted in any particular fashion relevant to design tasks. Persona and interface pairings were varied across participants using a Latin square ordering.

6.2 Results

A summary of salient post-study questionnaire results is shown in FIGURE 6.2. Participants found the general presentation of examples highly useful (mean=4.5, median=4.5, σ=0.53, on a 5-point Likert scale), and appreciated the ability to borrow features directly from example web pages (μ=3.9, $\tilde{x}$=4, σ=0.83). Participants found the adaptive browsing features to be helpful in finding examples, indicating the variety tool to be most useful while exploring the design space (μ=4.4, $\tilde{x}$=5, σ=1.01), although the similarity tool was also welcomed (μ=3.9, $\tilde{x}$=4, σ=0.78). In general, participants did not

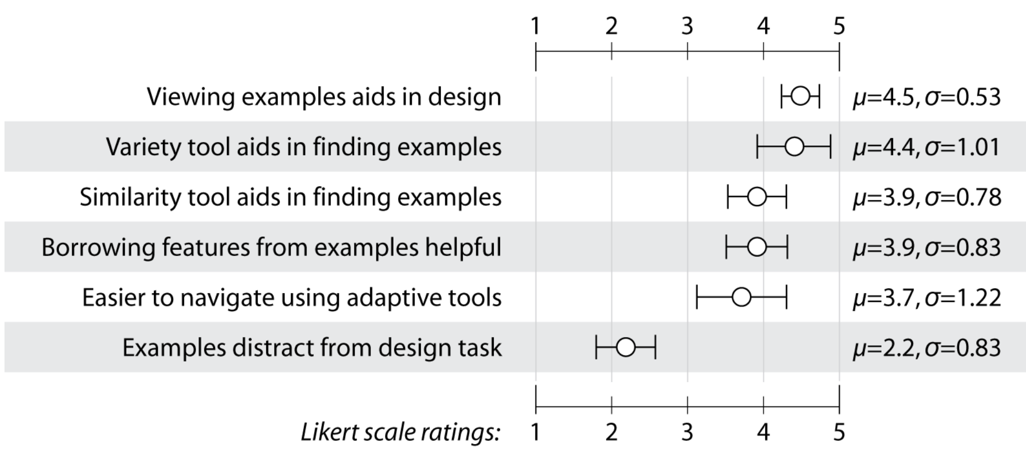

FIGURE 6.2 Summary of questionnaire results from the Adaptive Ideas web page builder user study.

find the examples to be distracting (μ=2.2, $\tilde{x}$=2, σ=0.83). Several users expressed a desire for the ability to browse along aesthetic or social attributes, such as formality.

6.2.1 Adaptive features versus standard features

Responses were positive but less conclusive on whether it was easier to navigate examples using the adaptive features interface (μ=3.7, $\tilde{x}$=4, σ=1.22). During the studies, however, we observed that several participants resorted to long stretches of "linear" browsing while using the standard features interface, during which they clicked on many examples in a row in order to examine them.

Interaction logs supported these observations. In the adaptive interface, users selected approximately *50% fewer items* for larger viewing (μ=195.8 in the standard features interface versus μ=96 in the adaptive case, $p<0.05$). We hypothesize that the variety and similarity tools lent themselves to more efficient exploration, allowing designers to quickly form a mental model of the design space.

6.2.2 Novice versus expert use

In post-study responses, novices especially approved of having examples integrated into the design tool; their responses were more positive than the overall average (μ=4.7, $\tilde{x}$=5, σ=0.49), and all of them expressed particular appreciation for the ability to request and view variety subsets (μ=4.8, $\tilde{x}$=5, σ=0.38).

The two self-rated experts differed strongly in their opinions about the use of examples for website design. One of the expert participants found the limitations of the example-borrowing interface annoying and thought the examples *distracted from the design task* by adding to screen clutter, wasting valuable screen space. The other experienced participant commented that the browsing of examples worked well with her personal strategy for this type of design task: "That's my philosophy of designing websites: I like to find a template or exemplar that I think is good and then tweak it by hand." On the whole, this expert felt that the example-augmented builder *aided her building strategy* by proactively offering examples and searches organized along relevant design axes.

We hypothesize that, while novices might uniformly find examples to be interesting, experts may have specific work methods that may or may not be compatible with examples. This suggests that future instances of example-augmented interfaces should allow power users to disable example display at their discretion.

6.2.3 *Study limitations*

There are a number of limitations to the study methodologies used. Since the study did not include a traditional (non-augmented) web page editor, it is unclear that users could accurately discern whether or not viewing examples aided them in design, though all participants had created at least one web page before and were thus familiar with the process. Similarly, while the quantitative result of 50% fewer example views was found to be significant ($p<0.05$), our hypothesis that this is due to the variety and similarity tools is purely based on researcher observations and participant responses to closed Likert-scale questions. A follow-up investigation with different study conditions (*e.g.*, offering different subsets of the adaptive tools) and more in-depth questioning could further clarify causes and effects.

6.3 Design Implications

The results described in this chapter support our hypotheses that adaptive interfaces can leverage design-oriented metadata facets to ease the task of accessing interesting design content (H2; see § 1.1), and increase exposure to and awareness of inspirational design materials without imposing significant additional user burden (H3).

Augmenting design tools with examples is a promising approach for providing design information and inspiration. This approach seems likely to generalize to other design domains; the only vital requirement is that examples have design facets which can be quantified and ordered in some way that is meaningful to a domain designer. Using design facets and subset selection criteria, example-augmented tools can automatically identify sets of inspirational examples without user intervention. We suggest that proactive presentation and facet-oriented browsing of examples can aid designers by *facilitating discovery and exploration of design alternatives*.

7 Conclusion

This dissertation demonstrated that a social approach to design artifacts—the sharing of visual design content, whether in the form of notebook sketches, digital photographs, or snapshots of existing designs—can support and augment design practice by facilitating collaboration between designers and improving visibility of design resources. These contributions are established in two applications: the iDeas design ecology and Adaptive Ideas. The iDeas design ecology examined how augmented interfaces could integrate physical and digital interactions in the service of early-stage design, lowering thresholds for digital behaviors such as search and sharing while retaining current paper practices. Adaptive Ideas showed that design tools could automatically display example designs to improve awareness and understanding of design alternatives, using design-oriented metadata and facet-based algorithms to select and present examples.

7.1 Contributions

We begin by restating the contributions listed at the beginning of the dissertation and summarizing how each of these contributions was achieved.

1 *Implementation of a system that uses augmented tools for capture and access of design materials*

A Lightweight hybrid mechanisms for supporting design documentation and annotation

The iDeas design ecology (see CHAPTER 3) enhances designers' existing documentation practices through the integration of augmented paper and digital tools, described in SECTION 3.3. It offers rich content annotation through the use of automatically captured metadata (*e.g.*, timestamps) and user-generated metadata (tags and annotations), described in SECTION 3.4.

B Designs for facilitating collaboration through explicit sharing of design artifacts

The iDeas system provides three major sharing mechanisms, described in SECTION 3.5: export of notebook contents as graphics to other programs; direct view of fellow designers' notebooks; and group notebooks, shared virtual repositories of design content integrated into the iDeas browser.

C Implementation of these techniques in a functional system comprising physical notebooks and other design artifacts

These tools and mechanisms have been integrated into a fully functional system, designed for deployment to actual users over significant periods of time. SECTION 3.6 describes the architectural challenges of the iDeas system and the hybrid approach we took to addressing them, integrating off-the-shelf components with novel research software to enable rich interactions.

D Longitudinal deployment and evaluation of the system's effects on design practice

We evaluated the iDeas design ecology in four deployments to student design teams spanning multiple months, as described in CHAPTER 4. In particular, we report on the high value of digitized notebook content (SECTION 4.3.2), the importance of fitting into existing digital practices (SECTION 4.3.3), the asymmetric dual media nature of designers' work practices (SECTION 4.3.4), and several challenges to adoption of augmented tools (SECTION 4.3.6).

E Design guidelines for integrating physical and digital interactions in creative work

We describe lessons learned in SECTION 4.4. Designers who actively used the iDeas tools found that the search and annotation features made the process of excerpting and sharing design content easier, and consequently did so more often (SECTION 4.3.2). However, users did not generally adopt the other sharing mechanisms introduced by iDeas. There were other problems (*e.g.*, ergonomics) which were not relevant to the research issues at hand, but which also depressed usage. Many users adopted the system despite these shortcomings, an encouraging sign that the augmented tools were actually valuable for design practitioners. Nevertheless, our findings suggest that adoption issues must be taken seriously in any longitudinal evaluation of emerging technologies.

2 Facet-based algorithmic approach for presenting design materials proactively in order to promote shared awareness and design inspiration

A Approach for increasing visibility through proactive presentation and facet-based browsing of design artifacts

Adaptive Ideas (see CHAPTER 5) embodies a novel approach to supporting design by example, making inspirational work more visible through proactive presentation and facet-based browsing of examples. We describe a computational technique which uses design facet metrics to chooses example subsets of interest (similarity and variety), and generates interface layouts automatically.

B Technical analysis of the feasibility of the approach

Our algorithmic analysis (SECTION 5.5.3) and research implementation (SECTION 5.6) demonstrate the feasibility of using this approach to augment current tools on current hardware for realistic data sets.

C Evaluation of utility through a first-use study of example reuse

The evaluation described in CHAPTER 6 suggests the promise of design by example modification for providing design information and inspiration. Proactive presentation and facet-oriented browsing of examples can aid designers by facilitating discovery and exploration of design alternatives.

7.2 Thesis Statement

To recap, the supporting hypotheses of this dissertation are:

H1 Lightweight digital capture can decrease the effort needed to share and annotate content generated during design activity.

The studies of the iDeas design ecology found that augmented tools encouraged rich design documentation and collaboration by decreasing the effort needed to share and annotate design content (SECTIONS 3.4, 4.3.2, 4.4).

H2 Adaptive interfaces that leverage the automatically captured and user-generated metadata afforded by the use of augmented tools can ease the task of accessing design content of interest.

Both the iDeas ecology and Adaptive Ideas enhance the retrieval, review, and reuse of design content by offering interfaces that leverage metadata to access interesting design content. The iDeas system uses automatically generated metadata associated with digital capture to enable rich browsing and search (SECTIONS 3.4, 4.3.2, 4.4). Adaptive

Ideas uses harvested design-oriented metadata to identify interesting sets of design examples for display (SECTIONS 5.3, 6.2, 6.2.3).

H3 *Proactive and reactive mechanisms for browsing and sharing content collections can increase exposure to and awareness of inspirational design materials without imposing significant additional user burden.*

Adaptive Ideas improves awareness of design resources by identifying and displaying inspirational sets of examples automatically, without need for user intervention (SECTIONS 5.3, 6.2, 6.2.3). It also offers controls for users to browse the space of design alternatives in a directed fashion when desired.

This dissertation shows that *augmented paper and digital tools can facilitate collaboration between designers and improve visibility of design practice through the sharing and proactive presentation of design content*.

7.3 Limitations

The term *design* refers to a broad class of disciplines, processes, and artifacts; the tools in this dissertation address highly specific aspects of design. The iDeas design ecology primarily addresses visual ideation, documentation, and reflection. Moreover, our longitudinal studies examine support for a particular discipline—in this case, interaction design—through the sharing and reuse of visual content taken from notebooks and digital photographs. There are many aspects of design not covered by iDeas; for instance, we do not deal with physical prototyping as often found in product design, nor do we address activities such as project management and scheduling, a central part of engineering design.

All of the courses in which we studied the iDeas ecology espouse particular approaches to the design process, with corresponding effects on design practice. Design notebooks were an integral component of course grades for students; this bias may have yielded a different pattern of notebook usage than other designer populations. Due to time and space constraints, student teams frequently divide their time between co-located meetings and remote collaborations, which may or may not realistically model other designers' work practices. One of the HCI courses studied involves several small projects throughout the quarter, often with different group compositions for each project; the capstone is a large implementation project and studio presentation. This high turnover of groups and projects certainly influenced the use patterns of sharing mechanisms in the ecology.

Similarly, the Adaptive Ideas research raises practical concerns which we do not address in this dissertation. Most notably, we do not investigate how a corpus of design examples would be built, nor do we deal with algorithmic implications of different corpus properties, such as corpus size and distribution of underlying examples. For the particular domain of web page design, we believe that scraping the web is a practical solution to finding candidate examples, but that annotating arbitrary web pages with the correct design-oriented metadata is a difficult and open question. We see the emergence of social algorithms (*e.g.*, folksonomies) as one possible source of metadata for more abstract design properties, including aesthetic judgments such as formality.

7.4 Future Work

This dissertation suggests several directions for future work in designing augmented tools to support design practice. First, because the augmented tools of the iDeas design ecology lower the threshold for integrating physical and digital design material, there are further opportunities for facilitating collaboration and visibility in design practice. The findings in this dissertation suggest that lightweight browsing and permissions mechanisms for shared content are important to future investigations in this domain.

Second, augmented design tools could integrate more advanced hybrid interfaces that use paper not only as a writing capture device, but as a digital input. The diversity of design sketching and note-taking activities may lack the inherent structure necessary for more complex augmentations such as the mixed media recognition of Rasa [53] or Designers' Outpost [38]. However, augmented paper could be used to provide lightweight control of corresponding features in the digital realm. For example, paper input could modify privacy settings for shared notebook materials (SECTION 3.5.2), lowering the barriers to use by offering both capture-time and browse-time controls.

Third, as discussed in SECTIONS 5.3 and 7.3, the design-by-example approach in this dissertation relies on having a corpus of examples annotated with design-oriented metadata. In the case of web page design, some of the relevant properties can be automatically harvested from HTML/CSS metadata. How to capture or infer other useful design-oriented properties (*e.g.*, aggregate features such as layout, or aesthetic values such as cuteness) is an open research question. Social networking software, in which groups of users collaborate or share information and produce useful metadata as a byproduct, is a potentially rich source of user-generated metadata for many domains.

Fourth, implicit in the design-by-example approach is an attempt to give designers a better "feel" for the design space by presenting examples that are representative of some subset of the space. The current Adaptive Ideas techniques only allow designers to pivot about specific examples (similarity) or along specific design axes (variety). Showing more explicit visualizations of the design space (*e.g.*, a two-dimensional rendering similar to FIGURE 5.2) could aid designers by giving them more direct handles to navigate and explore the space of design alternatives.

Finally, design tools that use adaptive and proactive presentation techniques could benefit from greater knowledge of design tasks (SECTION 2.6.1). The ability to track and understand current "design state" could enable important tools for iterative exploration, such as searching for examples with features similar to those ones already selected, but varied along other design dimensions. Understanding how to automatically perform these types of history- and state-based searches is another open topic of research.

7.5 Closing Remarks

Design thinking is a creative activity that involves making tradeoffs and solving problems; it is a process at once collaborative and personal, experiential and experimental, integrative and innovative. Designers call upon a variety of both physical artifacts and digital artifacts, each with powerful—but distinct—sets of affordances. This dissertation moves toward a vision of augmented design tools and interaction techniques that respect the best aspects of paper-based design activities while leveraging the dynamic properties of digital media, creating richer interaction experiences for all stages of design.

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APPENDIX A
iDeas Design Ecology Evaluation Questionnaire

This sample questionnaire was administered to participants in the Winter 2006 study of the iDeas design ecology, described in SECTION 4.2. In this study, the iDeas browser was referred to as the ButterflyNet software.

CS 247: Winter 2005-06 Idea Log/Digital Pen Experiment
End of Quarter Questionnaire

Thank you for participating in our study. This questionnaire will ask you about your experiences working with groups and with technology. Please answer each question carefully and truthfully.

Your name and information will not be shared with anyone outside the research team; as always, only anonymous, aggregate, and analyzed data may be published.

Name: ____

Flickr username (if applicable): ____________________________

Gender:

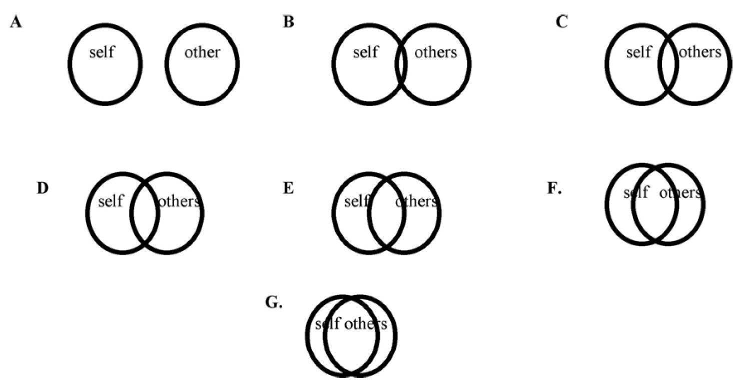
- ○ Male
- ○ Female

Part I: Final Project Group

1 How well did you know your teammates before this project? Answer the questions for each of your teammates. (Do not fill out question for teammate #3 if you only had two teammates, i.e., if your project only had three team members total.)

Before this project I was good friends with teammate #1	Before this project I was good friends with teammate #2	Before this project I was good friends with teammate #3
○ True	○ True	○ True
○ Neutral	○ Neutral	○ Neutral
○ Not true	○ Not true	○ Not true

2 By circling the appropriate figure below, please indicate to what extent you and the people in this group are currently **connected.**



Continue to next page →

3 We are very interested in learning how you feel about your group. Please circle the number on the scale below that you think best expresses your feelings on the items.

	Not at all				**Extremely Well**
Please indicate to what extent you would use the term "WE" to characterize you and the other people in your group.	1	2	3	4	5
Please indicate how well you **know** the other people in your group.	1	2	3	4	5
Please indicate how much you **like** the other people in your group	1	2	3	4	5
Please indicate how much you consider the people in your group to be **'a group'**.	1	2	3	4	5
Please indicate how **connected** to one another you consider the people in your group to be.	1	2	3	4	5
How **related** to one another are the members of your group?	1	2	3	4	5

4 The following questions ask about your communications between group members at different stages of the project.

How did you work when you were designing the project? *(mark all that apply)*	☐ Meeting in person	☐ Email or IM	☐ Alone
Which was the **primary** way you worked when designing the project? *(choose one)*	○ Meeting in person	○ Email or IM	○ Alone
How did you work when you were programming? *(mark all that apply)*	☐ Meeting in person	☐ Email or IM	☐ Alone
Which was the **primary** way you worked when programming? *(choose one)*	○ Meeting in person	○ Email or IM	○ Alone
How did you work when you were user testing and integrating? *(mark all that apply)*	☐ Meeting in person	☐ Email or IM	☐ Alone
Which was the **primary** way you worked when you were user testing and integrating? *(choose one)*	○ Meeting in person	○ Email or IM	○ Alone

Continue to next page →

5 We'd like to know more about your group interactions. Please rate the following statements with respect to how true they were for your group.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was a sense of intellectual excitement in our group.	1	2	3	4	5
There was clear leadership in our group.	1	2	3	4	5
We had equal voice in decision making.	1	2	3	4	5
We were efficient with our time.	1	2	3	4	5
We were highly organized.	1	2	3	4	5
We got along well interpersonally.	1	2	3	4	5
We had fun together.	1	2	3	4	5
I got to know people better.	1	2	3	4	5
I was able to contribute from my Idea Log.	1	2	3	4	5
I was able to learn from others.	1	2	3	4	5
I was able to teach others.	1	2	3	4	5
We were focused on getting a good grade.	1	2	3	4	5
We were focused on perfecting our skills.	1	2	3	4	5
We listened well to each other.	1	2	3	4	5
Our knowledge and skills were complementary.	1	2	3	4	5
Our Idea Logs built on one another's.	1	2	3	4	5
Our project turned out well.	1	2	3	4	5
We agreed on a common vision for the project.	1	2	3	4	5
The roles for each person were clearly defined.	1	2	3	4	5

Continue to next page →

6 Below are descriptions of typical problems that groups encounter when working together. Please rate the following statements with respect to how true they were for your group.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
There was a group member who did not take the work as seriously as everyone else.	1	2	3	4	5
There was a group member who did not want to share leadership.	1	2	3	4	5
There were communication problems due to language differences.	1	2	3	4	5
One or more of my team members was not a strong enough programmer to complete his or her part satisfactorily.	1	2	3	4	5
One person had to take the lead or pull the project together alone.	1	2	3	4	5
Everyone did not share the same expectations for the quality of the project.	1	2	3	4	5
Competition between group members hindered our ability to share using our Idea Logs.	1	2	3	4	5
Nobody was willing to take a leadership role.	1	2	3	4	5
The pressure of completing the project caused problems for my group.	1	2	3	4	5
The working styles of group members were different.	1	2	3	4	5

Continue to next page →

7 This question is about possible relational or learning outcomes from your work on the CS247 project. Please rate the following statements with respect to how true they were for you.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I developed and/or deepened a friendship with at least one group member due to the project.	1	2	3	4	5
After the project, one or more of my relationships with teammates was strained or awkward.	1	2	3	4	5
The project helped me develop deeper friendships with other class members (excluding teammates).	1	2	3	4	5
I feel that my level of programming expertise increased due to working on the project.	1	2	3	4	5
I improved my ability to teach others during the project.	1	2	3	4	5
I learned something new about programming from others in my group.	1	2	3	4	5
I taught at least one member of my group something new.	1	2	3	4	5

8 Please tell us about your feelings about the group and project overall.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I am satisfied with our final product.	1	2	3	4	5
I am satisfied with what we learned through the project.	1	2	3	4	5
I am satisfied with our team interactions over the course of the quarter.	1	2	3	4	5

Continue to next page →

PART II: Project Activities

Photos:

9 On how many occasions did you take **photos** for your project for this class?
- ○ None
- ○ One or two
- ○ Three to six times
- ○ Seven or more times

10 Of the photos you took for the class, how many did you **share with your teammates**?
- ○ None
- ○ About a third
- ○ Two thirds of the photos
- ○ I shared all of the photos I took

11 Of the photos you took for the class, how many did you **include in your homework writeups**?
- ○ None
- ○ About a third
- ○ Two thirds of the photos
- ○ I included all of the photos I took

12 Of the photos you took for the class, how many did you **post on ButterflyNe**t?
- ○ None
- ○ About a third
- ○ Two thirds of the photos
- ○ I posted all of the photos I took online

13 Of the photos you took for the class, how many did you **post on Flickr**?
- ○ None
- ○ About a third
- ○ Two thirds of the photos
- ○ I shared all of the photos I took online

14 How often did you **go see photos** on the Flickr site for the course?
- ○ More than once a day
- ○ Once a day
- ○ Three times per week
- ○ Twice per week
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

Video:

15 On how many occasions did you record **video** for your project for this class?
- ○ None
- ○ One or two
- ○ Three to six times
- ○ Seven or more times

16 Of the videos you took for the class, how many did you **share with your teammates**?
- ○ None
- ○ About a third
- ○ Two thirds of the videos
- ○ I shared all of the videos I took

Idea Logs:

17 How often did you use your **Idea Logs** for coursework?
- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

18 How often did you use your Idea Logs **outside of this class**?
- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

19 Which was your **primary** Idea Log, the paper notebook or the digital version?
- ○ The paper notebook
- ○ The digital version

20 Approximately how often did you browse **your teammates'** paper Idea Logs?
- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

21 Approximately how often did you browse **your teammates'** Idea Logs through ButterflyNet?

- More than once a day
- Once a day
- Once a week
- Once a month
- Irregularly or never

22 Before CS247, how many other courses had you kept Idea Logs for?

- None
- One previous class
- Two previous classes
- Three previous classes
- More than three previous classes

23 This Winter quarter, how many other courses are you keeping Idea Logs for?

- None
- One other class
- Two other classes
- Three other classes
- More than three other classes

24 In your own design process, how likely are you to keep an Idea Log?

Very Unlikely	Unlikely	Neither Likely Nor Unlikely	Likely	Very Likely
1	2	3	4	5

25 If you have other comments about Idea Logs or your group experiences, please include them here.

PART III: Hardware and Software

In the rest of the questionnaire, "pen" and "digital pen" refer to the physical device, while "ButterflyNet" refers to the software (Java notes browser).

26 How often did you use the digital pen for coursework?

- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

27 How often did you use the digital pen outside of this class?

- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

28 Is there anything that would have made the pens more useful to your participation and collaboration in the design project? If so, describe briefly. (Note that this question is asking only about the hardware—the physical pen—and not about the software.)

29 How often did you export or share your notes electronically?

- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

30 How often did you fill pages with design work (concepts, ideation, sketching, drafting, etc) **without** using the pens or notebooks provided by the experiment?

- ○ More than once a day
- ○ Once a day
- ○ Once a week
- ○ Once a month
- ○ Irregularly or never

31 For these times when you were doing design work without using the pens or notebooks provided by the experiment, what would have made you use them?

Continue to next page →

(Circle one value for each row.)

32 The ButterflyNet browser is:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Useful	1	2	3	4	5
Easy to Understand	1	2	3	4	5
Easy to Learn	1	2	3	4	5
Flexible	1	2	3	4	5
Awkward	1	2	3	4	5
Irrelevant	1	2	3	4	5
Distracting	1	2	3	4	5
Slow	1	2	3	4	5

33 Please indicate your opinion of the following statements about importing data into ButterflyNet.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found it easy to import my notes and pictures into the ButterflyNet system.	1	2	3	4	5
The mechanism for importing notes and pictures into the ButterflyNet system was awkward.	1	2	3	4	5
It took too much effort to import my design content into the ButterflyNet system.	1	2	3	4	5

Continue to next page →

(Circle one value for each row.)

34 Please indicate your opinion of the following statements about exporting data from ButterflyNet.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found it easy to export my notes and pictures to other programs using the ButterflyNet system.	1	2	3	4	5
The mechanism for exporting notes and pictures to other programs from the ButterflyNet system was confusing.	1	2	3	4	5
I found the ability to export my design content through the ButterflyNet system to be useful.	1	2	3	4	5
It took too much effort to export my design content to other programs using the ButterflyNet system.	1	2	3	4	5

35 Please indicate your opinion of the following statements about sharing data using ButterflyNet.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I found it easier to share my notes using the ButterflyNet system than through other channels (e.g., scanning, photocopying)	1	2	3	4	5
I found the ability to share my design content through the ButterflyNet system to be useful.	1	2	3	4	5
It took too much effort to share my design content using the ButterflyNet system.	1	2	3	4	5

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PART IV: Overall Evaluation of ButterflyNet

36 What aspects of the ButterflyNet desktop client did you particularly *like*?

37 What aspects of the ButterflyNet desktop client did you particularly *dislike*? What would you change?

38 What additional features would you like to see in ButterflyNet? What would it take for ButterflyNet to be truly useful to you?

Continue to next page →

39 How likely is it that you would integrate ButterflyNet as a regular part of your work practices *in a design course*?

Very Unlikely	Unlikely	Neither Likely Nor Unlikely	Likely	Very Likely
1	2	3	4	5

40 How likely is it that you would integrate ButterflyNet as a regular part of your work practices *for general coursework*?

Very Unlikely	Unlikely	Neither Likely Nor Unlikely	Likely	Very Likely
1	2	3	4	5

41 Are there certain types of courses in which you would be more likely to use the ButterflyNet system? If so, please list them here.

42 *(Optional)* If you have other comments about Idea Logs, your group experiences, or the ButterflyNet system, please include them here.

This is the end of the questionnaire.

Double check that you put your name on the questionnaire, then hand it to Björn, Heidy or Brian. Thank you for participating in the experiment!

APPENDIX

B Adaptive Ideas Evaluation Questionnaire

This questionnaire was administered to participants in the Adaptive Ideas study, described in SECTION 6.1.

Adaptive Ideas Post-Study Questionnaire

Thank you for participating in our study. This questionnaire will ask you about your experiences working with websites and website design tasks. Please answer each question carefully and truthfully.

Name: ____

E-mail address: ____

Part I: Current Practice
Describe your background with the World Wide Web and website design.

1. How often do you use the World Wide Web?

   ○ MORE THAN SIX TIMES A DAY ○ MORE THAN THREE TIMES A DAY ○ DAILY ○ WEEKLY ○ INFREQUENTLY

2. How many websites have you personally created?

   ○ NONE ○ ONE ○ TWO ○ THREE ○ FOUR OR MORE (SPECIFY: ____)

3. What tools for designing websites have you used, if any?

4. Do you have a *personal* website? If so, how did you design it? Describe briefly.

5. Do you have a *professional* website? If so, how did you design it? Describe briefly.

Part II: The Website Builder

Rate the degree to which you agree or disagree with the following statements.
(If you are unclear about the system names, please ask the study director for clarification.)

1. I felt that the examples were useful in designing websites.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

2. I spent a lot of time trying to find appropriate examples in the *Circle* system.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

3. I spent a lot of time trying to find appropriate examples in the *Square* system.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

4. I would like to use this interface in designing future websites.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

5. The presentation of examples interfered with my ability to design websites.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

6. I made a lot of mistakes while trying to copy and paste features using the system.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

7. The interface was easy to use for browsing example websites.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

8. The interface did not take too much effort to learn to use.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

9. It was hard to switch between editing and browsing tasks in the interface.

   ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

10. I did not find the ability to copy features directly from other websites to be useful.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

11. The ability to see items similar to a given item in the *Square* system was helpful in finding useful examples.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

12. The ability to see a variety of items along a given dimension in the *Square* system was helpful in finding useful examples.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

13. I found the presentation and use of example websites to be distracting.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

14. It was easier to navigate and browse the examples in the *Square* system than in the *Circle* system.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

15. I found the display of examples in the *Square* system to be natural and/or logical.

    ○ STRONGLY AGREE ○ AGREE ○ NEUTRAL ○ DISAGREE ○ STRONGLY DISAGREE

16. Is there anything that would have made the examples or the overall system more useful? If so, describe briefly.

17. Did you have specific problems using the website builder's interface? If so, describe briefly.

18. If you have any other comments about the system, please describe them briefly here. Thank you!