Automated Design of Paper Workbooks, for Electronic Learning Environments

Harini Sridharan Hari Sundaram Jennifer Brungart
Arts Media and Engineering Program, AME-TR-2004-12

e-mail:{harini.sridharan, hari.sundaram, jennifer.brungart}@asu.edu

ABSTRACT
The paper and the electronic worlds provide complementary affordances and we envision a framework where there is continuous transfer of knowledge between the two environments. This paper shall discuss the automatic generation of a paper workbook using principles of graphic design, a consequence of electronic world interactions. Our approach incorporates user context models as well a graphic design principles. User interaction in the electronic world affects the user context, thus critically determining media to be selected for paper. The paper workbook creation is then informed by design principles involving layout consistency, concept dominance, contrast and proximity. The media selection and the paper layout are both fully automated. Our preliminary experimental results indicate that the paper designs are well liked and deemed relevant to prior electronic interaction.

Keywords
Paper-electronic interaction, context-awareness, automated design and layout.

INTRODUCTION
In this paper, we describe a mechanism by which paper workbooks are automatically generated from electronic presentations based upon user’s learning goals and preferences. The technique also incorporates principles of graphic design when generating the workbook. The problem is important since both the electronic and the paper worlds provide complementary sets of affordances [2,3], and a complete system that informs each world of the knowledge gained in the other would be immensely helpful. This paper focuses on the automated creation of the paper world, from the electronic world. Our approach to the transformation of the electronic world using paper can be found in [6].

There has been a lot of prior work on the study of paper’s affordances and how this can be brought into electronic interactions [4,5]. However, there has been little focus on the how to automatically design on the paper world to complement the knowledge gained in the electronic world. There is also no focus on the idea of an electronic-paper continuous cycle to aid knowledge.

There are two key issues when transferring knowledge across media – (a) media selection and (b) the design of the paper world. In our approach, we have built simple electronic environment, to enable children to learn about concepts in geography [1]. As the user interacts with the electronic world, we track her user profile – this is continuously updated based upon user interactions. The media to be presented are selected based on the distance of the concepts that they represent, to the user context. We need to introduce new knowledge as well as maintain continuity with the electronic interaction. The media are laid out on paper using principles of graphic design. We shall incorporate traditional graphic design elements of consistency, contrast, dominance and proximity into our automated layout principles. The preliminary user studies indicate that the paper design was successful.

The organization of the rest of the paper is as follows. In the next section, we give an overview of our complete set-up. Following it, we will present our mechanism for media selection. We will then discuss our technique on automatically incorporating design and layout principles into the generation of the workbook. The experimental results are discussed in next section and finally we will present future work and conclusions.
THE ELECTRONIC-PAPER INTERACTION CYCLE
In this section we give an overview of the complete system which involves the following: (1) automated generation paper workbooks based on user context and interaction history and (2) automatically analyzing the user’s interaction on paper and feeding back this information into the electronic environment, thus forming a complete cycle to bridge the electronic and paper worlds.

The Electronic World
In our prior work [1], we developed an automatic electronic presentation system that dynamically adapts the media presented, to user context. The goal of the system was to create a learning environment that was user-centric and that allowed students to actively explore concepts in geography. It provided the users with an open-ended, activity-based learning experience. The system involved (a) a multimodal user context model that evolved based on the user’s interaction, (b) determining the duration of presentation of each media element by arriving at a relationship between the media’s complexity and comprehension time, and (c) and the idea of a knowledge flow graph that models concept relationship constraints to model the dynamics of the presentation. The environment included relationships about geography, that were provided by an expert.

The Role of Paper
We now seek to extend the electronic presentation framework to incorporate other medium such as paper. This is important because users when interacting with presentations or documents, often prefer to print them out on paper to enable ease of certain kinds of interactions, such as note-taking / annotations and also to have the flexibility of spatial layout of several sheets of paper on the desk. When a user chooses to switch from the electronic to the paper medium, a paper work-book is generated for her based on her user context and what she has learnt so far in the electronic medium. The workbook consists of six pages [Figure 2] with each page containing media associated with a certain concept. She can now interact with the pages using commonly used interactions such as handwritten notes, underlining what she thinks are important, moving the sheets around to arrange them in a way that helps her see relationships between the concepts of the different pages among others.

Completing the Electronic–Paper Loop
When the user has interacted with the paper workbook and wishes to switch to the electronic medium, the pages of the workbook are scanned, the user’s annotations detected, analyzed and then incorporated into the electronic world. In this paper we will focus on our technique to automatically generate paper workbooks based on user’s interactions in the electronic environment. We will mainly look into issues of how to select the media to be used in the workbook and how to present and place them appropriately.

MEDIA SELECTION
A key issue in transferring information from the electronic to the paper medium is to be able to pick media to be displayed on paper that is related to the current user context. When the user interacts with the electronic environment, the environment analyzes the user interaction updating its estimate of the user context. The goal of the system is to enable the user to learn as much information about the domain as possible in the time that she interacts with the system. Thus it is important that the user is presented with information that covers the domain breadth rather than depth.

As a strategy, we choose to present those concepts to the user that she has least knowledge about. As we create six-page paper workbooks, we decided to choose the first six least seen concepts, with each page representing one concept. In order to sustain the user’s interest we also need to pick those media elements pertinent to her current user context. The media selection algorithm is as follows:

1. Pick the concept amongst all of the domain concepts (specified by the domain expert). Choose that concept that the user has the least knowledge. In other words, that concept for which the average

![Figure 2: The paper work-book. The book is created using principles of graphic design through a context aware, automated procedure.](image-url)
weight of all its sub-concepts and associated concepts in the user context is minimum.

2. Select six sub-concepts of this chosen concept based upon the information flow path as dictated by the knowledge flow graph [ref. section The Electronic World].

3. Choose a subset of media elements associated with each concept such that the distance of these media elements from the user profile is the least. The distance function is from [1].

4. When the user interacts with the electronic environment, we assume that she would have spent the maximum amount of time on media of interest. Consequently, the weights of those concepts increase in her profile. According to the distance function we are using, the distance between a media element, \( m \) and the user profile is inversely proportional to the weights of concepts represented by \( m \) and weights of the concepts in the user profile. So the distance between a media element that is identical to important media elements that are a part of the user profile will be small. Thus, picking the media elements most similar to the user profile will ensure that these media elements will be of interest to her.

**DESIGN AND PLACEMENT**

We present the media on paper using an automated framework based on the principles of graphic design [7]. The paper workbook consists of six pages with each page consisting of media elements related to a single concept. Each page contains a bar code [ref. Figure 4] on one of its corners that encodes the user id and the page number. These barcodes are important in identifying the page, when the users scan in their annotated pages. The pages are also provided with text boxes [ref. Figure 4] where the user can take notes. We will now describe our design considerations.

**Design Consistency:** A key aspect of good graphic design is the visual consistency. The system chooses design elements of font color, font style and grid layout structure at random from an *a priori* fixed style set and retains these stylistic elements when designing all six pages. This creates visual unity throughout the six pages.

**Dominance:** In all the information that is presented to the user, we may wish to lay emphasis on certain specific concepts that we want the user to learn. We have incorporated tried and tested design principles [5] that are commonly used in books to focus user’s attention.

Text that are identified dominant by the system are made visually prominent by using a bolder typestyle, a more prominent color or by increase in size as compared to the surrounding text. Dominant images are emphasized by an increase in size, repetition of the image or a conspicuous bounding box. The design elements chosen to express dominance are maintained across all pages for consistency. Dominance of a text or image is computed as follows. A text or image, \( k \) is dominant if

\[
1 - d(k, \text{ the concept represented by the page}) > \beta < 1
\]

where \( d \) is the distance function and \( \beta \) is the threshold picked by experiment. The distance between a text and the concept represented by the page is the average distance [1] between this text and all the texts associated with the current page concept. The distance between an image and the concept represented by the page is the average distance between this image and all the cluster centers of images associated with the current page concept.

**Contrast:** This design principle states ‘when two items on a page are not meant to be similar, make them obviously different’. When a media element in a page is in contrast with the rest of the media elements of the page, then it is made to look visually contrasting to the rest of the media elements by applying one of the following principles: inversion/rotation of the media, use of a contrasting color or typeface from the surrounding media, misalignment with the grid layout. A media element, \( m \) is in contrast with the

**Figure 3:** Making important text stand out. The only two words that are of a different color from the rest of the text draw attention instantly. The figure on the right shows image dominance using both size and the bounding box.

**Figure 4:** A sample page that was generated automatically using principles of graphic design.
rest of the media of the page is computed if
\[
\frac{1}{N} \sum_{i=1}^{N} d(m, m_i) > \alpha; m_i \neq m
\]

where \(d\) is the distance function, \(m_i\) are the other media in the page and \(\alpha\) is the threshold picked by experiment.

**Proximity:** Grouping related items together automatically leads to each group being seen as a unit of information. Similar media elements are placed in close proximity to one another. If a media is similar to another media in one of the adjacent pages, the media is made to overlap both pages. This, apart from giving the sense of proximity, also creates a visual puzzle for the user. Figure 5 shows an image overlapping over two pages due to its proximity to concepts represented by both pages. Proximity of a text or a media element with a concept is just defined as the inverse of the contrast between them.

We believe that these design criteria are crucial in efficiently communicating information on paper. Once the pages are generated, the user can interact with these pages in any manner she wishes.

**EXPERIMENTS AND RESULTS**

We conducted experiments to evaluate two aspects of our automatic paper workbook generation algorithm: (a) appropriateness of the media selected and (b) effectiveness of the design and layout. We evaluated our models through a pilot user study with five users. **Evaluation of appropriateness of media selected:** Users were asked to use the system by interacting with the electronic environment first and then switch to the paper medium when they wanted. We generated paper workbooks using our technique and with a random selection of media from the electronic environment. This was to test if the users found our media selection to be correlated to the media in the electronic environment. All users preferred the workbook our media selection technique. **Evaluation of effectiveness of the design and layout:** Two kinds of paper workbooks were generated – one that incorporated design issues and one that did not. Both workbooks had exactly the same media elements in them. Some users were given the first workbook and some users the second. After reading each page of the workbook, they were asked to write down the top three concepts on that page that they considered were important. Users who used the workbook with the design issues incorporated, were much more likely to choose those concepts that the system considered important than the users who used the other workbook. They were also able to get the essence of the pages quicker due to the prominent emphasis on the dominant concepts, which also provided a kind of summary of the page, and due to the consistency of design.

**CONCLUSIONS**

In this paper, we presented our work on automatic generation of paper workbooks for learning based on user’s interactions in the electronic world. We detailed our media selection procedure that is based on user’s learning tasks and personal preferences. We analyzed design and layout issues discussed our technique for automatically incorporating these design principles into generation of the paper workbook. The user study gave encouraging results – implying that the users found our media selection technique and design principles satisfactory. We plan to address the following issues in future work – (a) additional interactions such as stacking, transparent sheets, folding, and (b) investigate additional spatial layout metaphors.

**REFERENCES**


