Designing Navigable Information Spaces

by

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B.S. Computer Science and B.S. Electrical Engineering
Washington University in St. Louis

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Abstract

Currently, computer users are "lost in hyperspace:" they have difficulty knowing where they are and locating the information they desire. To remedy this, information should be situated in an information space that enables people to explore knowledge in the same way they navigate in the physical environment. This thesis will enumerate a set of principles to guide information space design, enabling designers to create effective information spaces. The design principles fall into three categories: communication principles, which inform the spatial organization of information; wayfinding principles, which structure the space to allow successful navigation; and computational principles, which use the computational nature of digital media to enhance the information space. Two information spaces designed using these principles are presented and analyzed.

Thesis Supervisor: Randall Davis
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Chapter 1

Introduction

1.1 Thesis

> Reconsidering information-seeking behavior as navigation leads us to ask what a path through knowledge could mean. we claim that these paths can be created to support useful tasks, and we offer principles to guide the design and presentation of paths that communicate.

1.2 Information and Information-Seeking

A businessman *en route* to his office purchases a newspaper from a vendor. A student finds a book and checks it out from the university library. A woman searches for job listings using the World-Wide Web. Each of these individuals is participating in the process of *information-seeking.* Information-seeking is the domain of human behavior concerned with actively acquiring information from one's environment, usually to fulfill larger problem-solving goals (Marchionini, 1995). For the businessman, that goal is more effective business decision-making that day; for the student, the completion of a research paper; for the job-seeker, employment. information-seeking is a continuous, circumstantial process that is a part of individual problem-solving behavior at every level of description.

information-seeking is also a problem-solving behavior in its own right. It begins when the information-seeker realizes that he is lacking some knowledge which will help him fulfill a higher-level goal. This in turn leads to the gradual formulation of an information need: some description of the knowledge that would allow completion of the higher-level task (Taylor, 1962). This need, in turn, is translated into actions to retrieve media with the needed information.

An example. The student mentioned earlier is assigned a research paper in class. Having chosen a topic, say, nose morphology in vampire bats, he asks the professor for suggested sources; he mentions that there are two recent articles in the Journal of Vertebrate Zoology, but then rushes off to a faculty luncheon before he can provide any additional details.

The student goes to the university's library and uses its electronic catalog to retrieve the call number of the journal by a keyword search on "vertebrate zoology," and takes last year's volume off the shelf. Scanning the tables of contents, he finds the articles in question.

The example points out some of the kinds of knowledge and skills necessary to successfully complete an information-seeking task in a library setting:

1. Knowledge (or an assumption) that the most recent volume of the journal was located in the library;
2. Skill in using the library's electronic catalog system to find the call number of the journal;
3. Knowledge of the library's layout and its call-numbering system to find the journal among the stacks.

What makes effective information-seeking possible in this setting is the fact that the material in the library has been organized in a manner understood by its users, and that they can successfully apply knowledge of that organization to find material that meets their information need. In this case, the student was able to use the electronic catalog to match a journal title to a call number, and the layout of the library to match a call number to a location, to translate a need – "articles in a recent journal volume" – to a particular book in the stacks. It is precisely these kinds of structures that define what an information access environment is: a set of tools to allow a user to translate an information need into information-seeking actions to retrieve information that meets the need. As more and more information has become available and accessible in digital form, an important question has arisen that asks what kinds of tools our electronic information access environments should have.

1.3 Information-Seeking in the Information Age

A number of techniques have evolved for constructing electronic information access environments that organize on-line information. At first, the main organizational tool was the hierarchical directory structure provided by the file system of a personal computer or a time-shared mainframe. The user's personal information access environment consisted of his local disk or home directory, and information-seeking proceeded by moving from directory to directory and listing their contents. The user could distribute content to others by copying files to a shared directory or removable media. Organizing a large number of files required giving meaningful names to directories and subdirectories, and ensuring that a file was kept in the directory in which the user would most likely look for it. This method, the use of a hierarchical classification, has long been used outside of the electronic environment (for example, in library subject classifications (Immroth, 1980)).

Full-text indexing was developed to allow users to find documents containing words given by the user (Salton, 1968). It has proven very successful at satisfying information needs in which the user knows words specific to documents meeting the need and unlikely to be in irrelevant documents. Because it requires only that the full text of the documents is available, it can be used in conjunction with other forms of organization, such as a hierarchical classification.

In the 1980's, the idea of linking individual documents or parts of a larger document together into a hypertext began to be implemented on a wider scale with the development of commercial authoring and browsing tools (for example, HyperCard$^{\mathrm{TM}}$). The standarization of hypertext markup languages and transmission protocols, the distribution of free browser software, and the phenomenal growth of the the Internet all contributed to the creation of the World-Wide Web in the early 1990's. Hypertext is currently the primary organizational method for published online content. The techniques mentioned previously have each been successfully applied to assist information-seeking on the World-Wide Web with site catalogs and Web search engines.

Continuous advances in the underlying media and networking technologies have not only changed how information is accessed and organized, but the amount of information available to the average user. More and more of the growing body of human knowledge is available to a significant proportion of the population. At first, the issue was the the availability of information on-line: *Am I able to access what I want at all?* Now, however, the issue is how to find information that is most relevant to the task at hand: *How do I use the organization of the World-Wide Web to meet my information need?* Many individuals are concerned that their information-seeking strategies are insufficient – useful information is available to them of which they are unaware, or cannot find. One commentator calls this "information anxiety" (Wurman, 1989).

1.4 Information-Seeking as Navigation

In response to these issues, we propose that reconsidering information-seeking behavior as navigation through an information space gives insight into how we should structure our access environments to assist the information-seeker – namely, to use the same abilities that people use to navigate in the physical environment. We also claim that these spaces should be designed to facilitate a specific information access task.

To clarify what is meant by navigation in the context of information access, it is useful to state a list of ground assumptions about information-seeking in electronic environments (see Figure 1-1).

1. Only a small part of all the available content is visible to the user at once. In effect, the access environment defines a "window" into the available information, whose size is bounded by both the user interface technology (e.g., display resolution) and the ability of the user to comprehend a certain amount of information at once. This window could contain a list of bibliographic entries, a node in a hypertext, or a page in a large document.

2. Information access proceeds by moving this small window from one location to another. This could correspond to following a link in a hypertext to a new node, or moving down one level in a category hierarchy.

3. The information-seeker's decision on where next to move this window depends on four factors:

   (a) The current location. *What do I see through my window?*

   (b) Available moves from one location to another. *To where can I move the window in one step?*

   (c) Knowledge of the organization of the space itself. *In which direction will I be moving closer to material that meets my information need?*

   (d) The nature of the task, or the information need. *Am I browsing, learning, searching, or exploring? When am I finished?*

From these assumptions, we can characterize information access as navigation through an information space consisting of locations, views into the space through the intermediary

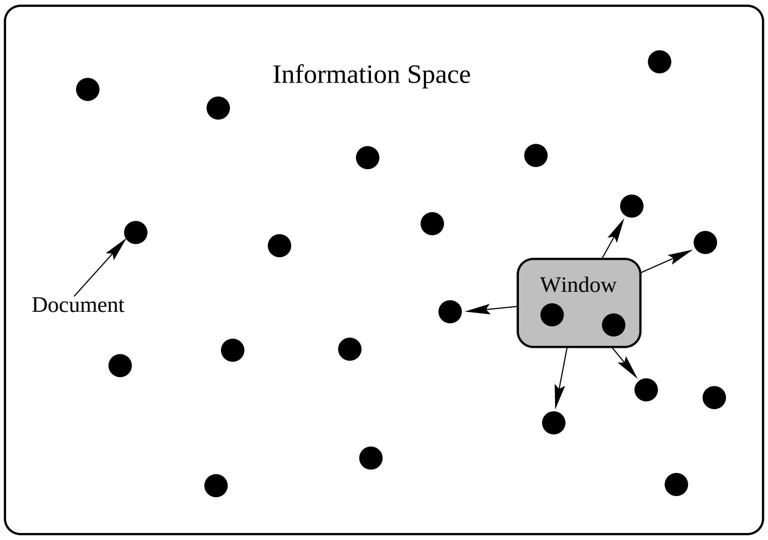

Figure 1-1: The information-seeking environment.

window, and moves that change one view to another. This way of describing the process gives us a new language for both the analysis of existing information access environments, and the design of environments that explicitly support navigation.

1.5 Overview of the Thesis

Each of the information access techniques described earlier – hierarchical classification, full-text indexing, and hypertext – can be thought of as defining a space of possible locations and moves. The next chapter examines how effectively (or ineffectively) those techniques provide affordances for navigation, and we conclude that effectively navigable information spaces must be explicitly designed with those affordances.

The question then turns to how we can take some collection of information and organize it into an effectively navigable space. Answering this question motivated the study of a kind of physical information space: educational museum exhibits. The analysis of seven educational museum exhibits and interviews with their developers and designers produced a collection of design principles for organizing information into spatial paths that communicate.

To test the validity of those principles, they are used to guide the design of two novel information spaces. The first, an early experiment in designing an information space, provides a survey view of the articles in the Journal of Artificial Intelligence Research for search, browsing, and retrieval. The second, the Course VI Information Space, provides both survey and immersive views of the subject listings for Electrical Engineering and Computer Science at the Massachusetts Institute of Technology.

The main points of the thesis are:

- The usual ways of organizing information are not entirely effective for the purposes of navigation.

- Information access environments should be *information spaces*, designed to allow navigation for an information-seeking task.
- Educational museum exhibits are examples of information spaces that communicate, and we study them to discover principles for designing digital information spaces.
- Applying the principles we have learned to design new information spaces permits evaluation of their effectiveness.

Chapter 2

The Problem: Poorly Navigable Spaces

Now that the process of information access in electronic environments has been posed as navigation through some type of space, it can be asked how well the commonly used information spaces mentioned in the introduction support the process of information navigation. The basic assumptions about information-seeking outlined above can be rephrased as a set of questions that can be asked about any information space:

1. *What can be seen through the information-seeker's window?*
2. *What is the nature of the moves from one location to another in the space?*
3. *How well does the space provide cues that enable effective information-seeking moves:*
   (a) *How does the information-seeker infer his present location?*
   (b) *What does the information-seeker know about the moves available at his present location?*
   (c) *What does the information-seeker know about the structure of the content of the space?*
4. *How well does it meet a particular kind of information need?*

We hope to show that although the basic techniques for information organization provide some of the features necessary for successful information-seeking, they do not inherently provide the affordances needed for navigation through an information space. Some of those affordances include *landmarks*, memorable locations with special significance; well-structured *paths*; and *maps*, survey representations of the space. The solution, then, is to design information spaces that employ these affordances to assist the information-seeker in his task.

2.1 Hierarchical Classification

Hierarchical classifications are used in such diverse applications as library subject classification (Immroth, 1980), Internet newsgroup hierarchies, and directories of sites on the World Wide Web (e.g., (Yahoo Incorporated, 1998)). In a hierarchical classification, a set of labeled nodes are arranged into a tree. The label given to a node indicates an attribute shared by the items of information attached to that node, and all of the node's children. Each node defines a category that proceed from the general (has fewer attributes) at the root to the specific (has more attributes).

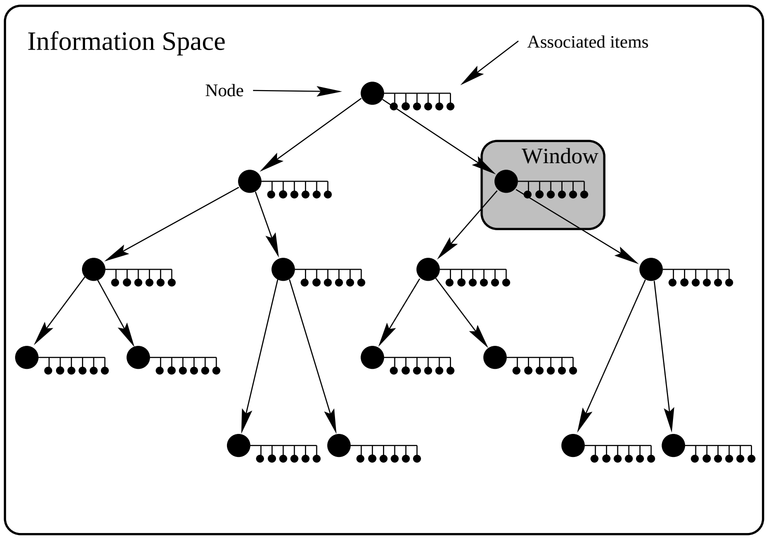

Figure 2-1: A hierarchical classification as an information space.

As an information space, a hierarchical classification looks like Figure 2-1. The information-seeker's window shows the current node and the items of information attached to it. Two kinds of moves in the hierarchy are available from this location. The seeker can move the window to the parent of the current node, corresponding to a move to a more general category (in that its label applies to a larger number of descendants), or to one of its children, a move to a more specific category. Or, the seeker can examine an item of information at the current node in more detail.

At each node, the seeker must decide whether the information needed is available at the present node, or if a move should be made up or down the hierarchy. Because seeking proceeds downward from the root node, a move up can be thought of as backtracking, debugging an incorrect choice made earlier in traversal – a difficult process, since every node already chosen has some relevance to the seeker's information need. The correction must take place at a sufficiently high position in the hierarchy to include the desired material in a subtree of the new node.

The choice of names for a node label is crucial, as it must indicate relevance for all of its descendants. Since combinations of binary attributes defined over a set induces a boolean lattice, a hierarchy must break this lattice at selected points. This means that cross-hierarchical links are required to supplement the tree structure of the hierarchy when categories do not strictly follow a subset relationship.

Obtaining a survey view of a hierarchy is also problematic. A breadth-first traversal of the hierarchy at a high level can communicate the topic structure of the content, but obtaining higher resolution surveys requires viewing an exponentially increasing number of nodes. Pictorial representations of hierarchies are possible, (Robertson et al., 1991), but the same exponential increase with depth presents special difficulties for visualization (Carrière and Kazman, 1995). Multiple traversals through the space will also gradually increase the number of nodes seen by the information-seeker, but a large proportion of the space will remain unseen. Landmarks, memorable locations that provide cues for orientation, are also not an inherent part of a hierarchy.

Hierarchies are well-suited for needs which can be fulfilled by narrowing down a from a general category of material to a more specific one, and one in which the category of the right specificity can be readily identified, so the seeker knows when to stop movement. Hierarchies, then, trade off the ability to reach any node by a potentially short path from the root with the risk of a wrong move requiring backtracking.

2.2 Full-Text Indexing

Full-text indexing makes the entire text content of documents available for term searching. The results of a search are an ordered list of documents, ranked by a measure based on the number of occurences of query terms in the text of each document. Documents with more occurences are ranked higher and presented first. Algorithms and implementations of full-text indexing are well-studied and well-represented in the literature (see, for example, (Frakes and Baeza-Yates, 1992) and (Jones and Willett, 1997)).

The type of information space created by full-text indexing system appears in Figure 2-2. The window shows the top-ranked documents found by the search system, according to the terms entered by the user. Each row in the space represents an ordering on the documents induced by a particular set of query terms.

The first move in such a space is the formulation of a new query to the system. Subsequent moves may refine the initial query by adding or removing terms, or begin afresh with an entirely new set of terms. The present location in the space is identified implicitly by the specific terms chosen for the current query and explicitly by the top documents returned by the system.

When first beginning an information-seeking episode, the user must solve the difficult problem of query formulation – selecting terms likely to be in documents of interest, but unlikely to be found elsewhere. Given that combinations all of possible terms in the document corpus are available as moves, finding where to begin in this space is a challenging task.

Once an initial query has been formulated, giving the user an initial location in the space, modifying that query corresponds to moving to a new location in the space. Again, the same problem arises: the system itself gives little guidance on which terms to modify, relying on the user to find a useful move among the many available queries.

Mapping the space is not possible by simply looking at the results of a number of queries. It is difficult to compose them into an overall picture relating the topic structure of the underlying corpus. The size, scope, and domain of the collection are difficult to infer from query results, and the user cannot relate a result as typical or representative of the entire collection. Landmarks are also not available in such a system.

Although a full-text indexing and search system is a powerful tool for information access, its limitations lie in the unstructured way it represents the underlying corpus. It relies on the user to find an initial combination of query terms that corresponds to his information need. Once formulated, every location in the space is immediately available, and the user must decide which of the many moves in this space are useful and which are not.

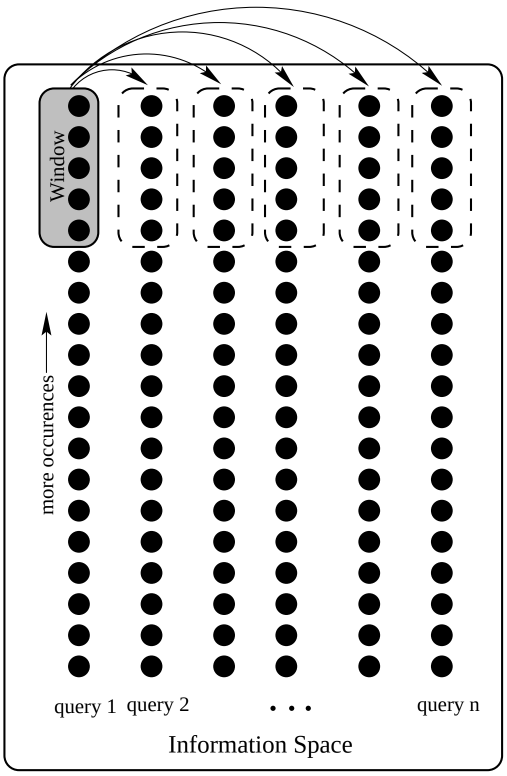

Figure 2-2: A full-text search system as an information space.

2.3 Hypertext

A hypertext system, as originally proposed by Vannevar Bush (Bush, 1945), is a way to link documents to form "associative trails" which could be named and stored for later recall and duplication. In practice today, the use of hypertext bears little resemblance to Bush's proposal. Instead of links encoding lines of reasoning or associations, they now serve many additional roles. In effect, following a link is now a content-free user interface action whose semantics must always be recovered from the link's context. The meaning of moves in this space are therefore nonuniform; they depend crucially on the user's location in the hypertext.

An information space for a hypertext looks like Figure 2-3.

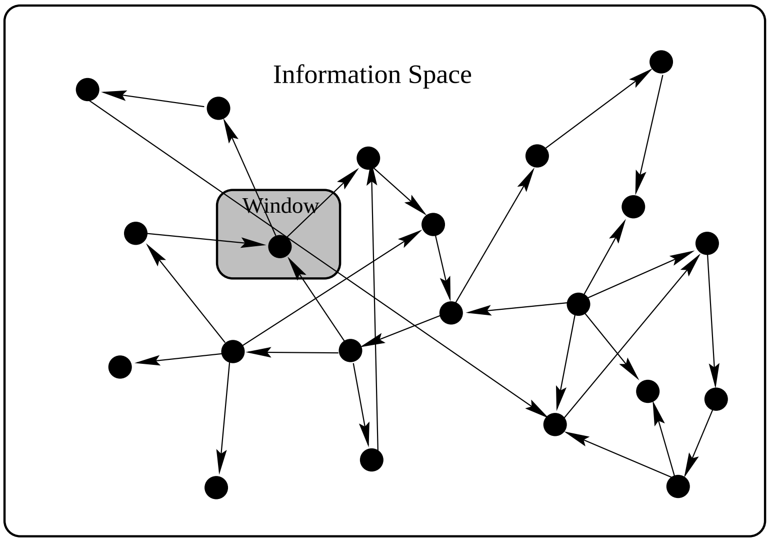

Figure 2-3: A hypertext as an information space.

The view through a window in this space is one node or document in the hypertext and the anchors denoting outgoing links. The overall topology of the hypertext is not apparent from this localized view, and ambiguous link semantics make the formation of a meaningful spatial representation problematic. In addition, arbitrary directed graphs cannot be drawn in a fixed-dimensional space without links overlapping, making the mapping of hypertext difficult.

Paths through hypertext lack explicit context and consistent meaning: the user can make large semantic jumps by taking a small step syntactically. Again, the basic elements required for effective wayfinding – landmarks, meaningful paths, survey representations – are not required in the hypertext model. All these factors interfere with navigation through hypertext, and lead to what is called being "lost in hyperspace:" the user not knowing where to go next, knowing where to go but not knowing how to get there, or not knowing where he is in relation to the overall hypertext (Elm and Woods, 1985; Edwards and Hardman, 1993).

2.4 The Solution: Navigable Information Spaces

Given that current information structuring techniques do not inherently incorporate all the affordances needed for orientation, navigation, and mapping, we need to design our information access environments to support these abilities explicitly. This is the core of what an information space is: a design commitment to environments that humans can use to navigate in the same way that they can navigate in the real world. Or:

> KNOWLEDGE NAVIGATION. To enable successful navigation in a collection of information, design a principled information space that users can navigate to search, browse, learn, and interact.

To be effective, an information space should fulfill certain requirements to enable people to use their real-world navigation skills within it. These include:

1. Orientation should be recoverable at every point in the space. The user should never feel lost.
2. The user should be able to make a correct navigation decision to take the right next step, even if the eventual destination is imprecisely known.
3. Information should be placed in the space should according to an organizing principle, and this principle should be communicated explicitly to the user. It is this crucial property that permits the user to form a conceptual map of the space: a correspondence between its spatial organization and the semantics of the information it contains (Lokuge et al., 1996).

An information space that fulfills these requirements can solve the problem of being lost in hyperspace. The user will always know his location relative to other information in the space and can effectively construct routes to search for the information he needs. The user can also browse through the space in a more undirected manner to look for information of interest, or take an instructive tour through the space that reveals the depth and breadth of its contents.

If an information space uses the same features that help us navigate in our physical environment, like landmarks, paths, and survey views, then the navigator can construct a spatial mental representation of it. The study of such *cognitive* or *mental maps* of physical spaces has concluded that multiple navigation experiences in the same environment allows individuals to estimate distances and directions to unseen objects, sketch maps of the area, and construct successful routes not used before (Siegel and White, 1975; Evans, 1980). Also, access to survey views or maps of a space can enable wayfinding performance similar to that afforded by route-following experiences (Thorndyke and Hayes-Roth, 1982; Golledge et al., 1995).

These abilities have special meaning in an information space. If information access is navigation, then successful wayfinding enables the user to meet his information need. And, since the space is designed around a principle reflecting its content, his mental map is a *conceptual map*: a map of the ideas, concepts, and material within the space. Multiple wayfinding episodes will reinforce his conceptual map, improving his knowledge of the space and what it contains.

Information spaces do not need to be three-dimensional and Euclidian in nature, but should be constructed so that users can apply the navigation skills they use in the physical environment. The basic elements mentioned earlier – landmarks, paths, and maps – will each play an important role as features in these spaces. Since information organization methods are not navigable in the same way that our physical spaces are, we need to look outside of the electronic realm for examples of navigable information spaces. This motivates the study of one kind of physical information space: educational exhibits.

Chapter 3

Educational Exhibits as Information Spaces

Information spaces, information access environments designed explicitly for user navigation, can provide an ideal environment to support information access tasks. By providing cues for orientation, the learner will always be aware of where he is in the material (how much have I seen? how much more to go?). By designing explicitly for navigation, the user will always know which path he is on, what choices are available at a junction, and where they lead. And, by virtue of the commitment to a spatial metaphor, a map of the information space can be created. This map serves both as a wayfinding aid during navigation, and as a way of concisely communicating the both the content and the organizing principles of the space in a pictorial way.

We want our information spaces to support useful information access tasks. So, the question now turns from *theory* – the desirable properties of navigable information spaces in general – to *design* – how one takes an idea, a collection of objects, or a mass of knowledge, and creates a concrete, useable artifact that serves the task and has these properties.

Many approaches are possible to this design problem. The fortunate situation in this case is that there are a large number of information spaces that confront and solve it well: educational museum exhibits. By this, we mean the kinds of exhibits found in science museums, natural history museums, or other kinds of museums, perhaps dedicated to a specific purpose, event, or idea. These exhibits take a set of physical, tangible objects and arrange them in space, presenting and annotating them appropriately to inform, entertain, and teach the viewer. They are environments that communicate, physical spaces created to faciliate a learning experience for the visitor.

Effective educational exhibits are also information spaces in every sense outlined here. By virtue of their existence in the physical environment, they should provide sufficient orientation cues to prevent a feeling of being lost. Some exhibits use basic architectural elements such as hallways, rooms, and doorways to create a well-defined circulation path; others allow freer movement. All effective exhibits, however, are constructed on organizing principles that give meaning to navigation in the space. And every exhibit studied uses some kind of map, either on a brochure distributed to viewers, displayed in the exhibit itself, or, most often, both. Educational museum exhibits are physical exemplars of information spaces that communicate knowledge and in many ways represent the ideal of an environment for doing so. They are immersive, interactive, and engaging, and they focus the entire attention of the visitor on the experience. Successful exhibits can make that experience memorable in ways that other media cannot.

3.1 The Search for Design Principles

We would like our information spaces to approach this physical ideal. But there remains an enormous gap between the raw electronic material and a finished product. For educational exhibits, in this gap stands a group of individuals – curators, exhibit designers, exhibit planners, graphic designers, and others – who are responsible for organizing, annotating, and presenting the materials that make up the exhibit.

Exhibit planners and designers, however, must deal with a very different set of constraints than one who would design an information space in a digital medium. They begin with a collection of (often) unique artifacts, which cannot be modified or duplicated. Materials, unlike pixels, have an associated cost, and the entire exhibit is mounted in a physically located space with fixed dimensions. The designers must accomodate the viewers' needs for personal space and room for comfortable circulation. And, of course, the exhibit must comply with the laws of physics!

Each of those considerations depends particularly on the *medium* of presentation, and how it is experienced as a physical space by its viewers. If we claim that these exhibits have interesting things to say about how we might create digital information spaces, we must isolate the aspects of design and interaction that would be applicable in both physical and digital media. Two such aspects of exhibits are:

1. Exhibits are spatial organizations of information. Any successful information space, whether physical or digital, must organize its material in an understandable fashion. The viewer, whether walking through an exhibit or navigating through a digital information space, can view only a small part of its content through his perceptual or digitally-mediated window. For communication to be successful, that movement should be informed by the organization of the space.

2. Exhibits are navigable spaces. Both physical and digital information spaces should have sufficient environmental cues to enable successful wayfinding. We want information spaces that not only communicate, but that are effectively navigable.

By focusing on how exhibits succeed in meeting those two requirements, we can use the design principles they were based on to make statements about how we might design digital information spaces. These two aspects of exhibit spaces, and the fact that we intend to implement digital information spaces, recommend a top-level division on those principles:

- *Design principles for effective communication.* The spatial organization of an exhibit is designed so that a path through it has meaning. For digital information spaces, we can use that path to organize an information map of the content, or allow the user to traverse that path in an information space.

- *Design principles for wayfinding.* We should organize our information spaces around the features people use to represent and navigate in their environment. Then, an information space will be both navigable and imageable, and a map of the space will be a conceptual map of its contents.

- *Design principles for a computational medium.* When an information space is implemented in a computational medium, as opposed to the physical medium of real-world exhibits, new functionality is available to support information navigation.

A design principle is a way to design an artifact to meet a requirement. A design principle for an electrical engineer might be "to reduce noise in a circuit, use a low-pass filter." It doesn't specify a particular circuit, or what kind of low-pass filter might be best. Its utility arises from its ability to help solve a wide class of problems, and in how it can be applied successfully in specific situations. So, how we will generalize what we learn from exhibits is to enumerate a collection of design principles that can be applied to information spaces.

What makes for a good design principle? A few properties of good design principles are:

- **Sufficient**, as opposed to necessary. It may be one way of many to meet a requirement.
- **Proven in practice.** Most effective principles arise not from unproven assumptions but induction on successful examples.
- **Specific.** Narrow enough so that firm conditions that indicate when it is and is not applicable can be stated, but broad enough to cover a useful class of problems.
- **Consequential.** The principle should have real consequences for the design, and reduce the design space under consideration in a meaningful way.

These properties suggest a general schema for presenting a design principle:

1. A concise statement of the principle in one sentence.
2. An explanation of the principle and its motivation or source.
3. A description of the conditions under which it could be applied.
4. An explanation of how it reduces the design space, that is, how it applies to an information space.
5. An example showing the principle in use.

This schema will be the outline for the presentation of the principles to follow. How these principles were arrived at, however, begins with the study of exemplary, physical information spaces: the educational exhibits.

3.2 Methodology

For each of the exhibits studied, there were two main sources of evidence: observation and mapping of the exhibit space and the items contained within, and interviews with the designers and developers of the exhibit. The exhibits were studied and mapped before the interviews to provide starting points for discussion.

Observation of the space proceeded by documenting of the location and describing of the items in the exhibit. For some exhibits, floor plans showing the content of the exhibit were not available from developers or designers. In this case, brochures distributed to the public which had a map of the exhibit were obtained and annotated with relevant features as the exhibit was traversed.

Noted features included:

- labels, signs, plaques, or other textual material, whether free-standing or mounted on walls;

- objects, artifacts, photographs, or artworks;

- audio-visual displays (for example, monitors playing audio or video loops) and separate theater areas with seating where films were projected periodically;

- "interactives" that allow the viewer to directly manipulate an object or model (for example, a working model of a machine, a hands-on activity, or a computer running a simulation program); and

- multimedia computer workstations allowing material stored on a hard drive or CD-ROM to be browsed interactively.

Significant environmental features of the exhibit space, such as wall treatments, carpeting, decorative motifs, and lighting were noted. Any brochures or printed matter distributed to the public was collected, and photographs of the exhibit space were taken when permitted.

After the exhibit was studied and mapped, interviews were conducted with some of those responsible for developing, designing, and maintaining the exhibit. Mounting an exhibit is an enterprise that requires the concerted effort of many individuals, but the focus was on those reponsible for the two aspects of exhibits mentioned before: exhibits as spatial organizations of information and exhibits as navigable spaces.

The precise roles played by individuals on an exhibit's design team and how they impacted those two aspects of exhibits varied with each organizational circumstance. Among those interviewed, however, some common terms were used to describe certain roles in exhibit development. They included:

- *exhibit designers*, who are responsible for the visual and environmental appearance of exhibits, the "look and feel," and the design of any special props, furniture, or visual material for the exhibit;

- *exhibit developers* or *planners*, who are responsible for the overall organization of the content of the exhibit, its spatial planning and layout, and, in some cases, the writing of label text; and

- *curators*, who maintain the exhibit's collection of objects and artifacts.

Of course, many others participate in the development process, such as graphic designers, content specialists, and educational or learning specialists.

Interviews were conducted in person or by telephone, beginning from a set of questions and topics outlined in Appendix C. The interviews did not proceed in a strict, question-answer format, but concentrated on topics that were most pertinent to the features of the particular exhibit and the role that individual played in its development.

The rest of this chapter contains plan maps of the exhibits, walk-throughs noting important features, and background on those interviewed from the design teams for the exhibits.

3.3 Leonardo at the Museum of Science

Leonardo da Vinci: Scientist, Inventor, Artist, was a temporary exhibit open from March 3 to September 4, 1997, at the Museum of Science in Boston, Massachusetts. Leonardo da Vinci was a Italian Renaissance scientist, inventor, and artist. His creative genius incomparably influenced Western art, his restless imagination envisioned flying machines centuries before their time, and his investigations into the human body produced the most accurate anatomical sketches to date.

The 1,400 m^2 (15,000 square foot) exhibit featured both original and reproduced sketches, notebooks, and manuscripts by Leonardo. It also had hands-on activities, models of his inventions, and original paintings and sketches by his contemporaries. Computer workstations and kiosks [1] scattered throughout the exhibit allowed visitors to explore multimedia CD-ROMs of Leonardo's manuscripts.

Referring to the map from the exhibit guide (Figure 3-1), the detailed floor plan (Figures 3-2, 3-3, and 3-4), and the exhibit catalog (Appendix A), we see that the viewer begins in the Object Theater. It has a ten minute presentation of three-dimensional objects, special effects, and video to introduce Leonardo's life and times. Then, he proceeds to the first section of the exhibit, entitled "Who was Leonardo?" It is divided into two rooms, "Introduction to the Renaissance" and "Florence in 1470," which together provide historical context (marked 2 on the plan in Figure 3-2), offer sketches from Leonardo's early career (6-13), and present labels describing the three main activities Leonardo engaged in throughout his life (3): scientific observation, invention, and artistic expression.

From there, the viewer could turn right into the two Art Studio rooms, or proceed on to the Art Gallery. These three rooms formed the next major section, "The Natural Artist." In the first Art Studio room, three artistic techniques Leonardo used, *chiaoscuro* (the realistic rendering of depth using light and shadow), perspective projection, and *sfumato* (the use of "smoke" or shading to suggest movement), are described on labels (21, 25, 27, 29), and exemplified in sketches by Leonardo (22, 24, 28) and a reproduction of the *Mona Lisa* (28). Hands-on activities encourage the visitor to draw in perspective (23) or to sketch a draped figure (26).

In the second Art Studio room, Leonardo's participation in the studio of the Florentine artist Verocchio is related. A wall-sized mural (41) shows what activities might have taken place in Verocchio's workshop: drawing, painting, sculpting, and casting, all at the same time. It also has a contemporary's sketch of the *Last Supper* and studies for a lost mural, the *Battle of Anghiari.* As the viewer moves into the Art Gallery, a free-standing easel with label text (45) describes his early years as an artist in Florence. The Art Gallery itself contains sketches and paintings by Leonardo, his contemporaries, and his followers.

The next section, "The Restless Inventor," has numerous sketches of inventions and engineering projects Leonardo proposed. The contents are spatially divided among the subjects of military machines, architecture, hydraulics, clocks, machinery, and flight. Hands-on activities in the center of the space illustrate the principles of hydraulics, arch-building, and flight (150, 162, 170, 171, 172, 178, and 179) and are interspersed with working models based on his sketches and notes. This area is introduced by a large free-standing label (183), "The Middle Years," which identifies this section with the period 1482-1506, when he was employed both in Milan and Florence.

[1] Computer workstations with an additional overhead monitor allowing bystanders to observe what the user is doing.

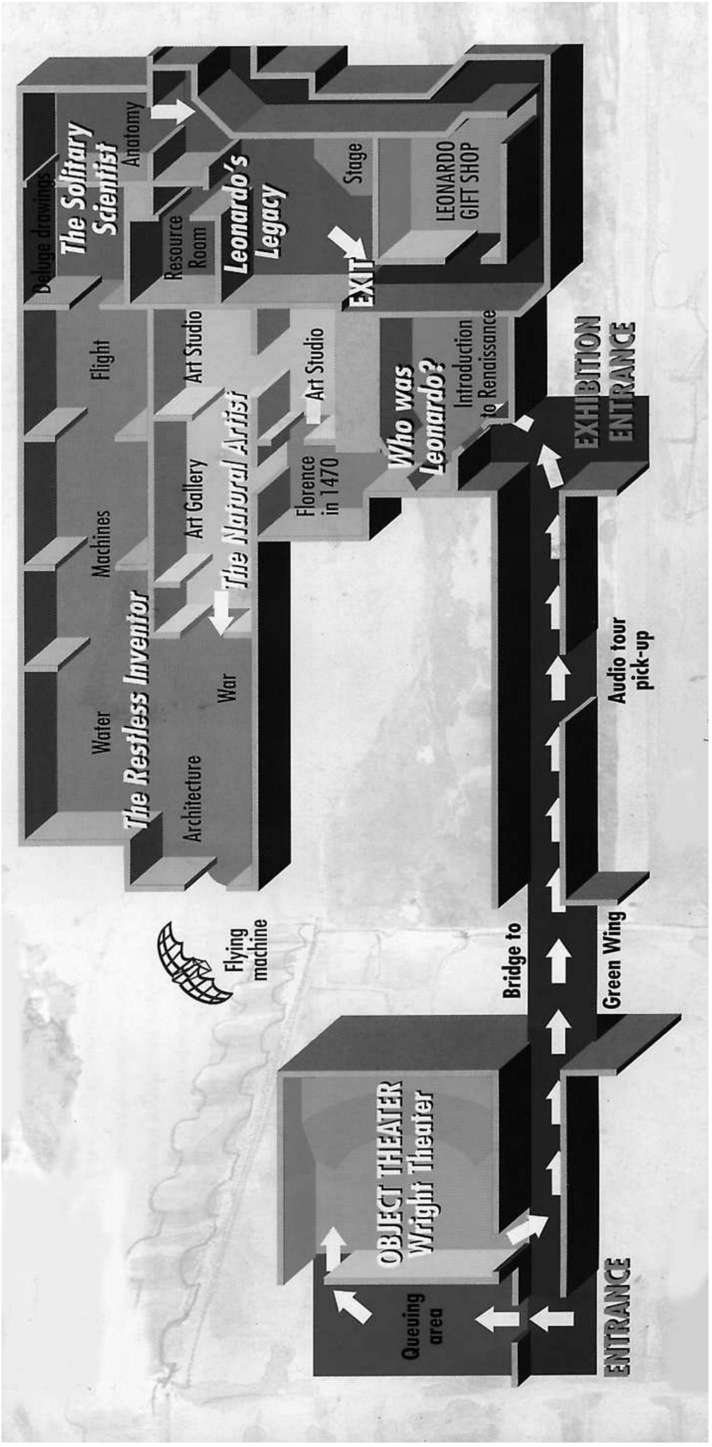

Figure 3-1: Exhibit map for *Leonardo*.

Figure 3-2: First section of the floor plan of *Leonardo*.

Figure 3-3: Second section of the floor plan of *Leonardo*.

Figure 3-4: Third section of the floor plan of *Leonardo*.

The final section of works, "The Solitary Scientist," has two rooms with his anatomical sketches and a strange series of drawings of cataclysmic floods (195-202). The section has labels (197, 205) that identify these works with his later years (1507-1519).

The last part of the exhibit has a legacy area that describes the influence of Leonardo's works on later artists, scientists, and inventors. Labels reiterate the three aspects of Leonardo's diverse genius (221, 222, 226, 227, 230), and a resource room with books and multimedia workstations lets the viewer explore further into Leonardo's works and thoughts. In addition to these ways of relating his legacy, a play staged hourly illustrates it dramatically. Finally, as the viewer exits the exhibit, he passes a table with feedback cards and sample responses.

Interviews took place with three individuals from the *Leonardo* design team. The first was with Mr. Lynotoyos, the exhibit designer (Lynotoyos, 1997) for *Leonardo*, the second with Edward Rodley, the exhibit planner for the exhibit (Rodley, 1997), and the third with Judy Rand, an exhibit consultant who advised the editing of the label text for the exhibit (Rand, 1997b).

3.4 The John F. Kennedy Museum

The John F. Kennedy Museum, located in the John F. Kennedy Library in Boston, Massachusetts, is devoted to the life and family of the thirty-fifth President of the United States. Originally opened with the Library on October 20, 1979, the museum was redeveloped and rededicated in 1993. The 1,700 m^2 (18,000 square foot) museum is comprised of an 18 minute introductory film and twenty one exhibits arranged in the main museum space, which exits onto a glass pavilion overlooking the Boston Harbor. Figure 3-5 is a map from the exhibit brochure, and Figures 3-6 and 3-7 are a floor plan of the exhibits. A catalog of their contents is in Appendix B.

The introductory film covers Kennedy's youth, wartime service, and early political career, ending at the 1960 Democratic National Convention. After the visitor exits the theater, he enters the first set of exhibits (marked 1 through 6 on the map), which illustrate the successful Kennedy campaign for President: his capture of the Democratic nomination (1-3), victory in the election against Richard Nixon (4-5), and his inaugural address (6). This first section of the museum, in particular exhibits 1-5, evoke an atmosphere of the campaign trail ("Main Street, USA" in 1960) with *faux* brick wall treatments, storefronts with period appliances and memorabilia, and a re-created campaign office. Monitors with video footage of campaign commercials and debates (catalog items M1-M6[2]), Walter Cronkite announcing election results (M19), and President Kennedy's inaugural address (M7) are also located here.

After passing the Presidential Seal, between Presidential and United States Flags (O9A and 09B), the visitor continues to a series of exhibits chronicling Kennedy's Presidency (7-15). The main hallway (7) is lined with cases of gifts from heads of state (O10, O11, and O12), and various photographs of Kennedy at the White House.

Exhibits branching off to each side of this hallway touch on a particular program or event in his administration. Exhibit 8 describes his Cabinet; 9, domestic and international affairs, featuring clips of a press conference (M8); 10, the Peace Corps; 11, the Cuban missile

[2] In this walkthrough, plain numerals refer to the exhibit numbers in Figure 3-5, while labels beginning with "O," "P," "M," or "L" refer to catalog entries in Figures 3-6 and 3-7 and Appendix B.

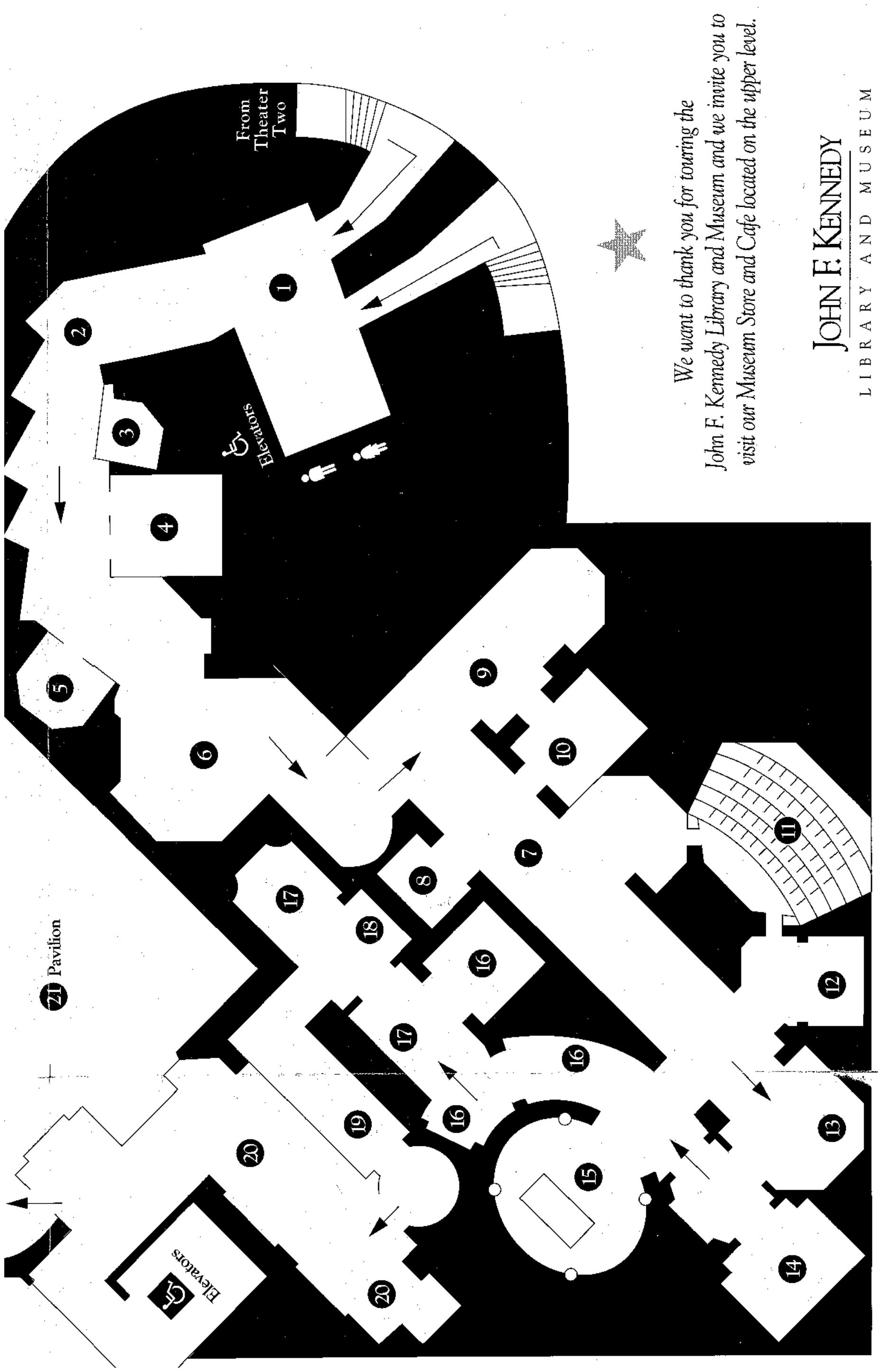

Figure 3-5: Exhibit map for the John F. Kennedy Museum.

Figure 3-6: First section of the floor plan of the Kennedy Museum.

Figure 3-7: Second section of the floor plan of the Kennedy Museum.

crisis, in a 17-minute documentary film (M10); and 12, the space program. The hallway is decorated in a manner reminiscent of the White House interior, with plush red carpets and wall colors chosen to match those of rooms in the White House at the time.

At the end of the corridor is a rotating exhibit (13). At the time of this survey, it had documents and photographs from a state dinner held in honor of Grand Duchess Caroline and Prince Jean of Luxembourg. A large, octagonal glass case situated in the center of the room contained the dress Jacqueline Kennedy wore that evening.

Turning right, an exhibit entitled "The Office of the Attorney General" presents the role and contributions of President Kennedy's brother, Robert F. Kennedy, during his tenure in the Kennedy Administration (14). Exhibit 15 recreates the Oval Office, with replicas of his desk and favorite rocking chair. Two videos play footage of important speeches during his Presidency, one on integration at the University of Alabama and the other on the Nuclear Test Ban Treaty.

Past the Oval Office, the remaining exhibits turn to the private side of the Kennedy family. Exhibit 16 contains photographs and memorabilia about the life and accomplishments of the First Lady, Jacqueline Bouvier Kennedy, while 17 traces the roots of the Kennedy family from Ireland to Boston (and back: President Kennedy returned to Ireland in 1963 on a state visit). Exhibit 18 shows how mental retardation was brought to public attention by the Kennedy family, and their influence on reforming public policy in this area.

Exhibit 19 is a darkened corridor with four monitors (M18) playing news footage of Walter Cronkite reporting John F. Kennedy's assassination. The visitor moves from there to a circular area with photographs of memorials to him around the world (O22) and then to a legacy exhibit (20), which illustrates the lasting accomplishments and influence of the Kennedy family. The exhibit exits onto a large pavilion overlooking the Boston Harbor where the visitor can reflect on what he has seen.

Interviews were conducted with Frank Rigg, Curator of Exhibits and Collections at the Museum (Rigg, 1998), and Jim Wagner, Curatorial Assistant (Rigg and Wagner, 1997).

3.5 The Space Race

This exhibit is located at the National Air and Space Museum, one of the museums of the Smithsonian Institution in Washington, D.C. It shows how the space programs of the United States and the Soviet Union began in competition, but later cooperated to achieve a permanent presence in space. It features original and scale models of space vehicles, rockets and missiles, reconaissance satellites, and space suits, along with technical specifications, historical material, and video footage. Figure 3-8 contains a floor plan of the exhibit.

It is situated in a multi-story, 930 m^2 (10,000 square foot) main space, with a 200 m^2 (2,300 square foot) adjoining space housing the Apollo lunar landing module. The exhibit is arranged as an *open* plan – the visitor, after entering from the main museum hallway at the bottom of the floor plan, is free to wander with few constraints on his movement.

The walkthrough will proceed roughly counterclockwise from the reconstructed V-2 ballistic missile at the bottom of the floor plan. From there, the visitor moves past the large, octagonal pit containing originals and replicas of military missiles and rockets. Visitors can descend stairs into the bottom of the pit to obtain a close-up view of the missiles and rockets. Labels arranged around the pit outline the origin of the space race as a quest for military supremacy in space.

Moving to the wall on the right side of the floor plan, the first set of labels, marked "The

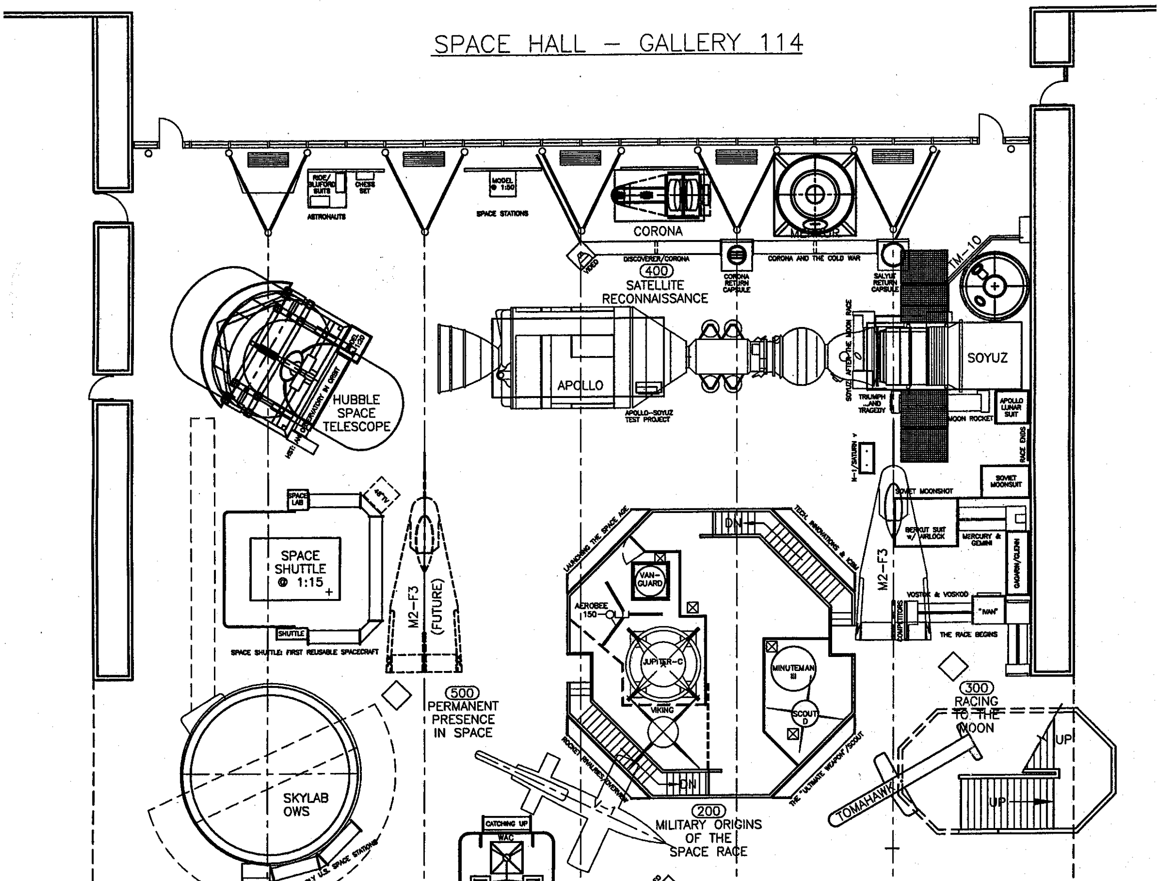

Figure 3-8: Floor plan of *The Space Race.*

Race Begins," describe how the race for space exploration began with the launching of the Sputnik satellite by the Soviet Union in 1957. Moving around the corner, further material relates how the next race was to send a man into space, a race the Soviets won with Yuri Gagarin's Earth orbit on April 24, 1961.

The next set of exhibits concerns the final milestone in the race for space exploration, that of sending a man to the moon and back again. Soviet and American lunar suits are featured, along with a label describing how the race ended on July 20, 1969 with the success of the Apollo 11 mission. Overhead, Soyuz and Apollo orbiters are docked together as they were in the Apollo-Soyuz Test Project, the first cooperative space mission between the United States and the Soviet Union. Also worth noting is a timeline mounted on the right wall above these exhibits, proceeding forward from 1957, the launching of Sputnik, to 1975, the date of the Apollo-Soyuz Test Project.

Turning left along the wall at the top of the plan, the exhbit traces the development of reconaissance satellites. Original Soviet and American satellites are featured, along with video footage of the Americans' surprising film recovery technique – literally snagging a parachuting film capsule out of the air with a passing aircraft.

Past the reconaissance section are exhibits on Russian and American space stations, the 1994 Shuttle-MIR missions, the proposed International Space Station, and astronauts' life in space stations. A test version (to scale) of the Hubble Space Telescope, a scale model of the Space Shuttle, and Skylab occupy the remainder of the main exhibit space. The adjoining space is occupied by the Apollo lunar landing module.

The photographs in Figure 3-9 can give a better idea of the scale of the objects in this exhibit. The first photograph looks down from a balcony over the exhibit floor towards Skylab in the background. A V-2 replica is visible in the left foreground, and missiles rising from the octagonal pit are in the right foreground. The second was taken from the exhibit floor, looking towards the Apollo-Soyuz modules past the missile pit.

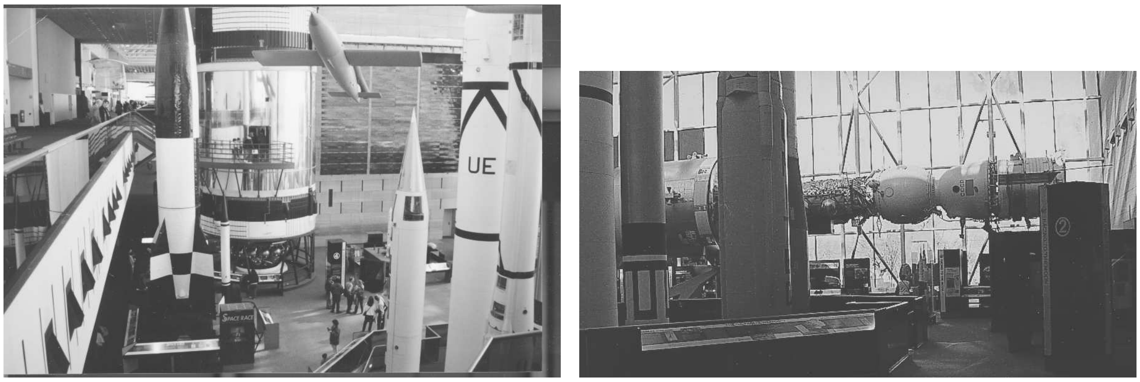

Figure 3-9: Photographs of *The Space Race*.

The designer of *The Space Race*, William Jacobs at the National Air and Space Museum, was interviewed (Jacobs, 1998).

3.6 Where Next, Columbus?

Where Next, Columbus? is an exhibit also located in the National Air and Space Museum.

A floor plan of the exhibit is found in Figure 3-10. It encourages the viewer to consider the future of space exploration, and speculates on future destinations for human and robotic explorers and the technologies that would take them there. The 950 m^2 (10,000 square foot) space is divided into five main sections.

Passing through the entrance at the lower right of the floor plan, the visitor encounters the first section, "Exploring This World." It briefly chronicles the history of European exploration of the New World, American exploration of the West, and the United States space program's successful manned mission to the Moon (see Figure 3-11).

The next section, "Challenges for Space Explorers," explores some of the dangers and issues facing humans when they venture into space. These include the risks posed by meteoroids and radiation, ways to stay physically fit in a near-zero-gravity environment, and the tradeoffs among propulsion technologies in space.

The third section, "Exploring New Worlds in Space," asks how we might go about exploring our nearest planetary neighbor, Mars. Some of the requirements of both a manned and unmanned mission are illustrated, and the possible role of autonomous robots on an interplanetary mission is explored. This part of this exhibit is situated in an environment that realistically simulates the surface of Mars (Figure 3-12).

Farther on, the room marked "Habitat" speculates on some of the means humans might use to survive permanently in outer space, such as hydroponic agriculture. A theater across the corridor screens a rotation of films on space exploration.

The final section of the exhibit, "To The Stars," asks if there are other worlds with intelligent beings beyond our solar system. This section describes the Search for Extraterrestial Intelligence (SETI) Project and has replicas of the plaques representing humankind to those who might recover the interplanetary satellites Pioneer and Voyager. A stellarium, showing the stars of the Milky Way as tiny points of light suspended in space, shows just how little of the universe we have managed to explore to date. The exhibit ends with an interactive survey that asks the visitor's opinions on space exploration and what resources should be dedicated to it.

William Jacobs also designed this exhibit, and it was discussed in the interview mentioned earlier.

3.7 Other Exhibits

Several other exhibits were also studied, and are more briefly described below.

3.7.1 The United States Holocaust Memorial Museum

This museum, dedicated to preserving the memory of the Holocaust and its victims, is located in Washington, D.C. It includes a three-floor Permanent Exhibit that chronicles the rise of the Nazi regime and anti-Semitism in Germany, the Final Solution and the Nazi death camps, resistance to the Nazis, and the camps' liberation.

Visitors begin with a 23 minute introductory film that explains the Museum's history and purpose and the significance of some of the architectural features in the museum. They are then directed to an elevator that takes them up to the fourth floor of the permanent exhibit, from which they descend to the Hall of Remembrance on the second floor. Maps from the exhibit brochure are in Figure 3-13.

Linda Melone, the Museum Specialist for Public Services, was interviewed (Melone, 1998).

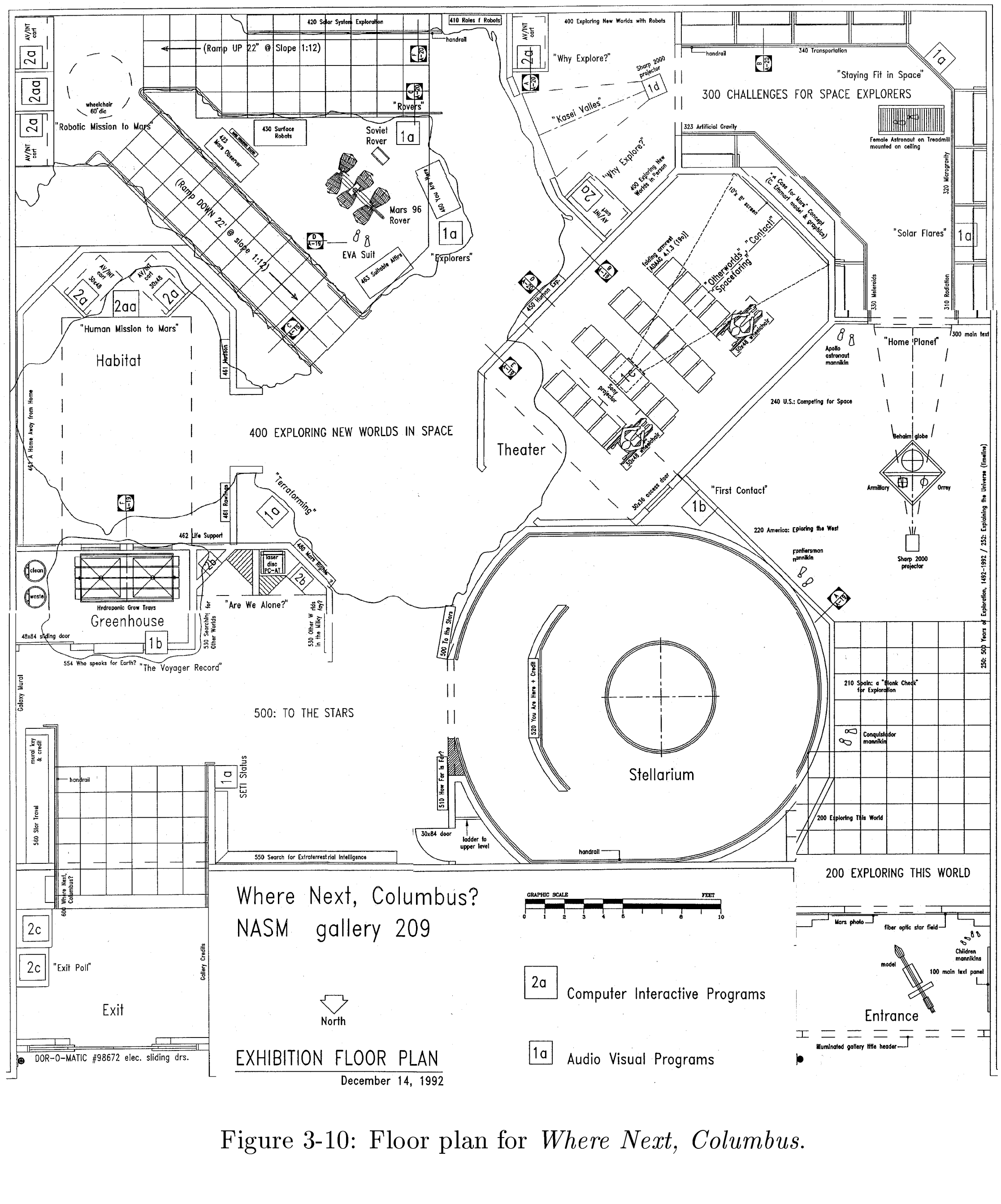

Figure 3-10: Floor plan for *Where Next, Columbus.*

Figure 3-11: The first section of *Where Next, Columbus.*

Figure 3-12: Left: An exhibit on Mars exploration in *Where Next, Columbus.* Right: An autonomous robot, based on Ghengis (Angle, 1989) (Brooks, 1989), and perhaps bound for Mars one day.

Floor

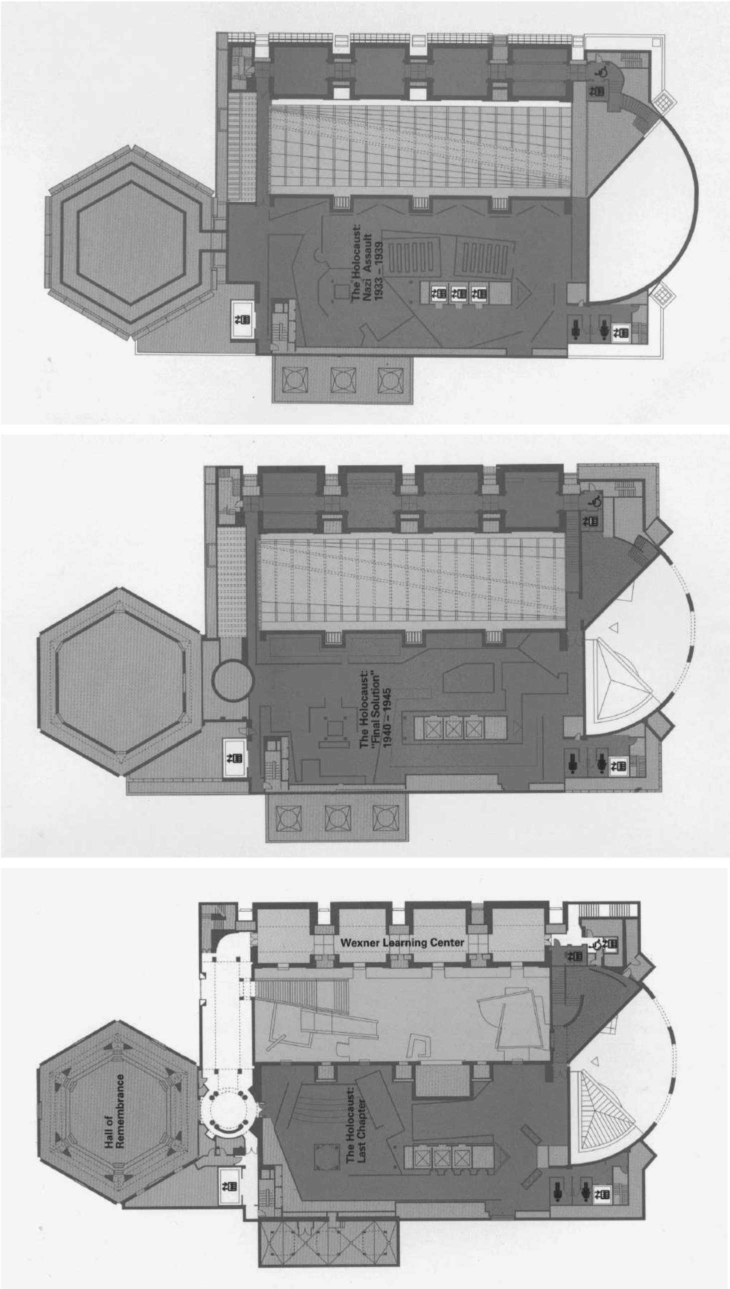

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Figure 3-13: Exhibit maps for the Holocaust exhibit.

3.7.2 Exploring Marine Ecosystems

This small exhibit, located in the National Museum of Natural History in Washington, D.C., educates the visitor about marine ecosystems: what they are, their importance to the global environment, how humans impact them, and how scientists study them. It compares two living models of marine ecosystems (the Maine rocky shore and a Carribean coral reef), illustrates the components of a marine ecosystem, and shows how humans can both preserve and destroy these environments. Bryan Seiling, the exhibit designer for *Exploring Marine Ecosystems*, was interviewed (Seiling, 1998). Photographs from the exhibit are in Figure 3-14.

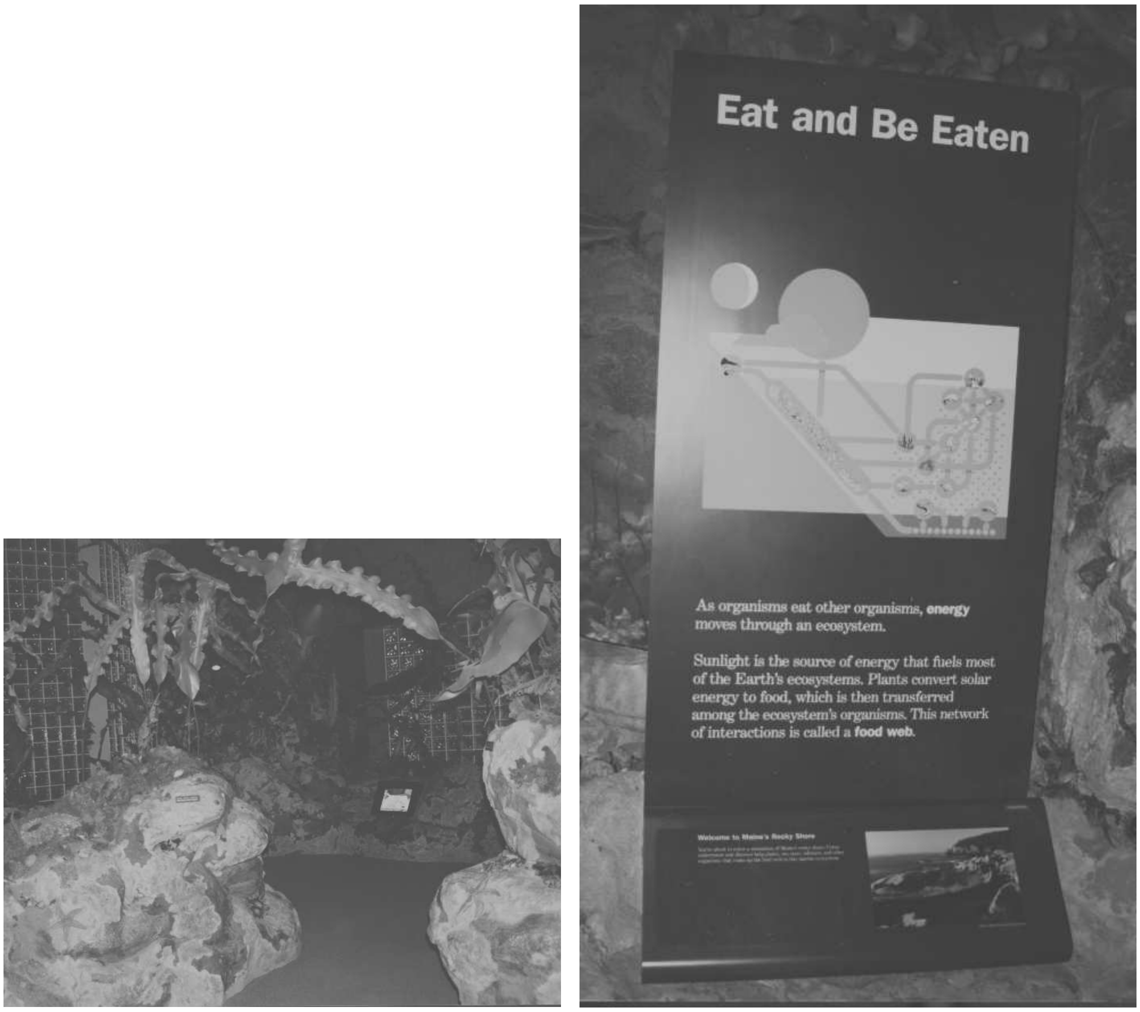


Figure 3-14: Photographs from *Exploring Marine Ecosystems*. Left: A simulated coral reef. Right: A label.

3.7.3 The Fossils Exhibit

This exhibit, also at the National Museum of National History, showcases the Museum's collection of plant and animal fossils. The multi-level exhibit is roughly divided into sections presenting fossils of marine creatures, dinosaurs, mammals, and plants. Photographs from the exhibit are in Figure 3-15.

Figure 3-15: Photographs from the Fossils exhibit. Left: Looking from a balcony at the rear. Right: A view through the plant fossils section.

3.8 From Exhibits to Principles

In the study of these exhibits and how they were designed common patterns emerge in the problem-solving process of creating these spatial information designs. We hope to capture these patterns in our design principles. By considering the two aspects of exhibits mentioned before – the spatial organization of information and navigability – we will be able to apply those principles to design digital information spaces.

These exhibits are not our only source of principles. We will also cite the established literature on exhibit development and design, as well as research in environmental cognition that indicates what kinds of physical spaces are effectively navigable. When a principle is exemplified in an actual exhibit, however, it gains immediacy, relevance, and additional validity.

Chapter 4

Design Principles for Effective Communication

The first class of design principles deals with effective communication. These principles are used by the exhibit devlopment design community to create effective educational exhibits. The source of these principles are interviews with exhibit designers and developers and the study of the literature on exhibit design and development.

In this context, communication means the presentation of material to an audience in an organized manner, with the intent of imparting some knowledge or understanding to that audience. Communication could be considered successful when most of that audience can demonstrate understanding of the material after the presentation.

Some examples of the kinds of communicative episodes that have a tutorial goal similar to an educational exhibit are attending a research seminar or a college lecture or watching an educational television program. In each of these episodes, the listener or reader experiences a selected quantity of content in a sequence predetermined by the communicator. This sequencing, necessitated by the fact that communication inherently takes place over time, follows a preset path through the material. When we can understand how to organize material along these paths that teach, it can give us insights as to how we can construct paths in information spaces that can also communicate effectively.

It is also important to remember the clear distinction between the single path through knowledge afforded by reading a book or attending a lecture and the multitude of possible routes available in an exhibit or an information space. Although most of the exhibits studied follows a generally linear circulation, there were still many opportunities for diversions, explorations, side-trips, and even backtracking by the viewer. Some exhibits (for instance *The Space Race*) abandon the notion of a main path entirely, but may still be effective exhibits. So, although we can use principles that order the material in a lecture to organize a path in an information space, we must remember that other means of organization are possible, and presenting information along a single path may not necessarily restrict navigators to follow that path exclusively.

In the exhibits studied there is some tension between the needs of communicative effectiveness and visitor exploration. The need for communication argues for fewer choices in navigation, while allowing the visitor to explore requires more open plans. Where an exhibit or an information space stands depends on the needs of the particular task. But, once a commitment has been made to creating one path or several to communicate, these principles can come into play to organize and present them effectively.

The principles are presented in no particular order, but instead are intended to be as self-contained as possible, with the hope that they can each be applied as needed. As with all heuristics, clean composition is not always possible; for some circumstances the requirements imposed on the information space by any pair of these principles could conflict. But, at least by listing a set of good ideas, a design space can be created in which the consequences of trading off one for the other can be explored.

In summary, the principles for effective communication are:

- Organize the presentation about a hierarchy of messages.
- Use a constantly evolving attribute of the material to sequence it along a path.
- Order the concepts so that earlier concepts facilitate the understanding of later concepts.
- Provide a memorable introduction and conclusion.
- Use multiple representations and media to communicate.
- Allow for multiple levels of engagement and understanding.
- Use an "environmental look" to provide thematic context.

4.1 The Principles

4.1.1 Organize the presentation about a hierarchy of messages.

The principle. This principle represents a commitment to design based on what the visitor should take away after a visit to the information space. The concepts to be communicated are stated as messages and organized in a hierarchy. Messages nearer the top are fewer in number but are the most important to communicate; they contain the concepts the viewer should understand to make sense of those lower in the hierarchy. In turn, messages lower in the hierarchy should justify and elaborate those higher in the hierarchy.

The message hierarchy can be divided into four levels of importance:

1. *The main message.* This is the one, central idea that every visitor should learn and take home from the space. It is the one-line "story" that the space tells. It should be able to be stated concisely in one sentence, and every piece of material in the space should support this main message in some way. Every visitor to an exhibit should be able to recall this central idea after leaving.

2. *Primary messages.* These are messages that directly justify the main message, and are few in number. Primary messages can provide a top-level division of the available space, with each division committed to communicate one primary message.

3. *Secondary messages.* These are ideas that should be communicated to every viewer, but may not be if the viewer is very interested in the idea. These are concepts which can be skipped without a loss of coherence. Secondary messages in an exhibit exist at the granularity of individual walls, labels, or a few objects.

4. *Tertiary messages.* These messages would be nice to communicate, but might suffer the consequences of limited space or budget and may not be included in the exhibit at all. These exist at the level of individual paragraphs of label text or one object in the exhibit.

Source. This principle was the main means of organization for *Leonardo* (Rand, 1997b). Judy Rand, a consultant to the design team for that exhibit, developed this system for exhibit organization while at the Monterey Bay Aquarium. Her system is also described in McLean (McLean, 1993).

Applicability. This system would work well when the purpose of the information space is to communicate one central idea or concept; or, conversely, if one main message can be constructed that fits the available material. The need to reinforce this main message with all of the material in the space requires flexibility in including and excluding material from the space. Judy Rand even implies that to ideally support the main message, material that does not fit it should be thrown out entirely (Rand, 1997b).

Design consequences. A commitment to a message hierarchy, and to using the available content to support that hierachy, requires answers to two questions about the information space. The first is to give a criterion judging the relevance of every item in the space: whether it supports the main message or one of the subsidiary messages in the hierarchy. The hierarchy itself is an equilibrium between what ideas can be supported by the available material, and what material should be used to support a set of messages.

The second question to be answered is what relative emphasis should be placed on the messages in the information space, and how much space they deserve. The main message is not tied to one area, but is reinforced throughout the space. Primary, secondary, and tertiary messages can be assigned specific (and successively smaller) regions in the space.

Note that the message hierarchy and the space assignment it guides do not necessarily constrain the sequence in which the messages are presented, or how viewer choices might affect the layout. Although exhibits that have a story to tell tend to be more effective when using a linear plan with one main path (McLean, 1993), other considerations come into play when the ordering of material becomes the issue.

An example. In *Leonardo*, the exhibit was organized around a message hierarchy that proceeds as follows (Rodley, 1997):

- The main message for the exhibit was that Leonardo used his powers of observation to be a scientist, inventor, and artist. This message was presented throughout the exhibit, explicitly by labels at the beginning and end of the exhibit (catalog numbers 3, 221, 222, and 223) and by hands-on activities that ask the viewer to observe (and draw and build) in the some of the same ways Leonardo did (catalog numbers 23, 26, 178, 179, and so forth).

- The primary messages for the exhibit were that Leonardo was a scientist, an inventor, and an artist. Each of these messages defined a major area of the exhibit, and upon entry to each of those areas the viewer was informed of it by banners hanging overhead with the titles "The Natural Artist," "The Restless Inventor," and "The Solitary Scientist" (catalog numbers 30, 173, and 205).

- Secondary and tertiary messages were tied to one area of the exhibit, and related to the primary message corresponding to that area. One interesting prop used in the "The Natural Artist" section of the exhibit is free-standing easels situated in both

Studio rooms and the Art Gallery (18, 31, 45, and 47). Placed near the entrances to these rooms, they commanded the viewer's attention upon entry and illustrated the secondary messages for each room.

For an illustration of how these messages mapped onto specific areas in the exhibit, see Figure 4-1.

4.1.2 Use a constantly evolving attribute of the material to sequence it along a path.

The principle. This principle guides the order of presentation of material along a path. Time and place are two common attributes used to sequence material in this fashion.

Time places the material in the context of external events and can illustrate causal relationships between an event at one point in time and earlier events. Navigating through time by traversing a spatial timeline creates a narrative: a story to tell, perhaps communicating the messages outlined in the first principle.

Using geography to place information creates an analogy between navigation along a path through knowledge and navigation along a path through a place in the real world. This creates an interesting cognitive economy: by reusing a viewer's geographical knowledge of an area, the organizing principle of the exhibit is known before he even steps inside, and a mental map of it is already available.

Source. Spatial timelines are in many of the exhibits studied. For *Leonardo*, the exhibit was divided into three sections, "The Early Years," "The Middle Years," and "The Later Years," indicated by label text on free-standing easels (catalog numbers 45, 80, and 197). The Kennedy museum progresses in time from the introductory film of Kennedy's childhood and education to his Presidential campaign, administration, assassination, and legacy.

Applicability. The use of spatial timelines is especially appropriate for biographical or historical material, or whenever a narrative can be built around the content. If each item is associated with a particular geographical place, then that can be an attribute that sequences the material.

Design consequences. This principle indicates a path through the content, such that a navigator following that path will trace an evolving attribute of that content. If the content is divided to support primary messages or concepts, this path can order them in the exhibit according to that evolving attribute.

An example. The Holocaust exhibit illustrates well how time can be used to provide a top-level division on an information space. The viewer descends from the fourth floor to the second floor, with each floor relating events for a period of time before, during, and after the Holocaust. Within each floor, material is not strictly arranged chronologically. The use of time organizes the exhibit spatially and conceptually into main sections.

4.1.3 Order the concepts so that earlier concepts facilitate the understanding of later concepts.

The principle. This principle presents another criterion for ordering, one which reflects the need for the viewer to understand certain knowledge at one point in a sequence and apply it to understand a concept at a later point in the sequence.

One way to illustrate this principle is to divide the content into a series of concepts to be learned and to draw a diagram illustrating which concepts need to be understood before other concepts make sense. For a brief example which applies this principle to Newton's

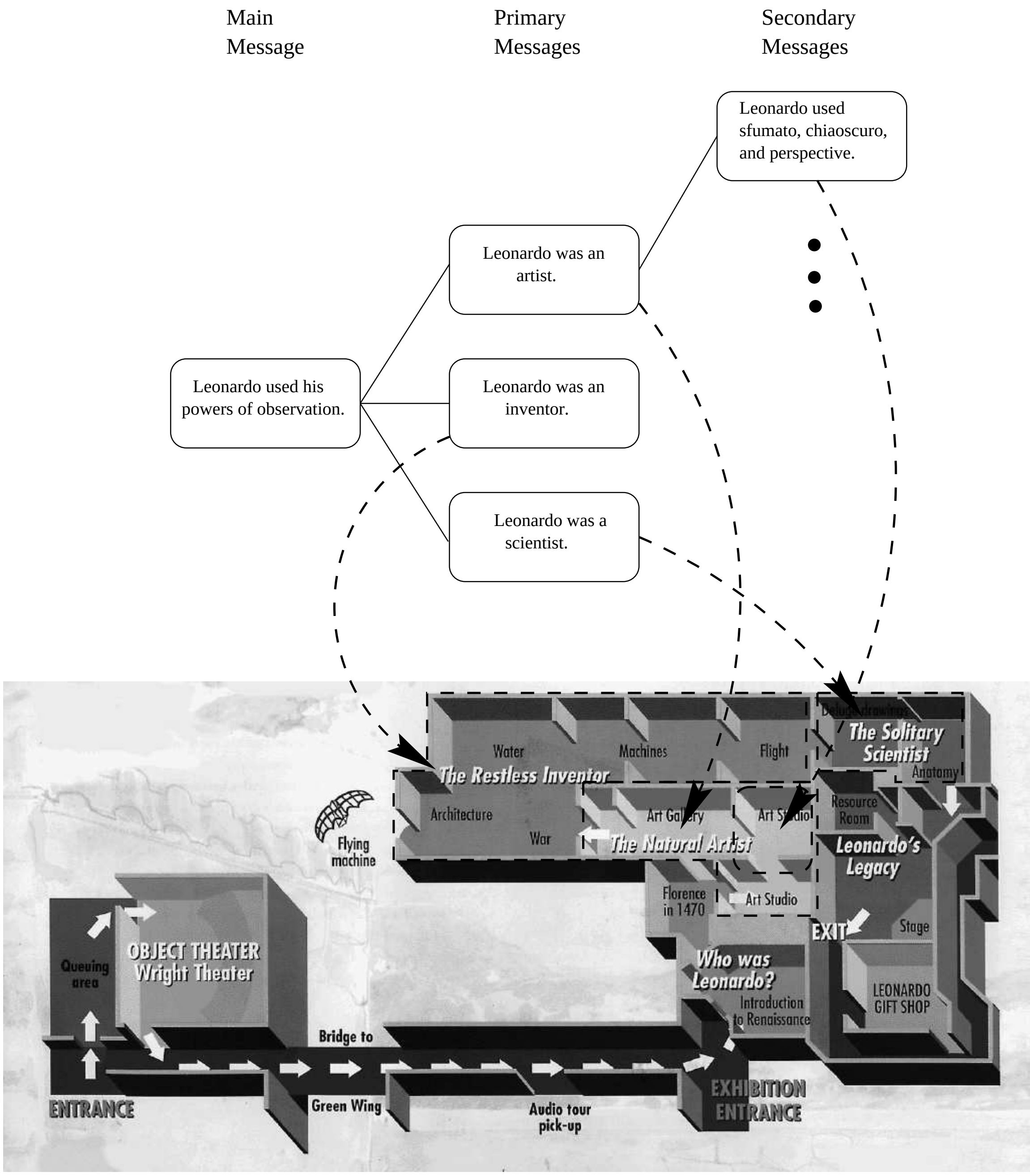


Figure 4-1: A partial message hierarchy and the areas associated with those messages in *Leonardo*.

second law, see Figure 4-2. Concepts such as “multiplication,” “squaring,” and “algebra” are needed to understand the formalism in which the law is expressed; and the concepts of distance, position, and speed are needed to understand how the law models the motion of objects in the world. The diagram represents constraints on the ordering of concept presentation, and indicates a set of feasible paths that present the material in a learnable fashion.

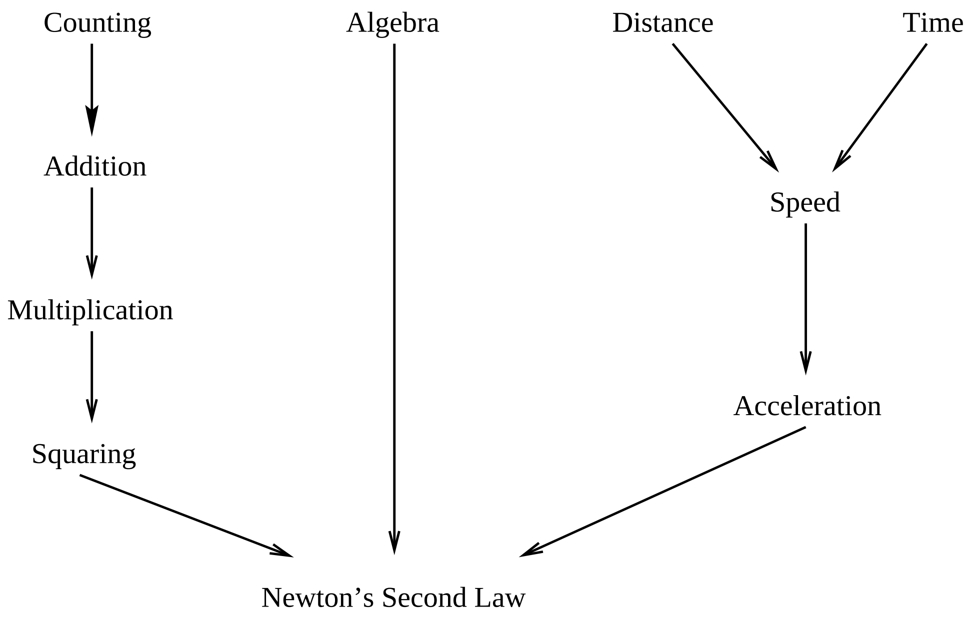


Figure 4-2: Concept hierarchy for Newton’s second law, $d = vt + \frac{1}{2}at^2$. Reproduced from (Miles et al., 1988).

Of course, one could extend this diagram forever, back to some *tabula rasa*. To constrain its extent, two criteria come into play. The first is an assumption about the base level of knowledge for the audience coming into the exhibit, so that some concepts can be expected to be known. The other is how much material is available to support communication of the necessary concepts. If a gap arises between the concepts in the base level of knowledge and the concepts supported by the material, additional content may need to be developed and presented to close that gap.

Source. This principle is discussed at length by Miles (Miles et al., 1988) as the main means of organizing an exhibit on Darwin’s *Origin of Species* at the British Museum (Natural History) in 1981.

Applicability. This principle is especially effective in scientific or technical domains, in which one level of factual knowledge provides the concepts necessary to understand a more advanced level. A rule of thumb might be: if the viewer needs to ask the question, “What is an X?” at some point in the exhibit, then a concept hierarchy can ensure that the question would have already been answered.

Design consequences. This principle governs the intellectual organization of an exhibit at a high level of granularity, by indicating specific “learning acts” that must occur in an area before the visitor moves on to the next area. For this purpose, linear plans that highly constrain the potential routes through the exhibit are preferred, so that the learning acts can occur in a proscribed order. If the concepts are thought of as messages in a message hierarchy, this principle could indicate the order of presentation at each level in the hierarchy.

An example. For the *Origin of Species* exhibit, a concept hierarchy was developed that communicated the ideas necessary to understand Darwin's theory of natural selection as an explanation of speciation (illustrated in Figure 4-3). This hierarchy was developed by first deciding on a terminal learning objective, the phenomenon of natural selection and its consequence, speciation, and then asking what concepts were needed to understand that goal concept. This proceeded until the assumed base level of knowledge of the audience was reached. For each concept found, preconditions for learning and a means of testing if it had been learned were specified. From this concept hierarchy, an exhibit brief was drawn up, which specifies a storyline for the exhibit, material explaining and supporting each concept, and a work schedule for mounting the exhibit.

This exhibit was mounted in a rectangular gallery which had been partitioned to create a linear circulation, also illustrated in Figure 4-3. The material related to each concept was arranged along the path according to its position in the hierarchy, thus presenting it in a learnable order.

4.1.4 Provide a memorable introduction and conclusion.

The principle. This principle emphasizes the importance of the beginning and the end of the exhibit. They are the first and last things the visitor sees. Introductions create expectations about what is to come, and conclusions unify and clarify what has been seen. The key message here is that they should serve the larger intent the exhibit, and fit within its organizational scheme.

Source. In nearly all of the exhibits studied, the introductory and concluding sections had special importance.

Applicability. Of course, the existence of introductory and concluding sections at all assumes a circulation pattern in which there is only one way in and out of the exhibit, which is not generally true. Also, the exhibit needs sufficient space to develop these sections significantly; in smaller exhibits, they may be abbreviated, or some of their functions integrated with the main body of the exhibit.

Design consequences. Not every exhibit needs an introduction or conclusion, but if communication (as opposed to exploration) is the primary goal, they can be greatly beneficial. What form they should take depends on the larger purposes of the exhibit, and how it is organized.

An introduction can serve several purposes. It introduces the environmental appearance or "look" of the exhibit. It can summarize the content of the exhibit; introduce a main message that the exhibit is to communicate; or present background material that aids in understanding the rest of the exhibit. It both draws the viewer into the space and creates a set of expectations in the viewer about what is to come.

The conclusion, meanwhile, serves as a transition out of the exhibit environment into more familiar territory. It can serve as a place of reflection, of interaction, or where what was learned in the exhibit is made relevant to the life of the viewer. A main messsage of the exhibit can be repeated here. Also, additional materials like books or multimedia workstations that encourage the viewer to explore topics of interest on their own can be placed here. It can also be a place where the viewer gives feedback to the designers, or evaluates how much he has learned.

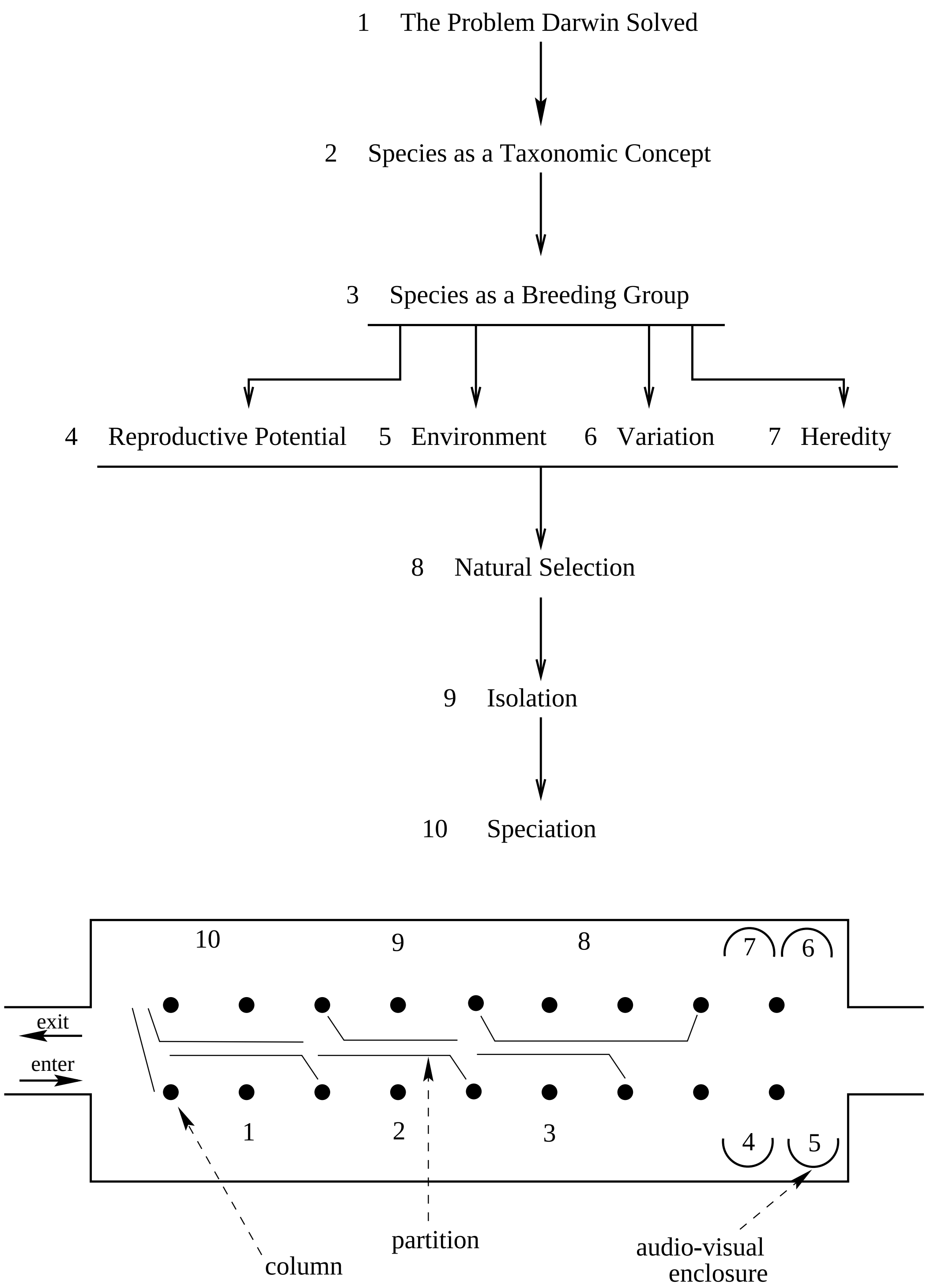


Figure 4-3: Concept hierarchy for the *Origin of Species*, and the gallery in which it was mounted. Reproduced from (Miles et al., 1988).

An example. Table 4.1 compares how some of the exhibits studied used their introduction or conclusion to serve some of the purposes mentioned here.

Exhibit	**Introduction**	**Conclusion**
Leonardo	A multimedia "object theatre" that introduces the primary messages of the exhibit, and labels with the main message and primary messages at or near the exhibit entrance	An area that illustrates the legacy of Leonardo's work as a scientist, inventor and artist; labels repeating the primary messages; a resource room with books and multimedia workstations; and a bulletin board with feedback cards and posted responses
The Kennedy museum	An 18-minute introductory film relating Kennedy's childhood, education, and early political career in a separate theater, which exits to the start of the exhibit space	A legacy area illustrating the effects of programs begun in his administration, progress on issues important to him and Robert F. Kennedy, and his influence on present leaders
The Holocaust Exhibit	A twenty minute spoken and film presentation explaining the background of the museum, its architectural significance, and how the viewer progresses through the exhibit	The exhibit exits into the Hall of Remembrance, where the visitor can light a candle in memory of the victims of the Holocaust and reflect on what he has seen

Table 4.1: Introductions and conclusions in exhibits.

4.1.5 Use multiple representations and media to communicate.

The principle. A representation is *how* you communicate an idea, and a medium is *what* you communicate it with. For example, to show how a siphon works, you could present the equations describing how fluid flows under the influence of gravity, a schematic of a siphon, a working model, or have the visitor try to build a siphon from components himself. These are multiple representations of the idea of a siphon. Each of these representations could be expressed in a variety of exhibit media: a label with text and images, a video loop, a physical model, or an interactive software program; however, a particular representation may be expressed more easily in some media than others.

So, the principle could be neatly summarized as: Say it more than once (multiple representations), and say it in different forms (multiple media). In this way, visitors with different learning styles, such as imaginative learners (those who ask, "Why?"), analytic learners ("What?"), common-sense learners ("How?"), and dynamic learners ("What if...?") can be accommodated. Multiple representations, in multiple media, make it more likely that every visitor will connect with one of the ways an idea is expressed.

The notion of individuals, particularly children, having learning styles was developed by Bernice McCarthy into the 4MAT educational curriculum devopment system (McCarthy, 1987). She combined Kolb's four stages of learning (Kolb, 1985) – concrete experience, reflective observation, abstract conceptualization, and active experimentation – with the two different ways the hemispheres of the brain perceive and process information to arrive at eight ways of teaching an idea. The system has been used to develop elementary school curricula that improve retention and learning attitude (Wilkerson and White, 1988).

The presence of multiple media relieves the monotony of exhibits that only have label text (what Judy Rand calls "books on walls"). They can also give the viewer a choice of how much time to commit to one part of the exhibit, say, either glancing at an object and moving on or staying and watching a two-minute video loop.

Source. Several of the designers interviewed mentioned the need to communicate the ideas of an exhibit in a variety of ways. Lynotoyos (Lynotoyos, 1997) characterized these methods as linguistic (reading), visual (seeing), and interactive (doing). *Leonardo* incorporates them with label text, artifacts and objects, working models, interactive multimedia, and hands-on activities. Each of these elements of the exhibit presents the main message of the exhibit in a different way.

For the Kennedy museum, the large amount of archival material available at the Library, especially film and video, gave the developers wide latitude in using multiple media. One theme of the exhibit was to expose younger visitors to Kennedy's voice and his ability as an orator. To do so, the exhibit contains twenty-one monitors showing video clips of campaign debates and advertisements, speeches, press conferences, and other events featuring John F. Kennedy (and others in the Kennedy family) dispersed throughout the exhibit. Jim Wagner mentioned that the audio-visual material animates the artifacts and first-person documents, but neither overpowers the other (Rigg and Wagner, 1997).

Applicability. Ideally, this principle should be used whenever possible. Unfortunately, there are differences in the availability, time, and cost associated with each media type, and using multiple representations to communicate the same idea takes space that could be used for presenting other material.

Costly media and the space for multiple representations should then be reserved for the main messages or concepts of an information space, those that deserve the most attention and emphasis.

Design consequences. This principle informs the mode of presentation of the ideas in an information space. Once the conceptual structure of the space has been decided, the task becomes to use the available artifacts or objects to communicate the messages or concepts in that structure. If the material is mostly textual or object-artifacts, adding dynamic (video, audio) or interactive media can enliven the artifacts.

If complicated ideas or processes need to be communicated, then it may be worth the effort to use multiple representations. For example, an exhibit on the peoples of Africa in the American Museum of Natural History illustrates the complicated relationship of the familial unit to larger African society in three ways: text, a two-dimensional diagram, and a three-dimensional model of the geneology of an African family (McLean, 1993).

An example. All of the exhibits combined media in a variety of ways: The Holocaust exhibit illustrates how they can be integrated into cohesive units of presentation. A significant part of the exhibit consists of series of dioramas, each with a very similar arrangement, schematized in Figure 4-4. The dioramas combine photographs, objects, text, and historic video clips into a presentation about a specific topic that can be examined and explored before moving on.

4.1.6 Allow for multiple levels of engagement and understanding.

The principle. This principle accounts for differing levels of interest in the visitor. For different parts of an exhibit, the visitor acts as a reader, consuming everything in front of

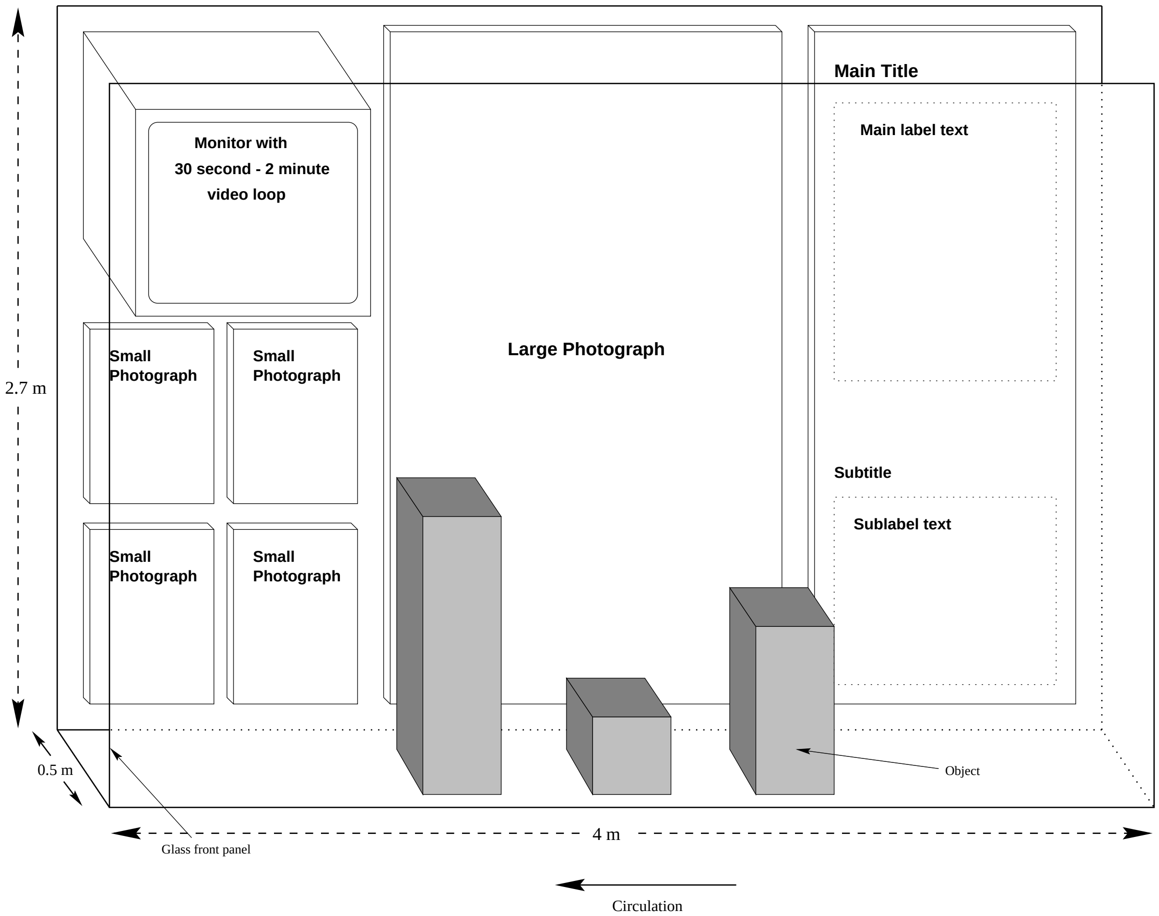


Figure 4-4: Typical arrangement of multiple media in a Holocaust exhibit diorama.

him; a browser, picking out details and pursing those in-depth; and a skimmer, noting the obvious and moving on. This principle allows a visitor to take something away from a part of the space no matter the amount of time they spend.

To accomodate these interaction styles, the exhibit should have something for each of them. For the skimmer, there should be a summary letting him acquire the most important facts with little effort. For the browser, there should be enough information for each topic to let him decide if he wants to read further. For the reader, there should be the depth he desires (and, perhaps, indications of where he can find more information).

Source. This idea is discussed in Miles (Miles et al., 1988) as a specification for a three-level exhibit structure. The first level contains the minimum detail needed to maintain a coherent theme. The second level of detail elaborates on the first, and provides the level of detail needed to make a "bridge" to the third level. The third level is an in-depth exploration of a specific topic, possibly relating current research in the area. These levels may be represented unequally in the exhibit (see Figure 4-5).

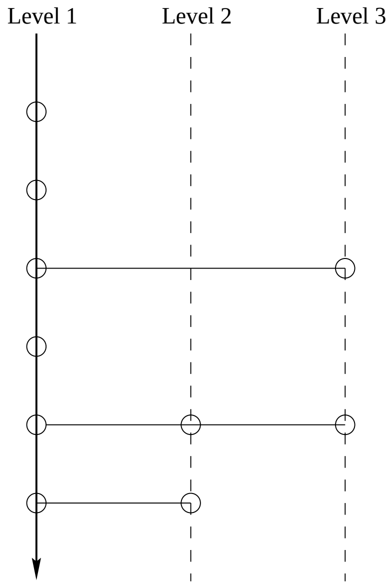


Figure 4-5: Levels of detail in an exhibit. Reproduced from Miles (Miles et al., 1988).

In the context of label design specifically, the principle is also related in a label writing manual by Rand (Rand, 1993). The manual recommends breaking label text into chunks or paragraphs. Each chunk has a prominent, bold subhead that summarizes the content of the paragraph, which may convince some viewers to read the entire paragraph. Others can glance at the summaries, get the gist of the label, and move on.

Applicability. This principle has the most consequences for the presentation of textual material, where the difference between a quick glance and a long read is greater than for an image. It also relates to decisions that inform navigation, in that a choice to move in a particular direction is determined in part by what the viewer can see down that potential route. The prominent features in that direction that are immediately and visually accessible are a valuable resource for the designer that can be used to let the viewer know what is available or intrigue him to find out more.

Design consequences. Each message, concept, or event in time that constitutes a unit of the exhibit can be stated at several levels of detail. Each can be summarized in one statement that is provided for the skimmer and browser. The rest of the detail can follow for the reader who desires more depth.

An example. Examples of labels from several exhibits show this principle in practice (Figure 4-6). This label, from *Exploring Marine Ecosystems*, summarizes its content with its title, "Eat and Be Eaten." The main body of the label contains a diagram of a coastal ecosystem and text explaining the concept of a food web. More detail is provided at the bottom of the label.

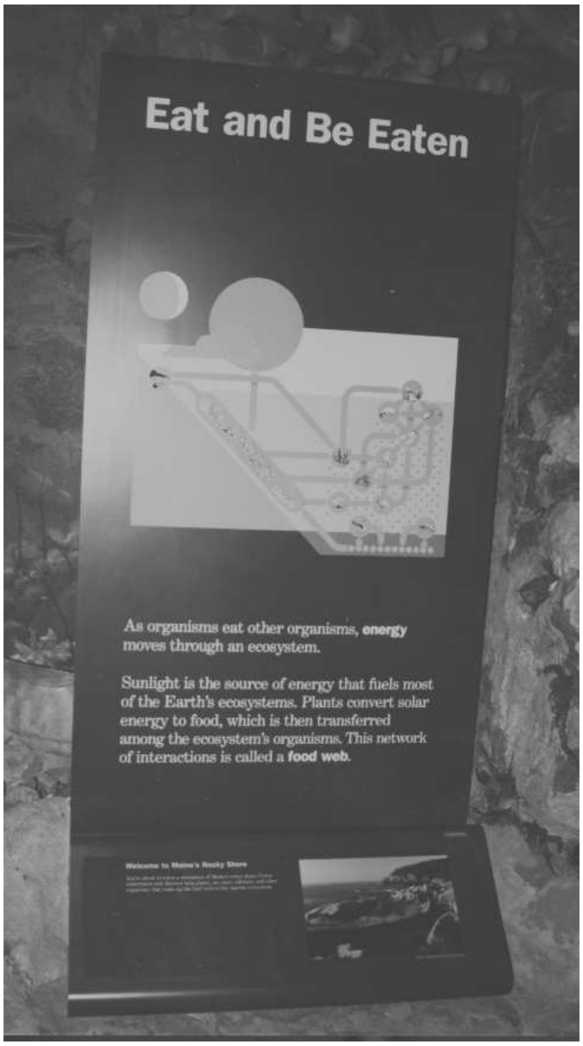


Figure 4-6: Levels of detail in an exhibit label.

4.1.7 Use an "environmental look" to provide thematic context.

The principle. The appearance of the container matters. For an exhibit, this includes the carpeting and floor treatments, wall color and treatments, decorative motifs on doorways, archways, and thresholds, and all manner of other environmental elements that, while not communicating information directly, enhance and enliven the visitor's experience.

Source. In an interview, Lynotoyos described an environmental look as the use of environmental elements (as opposed to artifacts and labels) to consistently denote a period, place, idea, and so forth. It prevents a stark, white-walls appearance to an exhibit, and its goal is to feel immersive without being intrusive (a "corner-of-the-eye" effect). The look can also showcase particular items or ideas in the exhibit.

Applicability and design consequences. For a given situation, this principle takes the appearance of the container into consideration as a way to communicate more effectively. The look can reinforce the space's content and themes and act as an aid to orientation by changing as the visitor moves through different parts of the space.

For a digital information space, the environmental elements take on a different character than for a physical exhibit space. Those structural elements in presentation include the color of text or the border of a window, for example.

An example. For *Leonardo*, the look was based on three ideas: a period (the Renaissance), a place (Italy), and an idea (architecture). It was suggested by many environmental elements: arches in thresholds and gateways, a mural depicting Vinci, Italy near the entrance, and blue marble wall treatments.

Other exhibits also used the look to create a sense of place (see Figure 4-7). In *Exploring Marine Ecosystems*, the first section of the exhibit is modeled after a coral reef, complete with kelp and divers. The simulated Martian surface in the room in *Where Next, Columbus* on Martian exploration is so accurate that NASA studied it to create their own models.

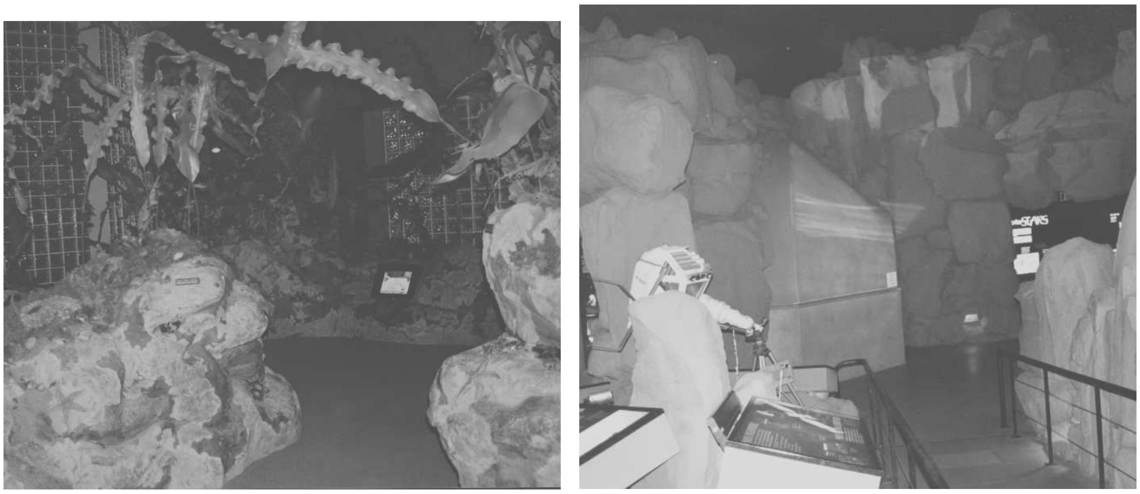


Figure 4-7: The environmental look in two exhibits. Left: From *Exploring Marine Ecosystems.* Right: From *Where Next, Columbus.*

4.2 Reflections

It was stated earlier that what makes an exhibit like a textbook, lecture, or television program is that communication takes place over time. What sets it apart from these other modes, and gives them the character of an information space, is that the visitor has choices in how they view the material.

As designers, we would like those choices to be informed and fruitful in accomplishing the navigator's task. Issues of orientation, wayfinding, and imageability – the navigator's ability to form a mental map of the space – will come into play as we ask how to design spaces that permit successful navigation, purposeful movement from one location to another in the space.

Chapter 5

Design Principles for Wayfinding

This set of design principles is concerned making information spaces effectively navigable. Navigability means that the navigator can successfully move in the information space from his present location to a destination, even if the location of the destination is imprecisely known. Three criteria determine the navigability of a space: first, whether the navigator can discover or infer his present location; second, whether a route to the destination can be found; and third, how well the navigator can accumulate wayfinding experience in the space.

The first criterion, successful recovery of location and orientation, asks the navigator if he can definitively answer the questions, "Where am I?" and "Which way am I facing?" A response to these questions could be verbal, such as "I am in Lobby 7, facing Massachusetts Avenue[1]," or written, by drawing an arrow on a map of the environs.

The second criterion for navigability is the ability to successfully perform wayfinding tasks. Successful wayfinding occurs when the navigator can make correct navigation decisions that take him from his present location to a destination that fulfills his larger purpose. Examples of such decisions are whether to continue along the present route or to backtrack, what turn to take at an intersection of paths, or whether to stop and aquire information from the environment to confirm the present route. Arthur and Passini call wayfinding spatial problem solving (Arthur and Passini, 1992), in which the navigator finds a satisfactory solution to a larger task through navigation.

The third criterion for navigability is how well the navigator can accumulate wayfinding experience in the space. The *imageability* of a large-scale space is the ability of a navigator to form a coherent mental image or map of it. Kevin Lynch, an urban planner, first investigated how the characteristics of an urban space affected how well people remembered features in it (Lynch, 1960). Lynch interviewed residents of Boston, Los Angeles, and Jersey City, New Jersey, and asked them to draw sketch maps of their city from memory. From these sketch maps and verbal interviews Lynch compared the imageability of the the cities: how well the sketch maps and interviews reflected the actual layout of each city. Lynch found that the respondents organized their city images using a set of common features: paths, landmarks, regions, edges (barriers), and nodes (intersections).

What makes Lynch's findings especially interesting is that the imageable or memorable features of a space are used by people to assist wayfinding. Landmarks are memorable locations that help to orient the navigator; regions are distinct areas that place him in one

[1]A well-known position and orientation on the MIT campus.

part of the environment; and nodes mark points where wayfinding decisions are made. Since a navigator's uses these features to record his past route-following experiences, a designed space that employs them should be more effectively navigable.

These last two criteria, wayfinding ability and imageability, have special relevance for information spaces. Wayfinding in an information space, we have argued, should correspond with information-seeking behavior in an information access environment. Successful wayfinding then implies that the user can use the information access environment to fulfill his information need. In a navigable information space, the problem of being "lost in hyperspace" (Edwards and Hardman, 1993) could then be solved.

In an imageable space, each episode of successful navigation can contribute in building a coherent mental picture of the information environment and of the content therein. Ideally, the user becomes more and more effective in fulfilling information needs every time he navigates through the environment. And in an information space organized on a principle relevant to the user's task, the mental map corresponds to a conceptual map of the content, reflecting important relationships in the information and the principles used to organize it.

The principles here come from both the study of museum exhibits and the research of environmental psychologists, cognitive scientists, and others who study how humans represent and navigate in the physical environment.

Principles for effective wayfinding include:

- Create an identity at each location, different from all others.
- Use landmarks to provide orientation cues and memorable locations.
- Create well-structured paths.
- Create regions of differing visual character.
- Don't give the user too many choices in navigation.
- Use survey views (give navigators a vista or map).
- Provide signs at decision points to help wayfinding decisions.
- Use sight lines to show what's ahead.

5.1 The Principles

5.1.1 Create an identity at each location, different from all others.

The principle. Give every location in a navigable space a unique perceptual identity, so that the navigator can associate his immediate surroundings with a location in the larger-scale space. It speaks most directly to the first criterion for navigability, the ability to recover position and orientation. This principle indicates that every place should function, to some extent, as a landmark – a recognizable point of reference in the larger space.
Source. The idea of places needing an identity for wayfinding is discussed in Arthur and Passini (Arthur and Passini, 1992). They introduce the notions of *identity* and *equivalence* for speaking of the perceptions of places. Identity is what makes one part of a space distinguishable from another, and equivalence is what allows spaces to be grouped by their common attributes. They argue that identifiable places form the building blocks of our cognitive maps and the spatial anchors for the decisions made during wayfinding.

Applicability and design consequences. Ideally, a space should have just enough differentiability for this principle to hold, but no more. Neon lights should not be necessary. And, if the information space is built around an organizational principle, differentiability may be reflected by that organization naturally. For example, suppose the navigator is traversing a spatial timeline. Then each location corresponds to a point in time, giving a ready-made identity to it.

An example. Perhaps the best way to illustrate this principle is to see what happens when it fails. Those familiar with the original text-adventure game ADVENT will know that the adventurer will eventually find his way into a part of the cave which the game describes as:

```
You are in a maze of twisty little passages, all alike.
```

No matter which direction the player moves, the system will again respond

```
You are in a maze of twisty little passages, all alike.
```

(unless the player is fortunate enough to emerge from the maze strictly by chance.) What to do?

An effective strategy is for the player to drop one of the items he is carrying in the room, then make a move and see what happens. When the player re-encounters a room with an item, the system responds

```
You are in a maze of twisty little passages, all alike.
There is a bag of coins here.
```

Now the room has an *identity*. The player can repeat this process to map out the entire maze as a directed graph, and emerge on the other side.

5.1.2 Use landmarks to provide orientation cues and memorable locations.

The principle. Landmarks serve two useful purposes. The first is as an orientation cue. If the navigator knows where a landmark is in relation to his present position, he can say something about where he is, and which way he is facing, in the space he shares with the landmark. A desirable property of a landmark for this use is visibility, the ability to be seen from a large surrounding area. Such global landmarks can help the navigator judge his orientation within a wide area, as opposed to local landmarks, which can be seen only in the immediate vicinity. A system of local landmarks which exhaustively cover the space can also provide the same cues as a single, towering landmark.

The second use of a landmark is as an especially memorable location. In his sketch-map interviews, Lynch noted that different respondents marked or mentioned many of the same places. It is these memorable places that can provide instant recognition of one's location. A shared vocabulary of landmarks provides the basis for verbal or written descriptions of locations or routes. Landmarks associated with decision points, where the navigator must choose which path of many to follow, are especially useful as they make the location and the associated decision more memorable.

Source. Lynch (Lynch, 1960) dicusses landmarks in an urban context at length, and describes their defining physical characteristic as "singularity, some aspect that is unique or memorable in context."

Landmarks were also evident in an exhibit setting. Landmarks such as the large water pump model in *Leonardo* (catalog number 112) and the octagonal case holding Jacqueline Kennedy's dinner gown (catalog number O26) were both physically large and visually distinct from their context, meeting Lynch's requirements as landmarks. Landmarks can be distinguished spaces as well as memorable objects; for example, the Oval Office exhibit marked the midpoint of the Kennedy museum.

Applicability and design consequences. A system of landmarks helps to organize and define an information space. However, they should be used sparingly; placing too many landmarks in the space belies their usefulness as memorable and unique locations. Landmarks, then, are a scarce resource that can be used not only to assist wayfinding but also to serve the space's larger purpose. Since a landmark defines a surrounding region to which it is adjacent, it could stand as a exemplar or representative for that region's content. Landmarks can also head paths emanating from junctions, and indicate what's down the road. Landmarks are the anchors along which paths are defined and our mental maps are built; they should reflect the top level of the organizing principle of the space.

An example. An interesting use of a landmark is found in the National Museum of Natural History's fossils exhibit. Near the entrance, a tall (approximately 20 meters high) "time tower" is visible from most of the central area of the exhibit (Figure 5-1). In a multi-level exhibit with a complex circulation pattern, it is a valuable physical landmark and point of reference with wide visibility. It also displays the time periods represented by the fossils in the exhibit and the corresponding terms associated with them. So, it serves as both a wayfinding aid and a way of communicating information important to understanding the exhibit.

5.1.3 Create well-structured paths.

The principle. Paths should possess a set of characteristics to be "well-structured." Well-structured paths are continuous and have a clear beginning, middle, and end when viewed in each direction. They should confirm progress and distance to their destination along their length. And a navigator should easily infer which direction he is moving along the path by its directionality or "sidedness." These concepts are summarized in Figure 5-2. A well-structured path maintains a navigator's orientation with respect to both the next landmark along the path and the distance to the eventual destination.

Source. The exhibits studied can each be thought of as a well-structured path. For those that were spatial timelines, the start of the timeline, its extent, and its end create the path. For those that communicated messages, movement from one message to the next marked progress. Exhibits with memorable introductions and conclusions have well-defined beginning and end-points for their paths.

Applicability and design consequences. This principle informs how the traversal of a pre-defined route will appear to the navigator. The features of a well-structured path should again correspond to concepts relevant to the content of the space. The beginning and end of the path form an introduction and conclusion, and progress is marked by moving from one concept or message to the next. A continuous path should have both shared attributes that define it as distinct from its context, and evolving or changing features that mark its length and connect one part to a subsequent part.

An example. The Kennedy museum, as a spatial timeline, was a well-structured path (again, refer to Figure 5-2). The beginning of the path is the 18-minute introductory film; progress is marked by proceeding through his campaign, administration, family life,

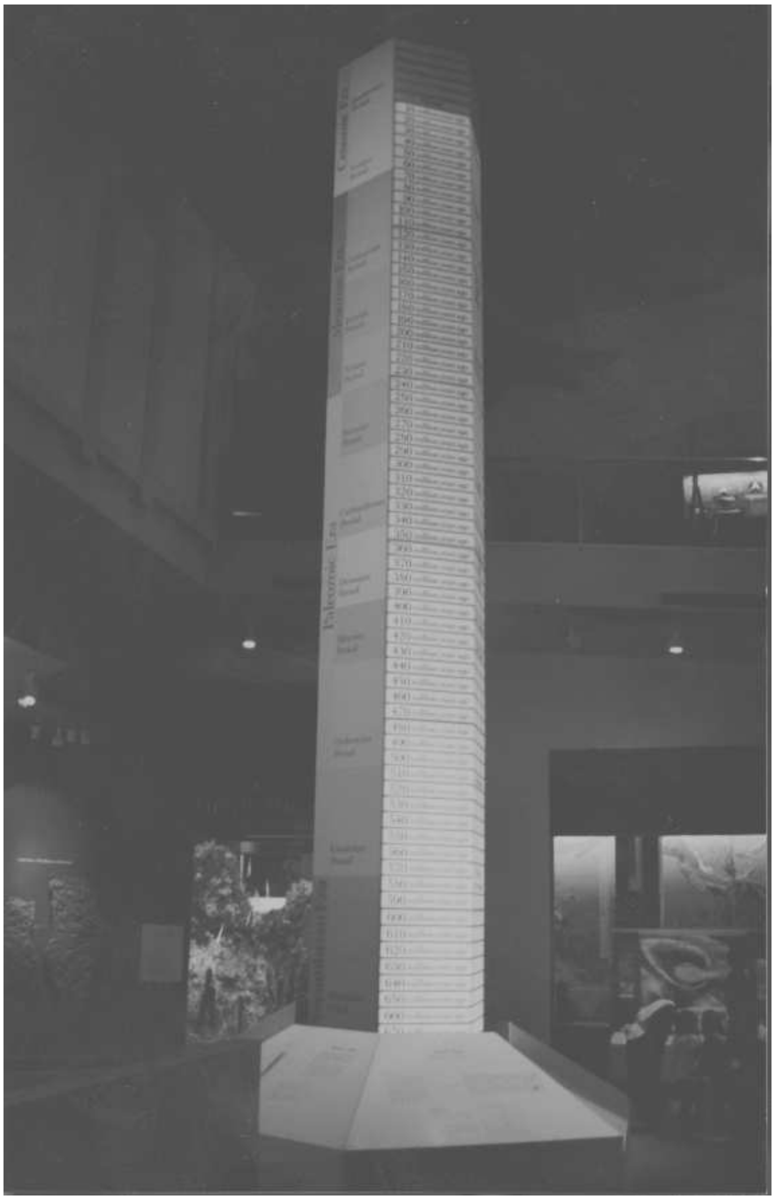


Figure 5-1: The time tower in the Fossils exhibit.

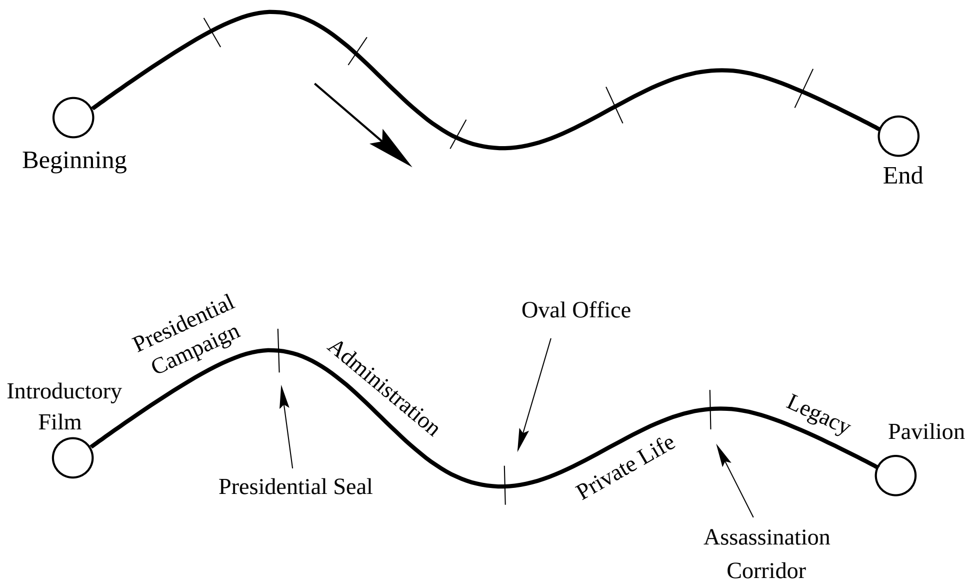


Figure 5-2: Well-structured paths. Top: In the abstract. Below: The Kennedy museum as a well-structured path.

assassination, and legacy; and the pavilion provides an end-point. Directional ambiguity is resolved by whether motion is forward or backward in time through the events in Kennedy's life.

Another example outside of the domain of exhibits are interstate highways. The entrances and exits along the highway are clearly marked by signs, and mile markers indicate progress and relative distance to destinations. In this case, the path is structured not so much by diversity of appearance or meaning, but by a system of signs arranged along its length.

5.1.4 Create regions of differing visual character.

The principle. Subdivide the space into regions with a distinct set of visual attributes to assist in wayfinding. The character that sets a region apart can be some aspect of its visual appearance, a distinction in function or use, or some attribute of its content that is consistently maintained within the region but not without. Regions may not have sharply defined boundaries, or their extent may be in some part subjective; but a minimal requirement is that there is a generally agreed space said to be within the region, and a surrounding area said to be outside it.

Regions assist wayfinding by providing another set of cues for recovering location. They associate a set of defining features with an area in space, and give a way of identifying a place as being in a certain region. When the navigator moves from one region to another, the shift in the character of the space is another fact that informs him of his location along the boundary of the two regions.

Source. Regions are used in exhibits in two ways. The first is as another aspect of the environmental look principle, from a wayfinding perspective. The consistent environmental elements that make for the visual identity of the exhibit as a whole define it as a region, apart from the rest of the museum. In addition, the distinct appearance of individual parts of the exhibit define sub-regions within that larger region.

The second is the use of enclosures to create regions in an exhibit. Moving from one room or gallery to another through a threshold makes explicit the motion from one region of the exhibit to another.

Applicability and design consequences. Regions allow the navigator to distinguish one part of the space from another and to know when he has moved across the boundary between two regions. These boundaries can serve as demarcations along a well-structured path through several regions. For communication, a region can correspond to some attribute shared by the content within, such as supporting the same message, teaching the same concept, or relating the same event.

An example. In *Leonardo*, Ed Rodley (Rodley, 1997) cited how visual elements marked the boundaries of the main areas of the exhibit; variations in color treatments of walls and moldings, archways of differing shapes, and differing light levels all reinforced the transitions through archways from one region to another. And, referring back to the message hierarchy for *Leonardo*, we see that each message corresponds to a particular, enclosed region of the exhibit (Figure 4-1).

5.1.5 Don't give the user too many choices in navigation.

The principle. If there is a story to tell, design the space so that it is coherent for every route the navigator might take.

Source. This principle was explicitly used to inform the design of the *Leonardo* exhibit. In particular, the visitor was given a choice at the "Florence in 1470" room to proceed straight ahead into the "Art Gallery" to or to veer right into the "Art Studio" rooms. According to Ed Rodley (Rodley, 1997), the exhibit was designed to repeat the messages conveyed in the Art Studio in a display in the Art Gallery, so that even if a visitor missed the "Art Studio" they would be exposed to these messages. This principle was applied throughout the exhibit, with the layout designed to ensure that people encountered the main points no matter what route they took.

Applicability and design consequences. This principle is best used when there is a story you want every navigator to see. This basic story should be communicated by every path the navigator can take through the space. Opportunities for detours, side-tours, and exploration can branch off of this main path, eventually returning to resume the main story.

This principle, and the underlying assumption of a narrative for the space, indicate that the organization should have a primary path for visitors to follow (for example, as in Figure 4-3). The underlying question that this principle tries to address is, how many choices should be made for the navigator? An answer is, enough for the navigator to learn what the communicators intend.

An example. We can also look at what happens when this principle is not applied. The original Kennedy museum had a plan in which the visitor entered a central area with his desk and had to then choose where to explore from this area (see Figure 5-3). By making a right turn, the visitor could skip the majority of the central area of the exhibit, possibly without being aware of it, and proceed to exit onto the pavilion. Frank Rigg noted this problem in an interview (Rigg, 1998).

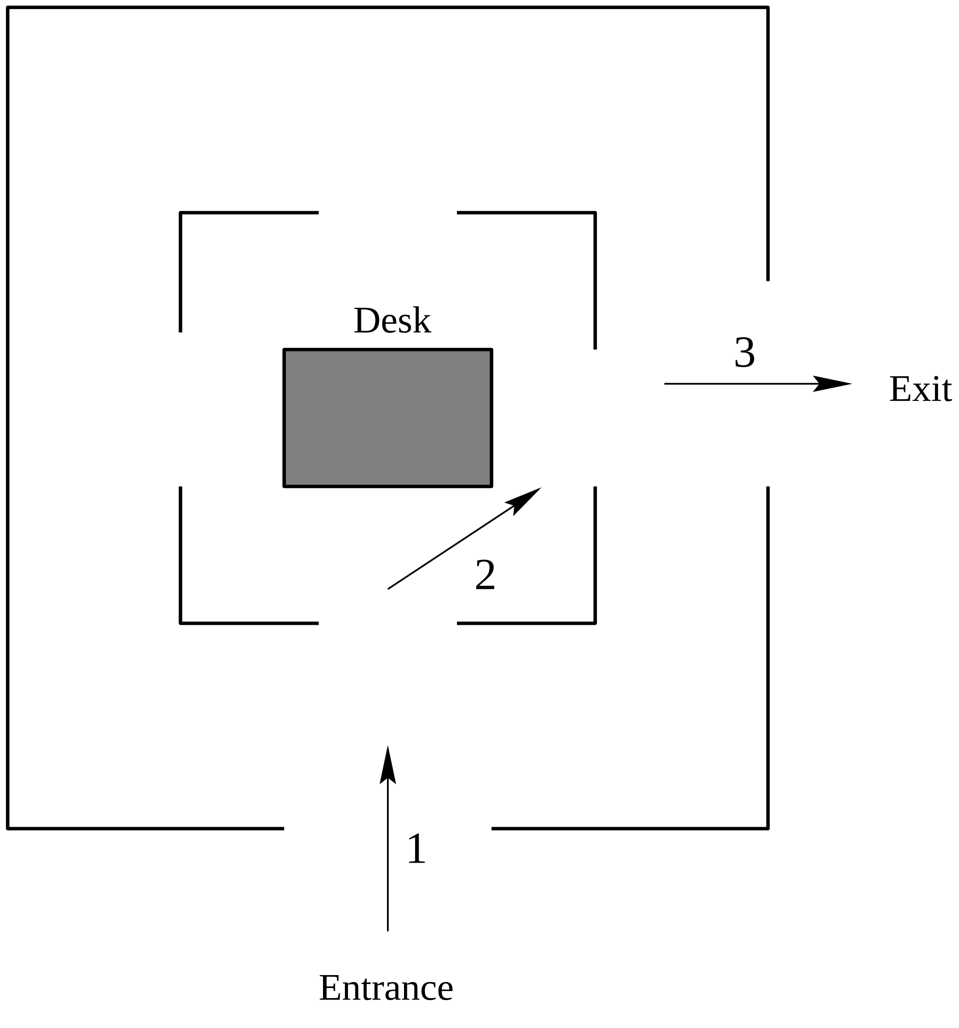


Figure 5-3: Schematic plan of the original Kennedy museum. Some visitors would enter from below (1) to the central area with his desk (2) and proceed directly to the exit (3).

5.1.6 Use survey views (give navigators a vista or map).

The principle. When navigating in any type of space, a map is a valuable navigation aid. It places the entire space within the navigator's view, and several kinds of judgements can be made readily:

- the location of the navigator, and what is in the immediate vicinity;
- what destinations are available, and what routes will take the navigator there; and
- the size of the space, and how far the navigator is along his chosen path.

In addition, the survey view provides a ready image of the space, which can provide the basis for the navigator's mental map. Several researchers have found that giving subjects access to only survey knowledge of an environment can give comparable or superior performance to knowledge gained from route-following experience on landmark estimation and sketch-mapping tasks (Thorndyke and Hayes-Roth, 1982) (Golledge et al., 1995). The navigator's mental map, primed with the image of his environment, can be augmented readily with experience gained from actual navigation in the space.

For an information space, a survey view has another role. It not only assists navigation in the space, but because the space corresponds to a conceptual organization of the information it contains, it serves as a succinct expression of meaningful relationships in that information. In more concrete terms, it assocaties the location of every document, image, or object with a message, a point on a timeline, or a concept to be learned. A map of the physical (or virtual) space can thus serve as an external representation of the conceptual map of the content. This conceptual map uses the navigator's ability to form mental representations of a physical space to store knowledge about conceptual relationships in the information space.

Source. Nearly every exhibit studied had a plan map either on a brochure distributed to visitors as they went in or mounted as wall plaques inside the exhibit itself.

Applicability and design consequences. Although it would seem to always be beneficial to provide a map, there may be sufficient wayfinding aids (such as signs and landmarks) already embedded in the space already to make a map unnecessary. Small spaces with which the navigator is already familiar may not need a map. A map can serve as reference material: available when needed, and able to be tucked away when not.

Maps are more useful when views in the space are insufficient to give information about unfamiliar regions, which is true in enclosed spaces with limited views in each direction.

An example. *Leonardo* had two maps situated at the entrances to the two latter sections of the exhibit (catalog numbers 74 and 148), identical to the map on visitor brochures (Figure 3-1). The Holocaust exhibit had wall-mounted maps at the beginning of each floor, labeled with each major section of that floor. Maps of the entire Holocaust Memorial Museum were also provided in visitor brochures (Figure 3-13).

5.1.7 Provide signs at decision points to help wayfinding decisions.

The principle. Place signs, when necessary, at decision points. Decision points are where the navigator must make a wayfinding decision (for example, whether to continue along the current route or to change direction.) A sign embeds additional information into the space to direct the navigator's next navigational choice. This information should be relevant to both the choices offered to the navigator at that point, and the larger goal of the navigational task. Simply put, a sign should tell the navigator what's in the direction it points, and the destinations so indicated should help the navigator reach his eventual goal.

Source. Passini describes this principle as part of his theory for wayfinding as spatial decision-making (Arthur and Passini, 1992) (Passini, 1984). According to this theory, a navigator begins with a high-level goal, and acquires information from his environment (or uses what he already knows about the space) to make his first move towards a top-level destination. At decision points along the route, the navigator combines observation of local features with previous knowledge of the space to make the proper navigational move.

When the navigator does not have previous knowledge of the space, or a map to refer to, only the local features at the decision point can inform his navigational choice. A sign placed at a decision point in this framework, needs to inform the navigator of the correct route.

Applicability and design consequences. When placing signs, we can ask two questions at the decision points in the space:

- *Should a sign be placed here?* Signs have navigational information that is authoritative and unambiguous. If the cost of making a wrong choice is high for the navigator or insufficient information is available from the view at the decision point for the navigator to make the correct choice, a sign is necessary.

- *What destinations should be included on the sign?* Considerations that come into play are the destination's frequency (*how often is it a navigator's goal?*), its importance or memorability (*is it a landmark, a place that could be used as a point of reference for other destinations?*), its immediacy (*how close is it?*), and its utility (*Does the destination help navigator complete a task?*). Each of these argue for adding a sign for that destination.

By design, signs must be in a location to acquire the navigator's attention, yet space for signage is a scarce resource. The benefits of signage must be weighed against the other potential uses for the space it occupies.

An example. One example of effective signage in action is at an airport. The environment may be completely unfamiliar to first-time visitors, and signs are the main means of directing them to their destination. Departing travelers have a typical routine of leaving from ground transportation or parking, checking in with their baggage, passing through security, and going to the departure gate. Arriving passengers must claim their baggage and proceed to ground transportation or parking. Effective signs in an airport both direct visitors at decision points to useful destinations and confirm their route along the way.

5.1.8 Use sight lines to show what's ahead.

The principle. Give the navigator a more extensive view in a particular direction and a goal to draw him in that direction. In an exhibit space, in which the first-time visitor has uncertain expectations as to its extent and purpose, sight lines are valuable means of giving enough information about what's ahead to encourage the visitor to move farther. Sight lines give long but narrow samples of unfamiliar space. Based on that sample, the viewer can determine if that direction is of interest or not.

To make a sight line interesting, the designer can provide a "wienie" – a goal to navigate toward. It might be some feature or object that is striking or unusual, something to spark the navigator's interest. It is the reward for choosing the path that it lies at the end of.

Source. This principle comes from Martin Sklar, president of Disney Imagineering, relating "Mickey's Ten Commandments" for museum exhibitions at the 1987 American Association of Museums Annual Meeting (McLean, 1993): "Create a 'wienie' [*sic*]... That's what Walt Disney called it...You lead visitors from one area...or one exhibit to the next by creating visual magnets. Reward people for walking from point A to point B."

Applicability and design consequences. Providing selective views into a larger space is a way of letting the viewer take a representative sample of what's available and letting him make wayfinding decisions on that basis. It could be thought of as an alternative to a sign; instead of telling him that the destination is down this path, you can show him where it is (although it might be far away). The information available at a decision point should also depend on what sight lines are offered by each of the choices. Sight lines and wienies are tools the designer has to lead the visitor from one part of the space to the next.

An example. Sight lines were important in the Kennedy museum. At the end of the main corridor, an octagonal case with Jacqueline Kennedy's dinner gown was visible from the beginning, and served to draw people forward through the corridor. The case was situated in a temporary exhibit space that formerly housed an exhibit on the Nuclear Test Ban Treaty, which apparently was less interesting; once the case was installed, it actually improved visitor traffic into the adjacent exhibit on Robert F. Kennedy (Rigg and Wagner, 1997).

Another example is from the original Kennedy museum, before redevelopment. In exhibit 17, a film clip of a press conference was activated by a floor sensor: the monitor in the exhibit was blank until the visitor stepped in. Visitors would glance into the exhibit, see a blank screen, and move on. Once the clip was made into a continuous loop, traffic flow improved into the exhibit.

5.2 Reflections

These principles can be roughly divided into two classes. The first class of principles, one through four, develop a basic vocabulary of spatial features that assist wayfinding and imageability: identifiable places, landmarks, paths, and regions. In an information space, these features should be used to communicate the conceptual organization of its content. It is this correspondence that makes meaningful navigation possible in the space.

Principles in the second class, six through eight, are about the views that the navigator has into the space, and how designers can provide the information necessary for wayfinding and decision-making. Survey views are maximal; they give the navigator the most information about the space at once. Sight lines are local views deep into the space in an interesting direction. And signs are the authorities in information spaces, providing locally relevant wayfinding cues.

The remaining principle, the fifth, ties the structure of the space to the task of interest – communication of some body of knowledge – by ensuring that the route the navigator takes will expose him to the ideas the communicator wishes to express.

Chapter 6

Design Principles for a Computational Medium

The first two sets of principles dealt with the spatial organization of information in museum exhibits, and the features in an environment that make it effectively navigable. We would now like to use the possibilities afforded by a computational medium to support the use of digital information spaces designed around those principles. They are some answers to the question, *What if we could implement an exhibit in a computational medium?* Instead of arising from the study of real-world exhibits they are driven by analogy to existing examples of user interface design.

A digital implementation of an information space is some collection of state in a computer (or a network of computers), and that state can evolve under program control and in response to users' actions. The most basic set of responses supported by a space are those that change the view of the space according to navigation actions by the user, but many other actions and responses are possible.

Given the wide range of possibilities in a computational medium, there is no claim that these ideas are comprehensive. Instead they are points of departure and development. Given that nearly all work to date on electronic information access environments has assumed a computational medium, the scope of these will be limited to ideas on how computation can specifically assist navigation in an information space.

In summary, the principles are:

- Use an appropriate mode of presentation.
- Allow for different velocities of movement through the space.
- Use route data for visualization, dynamism, and debugging.
- Use interactive media.
- When in immersion, give navigators a "you-are-here" map.
- Personalize the space.
- Use the space as an evolving repository of knowledge.
- Provide layers of information on the map.

6.1 The Principles

6.1.1 Use an appropriate mode of presentation.

The ubiquity of low-cost, hardware accelerated three-dimensional graphics capabilities in mass-market computers has made the real-time rendering of navigable, realistic three-dimensional scenes possible for many users. This capability makes three modes of presentation possible for an information space (see Figure 6-1):

- Immersive or first-person. The user sees what he would see if he were immersed in the three-dimensional environment, with a field-of-view about the same as in the real world.
- "Fly-over." The user manipulates the position of a viewpoint in the three-dimensional environment. This viewpoint is overhead or otherwise away from the space, which is in an orthographic or perspective view.
- Survey view. The user is presented a map of the space, and can manipulate his view on this map (say, by panning and zooming, or with a fisheye view (Furnas, 1986)).

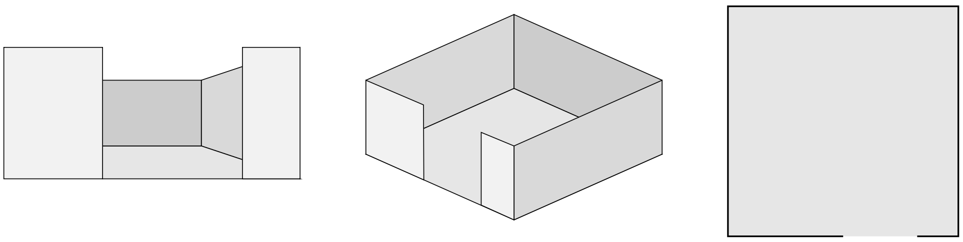


Figure 6-1: Viewpoints into an information space. Left: Immersive. Middle: Fly-over. Right: Survey, or map.

First-person views (such as the immersive view) are superior for realistic navigation; giving the user a location and orientation in the environment makes the analogue between navigation in the physical environment and navigation in the virtual environment the most straightforward. The disadvantages of immersion are that a constrained field-of-view requires the user to rotate him viewpoint to view his surroundings, and objects are most prone to occlude one another.

Fly-over views are a compromise. They let the viewer see more context in the space from his viewpoint, while still allowing the representation of three dimensions. One of the dimensions will need to be limited in extent so that there is a way of moving "above" all of the objects in the space.

Survey views offer the widest view of the information space, but provide the least detail at the top-level. Since the navigator's window is limited in extent, providing a view from higher and higher up necessarily gives less and less area, and thus less communicative capacity, to each item of information. To provide a higher level of detail at the user's focus the area of the window may have to be divided, with one part under the control of the other. An action a user takes in a wider view then leads to a view of more detail in the other part of the window, as in the left of Figure 6-2. Another way of providing more detail at focus is to enlarge the window at the point of the user's focus while still giving context, as through a distorting lens (what Furnas calls a fisheye view (Furnas, 1986)). This is illustrated on the right of Figure 6-2.

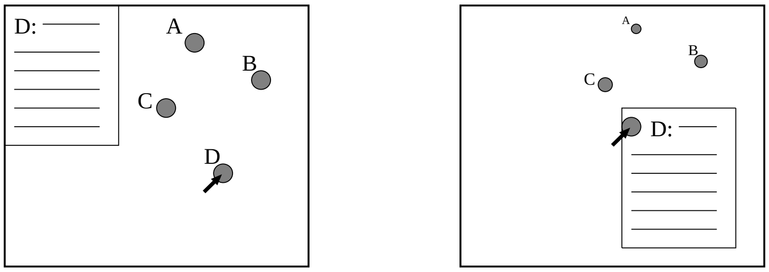


Figure 6-2: Multiple levels of detail. Left: A divided window. Right: A fisheye view.

6.1.2 Allow for different velocities of movement through the space.

This principle suggests that users should be able to move more quickly through the space according to their need to travel quickly to their goal. Instant movement from one point to another can induce disorientation in the navigator, especially when moving into unfamiliar territory. Non-instant but rapid and continuous movement can allow large distances to be crossed while providing a view of intervening territory, reducing the chances of disorientation.

Teleports (places where the velocity of the navigator changes) systematically arranged through the space can act as a sort of rapid transit system, ferrying users around to their destination in a known network. The transit stops themselves can function as landmarks, and should be arranged at convenient and central points in the space.

Teleports can be opportunistic as well, acting as a cross-reference linking an item of interest in one part of the space to an item far away. Opportunistic links are a way of selectively breaking out of the the static conceptual organization to provide more paths than a physical space itself would allow.

6.1.3 Use route data for visualization, dynamism, and debugging.

The routes a user takes through the space are a valuable source of data that can be used for a number of purposes. First, both the user's current route and previous routes can be visualized in the space (or on a map of the space). Routes can be annotated and shared with others, giving directions or pointing out interesting tours of the space.

A second role route data can take is as a source of dynamism in the space: changing the space depending on the route to the current location chosen by the user. If the intent of the space is to communicate or teach, the comprehension of the user can be tested at a point in the space before progress is allowed. Additionally, the user can be encouraged to backtrack if a required part of the space has not been seen yet. Or, if the user lingers in one part of the space for a long time, a level of interest in that region is implied. The user could then be notified of other parts of the space that might be interesting (Balabanović, 1997; Armstrong et al., 1995).

Route data accumulates over time, and can be used to detect when users have difficulty navigating in one part of the space. A high frequency of backtracking to a decision point can mark it as a place where a sign may be needed.

6.1.4 Use interactive media.

In museum exhibits, interactives that simulated working models of processes or ran other software needed separate computers. In a digital information space, these kinds of interactive objects can be integrated directly into the software implementation of the space without additional hardware support.

Digital representations of traditional media can also be enhanced. For example, three-dimensional objects, instead of being hands-off, can be manipulated and explored, possibly with a haptic interface (Salisbury and Srinivasan, 1997).

6.1.5 When in immersion, give navigators a "you-are-here" map.

The limited field-of-view and problem of occlusion in an immersive viewpoint makes it useful to refer to a "you-are-here" map, found in many buildings, public spaces, and most of the exhibits studied. These maps show a plan of the space with an arrow indicating the navigator's current position and orientation. In a computational medium, it is possible to make that reference available on demand at every point in the space. More generally, multiple viewpoints of the space are always possible, and coordinating immersive and survey views in this manner makes sense from a wayfinding perspective.

6.1.6 Personalize the space.

The presentation of the space to an individual user can be transformed by the user's preferences, both in content and visual appearance. Typefaces and color schemes can be specified by the user, or more complex transformations of the content can be performed according to the user's interests, goals, and task.

Too much personalization can have consequences. If all the users of the space have an entirely unique view of it, discussions about the content of the space will be difficult. A necessary condition might be to leave a constant, shared vocabulary of landmarks, paths, and regions that are constant for all users, so that at least some common points of reference remain if a shared experience is desirable.

6.1.7 Use the space as an evolving repository of knowledge.

The ability to add to the material in the space through the annotations of users makes the computational nature of a digital space especially powerful. Imagine a tour guide for an information space, which helps visitors choose destinations and navigate in unfamiliar territory. Instead of being referred to separately, it could be embedded in the space itself with relevant information available at decision points in navigation. As users navigate through the space they can add their comments and recommendations to the guide.

6.1.8 Provide layers of information on the map.

A map of the space can be dynamic as well. It can provide the means for visualizing some attribute of the content of the space, perhaps as a function of user input. A simple example is a full-text query. The results, represented as the number of occurences of query terms, can be visualized by changing the color of or a spatial dimension in each item of content.

6.2 Reflections

These principles briefly relate some of the capabilities of an implementation of an information space in a computational medium. Throroughly investigating and implementing any one of them is a substantial untertaking in its own right. However, they serve as starting points for exploring computational support for information navigation.

Chapter 7

The JAIR Information Space

The best way to test design principles is to put them into practice. For information spaces, this means finding a collection of information to organize, deciding on task and purpose, and weighing and applying the principles described to arrive at a solution.

The first problem thus approached was to design an information space for the Journal of Artificial Intelligence Research. This work was undertaken before the study of museum exhibits had begun, so it was informed by a smaller set of principles than were presented here. It was intended as an early experiment, a project in which a certain set of ideas were be tried out and their consequences evaluated. Although data on how people used the space was collected, a rigorous usability study was not the goal. Instead, aspects of the user interface were improved over time in response to individual users' feedback.

In this chapter we describe the nature of the information to be organized, the tasks supported by the space, how it was designed, and evaluate it as a new source of principles for design. In creating this information space, we discovered that the designer should:

- Consider the costs of both creating and maintaining the space.
- Try to design spaces for reusability.
- Listen to the users.
- Support multiple browsing behaviors.

7.1 The Task

The JAIR information space is an information access environment for the Journal of Artificial Intelligence Research, whose contents are available on-line. Such an environment is designed to assist the user in obtaining information which fulfills an information need (Belkin, 1978). In this case, the space assists the user in determining which articles are of interest and provides a means for downloading and displaying relevant articles.

The design of such an information access environment must take into account a typical user's knowledge of the domain, his familiarity with search tools and search strategies, and the nature of the information accessible from the environment (Marchionini, 1995). For the JAIR information space the typical user is assumed to be familiar with main topics of research within the field of artifical intelligence and the terminology used to describe them. Also assumed is familiarity with hypertext, common user interface widgets (such as buttons and scrollbars), direct-manipulation interfaces, and full-text search capabilities.

The nature of the information accessed through the space is described in the Journal's charter, excerpted here:

> "JAIR's editorial board is dedicated to the rapid dissemination of important research results to the global AI community. The journal's scope encompasses all areas of Artificial Intelligence, including automated reasoning, cognitive modeling, knowledge representation, learning, natural language, neural networks, perception, and robotics."

Specifically, this space encompasses all of the approximately 100 articles published in the Journal (at the time of writing). All of them are available in electronic form and can be downloaded and displayed by the user on demand from the Journal's Web site.

The specific tasks supported by the space are *search*, *browsing*, and *retrieval*. For this document collection, search is the ability to locate an an article based on specific criteria, such as title and author, or by the full-text of their contents. Browsing is scanning titles and abstracts of related articles of interest. Retrieval is the downloading of an entire article for reading.

7.2 Design of the Information Space

Once a set of user tasks has been decided on, the next task is how to represent information in the space. One way to do so is to assign dimensions or attributes to each item of information, and then to choose the mode of presentation for those dimensions.

For this space, the articles were placed in two dimensions, but the viewpoint is manipulable in three dimensions. Leaving the articles in two dimensions prevents occlusion, which is a recurring problem in a number of 3-D information visualizations (Carrière and Kazman, 1995) (Chuah et al., 1995) (Chalmers et al., 1996). The third dimension can then be left to represent additional information about the articles.

To make that dimension visible, the two-dimensional layout is displayed in orthographic projection with a manipulable viewpoint. The orthographic projection preserves distance relationships consistently throughout (as opposed to a perspective projection). The manipulable viewpoint allows the user to adjust the visualization to shift focus. It also prevents occlusion and gives the impression of exploring a concrete object instead of viewing an image.

7.2.1 Article layout

Previous designs that arrange documents in two dimensions use the documents' term-vector similarity to each other (Chalmers, 1993) or preset queries (Olsen et al., 1993). Instead, we chose to first classify the articles into categories based on the major subtopic of AI they addressed, then to use that classification as the basis for spatial layout. In this way, a two-level hierarchy is used for positioning: primary positioning among categories and secondary positioning within categories. The circular perimeters of the categories makes the layout resemble a projected, one-deep cone tree (Robertson et al., 1991). For the layout of the categories in information space, see Figure 7-2.

Since the classification was a simple partition on the articles, the articles are positioned equidistantly about category centers. The radius of a circle category is proportional to the square root of the number of articles in the category, so that the area of the circle is

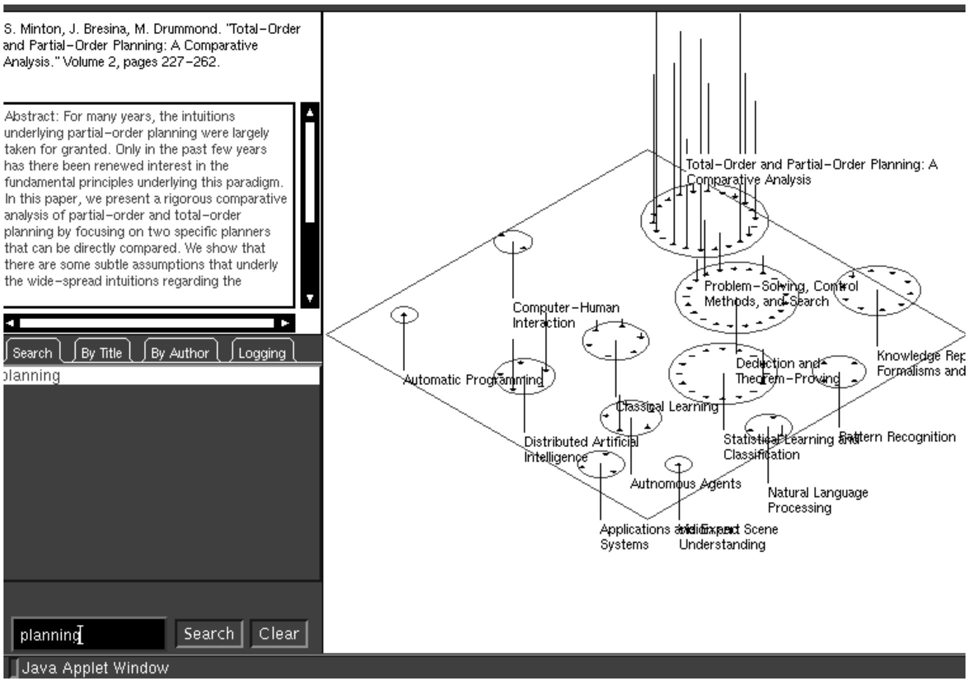


Figure 7-1: The JAIR information space, after a query on "planning."

proportional to its size. In this way, a judgment can be made about the relative distribution of articles among topics. This arrangement also facilitates browsing with mouse movements by maintaining a regular spacing among the articles.

The classification was performed manually. The topics for AI were chosen from the 1991 ACM Classification System. Seventeen of the articles were given a primary category and a secondary category because they were judged relevant to more than one topic. These secondary category assignments were used as the metric for category similarity; the more articles assigned to a pair of categories, the higher the similarity value.

Kruskal's multidimensional scaling algorithm (MDS) was used to arrange the locations of categories in two dimensions (Kruskal, 1964a) (Kruskal, 1964b). MDS attempts to find an arrangement of items in which the rank-ordering of dissimilarities among items is most closely preserved by the ordering of distances between them. In this case, dissimilarity between categories i and j that have $shared(i,j)$ articles assigned to both was computed by

$$dissimilarity(i,j) = \max_{k,l} shared(k,l) - shared(i,j).$$

MDS performs a gradient search in a nm-dimensional space to arrange n items in an m-dimensional space. The search attempts to minimize the stress of an item arrangement, which measures how well the distances between items preserve the dissimilarity measure. Kruskal's algorithm was modified to subtract the radii of a pair of categories from the distance between them to prevent category overlap. The desired interpretation of the category layout is that, on average, categories with more shared articles are closer together, and more similar in that sense, than categories with fewer shared articles.

Colors were chosen to emphasize the information-bearing elements of the visualization,

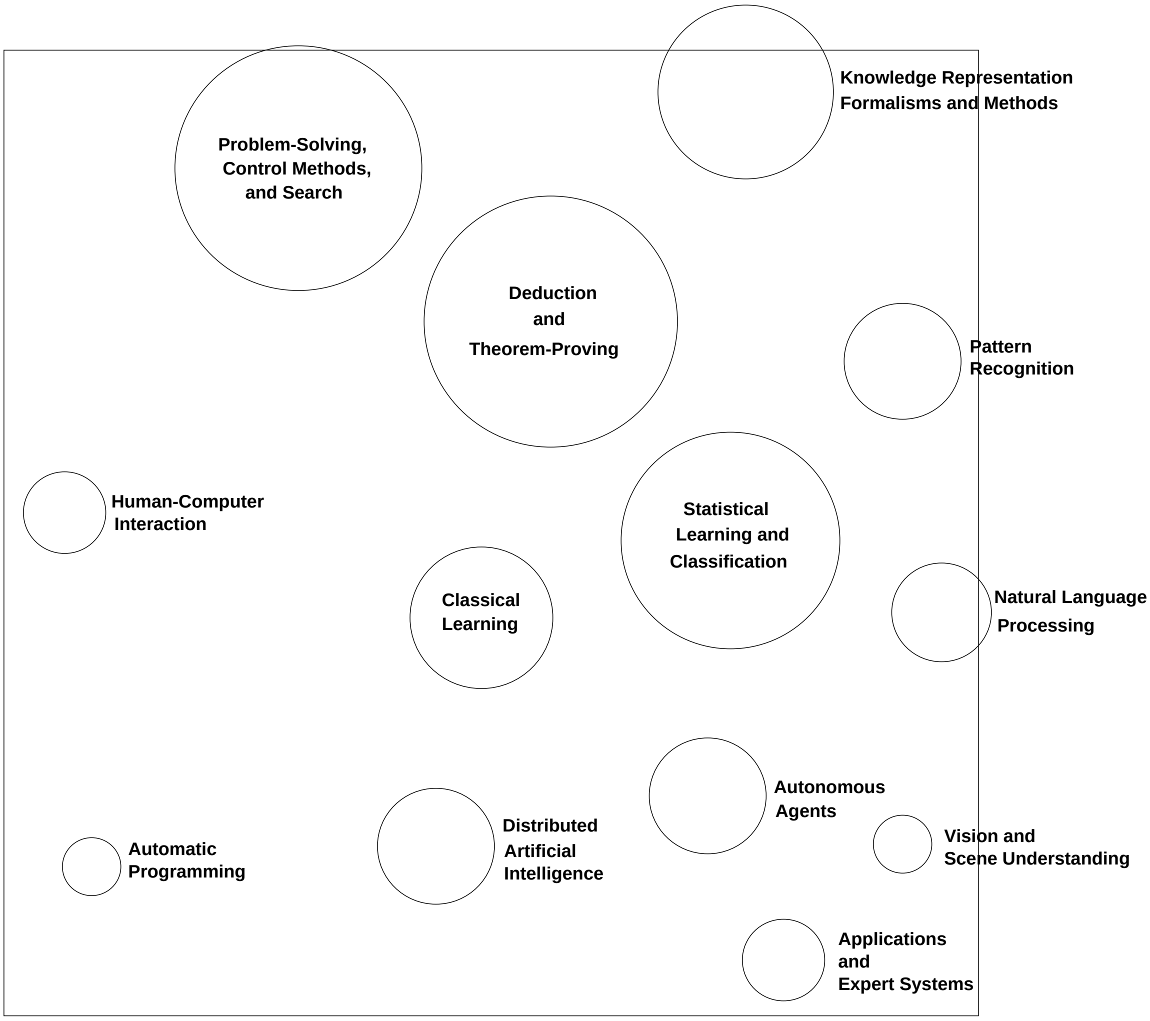


Figure 7-2: The layout of categories in the JAIR information space.

and to render structural elements more subtly. This prevents the visual distractions Tufte (Tufte, 1990) calls "chartjunk," which hinder perception and interpretation without adding information content to the visualization. For example, the most important parts of the visualization for determining topic relevance and article access are bright green and yellow. Structural features, such as the category perimeters and the ground plane, are in dim gray.

7.2.2 Additional features

Information retrieval using a full-text index has proved to be an effective information access tool (Salton, 1989). The JAIR information space permits multi-term searches, with the results displayed as lines rising above icons. Two features are worth noting:

- Search terms are kept in a per-session history list. The terms used in the last query are highlighted; terms can be added and removed from a query to quickly compose a new query by selecting and deselecting terms from the list.

- The result lines are broken into color segments, with each segment proportional to the number of occurrences of a term in the query. The line is scaled by the number of terms in the query. This permits comparison of results among successive queries, even if they use different numbers of terms. The segmentation also allows "visually boolean" scanning, by presenting the relative distribution of occurrences among all terms simultaneously.

Since downloading and viewing articles are time-consuming operations, any means of conveying more information about an article's contents beforehand is useful. The information space is augmented with a details-on-demand (Shneiderman, 1996) feature that displays an article's full bibliographic entry and an excerpt of the abstract when the mouse pointer is moved over the corresponding article-icon. This facilitates rapid browsing of a category's contents.

Finally, when accessing an article, all of the document formats associated with the article are presented as choices for downloading. In this way, the user can choose to view the article as HTML in the browser window, or download compressed or uncompressed PostScript versions. Each of these options has tradeoffs in download time and convenience for viewing, saving, or printing. Many articles also have additional files as appendices, which are accessible from the same list.

7.2.3 Platform choice

The ideal implementation environment would be integrated with the existing online information infrastructure in which JAIR is published and require minimal user maintenance or client resources. The Java implementation and associated libraries integrated with popular Web browsers satisfy the first two criteria, but resource requirements are problematic for older systems. Performance degradation occurs primarily in viewpoint manipulation, so that the application is slow, but functionally usable, as the articles are still accessible from the browsable lists.

The information space was implemented and made publicly available on the JAIR Web site.[1]

[1] The space can be viewed at `http://www.ai.mit.edu/projects/infoarch/jair/jair-space.html`.

7.3 Using the Space

This section contains the instructions given to users of the space when they first access it.

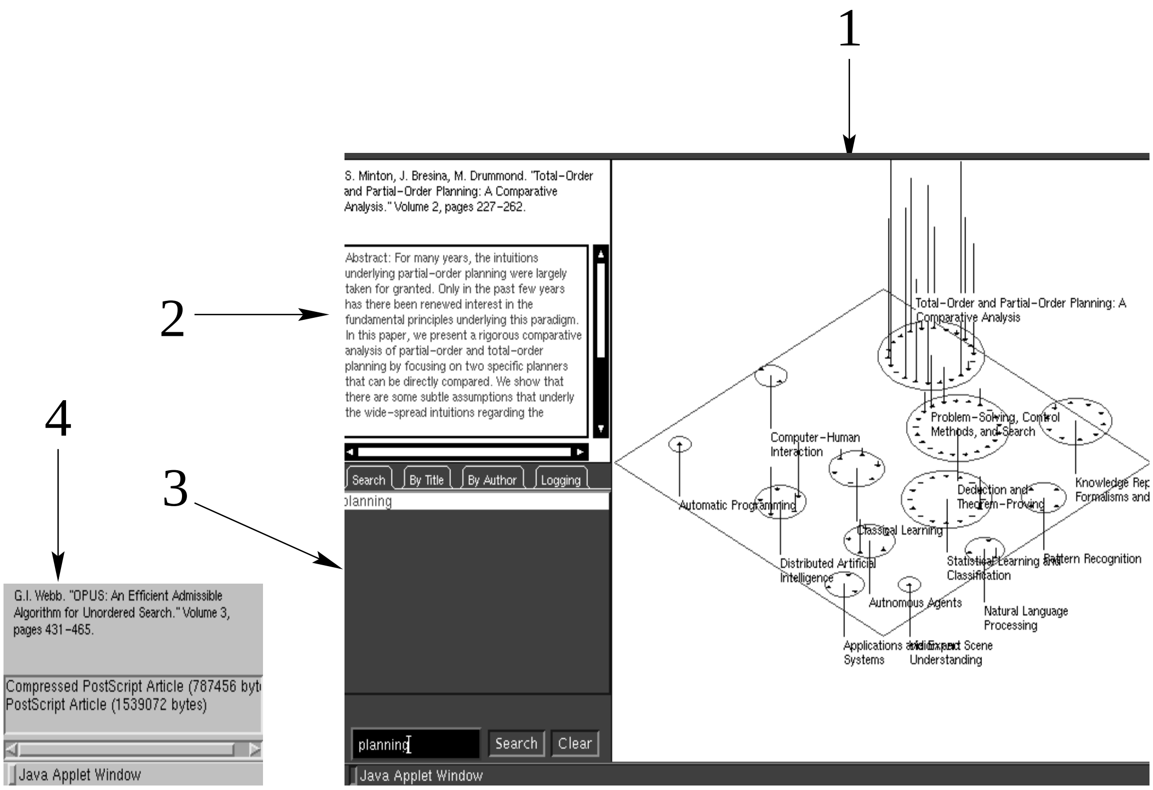


Figure 7-3: Figure accompanying instructions for the JAIR information space.

Referring to Figure 7-3, Panel 1 contains a ground plane situated in a projection of a three-dimensional space. The yellow square icons on the plane represent published articles in the Journal of Artificial Intelligence Research. Each icon is arranged equidistantly about a label describing a category to which the article has been assigned. The area of the circle around each category label is directly proportional to the number of articles assigned to that category. The categories are arranged so that a pair of categories which have more articles that could have been assigned to both are closer together than a pair of categories that have fewer or no such co-assignments.

The user can manipulate his viewpoint into this space by using the mouse to pan, zoom, and rotate it. Passing the pointer over an icon will cause the full bibliographic entry and an excerpt of the abstract to appear in Panel 2. Clicking on an icon will will cause the Access window (4) to appear, which lists all of the files associated with that article (an article may have versions in PostScript or HTML, and the PostScript file may be compressed). Some articles also have additional files on-line as appendices. Double-clicking on a file description in the Access Window will cause it to be loaded into the user's browser; whether that file is displayed in the browser, displayed by an external program, or saved to disk depends on the browser's configuration.

The tabbed panel (3) allows the user to construct full-text queries of the articles, as well as to browse the articles by author and title. Query results are displayed as segmented lines drawn upward from the icons on the ground plane. The length of each segment is proportional to the number of occurences of a term in the query. The bottom most segment of the line corresponds to the first search term, the penultimate the second, and so forth. Search terms are kept in a history list on the search panel, and those used in the last query are highlighted. Terms can be added or removed to construct a new query by selecting and deselecting words from the list.

The articles can also be browsed by scrollable lists sorted by author and title in the same tabbed panel. Double-clicking on an item in these lists will list its files in the Access window for downloading.

7.4 Usability Results and Improvements

After the information space was made available to the public, numerous responses were received by electronic mail. Some suggested usability enhancements to the information space which were later added, including:

- A "clear" button on the query field (Littman, 1997).
- A scroll bar for the abstract texts, so that the entire abstract could be viewed. Previously, only an excerpt of the abstract was visible (Littman, 1997).
- A way of showing the title of the article under the mouse pointer, so that the title appears "in the space" instead of only as part of the bibliographic excerpt in the upper left (Toldo, 1998).
- A way of highlighting an article in the space when it is being browsed in the author or title lists (Toldo, 1998).

As articles are continually published by the Journal, they need to be integrated into the information space. Since the layout was based on the relationships between categories, and not the articles themselves, the articles can be incrementally added to categories without greatly affecting the category layout. The only change is that the radius of each category grows as $1/\sqrt{n}$. If a newly published article were relevant to more than one category, however, then it would be necessary to run the multidimensional scaling algorithm again and rearrange the categories.

Two different navigation styles were also tried for the space. In the first, the viewpoint was static, so that it appeared that the user was manipulating the ground plane that held the articles. The plane could be rotated or zoomed to focus on a smaller part of the space. In this way, the space acts more like a map that is directly manipulated by the user.

The second mode of interaction was one in which the viewpoint was dynamic; it could be panned, zoomed, and rotated, giving the impression that the user was moving through the space. This style is more navigational, giving the user a sense of having a location and orientation in the space. These two styles can be selected by the user in the "Options" tab.

7.5 Evaluation

The evaluation presented here will focus on two questions we can ask about an information space. The first is how well it supports useful tasks, in this case, search, browsing, and retrieval. The second asks what are the engineering costs of creating and maintaining the environment.

7.5.1 Task support

Documents can be retrieved from the space by two search methods. If the user knows the title or author of a desired article, the article can be retrieved by scrolling the alphabetical title and author indices. If the user knows words likely to appear in articles of interest, he can perform a full-text search and see the distribution of search results on the articles in the space. This illustrates a benefit of using a map to represent an information space; it allows interaction between search and browsing, so that a full-text query or a selection from an index can give the user a starting point for browsing.

Browsing within categories is accomplished by moving the mouse pointer from document icon to document icon and examining the abstract and article title that are displayed in the upper-left hand corner. Since no other user action is required, he can rapidly browse the articles in a category by rotating the mouse pointer around the circle of document icons. This action requires precise mouse movements, and may pose difficulties for some users.

Browsing among categories is done by making a larger move of the mouse pointer from one category circle to another. Ideally, the similarity metric used to arrange the categories should indicate some relationship between the categories, giving this larger move some clear semantics in the space. However, the use of an arrangement in a space of lower dimension than the $n(n-1)/2$ possible relationships between categories creates false positives: categories that are placed close together but that are dissimilar.

Also, many of the inter-category distances are about the same for the larger categories, making fine discriminations about similarity difficult. The category layout is best seen as a rough arrangement that gives some structure to the space, without being a driving criterion for browsing actions.

7.5.2 Usage logs

To get some sense of how users were browsing through the space, usage data was collected for an interval of two weeks after the space was made available to the public. The sequence of articles over which the user passed the mouse pointer and which articles were downloaded was recorded. The sampling was intended simply to obtain examples of user behavior, and not for statistical evaluation.

Three logs showing different kinds of browsing behavior are visualized in Figure 7-4. The browsing path between successive articles is drawn as a line, and a downloaded article is marked with a dot. The user on the left browsed a subset of the categories extensively, and downloaded several articles from them. The middle user covered every category, moving quickly from one to the other. The user on the right browsed primarily within two categories and made only four long-distance moves between categories. The variety of browsing behaviors observed suggests that browsing is driven both by user style and needs and the structure of the space.

Many users browsed only briefly, however. In the sample taken, about 60 percent of the logs showed very brief or no browsing activity.

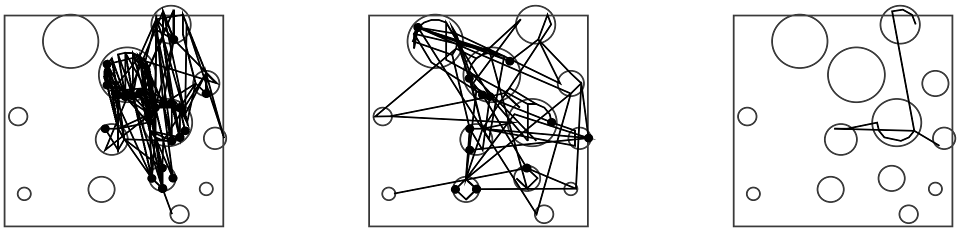


Figure 7-4: Examples of log data for the JAIR information space.

7.5.3 Engineering issues

For any information access environment, issues of design cost and maintenance are of practical importance. The JAIR information space had a high design cost; creating the initial document layout required hand-classifying the articles, noting which had primary and secondary categories, and running the multidimensional scaling algorithm. However, once the initial layout was in place, adding additional articles as they were published only requires classifying them appropriately and adding them to the bibliographic database, without recomputing the initial layout (unless they are classified in more than one category). The JAIR space could be characterized as having a large fixed cost, but a smaller marginal cost.

Another engineering issue is how well the design scales to include more articles. Two dimensions along which the space can scale with more articles and categories are the area occupied by the categories and levels of abstraction in the categorization. However, as these increase, issues of visibility and navigation come to the forefront – can we make every article visible (and accessible), and if not, how do we move between views of sets of articles? Although the space could be adapted to accomodate these requirements, its current presentation was designed for a few hundred articles at most.

The design could generalize to search and browse document collections with a meaningful top-level categorization. When bibliographic information for the documents is available, the list browsing and details-on-demand features can also be used. Full-text searching is also possible when the text of the documents is available.

7.6 What was Learned

Although the JAIR information space was designed before many of the principles described earlier were set, it does exemplify the use of several of them. In particular,

Allow for multiple levels of engagement and understanding. The user can first skim article titles by rapidly browsing with the mouse. For more detail, he can read abstracts and bibliographies in the upper-left window. Finally, he can select and download entire articles relevant to his need.

Create regions of differing visual character. Each category defines an enclosed region in the space, demarcating a collection of articles on a similar subtopic of AI. The user can browse a region and know that all of the articles within are related.

Use survey views (give navigators a vista or map). The space can show all of the articles at once, and lets the user make large moves in the space if desired. The map succintly displays the distribution of articles across the categories, and lets the user maintain

his orientation in the space.
Provide signs at decision points to help wayfinding decisions. Each region has a label identifying the category of the articles it contains below the ground plane, and the title of each article appears above the ground plane. In a survey view, when there are many choices where to go next, signs provide important directions to the user.
Use route data for visualization, dynamism, and debugging. Although users' paths were not visualized in the space, the log data allowed the designers to reconstruct them later. The reconstructed paths demonstrated that users have different browsing strategies in the space.
Provide layers of information on the map. The additional dimension provided by the survey view was used to visualize the results of full-text queries on the articles. This additional layer of information on the map gave users starting points for browsing and retrieval.

Some new principles were discovered from the experience of designing, maintaining, and improving the JAIR information space:

- *Consider the costs of both creating and maintaining the space.* Creating the JAIR information space was time-consuming, requiring the selection of appropriate categories, category layout, and hand-classification of all of the already-published articles. Maintenance, however, can be done in an incremental fashion by adding new articles to the bibliography database as they are published without altering the rest of the visualization.

- *Try to design spaces for reusability.* If a existing design can be readily adapted to other domains, the time needed to construct new visualizations can be reduced. As mentioned above, the JAIR information space can be adapted to other document collections with a small corpora size and a meaningful top-level categorization.

- *Listen to the users.* Using electronic mail as a mechanism for user feedback led to several improvements in the usability of the interface.

- *Support multiple browsing behaviors.* The usage logs show that some users prefer to stay within a local region, and infrequently make moves from one category to another, while others make large moves in the space. In a space designed for browsing, the ability to make both large and small moves quickly as the user's focus changes is essential. The survey view afforded by the JAIR information space fulfilled this need.

Chapter 8

The Course VI Information Space

As a second design exercise, the subject[1] catalog for Course VI (Electrical Engineering and Computer Science) at MIT was arranged in an information space. This was undertaken after the study of museum exhibits, so that its design reflects what was learned from them.

We discuss this space in a similar fashion to the first, by describing the nature of the information, the user tasks to support, the design of the space, and what was learned. In this case, we discover that

- effective maps make for effective immersive spaces;
- inconsistency in applying the organizing principle is tolerable; and
- decision points in an information space should be choices faced by the majority of its navigators.

8.1 Course VI at MIT

The EECS Department offers about 170 subjects each term. Four of the subjects are core subjects (6.001, 6.002, 6.003, and 6.004), which are the first subjects taken by all undergraduates and are a prerequisite for most further classwork. Most of the remainder of the subjects are divided among seven concentrations: Bioelectrical Engineering; Artificial Intelligence; Theory of Computation; Computer Systems; Systems, Communications, and Control; Circuits; and Electromagnetics. Undergraduates begin classwork in a concentration by taking a header subject (6.011, 6.012, 6.013, 6.014, 6.021, 6.022, 6.033, 6.034, or 6.046), which is usually a prerequisite for elective undergraduate and graduate subjects in that concentration. There are also some subjects in the catalog not assigned to a concentration. These include listings for research, teaching, internships, and independent study.

For graduate students, the subject requirements vary by their area in Course VI. An area for a graduate student corresponds roughly to a concentration for an undergraduate, although the match is not precise. The graduate areas include Biolelectrical Engineering; Computer Science; Systems Communication, Control, and Signal Processing; Electronics, Computers, and Systems; Materials and Devices; and Energy and Electromagnetic Systems.

[1]A "subject" at MIT is what most other universities call a "course" or "class."

8.2 The Task

A first consideration is the audience and their needs for accessing the subject listing. Three groups of people that might need the information in the catalog are:

- Those completely unfamiliar with the subject catalog, such as prospective students deciding whether to attend MIT, or a continuing student deciding whether to select Course VI as a degree program.
- Undergraduate students in Course VI selecting subjects for the upcoming term. They have already taken some subjects in Course VI and would like to know what additional subjects are available in their concentration.
- Graduate students in Course VI who are have similar needs to undergraduates, but will not need to take core or header subjects. They may have different subject requirements according to their area.

Of course, faculty, staff, and those outside MIT also access the catalog for a variety of reasons, but those three situations represent typical examples of use. For Course VI students, the task is subject selection, while prosepctive students would like a broader view of degree programs and subjects. An organizing principle for the space that helps these users accomplish their information-seeking tasks would meet their information needs.

8.3 Design

The need for students to select subjects at the beginning of each term suggests an organizing principle for the space. At that time, a student references the catalog, chooses subjects, completes them, and moves one term closer to graduation. Subject selection becomes one step forward in a path that begins when the student enrolls at MIT, and ends when the student graduates with a degree and pursues career options. This kind of path is a *spatial timeline* through the curriculum, corresponding to the sequence of subjects chosen by a student during his academic career. This organizing principle for the space is "provide paths to a degree through the subjects in Course VI."

The difficulty with presenting all the possible sequences of subjects that lead to graduation is that there are many that fulfill the requirements of a degree program and the prerequisites of the individual subjects. Students have great flexibility in choosing the order of electives after prerequisites are completed, and so a space that tries to present all paths violates a principle stated earlier: *don't give the user too many choices in navigation.* An early design for the space, which presents the paths that are possible according to concentration and subject prerequisites, is in Figure 8-1. Beginning from the core subjects in the center, the student can move past a header subject into a concentration represented by a shaded region. Once there, he can only reach advanced subjects by taking paths that pass through their prerequisites.

This early space is problematic in that it assumes that taking a prerequisite limits all remaining selections to only the subjects that require that prerequisite. Its paths are not well-structured since they do not have a meaningful destination; they abruptly stop, dangling in mid-region. And, the subjects not assigned to a concentration are relegated to the right side of the space, outside of a meaningful region.

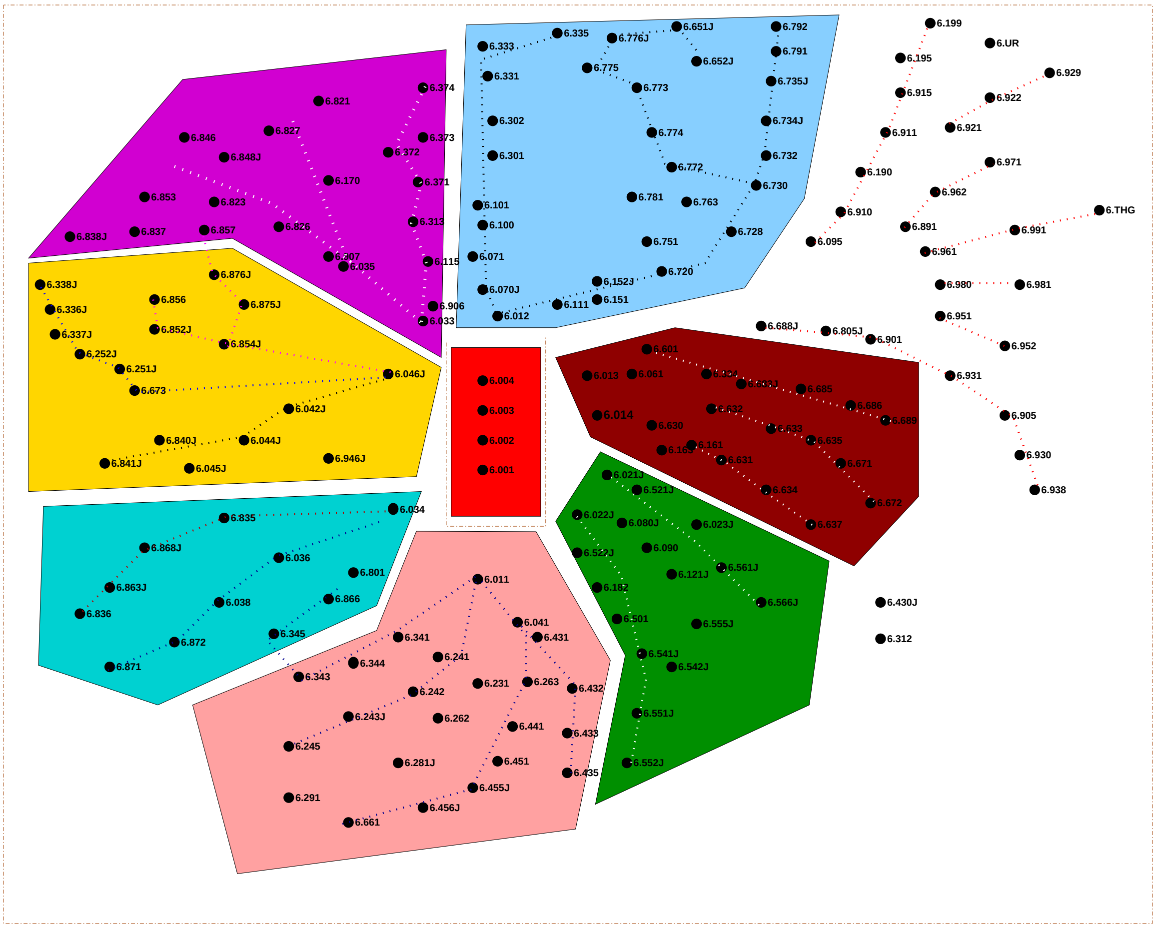


Figure 8-1: Early design for the Course VI space.

To resolve these issues, an explicit path through this space should represent the common, rather than individual, choices that students face in selecting subjects in Course VI. A sketch of those common choices are,

1. Beginning by choosing MIT for undergraduate or graduate education.

2. Choosing Course VI as a major.

3. For undergraduate students:

   (a) Choosing a degree program (Bachelor's of Electrical Science and Engineering, Bachelor's of Computer Science and Engineering, or VI-3, which permits a broad selection of subjects).
   (b) Taking core subjects.
   (c) Choosing a concentration by taking the header for that concentration, then taking undergraduate and graduate electives to meet its requirements.
   (d) Finishing with an undergraduate thesis, receiving a degree, and continuing education or searching for career opportunities.

4. For graduate students:

   (a) Choosing a degree program (Master of Science, Doctoral, or Master of Engineering).
   (b) Choosing an area within Course VI.
   (c) Selecting graduate-level subjects to fulfill the area's requirements.
   (d) Finishing with a thesis, receiving a degree, and beginning the search for career opportunities after graduation.

These common experiences include two major decision points for Course VI students: whether the student is entering as a graduate or undergraduate, and the concentration or area in which his education will focus. The paths these allow are summarized in the diagram in Figure 8-2.

The introductory sections of the space, labeled "MIT" and "Course VI," provide information to students who are considering attending MIT, or choosing Course VI as a major The student can then choose the graduate path or the undergraduate path, according to their educational level entering MIT. The graduate path leads to a graduate lobby, which provides information on graduate degrees and the subject requirements of the graduate areas. The undergraduate path leads past core subjects and math prerequisites to an undergraduate lobby, which has information on undergraduate programs and degrees, and the requirements of the different concentrations.

The purpose of these lobbies is to keep with the principle that states *provide signs at decision points to help wayfinding decisions.* They allow the student to make an informed choice of concentration at that decision point, and informed subject selections once inside a concentration.

The space then branches out into the concentrations, where the subject listings for header and elective subjects are situated. The dotted line through these areas indicates that the navigator should be free to move among these areas, reflecting the fact that the choice

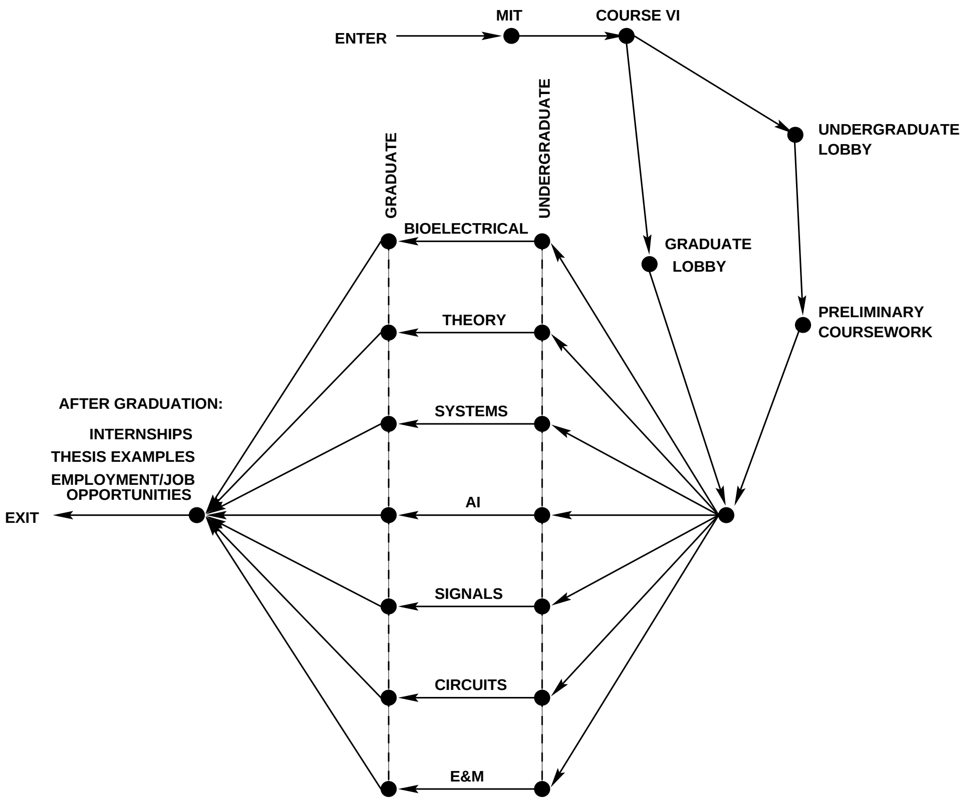


Figure 8-2: Conceptual layout of the Course VI information space.

of one concentration does not exclude the selection of subjects from other concentrations (and, in fact, the electives overlap in many cases).

The space concludes with an area that has research, teaching, and internship listings, information on job opportunities, and examples of theses whose research relates to each of the concentrations. Now, the path through the space is well-structured, with an introduction, decision points along its length, and a conclusion. Each path through the space represents a possible route to graduation. The student can step onto the path at an appropriate point in his program and browse information to take a next step towards the goal of a degree.

8.3.1 The Script

This high-level description of the space was further elaborated in a script that listed what material would be placed in each part of the space. Material for parts of the space other than the subject listings was obtained by linking to on-line documents already available from MIT, the Department, or student groups.

There are between thirteen and twenty-eight subjects that are headers or electives in each concentration. Some way of subdividing them to provide for multiple levels of engagement was necessary; simply listing them all would give the user too much to browse through at once. Therefore, the subjects were placed into groups of up to seven subjects based on subtopic areas within each concentration.

An additional issue was where to place subjects not associated with a concentration. These subjects included individual study, engineering management, and intellectual property. These were placed in a separate part of the space, labeled "Other Topics."

8.3.2 The layout

To transform the script into an actual space, imageable environmental features – landmarks, paths, and regions – were associated with elements of the space:

- Each node in the diagram in Figure 8-2 became a *region* with a distinct visual character.
- The header subject(s) for a concentration became *landmarks*, associated with the region corresponding to that concentration.
- The *paths* through the space connected the regions together in the manner already described.

8.4 The Course VI Information Map

The first product of this design is an information map of Course VI, illustrated in Figure 8-3[2].

The user is first presented with a window that explains the organizing principle of the map and its contents. The user can then click on each text label in the map to obtain more information about what it describes. For subject numbers, this is a listing from the on-line catalog which includes the subject's title, instructor, description, and so forth. Note that the subjects in a group, and the groups themselves, are not arranged in a particular order;

[2]The map is available at `http://www.ai.mit.edu/projects/infoarch/course-VI/course-VI-map.html`

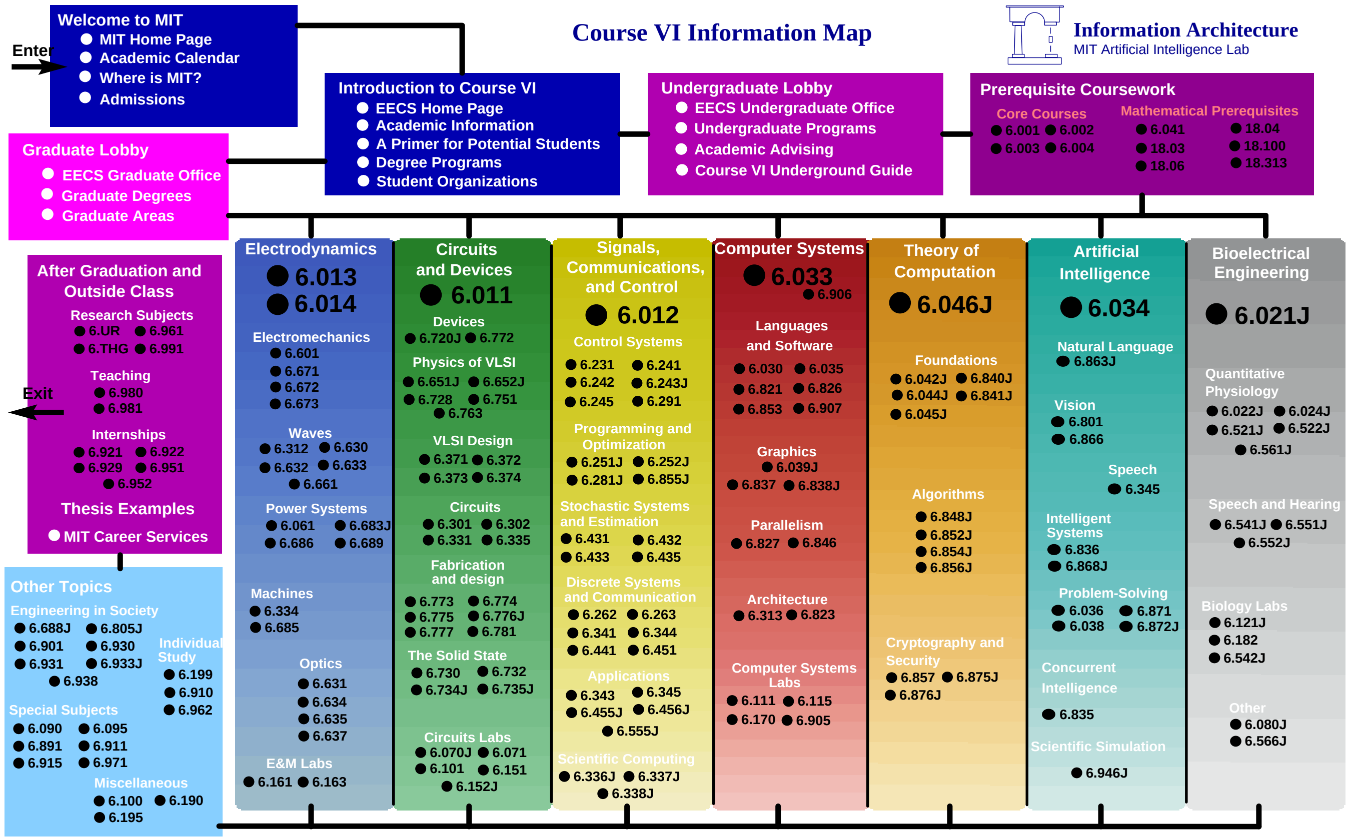


Figure 8-3: The Course VI information map

the many possible routes through a concentration suggest that user choice should be the driving criterion when inside a region. The regions for each concentration are shaded from darker at the top to lighter at the bottom, giving that portion of the path a directional gradient.

For groups of subjects, such as "Speech and Hearing" under Biomedical Engineering, the additional information provided is a list of the subjects' titles. The main title of each region is linked to a description of that region's contents. Labels with white bullets are linked to external documents, which are viewed in a separate window.

The advantage of the map is that it makes the entire catalog one mouse click away, making navigation in this sense easy. Users can move instantly from one concentration or group to another to browse subject listings, while viewing information on degree programs and requirements in another window.

The disadvantage is that users can move instantly from one location to another, meaning that navigation can be difficult. To locate the next desirable item of information, the user must combine his knowledge of the organizing principle of the space while scanning the text labels for words relating to his information need. To one unfamiliar with the subject numbers of Course VI, the only meaningful text available is the titles of the subject groups. And, if the words describing the groups cannot be related to his need, then information-seeking will be difficult.

8.5 The Course VI Information Space

An alternative to the information map is an immersive information space developed around the same script. The basic arrangement of paths and regions suggests an analogous immersive space, as seen in Figure 8-4. The organization of the material in the space is summarized in Figure 8-5.

The visitor enters on the upper left, and passes through the first two sections of the space corresponding to the "Welcome to MIT" and "Introduction to Course VI" regions on the information map. Two routes, one passing through a graduate lobby and another through the undergraduate lobby, lead to a main hallway on the right. From this hallway, each concentration leads off to the left through a long corridor. A break in the middle of the corridor allows circulation from concentration to concentration.

At the head of each concentration corridor is a the landmark header subject for that concentration. The sight line down each corridor leads to a wienie of a thesis example situated at the end. Along the corridor, the titles and numbers of the subjects are arranged along the wall in under the same groups as in the information map. The title of the group above the subjects provides a way for the user to assess the relevance of those subjects before moving to the next group.

Signs are placed at decision points in the space (see Figure 8-6). In this space, there are four main decision points. The first is where the undergraduate lobby branches off from the graduate lobby. Here, a sign is placed showing the direction to either lobby. The second is where the user chooses a concentration corridor after leaving the lobbies. Here, the wall leading into the corridor is labeled with the title of the concentration. The third is where the corridors are broken to allow circulation between them. The walls here are labeled in a similar fashion, but in both directions. Finally, as the user leaves the corridor signs labeled "Exhibit Continues" direct the user to the final sections of the space.

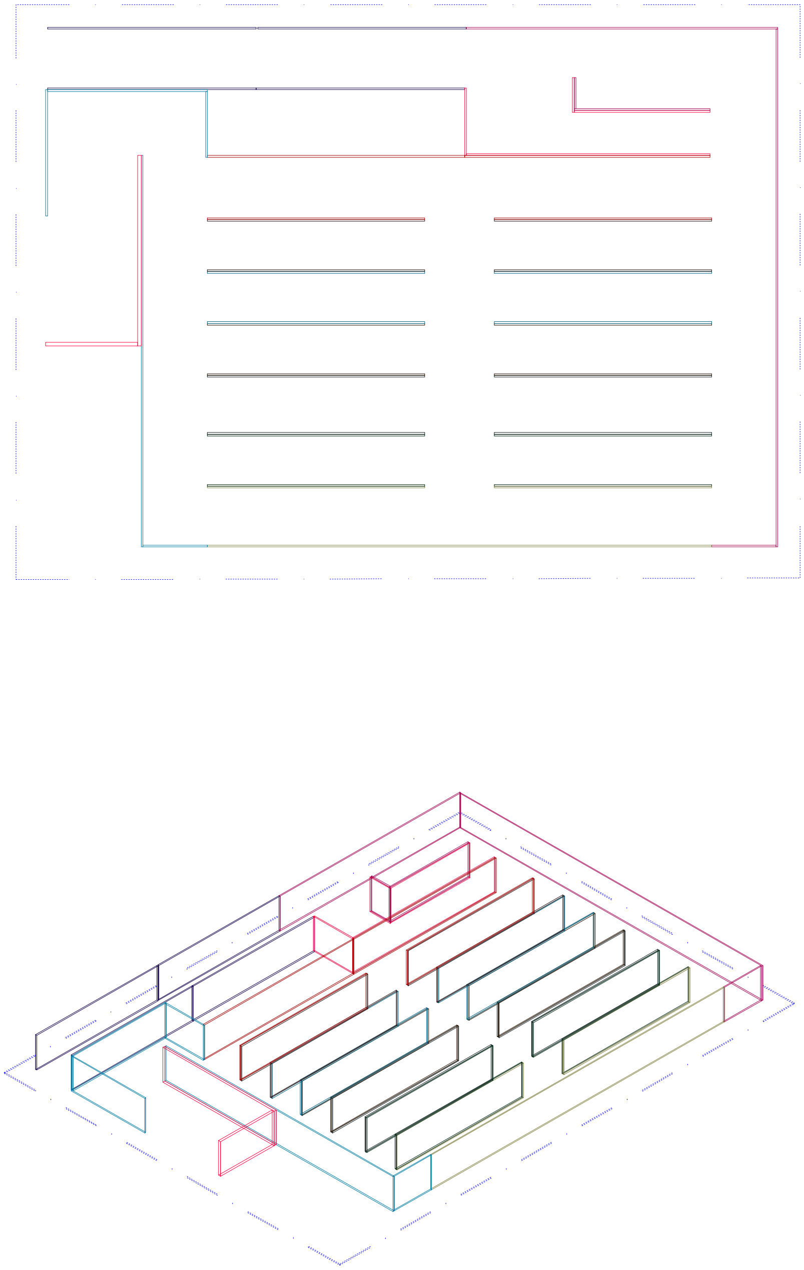


Figure 8-4: An immersive Course VI information space, plan and isometric views.

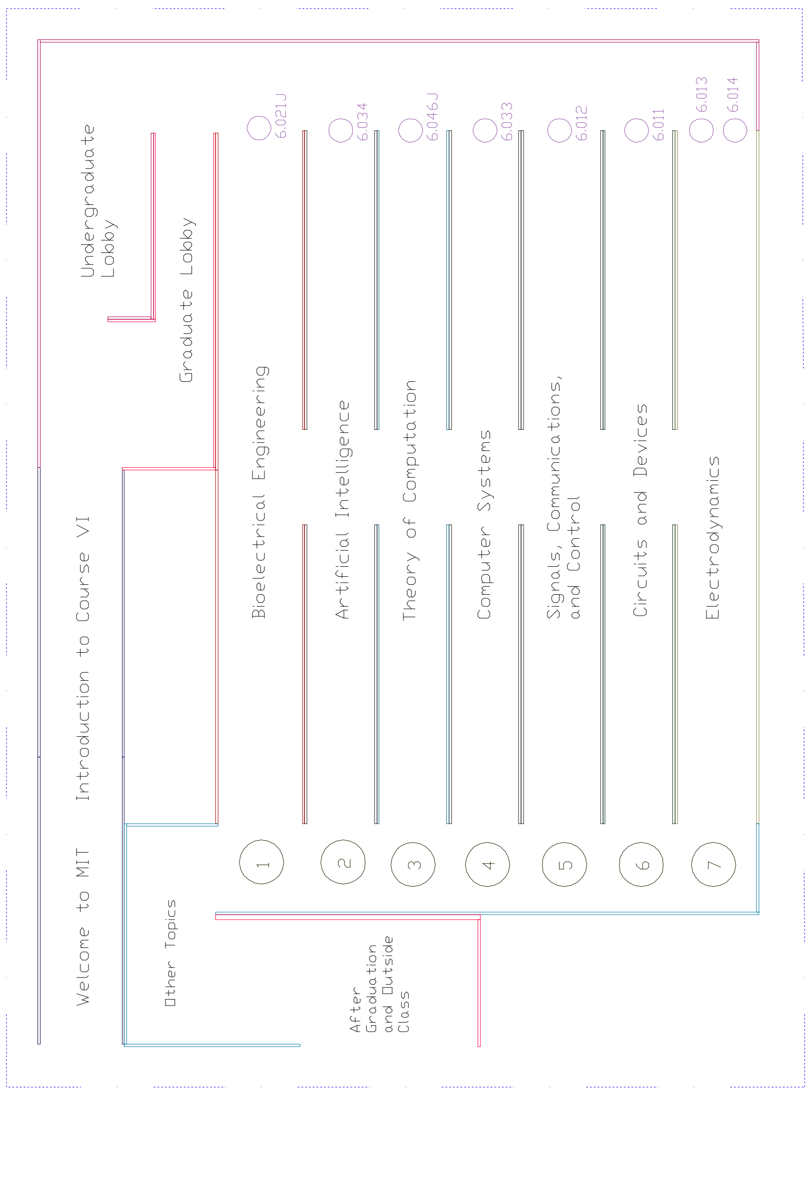


Figure 8-5: Main features of the Course VI information space.

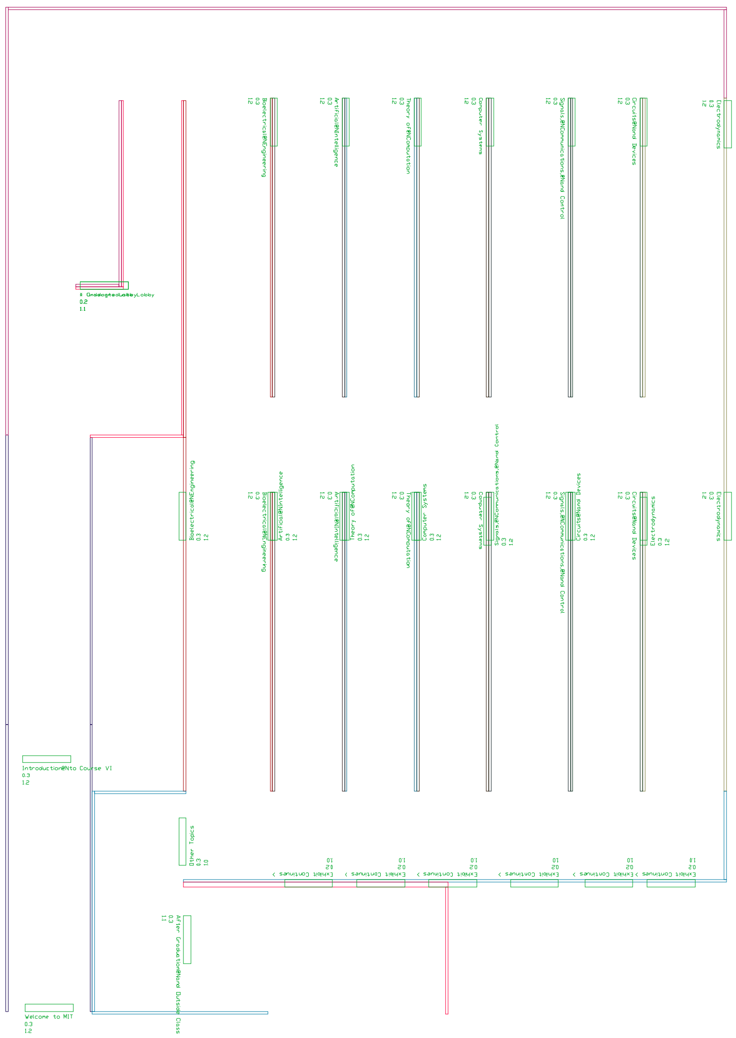


Figure 8-6: Signs in the Course VI information space.

The space was implemented in VRML and made available to the public[3]. The user can navigate through the space and click on any text label in the space and find out more information about what it describes. In addition, a "you-are-here" map on the right-hand side of the window shows the user's current location and orientation in the space with respect to walls nearby 8-7.

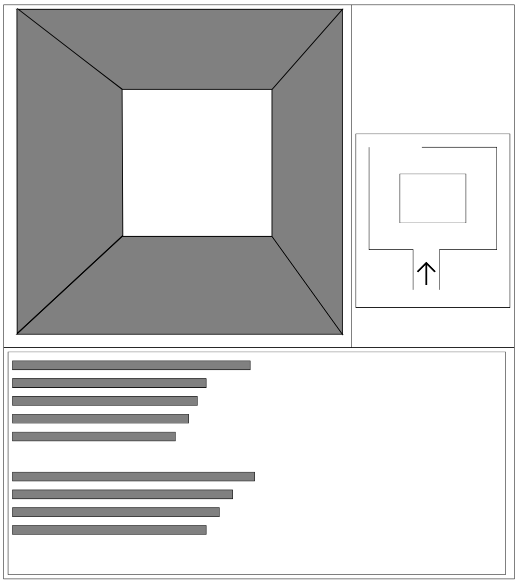


Figure 8-7: Interface to the Course VI information space.

8.6 What was Learned

The design of the Course VI space was guided by a number of principles discussed earlier. The first was a principle for effective communication: *use a constantly evolving attribute of the material to sequence it along a path.* When a student makes progress along a path in the Course VI space, he is moving closer to the goal of graduation. Also, movement from one region to the next indicates that a period of time has passed in the student's education. Two attributes evolve together on a path in this space: progress toward a degree, and the elapsed time in the student's career.

Once that commitment was in place, the arrangement of the basic environmental features proceeded according to design principles for wayfinding. The header subjects serve as landmarks in the space, and regions delimit related subjects or other information. Paths are well-structured by having a common beginning and end, and are marked by progress from region to region. The information map acts as a survey view of the space, which can be referred to before or during immersive navigation, or used separately.

In the immersive space, sight lines allow views from the header subject to the wienie of a thesis in each concentration corridor. Signs are distributed throughout the space to

[3]The space can be viewed at
`http://www.ai.mit.edu/projects/infoarch/course-VI/course-VI-space.html`

guide the user at decision points. The "you-are-here" map on the screen also helps the user wayfind in immersion.

Three more principles were discovered by the design of an information map and an information space for Course VI:

- *Effective maps make for effective immersive spaces.* By finalizing the organization of the space as a map first, it made concrete decisions about the arrangement of its basic elements: paths, regions and landmarks. Maps clarify the conceptual organization of the space before the challenges of an added dimension are faced. It also allowed "mental walkthroughs" of the immersive experience before the immersive space was built.

- *Inconsistency in applying the organizing principle is tolerable, if explained.* If the inconsistency does not affect the user's ability to perform the task. For example, on the information map every path passes through the region titled "Other Topics," although those subjects are not required for graduation like those under "Prerequisite Coursework." In this case, the labels of the regions help to disambiguate a true application of the organizing principle from the need to put unclassified subjects somewhere in the space. While exhibit developers may have the freedom to remove superfluous artifacts from an exhibit, in an information space all necessary material must be included.

- *The decision points in the space should be choices faced by the majority of users.* Reducing the number of decision points is important for creating a coherently structured space. The original Course VI map had too many decision points, and most of them were irrelevant to the educational choices facing an individual student. The revised map restricted the decision points to those that were educational choices faced by all of the audience. The principle this suggests is that decision points in an information space should be choices faced by the majority of its navigators. Or, the road rarely taken is not worth building.

Of course, many improvements to the information space are possible, especially by using the computational nature of the implementation medium. Closely linking the space with the on-line registration system at MIT could allow the user to visualize his current registration, which subjects were needed to graduate in his program, and what subjects are available this term given his time schedule and prerequisites already taken. The listings could also be indexed by instructor, time, the full text of their descriptions, and so forth, and results of queries on those fields visualized on the map or in the space. These capabilities would help alleviate the vocabulary problem by giving the user more ways to locate subjects of interest.

By organizing the space around a user's educational choices and goals through his curriculum, he can place himself at a point in the space and acquire information needed to make subject selection decisions. In this way it meets the information needs of the three individuals listed earlier: the prospective student, who browses the material at the start of the space and the prominent header subjects; the undergraduate, who needs to complete core subjects and math prerequisites before moving into a concentration; and the graduate student, who dives directly into the subject catalog. All these paths end by finishing with a degree and exiting the space (and MIT).

Chapter 9

Conclusion

Taking a step back and reviewing all of the principles discussed so far, we can see how they combine to provide a set of conceptual tools for designing navigable information spaces (Table 9.1).

They seem diverse in intent and scope, but together provide a set of preliminary guidelines to design for information navigation. They are best-suited for spaces that communicate by providing a meaningful path through the content of the space. A space that lets the navigator move as quickly as possible to information of interest would have a different character, and require a different set of design principles. Put another way, a library is organized very differently than an educational exhibit. Even so, some of the principles would still apply in a space designed for efficient searching, where there are many navigation choices to make and design for effective wayfinding becomes paramount.

9.1 Related work

The field of information visualization seeks to graphically depict existing document structure. Relevant to this thesis are visualizations that employ a spatial metaphor, or interaction based explicitly on navigation. The Galaxy of News system constructs a three-dimensional information space of words from news stories that users can fly through (Rennison, 1994). The VIBE system places document icons in two dimensions based on term-vector similarity to pre-stored queries (Olsen et al., 1993). The Harmony VRWeb browser embeds hyperlinks into a three-dimensional model of the city of Graz, Austria (Andrews, 1995). Xiong is developing a system to transform Web sites into navigable, immersive environments that support social interaction among browsers (Xiong, 1997). Cone trees, three-dimensional visualizations of tree structure (Robertson et al., 1991), have been used for Web sites (Carrière and Kazman, 1995), a large medical article classification scheme (Hearst and Karadi, 1997), and other hierarchies. Information visualization focuses on presenting existing structures spatially, as opposed to designing a space that incorporates a novel organizing principle. For a survey of recent work in information visualization, see (Card, 1996).

Some researchers have designed information spaces to explicitly represent and support cognitive mapping. Trajectory mapping (TM) (Richards and Koenderink, 1994) is a technique that combines subjects' associations among subsets of information items to construct a path through them. This technique was applied to visualize an information space of tourist attractions in Boston (Lokuge et al., 1996). Other work has focused on making an existing information landscape more imageable (Chalmers et al., 1996; Chalmers, 1993).

Design Principles for Effective Communication
Organize the presentation about a hierarchy of messages.
Use a constantly evolving attribute of the material to sequence it along a path.
Order the concepts so that earlier concepts facilitate the understanding of later concepts.
Provide a memorable introduction and conclusion.
Use multiple representations and media to communicate.
Allow for multiple levels of engagement and understanding.
Use an "environmental look" to provide thematic context.

Design Principles for Wayfinding
Create an identity at each location, different from all others.
Use landmarks to provide orientation cues and memorable locations.
Create well-structured paths.
Create regions of differing visual character.
Don't give the user too many choices in navigation.
Use survey views (give navigators a vista or map).
Provide signs at decision points to help wayfinding decisions.
Use sight lines to show what's ahead.

Design Principles for a Computational Medium
Use an appropriate mode of presentation.
Allow for different velocities of movement through the space.
Use route data for visualization, dynamism, and debugging.
Use the full range of media available in a computational environment.
When in immersion, provide a "you-are-here" map.
Personalize the space.
Use the space as an evolving repository of knowledge.
Provide layers of information on the map.

Design Principles from the JAIR information space
Consider the costs of both creating and maintaining the space.
Try to design spaces for reusability.
Listen to the users.
Support multiple browsing behaviors.

Design Principles from the Course VI information space
Effective maps make for effective immersive spaces.
The decision points in the space should be choices faced by the majority of users.
Inconsistent organization is tolerable, if explained.

Table 9.1: Summary of design principles.

In this work, an existing visualization of research articles was augmented with static imageability features such as paths and regions, and dynamic features that enlarge document titles according to user focus.

Furnas describes information navigation in terms of effective view traversibility (EVT) and effective view navigability (EVN) (Furnas, 1997). An information space that is effectively view traversible maintains relatively short path lengths as the number of nodes or views grows. For example, a hierarchy is efficiently view-traversible because the longest path in a hierarchy with branching factor b remains $O(log_b n)$ as the number of nodes n increases.

Efficient view navigability requires that the navigator can find his way to a goal in the space. To do so, he examines the local "residue" of the goal in the current view – information that would lead him to move closer to it. An example of such residue is the label of a node in a hierarchical classification, which indicates an attribute shared by all of the items in its subtree. The principle that states "provide signs at decision points" can be reinterpreted as ensuring sufficient local residue to make the information space effectively view navigable.

Hypertext researchers have argued for more effective spatial represention of hypertext for some time (Dieberger, 1997; Masuda et al., 1994). Kaplan and Moulthrop argue that attempts to map the n-dimensional "semantic space" of a hypertext onto two- or three-dimensional representations will always be imperfect (Kaplan and Moulthrop, 1994). Hypertext representations carry over the underlying link-node structure of the hypertext model and its visibility and mappability constraints.

Finally, Zellweger introduces the notion of scripted documents, which explicitly support authored paths in a hypermedia system (Zellweger, 1990). The path scripts could specify sequential paths, in which the viewer sees a preset sequence of documents; branching paths, in which the viewer could make a choice between one of two paths; and conditional paths, in which the next document presented is conditional on some author-specified test.

9.2 Process

One topic that has not been addressed in depth or generality is process, a procedure for taking a collection of information and applying these principles to generate an information space. The ordering of the presentation of the principles is suggestive of the notion that conceptual organization should precede spatial organization, and the computational medium used to enhance the space whenever possible. In a given situation, though, the principles can interact nonlinearly, with the application of one impinging on the requirements of another and forcing tradeoffs.

Those considerations granted and using what we have learned from the two spaces described here, we can make a brief sketch of a process for designing spaces that communicate:

1. Consider the audience and the nature of their information needs.

2. Decide on concepts, messages, or a common, evolving attribute. Consider the introduction and conclusion.

3. Decide on attributes of the space, such as landmarks, paths, and regions that correspond to the organization decided in step 1. Consider the environmental look of the space, and how it can vary from region to region.

4. Place those attributes spatially according to how the principle in step 1 organizes the information.

5. Verify that the space is navigable: *Does the navigator have the information needed, such as signs, sight lines, and maps, to make wayfinding decisions? Does the navigator have "wienies" to pull him forward through the space?*

6. Choose the mode of presentation (map-like or immersive) and enhance the space with the affordances of a computational medium.

A process will also have to account for the fact that information is inherently dynamic. Its veracity and relevance to an audience changes over time. This is reflected in the need to augment the JAIR information space with articles as they are published, and to add and remove subject listings from the Course VI information space for each term. Any implementation of an information space will need to address issues of dynamism and maintenance.

We would also like to have tools that can automate the application of any of the principles presented above. A system that can take a database or hypertext and delineate useful landmarks, paths and regions, or trace out conceptual dependencies (even in an approximate fashion) would be of great use in sketching out an information space. The capabilities of such a tool would depend crucially on how well-structured and annotated the original source of information is, however.

The greatest benefit, though, could come from capturing an information space as a solution to a design problem in a way that could be applied to similar problems. Perhaps a relatively small number of effective clichés of spatial organization, for communication, search, or another task, are all that is needed to account for a large number of these solutions. Such clichés are exemplified by libraries, bookstores, and trade-show exhibits, in addition to the educational exhibits. In this case, another thrust of inquiry would be to identify and generalize these clichés as sources of knowledge for design by analogy. Process, then, could become the application and specialization of the appropriate cliché to the information collection at hand.

9.3 Moving On

We began by presenting information-seeking as navigation through an information space, and by asking how we can structure that space to facilitate a particular information-seeking task. This motivated the study of educational museum exhibits, exemplars of physical information spaces that communicate effectively to their visitors by allowing them to navigate through knowledge. The result is a collection of principles, which are guidelines for taking a collection of information, organizing it spatially, and presenting it to an audience.

Two questions about those principles that can be answered by the experience of designing more spaces are,

- *What principles are we missing?* Both information spaces designed as part of this thesis suggested more principles to add to the list. The list will probably never be complete, and as it grows we will need better ways of dividing them up by their requirements and their impact so that the designer can better choose which are relevant to the problem at hand.

- *When does a principle not work?* Negative results are especially useful because they indicate when the assumptions behind the principle are underspecified, and it was used in an inapplicable situation.

To make our list of principles more complete and effective, we can also look to other physical spatial organizations of information. For example, libraries can provide a rich source of knowledge about building spaces for both browsing and retrieval. Study of the process of building an effective library classification system for subject browsing could provide principles for spaces that are used more like libraries.

And finally, we can evaluate how the spaces are used, and whether the users can solve useful tasks in them. In a space that communicates, we can test what knowledge the user has gained by navigating through the space, as well as noting any wayfinding difficulties the user experiences in the space.

All of these steps take us closer toward a collection of design principles that can help users navigate through the increasing volume of information available in electronic form. It is hoped that a eventually a sufficient set of principles can be found that will bring clarity and insight to a broad conceptual framework for organizing information for navigability.

Appendix A

Catalog of the Lenardo Exhibit

This appendix lists all of the items used in the Leonardo exhibit at the Museum of Science, in Boston, Massachusetts. The icon legend and numbering system are used in the plan map of the exhibit, found in Figures 3-2, 3-3, and 3-4.

The catalog is divided first into the major areas of the exhibit, and then into the individual galleries and subareas, also shown in the plan map. The abbreviation "L," used throughout the catalog descriptions, always refers to Leonardo, the man.

Original manuscripts and artifacts are denoted by "(original)," with all other items being reproductions. The titles of artworks and drawings are in italics, followed by the year they were completed. If the work is not by Leonardo, the artist(s) are listed, and for larger paintings and models, the approximate dimensions are noted.

For panels (wall-mounted labels) denoted by "Panel:," an illustrative excerpt of the label text or a brief description of its topics are provided.

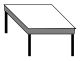
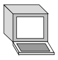
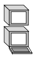
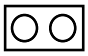
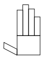
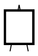
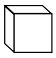
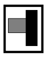
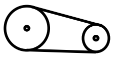
	Desk with items on top
	Manuscript (bound or unbound)
	Multimedia Station (no monitor overhead)
	Multimedia Station (monitor overhead)
	Video loop
	Hands-on activity
	Informative panel
	Informative easel
	Drawing (chalk, ink), subjects: C – caricature; S – study; D – mechanical design; A – anatomy; W – deluge; P – portrait; O – other
	Statue
	Painting by Leonardo
	Painting not by Leonardo
	Banner
	Working invention
	Exhibit map

Table A.1: *Leonardo* icon legend

Who Was Leonardo?

Introduction to the Renaissance

1 Desk with manuscript samples, notebook, implements; information on lost notebooks

2 Panels: The early Renaissance; period world map, Nuremburg Chronicle, early landscape by L., birth, stories of early evidence of artistic ability; historical context: Giotto's lifelike wall paintings, capture of Constantinople, printing press, world exploration

3 Panels: "Scientist," "Inventor," "Artist"

4 Manuscript B; notebook *Treatise on Painting* printed 130 years after death, first publication of any L. work (original)

5 Speculation on why he wrote backwards (left-handed), activity writing while looking in mirror

Florence in 1470

6 *Caricature of a Laughing Man*, 1495

7 *Head of a Man (Three Poses)*, 1502

8 *Caricature of an Old Woman*, 1495

9 *Profile of a Man*, 1495

10 *Caricature: An Old Man*, 1490

11 *Head of a Young Woman*, 1483

12 *Head of a Young Woman*, 1475

13 *Old Man and Young Man*, 1495

14 Panels: L. leaves Vinci for Florence; Florence as international character, art center, the Medicis; first job as an apprentice in an art studio

The Natural Artist

Art Studio I

15 *Study of a Lily*, 1475
16 *Study of a Hand, with Notes*, 1504
17 *Madonna with Child and Cat*, 1480
18 Easel: tutelage under Verocchio; techniques: perspective, *chiaoscuro*, *sfumato*
19 Panel: note on reproductions, "sorry, no originals"
20 Perspective figures, both 1510
21 Panel: perspective
22 Architectural study for *The Adoration of the Magi*, perspective construction
23 Activity: table for drawing in perspective ("Leonardo's Window")
24 Drapery studies, all 1475
25 Panel: *chiaoscuro*
26 Activity: draped manequin, outline figures to draw on
27 Panel: *sfumato*
28 Gothenburg *Mona Lisa*
29 Panel: *sfumato*

Art Studio II

30 Banner: "The Natural Artist"
31 Easel, "The Natural Artist:" Verocchio tutlage; acceptance into Florentine painter's guild from age 20 to 25
32 *Study of a Horseman*, 1478
33 *Study of a Horse's Hind Legs*, 1508
34 Panel: "A magnificent mural is gone forever..." (*Battle of Anghiari*)
35 Studies of soldiers, women, and horseman, 1504
36 Panel: "L. had bad luck with his two major frescoes..."
37 Panel: "Lots of churches had Last Suppers but this one was completely original..."
38 Sketch of L.'s *Last Supper*, by Figino, 1540 (original)
39 Video loop on paintings
40 Panel: Verocchio's workshop
41 Mural of Verocchio's workshop with small panels explaining activities depicted
42 *Cherub with a Dolphin*, attributed to L.
43 Panel: "L. painted what clients hired him to paint (but he didn't always finish)"
44 *Child with Lamb*, 1500; *Study for the Nativity*, 1495
45 Easel and figure: The Early Years, 1452-82
46 Desk with pigments, scrolls, etc.

The Art Gallery

47 Easel: "His unique style attracted students and influenced others..."
48 *Monna Wanna*, Salai, 1515
49 *The Kissing Infants* by L.'s workshop, 1510-15
50 Hutch: "Three bold new techniques made this painting look real:" drawing in perspective, light and shadow, and distance (illustrated on *The Annunciation*)
51 *Five Grotesque Heads*, *Studies of Heads*, *Caricature*, *Caricature*, by Wenzel Hollar, 1645
52 *Pietà*, by Bramantino, 1515 (original; 5.5 by 7)
53 Caricatures, *Head of a Horse*, by Melzi, 1550 (original)
54 Panel: "Who painted it? When? Where?"
55 *The Virgin and Child with Infant St. John the Baptist*, attrib. Michaelangelo, 1500 (original)
56 *St. Catherine and St. Jerome*, attrib. Raphael, 1497 (original)
57 *Young John the Baptist*, by Raphael's workshop, 1517 (original; 6 ft. by 6 ft.)
58 *Young John the Baptist*, by Raphael's workshop, 1517 (original; 3 ft. by 4 ft.)
69 *The Virgin of the Rocks*, by Bramantino, 1500-50 (original; 2 ft. by 4 ft.)
60a Panel: "Compare these two paintings..."
60b *The Virgin of the Rocks*, 1510 (original; 5 ft. by 6 ft.)
61 *The Angel in the Flesh*, 1513-1517 (original), mounted in clear plastic so that the inscription on back can be seen
62 *Mother and Child*, 1483 (original)
63 *The Holy Family*, 1530 (original; 3.5 ft. by 4 ft.)
64 *Bust of Christ as a Child*, attrib. L., 1495 (original)
65 *The Wax Horse*, attrib. L., early 1500s (original)
66 *St. Catherine of Alexandria*, by Giampietrino, 1540 (original)
67 *Madonna of the Yarnwinder*, copy of a L. painting (original)
68 *Mary Magdalene*, by Giampietrino, 1515-20 (original)
69 *Madonna del Latte*, copy of a Correggio, 1500s (original)
70 *Praying Abbott*, by Cesare do Sesto, 1507-14 (original)
71 *Horse of the so-called "Opus Praxitelis"*, by Volterra, a follower of Michaelangelo, 1550 (original)
72 *Two Studies of a Blessing Infant Jesus*, by Luini, 1500 (original)
73 *Head of an Old, Bearded Man*, by Perugino, 1500 (original) (mocked by L.)

The Restless Inventor

74 Map: Exhibit plan

War

75 Panel: "He sent out this 'resumé,' hoping for a job as a military engineer"
76 Letter to Duke of Milan, 1482
77 Panel: "He dreamed of a giant horse"
78 Hoof of L.'s horse cast in Pennsylvania
79 Desk under panel with sketches for statue and clay model
80 Panel and figure: 1482-1506: The Middle Years; L. sent to Milan to be a musician; design of huge horse statue
81 Panel: "L. hated war but created deadly weapons"
82 Map of Milan, 1497-1550
83 *Fortress*, 1508
84 *Fortress*, 1505-10
86 Model: Steam cannon (probably built in L.'s lifetime)
87 *Rolling walkway*, 1480
88 *Ladder pusher*, 1480
89 *Machine guns*, 1482, basis for
90 Model: Machine gun
91 *Giant crossbow*, 1485
92 *Stone-thrower*, 1485
93 *War chariots with sickles*, 1485
94 *Gun-firing mechanism*, 1513

Architecture

95 Panel: "From bridges to city plans, L.'s dreams and designs were ahead of his time"
96 Computer kiosk – architecture
97 Codex Trivulzio, 1487
98 *Cathedral dome*, 1487
99 Bound volume: *De Architectura*, written 33 B.C., edition 1512, inspired L. (original)
100 *The royal city Romoratin*, 1517
101 Manuscript A, 1492
102 *City plans*, 1513
103 Panel: "Leonardo studied the arch, one of architecture's building blocks"

Water

104 Panel: "Water flows through L.'s drawings"
105 *Water flow*, 1508
106 *Water flow study and musing old man*, 1513
107, 108 Activity: How obstacles impede water flow
109 *Canal, locks, and weirs*, 1482
110 *Florentine canal map*, 1495
111a *Florentine canal plan*, 1495 (original)
111b *San Cristoforo canal*, 1509
112 Model: Water pump (large; 10 ft. by 10 ft.)
113 *Ivrea canal*, 1495
114 *Naviglio canal notes*, 1508
115 *Design of a water pump*, 1490
116 Codex Forster III, 1493
117 *Water-moving machines*, 1480
118 *Hydraulic machine*, 1490
119 *Turbine wheel*, 1510
120 *Water wheel*, Melzi, 1510
121 *Sketches and notes*, 1497

Machines

122 *Map, geometric, and mechanical studies*, 1500
123 *Perpetual motion machine*, 1495
124, 125 *Two gear models*, 1480
126 Panel: "From wind meters to the first automobile"
127 Model: Wind meter
128 Model: Hygrometer
129 Codex Forster I, 1505
130 *Oil lamp with reflecting mirror*, 1505 (original)
131 *Optical lens grinders*, 1505

Clocks

132 Panel: "By understanding clocks, L. hoped to understand all machines"
133 *Clock movement*, 1495-98
134 Model: Lunar clock after a sketch by L.
135 Model: Clock after a sketch by L., 1500?
136 Model: Clock after diGiorgio, 1475-80
137 Model: Clock after Galileo Gallei
138 *Time instrument*, 1495-97
139 *Spring studies*, 1495-98
140 *Spring drive mechanism*, 1495-98

Flight

141 Panel: "L. was the first scientist of flight – his ideas pushed the edge"
142 Manuscript K, 1507
143 *Human flight*, 1495
144 *Birds in flight*, 1507
145 Model: Airplane propulsion system
146 Manuscript E, 1513
147a Panel: Glider reproduction
147b Model: Glider reproduction
148 Map: Exhibit plan
149 Kiosk
150 Activity: Comparison of L's parachute design with modern parachutes
151, 152 Models: Parachutes
153 Workstations

Machines

154 *Textile spinning machine*, 1495
155 Manuscript: *Divinae Proportionae*, L illustrated for a Pacoli, 1509
156 Model: Wire strength tester
157 Model: Roller bearings
158 Video loop on inventions
159 Kiosks

Musical instruments

160 *Musical instruments*, 1493
161 Lira (lute) in the shape of a boar's head

Mid-space activities and models

162 Activity: "Use your arms to fly"
163 Model: Sprial helicopter, 1486
164a Model: Screw cutter
164b Model: Coin stamper, 1504
165 Model: Odometer, 1480
166 Model: Printing press, 1495
167 Model: Hydraulic screw, 1487
168 Model: Circular structure with workstations, kiosks
169 Model: Paddle boat
170 Activity: Falling water
171 Activity: Water pressure I
172 Activity: Water pressure II

Mid-space activities and models (continued)

173 Banner overhead: “The Restless Inventor”
174 *Bridge construction*, 1500
175 *Digging machine*, 1500; underneath letter to Sultan Bazajet proposing to build bridge over Bosporus
176 *Rotary crane*, 1497
177 *Machines for lifting columns and heavy weights*, 1480
178 Activity: Build an arch
179 Activity: Build a bridge
180 Model: Tank, 1485
181 Model: Seige ladder, 1505
182 Model: Two-story bridge, 1487
183 Double-sided panel: “The Restless Inventor,” the Middle Years (1482-1506)

The Solitary Scientist

Anatomy

184 Panel: "L. wanted to know how our bodies worked"
185 *The skull*, 1489
186 *Proportions of the face*, 1490
187 *A bear's paw*, 1493
188 *The head and neck*, 1488
189 *Organs of the female body*, 1507
190 *Muscles and bones of the leg and hip*, 1507
191 *The digestive system*, 1506
192 *The lungs and urinary system*, 1509
193 *Description of human intercourse*, 1510
194 *Embryonic development*, 1510-1513

Deluge Drawings

195 *The Pointing Lady*, 1516
196 *Cloudburst Above a City*, 1516
197 Panel and figure: The Later Years (1507-1519)
198 Desk with sketches
199 *The Great Flood*, 1516
200 *The Great Flood*, 1516
201 *Flood over Fallen Trees*, 1516
202 *Apocalyptic Storm*, 1517
203 Panel: "Later in life, L. thought about the end of the world"
204 Manuscript: Description of the great flood, 1516
205 Double-sided panel; W side: The Solitary Scientist "L. dissected dead bodies ... he never stopped looking, thinking, and experimenting;" E side: "What kind of scientist was L.? Observing, reasoning, and experimenting were all part of doing science." Banner above: "The Solitary Scientist"

Anatomy

206 Panel: "Dissecting dead bodies was the best way to learn about them, but it was a messy business"
207 *The neck and shoulder*, 1510
208 *Human sound production*, 1510
209 *Heart and lung of an ox*, 1513
210 *Studies of the skeleton*, 1510
211 *Studies of the mesentery*, 1510
212 *Muscles of the spine*, 1510
213 Panel: "L. planned to publish an anatomy book"
214 *Study of fetal development*, 1510
215 *Studies of the brain and male genetalia*
216 Activity: Scientist dissecting animal organs
217, 218 Activities: "Explore the human body like L.;" models with removable organs

Leonardo's Legacy

219 Panel: "His last years were spent in France...after he died his genius was forgotten"
220 Panel: L's last studio; "L, growing old and weak, continued to work"
221 Panel: "Scientist"
222 Panel: "Artist"
223 Panel: "Scientist: L lived before modern science, but his methods were scientific"
224 Panel: "L's legacy: Art"
225 Panel: "L's legacy: Science and Invention
226 Panel: Artist I "No other artist is remembered as well"
227 *Monna Wanna*, Ducayer after *Mona Lisa*, 1600
228 Panel: Artist II
229 *300 Are Better Than One*, Warhol, 1963; *LHOOQ*, Duchamp, 1919
230 Panel: Inventor "L dreamed of wonderful machines"
231 Feedback cards, bulletin board with selected responses

Appendix B

Catalog of the JFK Exhibit

This appendix lists all of the items in the JFK exhibit at the John F. Kennedy Library and Museum, in Boston, Massachusetts. The entries in the catalog are referred to in the plan map of the exhibit, shown in Figures 3-6 and 3-7.

The entries are divided into five types. An “L” entry is a text label, an overhead banner, or a wall plaque or sign. An “M” entry is a video monitor with a continuously running video loop. An “O” entry is an object or physical artifact, or an item that does not fit into the other categories. “P” entries are photographs, and “N” entries are free-standing newspaper boxes with period newspapers inside them.

“JFK” refers to John F. Kennedy, Jr., “RFK” refers to Robert Kennedy, and “Jackie” refers to Jacqueline Kennedy Onassis (née Bouvier).

Labels, Banners, and Plaques

L1 The Presidential Debates: 70 million watched
L2 The 1960 Presidential Campaign
L3A Banner: "Detroit is for Kennedy"
L3B Banner: "Indianapolis is for Kennedy"
L4 "A Family Campaign"
L5 "The Margin of Victory"
L6 New Frontiers: tasks JFK had to accomplish between November and Jananuary
L7 The Presidency: legislative initiatives, the Cold War, his popularity, racial tension, and the recession
L8 "Cabinet Room"
L9 The Kennedy Team: both Republicans and Democrats, youthful, intelligent
L10 The State of the World, 1/20/61: the turmoil of the Cold War
L11 Alliance for Progress (improved relations w/Latin America); Food for Peace (humanitarian aid)
L12 "Peace Corps"
L13 Bulletin board with Peace Corps newsletter, posters, map of volunteer locations
L14 The Peace Corps: inspired by University of Michigan campaign stop; Sgt. Shriver appointed head
L15 "Situation Room"
L16 On the Brink: U2 plane; photos of Cuban missile base 10/14/62; naval blockade 10/22; secret negotiations; Soviet withdrawal 10/2
L17 JFK's report to the American people 10/22/62
L18 communication: Kruschev to JFK 10/26/62
L19 communication: Castro to Kruschev 10/26/62
L20 "Space Program"
L21 "The Space Program"
L22 "Ceremonial and State Events"
L23 "Office of the Attorney General"
L24 "RFK and JFK: A Special Relationship"
L25 "The Oval Office"
L26 describes items in Oval Office exhibit
L27 "The Seat of Power:" typical day in JFK's Presidency
L28 "Saving Egyptian Temples"
L29 "Jacqueline Bouvier Kennedy"
L30 "Joseph Kennedy: Patriarch and Mentor"
L31 "A Legacy of Hope"

Continuous-loop Video Monitors

M1	Nixon/Kennedy campaign advertisements
M2	Clips from 1960 Campaign and Debates
M3	Clips from 1960 Campaign and Debates
M4	Clips from 1960 campaign and debates
M5	Clips from September 26, 1960 debate
M6	Clips from September 26, 1960 Debate
M7	Inagural Address, January 20, 1961
M8	clips from press conferences
M9	Peace Corps speech on White House lawn and Peace Corps footage (approx 1 minute)
M10	Cuban Missle Crisis film
M11	JFK announcing space program; launch of John Glenn
M12	interview with RFK
M13	speeches on integration at the University of Alabama (June 11, 1963) and the Nuclear Test Ban Treaty (July 26, 1963)
M14	excerpt of Jackie's White House tour broadcast
M15	Home movies from JFK's youth
M16	Jackie footage
M17	Footage of visit to Ireland
M18	Loop of Walter Cronkite reporting JFK's assassination
M19	Walter Cronkite announcing election results
M20	RFK on Vietnam, Presidential candidacy, Martin Luther King assassination
M21	space program; signing of Civil Rights bill
M22	JFK's influence on President Clinton

Objects and Artifacts

O1	Appliances from 50's/60's; radios; turntable
O2	50's/60's memorabilia
O3	Posters, stickers, and flyers from campaign
O4	Bench: "Kennedy for President"
O5	Memorabilia from 1960 campaign
O6	Table: memorabilia, Anti-Catholic flyers, use of polling in campaign
O7	Walter Cronkite announcing election results
O8	*Newsweek* and *Time* announcing inaguration, an invitation, newspapers, other memorabilia
O9A	Presidential Flag
O9B	United States Flag
O10	Gifts from Emperor of Ethopia, President of Panama, First Lady of Columbia, King Hassan of Morocco, and the Shah and Empress of Iran
O11	Case with scrimshaw gifts
O12	Case with gifts from President of Togo, King Hussein of Jordan, President Maga of Dahomey
O13	Life article on Cabinet
O14	Poster on Cabinet and staff
O15	Newspaper front pages on Laos, Cuba; White House memos on Cuba; speech at Berlin, 6/26/63; Congo
O16	Gifts from Kruschev and the Prime Minister of Great Britian
O17A	Political cartoons from Cold War
O17B	Case with journal entries, poems, photos, newsletters, map of volunteer locations
O18	Space suit; media on John Glenn
O19	Models of Saturn IV rocket and Gemini space capsule; NASA memos, photos, media on Soviet orbiter
O20	Memos and letters of Jackie's request to Basil Rathbone to read speech from Henry V at White House dinner
O21	Dolls and gifts from the Grand Duchess and Prince Jean to Kennedys
O22	letter to M. Webb on paperweight designs from Jackie
O23	Paperweights designed by D. Webb featuring precious American minerals used as state gifts
O24	Program from state dinner: "Poetry and Music from Elizabethan Times"
O25	Table arrangement diagram; dinner menu; toasts
O26	Silk gown Jackie wore to dinner
O27	Painting of a ship RFK served on: USS Joseph P. Kennedy
O28	Gifts from heads of state
O29	"New Directions in Justice:" race riots at Ole Miss; RFK's part in integration

Objects and Artifacts (continued)

O30	New York Times front pages on Mississippi, Alabama riots; gifts; book: *The Enemy Within* (work on Labor Rackets Committee); desk memorabilia
O31	Case with Inagural medal, bookends, desk set from President Charles de Gaulle, stuffed birds, other desk items
O32	Globe
O33	Ship models
O34	Rocking chair
O35	Replica of *HMS Resolute* desk
O36	Other desk items: scrimshaw, PT109 model, ashtray, goblet from New Ross, Ireland
O37	Dress that Jackie wore on White House tour
O38A	Memo from Jackie to JFK on saving temples at Abu Simal
O38B	Plans for saving temples
O39	Statue of a standing man (2400 B.C.), gift from President Nassar of Egypt
O40	Jackie's design for the statue base
O41	Photos and memorabilia from youth
O42	Navy memorabilia, coconut
O43	JFK's favorite books (incl. *Profiles in Courage*, written in 1955
O44	Case with Jackie childhood memorabilia: family photos, camera from Washington Times-Herald, scrapbook from trip to Europe, photo
O45	Trompe d'oeil closet replica with coats and "favorite things"
O46	Advocacy for National Cultural Center
O47	International popularity; Asian trip: gifts from Pakistan, Jaipur
O48	Jackie Kennedy watercolor: "The White House Long Ago"
O49	Mental retardation: the emergence into public awareness. Kennedy foundation award
O50	Kennedys and Fitzgeralds: Roots
O51	Sign: "Exhibit Continues"
O52	Backlit slide of JFK memorial
O53	Binders: EK on issues; drawers: EK/RFK campaign souvenirs
O54	Drawers: JFK library corps; RFK action corps
O55	Binder on space missions
O56	Books on space program; drawers on space; backlit photo of astronaut on moon
O57	Drawers on womens' rights, national service
O58	Moon rock; Apollo patches; media
O59	Drawers: The Kennedy Center/Hemingway Collection
O60	Binder: JFK Foundation awards and programs
O61	Drawers: physical fitness and consumer rights
O62	Drawers: Special Olympics and mental retardation

Objects and Artifacts (continued)

O63	Log book
O64	Very Special Arts (arts programs for the disabled); Presidential Medal of Freedom; Kennedy Center for the Performing Arts
O65	workstation: "Kennedy Legacy Archives": JFK speeches, legislation, programs/policies, oral history, RFK, reading lists
O66	section of Berlin Wall

Photographs

P1	Pablo Casals in concert at White House, November, 1961
P2	1961 Cabinet meeting (JFK disliked long, formal meetings)
P3	1961 press conference
P4	Speech to Burros club in Rose Garden (Democratic Congressional aides)
P5	Photo-op with civil rights leaders (including Martin Luther King), Aug 28, 1963 March on Washington For Jobs and Freedom
P6	Arrival ceremony for Dr. Scermarche, Prime Minister of Somali Republic on South Lawn
P7	Harry Truman playing at White House dinner in his honor, 1961
P8	JFK ascending staircase with Jackie, the President of Sudan, and others
P9	Guests at 4/29/62 White House dinner honoring Nobel Prize winners
P10	JFK State of the Union address, 1/14/63
P11	JFK giving Astronaut Cooper NASA Distinguished Service medal in Rose Garden
P12	Photos of each of the Cabinet members and others
P13	Large photo of Cabinet swearing-in ceremony
P14	Photos of White House staff
P15	Large map of the world with unstable regions at the time marked
P16	Photos: JFK describing Peace Corps idea at 2 a.m. at a 10/18/60 campaign stop at the University of Michigan
P17	Photos: JFK watching Shepard's flight into upper atmosphere; Glenn showing JFK Frienship 7 space capsule; JFK presents Collier trophy to Project Mercury astronauts
P18	Kennedys and Grand Duchess Caroline and Prince Jean of Luxembourg
P19	JFK introducing the Grand Duchess and Prince Jean to performers
P20	Basil Raithbone reading
P21	Large, wall-sized photograph of JFK and RFK
P22A	RFK at Berlin Wall
P22B	RFK speaking to job discrimination protesters
P23A	RFK and Ethel Kennedy with Robert Frost
P23B	RFK with JFK at job discrimination protest

Photographs (continued)

P24	RFK in Berlin 2/22/62
P25	RFK in Indonesia February 1962
P26	RFK as Chief Counsel on Senate Labor Rackets Committee, 1957
P27	Painting: *Dressing Down, the Gully* (favorite of JFK)
P29	Family photographs
P30B	Photos from youth
P30A	Jackie and JFK walking to stand at Inagural parade
P31	Photo of trompe d'oeil closet in White House dressing room
P32	Photo and memorabilia from Ambassador to India
P33	National Association for Retarded Children Oval Office photo opportunity
P34	JFK's June, 1963 Ireland visit
P35	Kennedy family portrait, London, just before WWII
P36	Other members of Kennedy family

Newspaper boxes

N1	Jack in Walk; 7/14/60; Boston Globe
N2	Nomination; 7/14/60; New York Times
N3	Nixon/Kennedy debate; 9/27/60; St. Louis Post-Dispatch
N4	Kennedy Near Victory; 11/9/60; Des Moines Register
N5	Kennedy Wins; 11/9/60; San Francisco Chronicle

Appendix C

Interview Questionnaire

This appendix contains a standard set of questions and topics for discussion that guided the interviews with exhibit designers and developers.

Interview Questions for Exhibit Designers

I. **The Designer and the Design Process**

1. How did you become an exhibit designer?
2. What educational background do you have? Training? Apprenticeship? Professional experience?
3. What do you use to help you design (blueprints, storyboards, simulations, mock-ups/models?)
4. What resources are available to help designers (textbooks, manuals, organizations)?
5. How does the design process begin?
6. What kinds of documentation are kept during design?
7. What other exhibits have you designed? What other work do you do besides exhibit design?

II. **Designing**

1. How did you begin even to approach the design of the exhibit?
2. What decisions were made first, and what was left until later?
3. What were your design goals for the exhibit?
4. Did you have constraints on space? A space budget? Fixed rooms?
5. Who decided what was included and what was left out?
6. Did you collaborate with other designers?
7. Did you consult curators? Historians? Others?
8. Did you study other exhibits? Have you designed similar exhibits in the past?
9. Did you do any background research?

III. **The Exhibit and its Viewers**

1. Who were you desiging it for?
2. Did you think in terms of "telling a story" as a viewer proceeded through?
3. What experience is a viewer supposed to have in the exhibit?
4. What elements were to be emphasized? How did you decide how much space each element received?
5. What was a viewer to take away, or remember most, from the exhibit?
6. How did you keep people from getting lost?
7. What were the roles of annotative elements in the exhibit (signs, banners, maps)?
8. Did you think about how long people might spend at different parts of the exhibit? How they move about within the exhibit space?
9. Why did you order the rooms in a particular way?
10. Within a smaller region (a room, a wall) why did you arrange things in a particular way? Specifically...

11. Did the interaction between the many media types represented in the exhibit influence your design?

IV. **Evaluation and Design Alternatives**

1. What were the best aspects of the exhibit? What worked really well?
2. What do you wish you could have done, but couldn't because of time, money, space, etc.?
3. What if you had another floor? A larger space? More items?
4. Did you have to leave anything out?
5. What didn't work so well? Would you have done anything differently, if doing it over again?

Appendix D

Museum Locations

This appendix contains a list of the addresses of all of the museums whose exhibits were studied in this research, the names of the exhibits themselves, and the names of the affiliated individuals who were interviewed.

Museum of Science Science Park Boston, MA 02114-1099	*Leonardo: Scientist, Inventor, Artist*	Mr. Lynotoyos Edward Rodley Judy Rand
The John F. Kennedy Library and Museum Columbia Point Boston, MA 02125	*The John F. Kennedy Museum*	Frank Rigg Jim Wagner
The National Air and Space Museum Sixth and Independence Avenue, S.W. Washington, DC 20560	*The Space Race* *Where Next, Columbus*	William Jacobs
The National Museum of Natural History Tenth and Constitution Avenue, N.W. Washington, DC 20560	*Exploring Marine Ecosystems* *The Fossils Exhibit*	Bryan Seiling
The United States Holocaust Memorial Museum 100 Raoul Wallenberg Place S.W. Washington, DC 20024	*The Permanent Exhibit*	Linda Melone

Table D.1: Addresses and interviewees of the exhibits studied.

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