

Human-Computer Interaction Series

Jürgen Steimle

Pen-and-Paper User Interfaces

Integrating Printed and Digital
Documents

Forewords by
James D. Hollan
and
Max Mühlhäuser

 Springer

Human-Computer Interaction Series

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Human-computer interaction is a multidisciplinary field focused on human aspects of the development of computer technology. As computer-based technology becomes increasingly pervasive – not just in developed countries, but worldwide – the need to take a human-centered approach in the design and development of this technology becomes ever more important. For roughly 30 years now, researchers and practitioners in computational and behavioral sciences have worked to identify theory and practice that influences the direction of these technologies, and this diverse work makes up the field of human-computer interaction. Broadly speaking it includes the study of what technology might be able to do for people and how people might interact with the technology.

In this series we present work which advances the science and technology of developing systems which are both effective and satisfying for people in a wide variety of contexts. The Human-Computer Interaction series will focus on theoretical perspectives (such as formal approaches drawn from a variety of behavioral sciences), practical approaches (such as the techniques for effectively integrating user needs in system development), and social issues (such as the determinants of utility, usability and acceptability).

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Foreword

Computers provide the most plastic medium for representation, communication, and interaction we have ever known. The computational medium is plastic in the sense that we can employ it to:

- mimic other media (e.g., books, newspapers, magazines, photographs, audio recordings, and films), devices, and mechanisms of interaction,
- create models that represent, with ever increasing fidelity, the physical world, spanning from models of atoms and molecules to those used to forecast weather or to guide spacecraft to destinations far from earth,
- provide virtual worlds that range from the simple metaphorical desktop of the graphical user interface to the amazing digital effects and virtual characters of current films, or
- combine the real and the virtual (e.g., in robotic surgery the tremors of a surgeon's hands are removed as he or she interacts with a computer interface remote from the patient).

This plasticity and the myriad ways computers are now enmeshed in our personal and professional lives and in the infrastructure of science and society present enormous opportunities and challenges. Computationally-based forms of communication and interaction are changing the world in which we live and the ways we interact within it.

With each new technology we seem characteristically drawn to focus almost exclusively on the new opportunities it presents and how it might replace older technologies, frequently forgetting, or at least not adequately appreciating, that new technologies must exist and evolve in ecologies comprised of older technologies as well as webs of established cognitive and cultural practices. Understanding how a new technology meshes and interacts with existing ecologies and practices is as fundamental and important a component of design as the new opportunities it creates.

From the beginnings of the modern computer at Xerox Parc in the early '70s one consistent refrain has been that new computational devices would replace paper and the future would be increasingly paperless. As every office and home continues

to bear witness, and as is well documented in Sellen and Harper's seminal book, *The Myth of the Paperless Office*, we are far from becoming paperless, continuing to exploit both digital and paper media. Following Wellner's early digital desk explorations there have been a series of innovative investigators exploring not how to replace paper with digital tools but rather how to combine the two. Stellar examples of this approach are Guimbretière's *Paper Augmented Digital Documents*, Yeh's *Butterflynet*, Liao's *PapierCraft*, Tabard's hybrid notebook, and Signer's and Weibel's work to support interaction across the paper-digital divide. The most recent advance in this line of research is the excellent thesis work of Jürgen Steimle that is the basis of the present book. Steimle confronts the complex and crucially important issue of how to bridge and combine digital and paper worlds so as to facilitate access to the best of each.

In this book Steimle addresses the question of how to design interfaces that integrate traditional pen-and-paper-based practices with digital media. He begins with a comprehensive survey of pen-and-paper computing in which he covers the technologies involved, existing toolkits and applications, and characterizes an underlying model of generic core interactions as a basis for developing principles and guidelines. Based on this model he describes CoScribe, a novel modular framework to support collaborative paper-based work. CoScribe provides an integrated environment that supports multiperson collaboration with multiple documents. It is unique in addressing the complex challenges involved in supporting asynchronous shared handwritten annotations and hyperlinking between printed and digital documents. The exposition using scenarios, detailed descriptions of the technologies, and careful empirical evaluations is compelling and advances both the science and technology of interface design. While the focus of the book is on pen-and-paper interfaces, everyone interested in how to design for real-world activity will profit from reading this book.

San Diego, October 2011

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Foreword

The mass deployment of Smart Phones, Netbooks, and Web tablets has made computing essentially pervasive and ubiquitous – yet to date, there is only one truly ubiquitous information processing technology: pen and paper. Imagine the wealth of paper variants that may populate the venue of a creative and information-centered workshop: little Post-it notes and snippets, sturdy colored cards, numerous piles of memos and notes, groupings of bound or stapled documents, annotated leaflets and brochures, journals and magazines along with ready-made, commented laser copies of relevant contents, binders and folders full of classified information, flipcharts and wall-covering series of charts and other drawings, not to mention waste baskets, full to the brim with torn and crumpled sheets, . . . the list is endless. And it is still a long way to go until we can use and afford computers in the same quantity and variety, and with such simplicity and carelessness.

On the other hand, computers can handle information in a way that paper will never be able to: store and archive in ‘infinite’ quantity with an ever smaller footprint, search and analyze, transmit, copy, and share at virtually no cost at lightning speed, edit and interconnect, . . . again, the list is endless. Given these considerations about the uniqueness and ubiquity of both paper and computers, the present book is long since overdue: a thorough, concise, and well-organized compendium of marriages between paper based and electronic documents.

This book, a revised and extended version of Jürgen Steimle’s award-winning computer science dissertation, provides the reader with a broad and extensive overview of the field. The state of the art is covered in a most up to date, complete, and systematic way, so as to provide the full picture of pen-and-paper computing like no other reference before.

The contributions made with regard to modeling the interaction with pen-and-paper interfaces provide an unprecedented theoretical foundation and organization of the subject matter, helping to structure and order the problem and design spaces in a rather unique way. The book proposes information ecologies as the appropriate theoretical perspective for designing pen-and-paper interfaces. This involves taking a broad view and looking at all the ingredients that largely influence the interplay of humans and machines in the context of information handling: current and related

documents, cognitive and social networks, past actions and future-oriented intentions. The author presents an elegant ‘building set’ of core interactions helpful in designing solutions that address the diversity of such ecologies.

Retaining the holistic approach of the book, the third part presents an integrated set of interaction techniques for the most relevant human document processing activities: collaboratively annotating, combining (linking), and classifying (tagging) documents. Here, the aforementioned systematic theoretical framework forms the basis for the cleanest and most flexible approach known in comparison to related work. Regarding cross-media annotation, the presented approach provides an impressive proof of the huge potential that lies in joining the individual strengths of the two technologies, paper and computing. As to combination i.e. hyperlinks, a rather small advancement in hardware is provided as a basis: the enabling of Anoto technology for use with both computer screens and traditional paper. This small technical contribution enables a huge effect with respect to eliminating seams and hurdles between the two technologies. Finally, concerning classification (tagging), the author provides smart and elegant means for tagging documents with predefined classes, but also with arbitrary tags that are defined on-the-fly. Here and in the aforementioned contributions, the author proves to be quite resourceful when it comes to leveraging the strengths of paper as a technology, such as the flexible interplay of many paper sheets, but also when it comes to coping with its limitations, such as the lack of inverse operations for writing or cutting.

In short, the present book promises to be an exciting source of information for IT professionals (trying to understand the cutting-edge field of pen-and-paper computing), researchers (interested in an overview of prior research and in the substantial original academic contributions presented in this book), and HCI experts (seeking insights into the comparatively young field of pen-and-paper computing as well as on the advancement of their field in general).

Darmstadt, October 2011

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Chapter 1

Introduction

The paperless office is a myth (...) because (people) know (...) that their goals cannot be achieved without paper. This held true over thirty years ago when the idea of the paperless office first gained some prominence, and it holds true today at the start of the twenty-first century. (...) It will hold true for many years to come.

A. Sellen and R. Harper, The Myth of the Paperless Office

Paper has been used over thousands of years. Even though digital media are getting increasingly more sophisticated, paper is surprisingly persistent. Paper is certainly used differently than some decades ago. However, even at the beginning of the twenty-first century, it is still pervasive in our homes, workplaces, schools and universities.

During the last decades, many attempts aimed at replacing paper documents by digital media. Desktop computing, word processing, electronic mail and the World Wide Web have been considered to have a large potential for replacing paper. In contrast, paper was considered a symbol of old-fashioned technology. However, the numerous predictions of the paperless office have not become reality [131].

Where does this omnipresence of paper stem from? Why cannot paper be easily replaced by computer technology? The longevity of paper cannot be merely attributed to shortcomings of current display technology, such as limited screen size, resolution and contrast. A large body of research shows that paper supports a wealth of interactions that have a number of inherent advantages over digital technologies. To state only some of these advantages, annotating paper documents with a pen is easy, flexible and smoothly integrated with reading. In addition, paper renders information tangible. People can utilize their both hands for interacting with it and get tactile-kinesthetic feedback. This provides for effectively navigating within a document, for example when thumbing through a book and sensing the appropriate number of remaining pages with one finger, but also for sorting and structuring paper-based information. These are only some examples of the advantages of paper documents, which we will identify in more detail below.

Despite these advantages of paper, it is a matter of course that digital media have other, equally important benefits. For instance, digital documents can be efficiently searched, archived and shared over a distance. Moreover, they can include dynamic contents, including audiovisual and interactive media. In addition, albeit it is relatively inexpensive to produce paper and to print on it, the cost of dealing with paper documents after printing – delivery, storage and retrieval – can be much higher than the respective cost of digital documents [131].

Due to the unique benefits of both worlds outlined above, people typically use not only paper or only digital documents. Rather they *combine* both worlds. Depending on the type of information and the context of use, some information is preferred in a printed form while other information is accessed using digital technology. For example, paper might be preferred for reading a longer document, while a computer might be the tool of choice for composing new documents or for looking up information on the Web. This combined use of printed and digital documents leads to disruptive transitions. Users must cope with different representational media as well as with different interactions and tools. Most important, while many digital documents can be easily printed on paper, the reverse direction is more challenging. It is still difficult to efficiently digitize paper-based information.

During the past two decades, a new area of research has formed that develops technical solutions for the integration of paper-based and digital information. Rather than replacing one medium by the other, the main goal of this strand of research is to reduce the gap between printed and digital documents and to combine the best of both worlds. Since many paper-based activities also involve using pens, most interfaces do not only support using physical paper, but also physical pens, and make both of them key elements of digital user interfaces. This presents novel opportunities for improving computer support for document-based activities. Research on Pen-and-Paper User Interfaces can be assigned to the fields of Ubiquitous Computing and Tangible User Interfaces, which aim at extending computing beyond the computer desktop into the physical space that surrounds us.

The present books inscribes into this strand of research and focuses on how to integrate pens, physical paper, and computers. The main question addressed in this book is as follows:

How to design user interfaces that effectively integrate traditional pen-and-paper-based practices with digital documents?

Our answer is three-fold. Each part of the book addresses this overall question from a different perspective:

First, this book provides a comprehensive overview of prior research on Pen-and-Paper User Interfaces. At the time of publication of this book, this is the most complete and up-to-date survey of the field. It gives extensive insights into technologies, technical frameworks and existing concepts for user interfaces.

Second, looking at Pen-and-Paper User Interfaces on a rather abstract, conceptual level, the book introduces a generic interaction model. Going beyond the individual interaction techniques presented in prior work, this model provides systematic guidelines for designing Pen-and-Paper User Interfaces.

Third, the book provides a concrete instantiation of the model: the CoScribe framework. CoScribe introduces an integrated set of interaction techniques that sup-

port effective knowledge work¹ with documents. We introduce novel concepts that support collaboration on various levels, integrate paper and screens closer than before, and make ample use of the physical flexibility of paper. All these techniques are generic and can be easily integrated into user interfaces that target different work settings.

This introductory chapter serves for framing the topic of this book. In order to understand what is so specific about paper, we first provide a synopsis of prior research that has examined the affordances of paper. Next we will present our approach – integrating printed with digital documents – and introduce the basics of Pen-and-Paper Interfaces. This allows us to outline key challenges that will be addressed in this book. Finally, we provide an overview of the chapters and guide readers through the book’s structure.

1.1 Why Using Paper Documents?

With the advent of word processing, electronic mail and the World Wide Web, many experts predicted that the end of paper use in offices was imminent. Entire companies attempted going paperless, thereby banishing the symbol of old-fashioned technology. However the paperless office has failed to materialize. A number of similar predictions of paperlessness can be traced back in the history until the 19th century [131]. Paper survived each of them.

Recently, novel technologies, such as e-book readers and tablets, have come to the market. Printed newspapers see themselves challenged by online information portals. A growing number of scientific works get published solely online. Again many commentators prognosticate that paper is becoming passé. Indeed, electronic media are currently pushing back paper to some extent in publishing. While in the 1990s, paper production was constantly increasing, paper consumption currently seems to have reached a plateau and remains approximately at the level of the year 2000 [13].

However, this does not mean that we will go paperless to work. The key point is that the publication medium is not necessarily the medium that we use for eventually working with the document. For instance, Sellen and Harper showed that the electronic access to documents made possible by the World Wide Web did not reduce but it even increased paper consumption. One reason is that people prefer reading long documents on paper [131]. This still holds true for state-of-the art e-readers and tablet devices [153, 103]. Hence, even at the beginning of the twenty-first century, paper remains a key information medium that is omnipresent in our homes and at our workplaces.

In this section, we discuss what are the affordances of paper that make it such a pervasive medium, despite all advances in technology. What affordances are likely

¹ Following Drucker [25], we define *knowledge work* as a category of work which primarily deals with using and developing information. Some very obvious examples of knowledge workers are: scientists, teachers, students, librarians, engineers, lawyers, journalists.