REVEALING HIDDEN STRUCTURE: VISUALIZING BIBLIOGRAPHIC COUPLING AND CO-CITATION RELATIONS IN MULTIMEDIA COLLECTIONS

by

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ABSTRACT

Many digital collections share a common structure in which a collection, the objects collected and the meaning of the collection can be separately considered. We present a data structure comprising exhibitions, annotations, and resources (EAR) as a general device for organizing such collections. People author EAR structures and other people value these acts of authorship in understanding a large collection. Through co-citation and bibliographic coupling, EAR structures form a general graph that is hard for people to interpret. My research hypothesis is that recognizing, analyzing, prototyping and evaluating the EAR triangle can result in both generalizable insight and new tools for information visualization and system design. I introduce NEAR, a graph visualization tool aimed at helping people understand and use EAR structures. The design, implementation and evaluation follow a user-centered design process in three spiral cycles. The thesis concludes with a discussion of the design and its generalizability.

To my wife Zhenyu, the wise part of myself and very special to me.

She always stays on my side with dedication and love.

Much of what I am and a large amount of all I have done are on her account.

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1 INTRODUCTION

1.1 Background

The Internet has caused a flood of information, and what we most easily see is the information itself: the surface of the flood. Underneath and much more vast are the relations among the information elements. In a computer supported collaborative working environment, the connection between user to user, user to data and data to data, is getting tighter and more complicated. Some of these connections are built by users intentionally, while others may be built without their awareness. For example, shopping activities naturally build connections between customers and products.

The concept of "collaborative filtering", which was initiated about 10 years ago, describes a method of making automatic predictions (filtering) of the interest of a user by collecting taste information from many other users (collaborating) (Shardanand and Maes 1995). It has now been widely adopted on e-commerce websites, such as Amazon.com, to recommend products based on other users' shopping experience. In this scenario, a user's shopping experience forms product-to-product and user-to-product connections. Through analyzing such relations, patterns can be found to guide new users. In many cases, the pattern underneath is hard to disclose. In digital galleries or online discussion boards, people's comments on objects or topics provide ideas from different perspectives. Different users may have different views, sometime these views may even contradict each other. There is no way to predict a person's thinking, and none of these thoughts can be seen as useless.

Considering human factors in information retrieval in digital space, users want to retrieve useful and understandable data. Interpretations, explanations and comments on the same subject or related subjects existing throughout digital space are useful for the user who seeks to fully understand the subject. However, such context information may be hidden under the surface, which makes it difficult to collect and display to users. Also the information space can be enormous due to the large scope and freedom that the Internet provides. This fact makes information retrieval even more difficult.

One approach to reveal relations and support information retrieval is to employ information visualization techniques. These techniques show relations and context information by taking advantage of the human perception system. They visually represent seemingly abstract data and expose the underlying relations among the information. A successful visualization requires complete understanding of the visualizing domain, and careful consideration of display space, dynamic and static needs, 2D or 3D representation, and interactive capabilities.

1.2 Objectives of the Research

Collection and resource structures can be seen everywhere in digital space from the file system hierarchy to web pages within a website. Such structures can appear in e-commerce systems, digital galleries and discussion boards. After considering human factors in setting up the collections from resources, I propose the concept of Exhibition, Annotation and Resource (EAR) structures to reflect the cultural information assigned to the data. A *resource* is a piece of information or an object that is of somebody's interest in the digital environment. An *exhibition* is a collection of such resources. An *annotation* is created to furnish critical commentary or explanatory notes to the resources or the exhibition.

Due to the nature of digital space, digital works can be easily cloned and referenced among different Exhibitions (collections). These acts generate web-like data structures and create co-citation and bibliographic coupling relations. The inclusion and reference relations among EAR objects are obvious. If we exam them microcosmically, we will find that the data are still organized in a tree hierarchy or link structure, but the cross links among objects makes the connection more complex and induces more valuable information. Citation-index research has found that co-citation and bibliographic coupling of information is valuable in clustering objects and measuring similarity (Kessler 1963; Small 1973). However, such information is often hidden underneath the direct links. My research hypothesis is that recognizing, analyzing, prototyping and evaluating the triangle of EAR structure can gain a generalizeable insight and help to create new kinds of tools for information visualization and system design.

To find an efficient method to reveal relations among EAR objects and help users browse, navigate and retrieve information effectively, I propose and develop a compact visualization panel called "NEAR" (Navigation Exhibitions, Annotations and Resources) to visualize the EAR objects and their relations in a generic repository A•VI•RE (A Visual Rete, available http://www.avire.ca). There are three main components in a NEAR panel: icon design gives users an overview of each individual EAR object; a node link graph represents the bibliographic coupling and co-citation relations; and interaction design allows users to drill down to reveal the direct inclusion relations and execute visual Boolean queries. The system also provides three different view options (exhibition view, annotation view and resource view) to accommodate users' attention shifts and changing needs.

In currently research and applications, most hierarchical visualizations treat the collections and resources as first class objects, show the hierarchy relations between them, and leave the annotation as second level objects. In NEAR, annotations are treated as first class objects that are as important as exhibitions and resources. Also, indirect relations (bibliographic coupling and co-citation) are shown as first class relations in NEAR while using interaction to review the inclusion relationship.

1.3 Structure of this Thesis

This thesis' seven chapters are organized as follow: the research objects and domain, why such objects and their relations are important, and how to visualize and make good use of such information.

In the second chapter, I propose the concept of the EAR data structure, and examine its existence in physical and virtual libraries, e-commerce systems, academic repositories and open access systems (e.g. wiki). I also discuss how human involvement creates, affects and assigns meaningful information to EAR data, and how we can use such information to further understand users' preferences and to support collaboration.

Chapter 3 is devoted to introducing the details of EAR structure. I discuss the relations among EAR objects from direct relations such as link and back-link, to indirect hidden relations such as bibliographic coupling, co-citation and similarity. User behaviour in the information retrieval process is discussed in the later section of this chapter. Furthermore, to answer the question of how EAR relations can be used to improve users' experience, I argue that a direct presentation of the EAR relations (visualization) is an efficient approach to support users' information retrieval and understanding of such information.

As a literature review section, the fourth chapter covers the reviews of representing objects and contexts with visualization methods, along with related theories, technologies, design projects and key qualities in making effective interactive systems. In this section, I discuss the use of icons to represent attributes of individual objects, and how to apply tree algorithms and the Sugiyama algorithm in reducing cross edges in the node-edge graph that represents relations between objects. Techniques of *Overview / preview* and *focus+context* in visualization system design are beneficial for users to get detailed information about the target as well as keeping the context present. In the later section, a compact visualization of email threads (Thread-arcs) is analyzed and discussed in detail. Principles from this visualization (compact, stable and anchored visualization) are used as primary principles for visualizing EAR objects. Finally, I discuss immediacy and direct manipulation as some key design principles of interactive visualization systems.

There are two implementation chapters in this thesis: Chapter 5 and 6. The beginning part of Chapter 5 introduces the A•VI•RE repository system, an online space where different users play together in different roles to create a large social entity. Several usability issues of A•VI•RE and key qualities of improving the system are addressed. In the last part of the chapter, I illustrate and evaluate the first and second design spiral cycles of the NEAR system.

Considering all the principles discussed in the previous chapters, and the lessons learned from the first two design cycles, Chapter 6 focuses on introducing and discussing the implementation in a new design cycle of “NEAR”. The three main components (icon, interaction and graph), and three different views when a user focuses on different types of the EAR objects are explained in detail.

The final chapter concludes my research and considers applying my research outcome to other domains to support issues such as scaffolding design in online education and paper searching activity in academic repositories and libraries.

2 DOMAIN OF INTEREST - SOCIAL JUSTIFICATION

We can easily find examples of Exhibitions, Annotations and Resources (EAR) structure in a museum. A museum presents several different themed *exhibitions* of artworks each of which can be seen as a *resource*. Visitor comments on these exhibits are *annotations*. The EAR structure not only exists in museums, but can be found in many other domains. Annotations may go beyond text. For instance, users' navigation, decisions and activities can also be treated as a kind of hidden annotation especially in a collaborative environment. In the following section, I will argue that the EAR structure is one of the basic relations in a variety of contexts.

2.1 The Structure of Exhibition, Annotation and Resource (EAR)

The Exhibition, Annotation and Resource (EAR) structure is ubiquitous. This research will emphasize its digital form. The physical analogues, such as library catalogues and museums, are only used as points of reference. In this research, each of the three terms has an operational definition. The original meaning of *resource* can be described as "something that can be used for support or help", or "an available supply that can be drawn on when needed." In EAR structure, a *resource* is a piece of information or an object that is of interest to someone in the digital context. It could be a digital artwork, several lines of programming code, a shopping item, a research paper, or anything useful and collectable. An *exhibition* is a public display of a collection of such resources, where "public" is a choice made in the context of the exhibition. A special case is that one exhibition may only be accessible by its creator, in this case, the exhibition is "public" to the exhibitor. Following are some exhibition examples. An online museum has collections of notable objects in context, while in Object-oriented programming, a class and its methods can also be recognized as a collection and its resources. A filled shopping cart is a collection of shopping items, and to write a research paper, the author has to collect and review many related documents to build a bibliographic list. An *annotation* is created to furnish critical commentary or explanatory notes to the resources or the exhibition. It could appear as a museum review report, a piece of comment between lines of code, a customer's shopping feedback, or a literature review across several related papers.

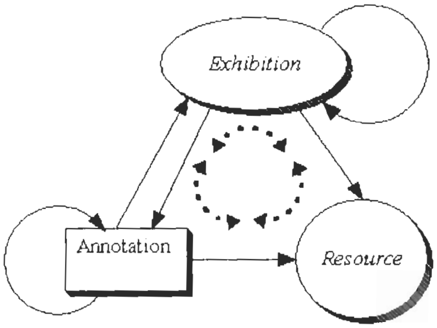

Figure 2-1 Diagram of EAR Structure[1]

The diagram in Figure 2-1 presents an interesting triangle relation between exhibitions, annotations and resources. The solid arrows (outer triangle) in the diagram represent the most obvious inclusion relation among these objects: an exhibition contains annotations and resources, and an annotation references resources and the exhibition. However, the relation is not unidirectional. Resources enrich and provide the evidence to support the annotations and exhibitions, and annotations assign meanings and comments to exhibitions and resources. Therefore the three objects are actually united together, and

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[1] Copyright: Yingjie Chen, 2006.

the inside circular arrows indicate such two-way influences. Since resources are selected and gathered by exhibitors based on certain purposes (preference, usage or convenience) and the emphasis is highlighted by annotations, information around an exhibition is much more abundant than a simple collection. Annotations are generated from users' interpretations of resources and the exhibition. Since users' perspectives usually differ, annotations can provide a variety of understandings around the same resources. Exhibition, annotation and resources construct the triangle EAR relation which can be observed in many instances in the digital environment, and none of the three parts can be omitted. My global research hypothesis is that recognizing, analyzing, prototyping and evaluating this triangle may result in both generalizeable insight and the creation of new kinds of tools for information visualization and system design.

2.2 Examples of EAR structures

2.2.1 In Physical Museums and Digital Museums/Galleries

A physical museum is a place devoted to the acquisition, conservation and educational interpretation of objects having scientific, historical, or artistic value. It demonstrates a well-designed experience of navigating through large collections of exhibits. The layout and paths in the museum are carefully designed to guide visitors to follow a path, while text, audio and video displays guide visitors through the intended path. All these displays are a kind of annotation made by curators of the museum. Being the primary authorities of the museum exhibition, they arrange and organize the resources based on their perspective and understanding of resources. Usually next to the exit of the museum, there is a guestbook for visitors to leave comments. A visitor can act as an annotator to link, evaluate and compare exhibits, and their comments are valuable for both of the museum's curators and future visitors. Curators will know whether or not the visitors enjoy the experience they provided and will learn how to improve the design. Currently, these comments usually cannot be viewed by other visitors in a physical museum. However, such comments could provide other visitors with information about where others have lingered the most in the past and which parts they may have skipped. New visitors could learn from previous visitors, and also see other perspectives of the museum's displays. In principle, digital technology can make these annotations available for public use.

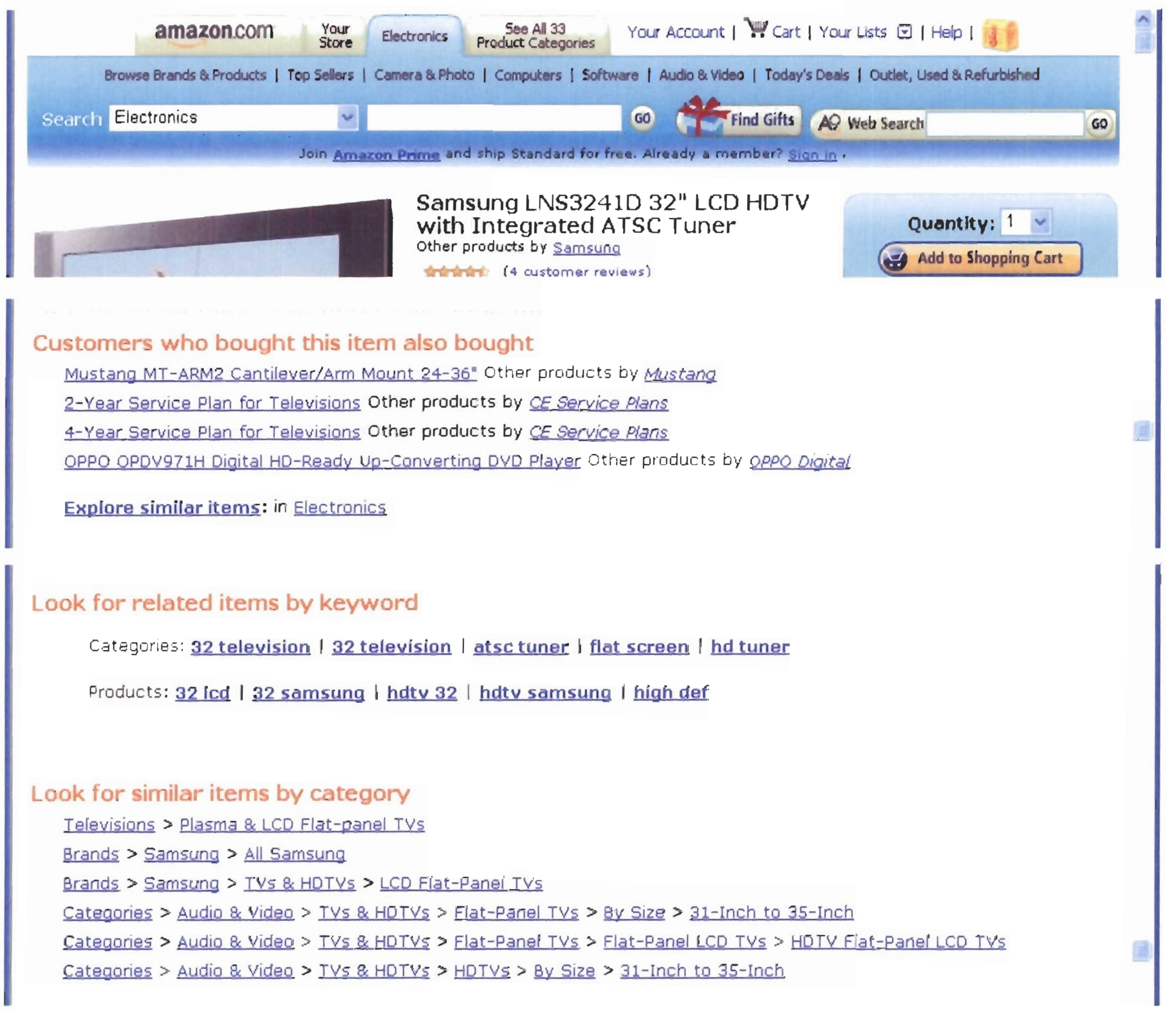
The design of a digital virtual museum/gallery might follow the features of its physical counterpart, but here the structure of EAR exists even more obviously. The website of the Metropolitan Museum of Art (available at http://www.metmuseum.org/) is a typical online museum. There are about 6,500 items catalogued by permanent collections such as American Decorative Arts, Ancient Near Eastern Art, the Cloisters, etc. In a collection page, a series of highlighted artworks are presented as thumbnails in a time sequence. A click on the artwork thumbnail leads users to a detailed introduction of the artwork. To support audiences who want to explore and learn more about the exhibits, the curators have created different annotations: "just for fun" (to explore new ways to see arts), "a close look" (to learn the how and why behind some exhibits), "themes and cultures" (to discover cultures, past and present), "artists" (to step into an artist's world) or the "timeline" (to explore the artworks through a timeline visualization). A physical museum sometimes has related items in a glass cabinet as a group with explanting captions. This kind of categorization is much more flexible in virtual space because there is no technical limitation to copying or linking. One item can be included in different exhibitions to provide visitors with multiple viewpoints of the same item.

In the online museum of Metropolitan Museum of Art, the EAR structure is clear. An exhibition is the collection of artworks and their captions, the resources are the exhibited artworks, and annotations include the introduction of the exhibition, captions of exhibiting objects and visitors' comments.

2.2.2 In E-commerce Systems

E-commerce is the online transaction of business, featuring linked computer systems of the vendor, host, and customer. The EAR structure is also evident here where products are resources to be selected and collected. They are categorized based on their usage and features, so one product may be included in multiple categories. Product departments such as "computers," "furniture" and "homeware," and detailed categories such as "17 inch LCD monitor," "reclining leather sofa" and "coffer grinders" are all exhibitions. In fact, the whole website is an exhibition. The product feature descriptions of each product are annotations for these exhibitions. In an e-commerce system, another kind of exhibition that is organized by buyers is their shopping carts. Products selected in a shopping cart usually come from different categories, but all meet the customer's own shopping interests. For this type of exhibition, the system's recommendations, customers' comments and feedback are the annotations.

In e-commerce systems, such as the online bookstore Amazon.com (Linden et al. 2003), *collaborative filtering* (CF) has been widely used to make recommendations for later users. CF is a method of making automatic predictions (filtering) about the interests of a user by collecting taste information from many users' experiences (collaboration).



Search: Electronics

Join Amazon Prime and ship Standard for free. Already a member? Sign in.

Samsung LNS3241D 32" LCD HDTV with Integrated ATSC Tuner
Other products by Samsung
(4 customer reviews)

Quantity: 1

Customers who bought this item also bought

Mustang MT-ARM2 Cantilever/Arm Mount 24-36" Other products by *Mustang*
2-Year Service Plan for Televisions Other products by *CE Service Plans*
4-Year Service Plan for Televisions Other products by *CE Service Plans*
OPPO OPDV971H Digital HD-Ready Up-Converting DVD Player Other products by *OPPO Digital*

Explore similar items: in Electronics

Look for related items by keyword

Categories: **32 television** | **32 television** | **atsc tuner** | **flat screen** | **hd tuner**

Products: **32 lcd** | **32 samsung** | **hdtv 32** | **hdtv samsung** | **high def**

Look for similar items by category

Televisions > Plasma & LCD Flat-panel TVs
Brands > Samsung > All Samsung
Brands > Samsung > TVs & HDTVs > LCD Flat-Panel TVs
Categories > Audio & Video > TVs & HDTVs > Flat-Panel TVs > By Size > 31-Inch to 35-Inch
Categories > Audio & Video > TVs & HDTVs > Flat-Panel TVs > Flat-Panel LCD TVs > HDTV Flat-Panel LCD TVs
Categories > Audio & Video > TVs & HDTVs > HDTVs > By Size > 31-Inch to 35-Inch

Figure 2-2 Screen shots of Amazon.com while searching for a television[2]

In Figure 2-2, when a user is searching for a TV on Amazon, an item list is generated from other customers' experiences that guides the user while promoting other TV related products. There are three different kinds of EAR structures in this single webpage. First, the user's shopping cart is an exhibition of purchased products, from which the system can infer the relation among different products based on user

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[2] Screenshot reprinted by permission of Amazon.com

preferences. For example, many previous customers who bought the LCD TV also bought the wall mount, the extension warranty and a DVD player. Therefore a new customer might also consider these products. Secondly, the product's feature description is an exhibition of keywords, and the system can use these keywords to recommend related products. Finally, a product category is an exhibition of products, and the system can suggest other products in the same category.

In most E-commerce systems there are functions that allow users to provide feedback or reviews of products. Such reviews are useful annotations. The technology of collaborative filtering will also actively link resources from different exhibitions and recommend these to new customers. In turn, it actually acts as an automatic "annotator".

2.2.3 In Academic Repositories

A digital repository is a system that is responsible for the long-term maintenance of digital resources, as well as for making them available to communities agreed upon by the depositor and the repository. It is a system where digital content assets are stored and can be searched and retrieved for later use. Higher education has a history of maintaining repositories that contain works of lasting intellectual value. This includes both primary sources that open up and support new lines of scholarship in the arts and sciences, and secondary sources that record and disseminate scholarly activities. These repositories are called libraries, and libraries have been re-imagining themselves in the face of digital technology. Academic repositories such as digital libraries and scholarly forums also contain EAR structures. An example is LibraryThing (http://www.librarything.com/ 2006), a digital space that enables people to set up their own catalogs and share their readings with other users. In its description, LibraryThing is introduced as "helping you create a library-quality catalog of your books. You can do all of them or just what you're reading now. And because everyone catalogs online, they also catalog together. LibraryThing connects people based on the books they share." (http://www.librarything.com/tour/)

Considering the EAR structure in LibraryThing, we can say that the catalogs made by users are exhibitions, the reviews and rating of books are annotations, and the books collected by users are resources. In addition, there are two kinds of information web pages acting as annotations. The book information page presents users with library-quality data, and the social information pages show users who else have catalogued this book and how they describe and evaluate it. Moreover, the blog widget in the LibraryThing provides a place that allows users to share his/her ideas. This blog is also a type of valuable annotation.

Profiles of different users connect users who share the same book. With over 79,000 users and 5.6 million books in the system, users can find some "eerily similar" cases. Through analyzing the data, LibraryThing is able to know how books connect, providing some of the best recommendations on the web. LibraryThing also can "analyze your entire catalog and come up with 100 or so books you might want to check out" (http://www.librarything.com/tour/8)

Users (researchers or scholars) who use online academic repositories such as LibraryThing need both social and technical support to navigate through the databases and search for useful information. There are several features in these systems. First, similar to online customers' who collect shopping items in their virtual shopping carts, users identify favourite books and save the related information in their catalog. Second, in the process of decision making, users tend to respond to the advice of others who have made the decisions before (Schotter and Sopher 2001). Researchers frequently read reviews made by other professionals. Third, although all the activities take place online (at different times and from different locations), various research communities build up gradually based on similar research interests in academic repositories. LibraryThing groups and supports such communities by allowing users to create and join groups on LibraryThing. “You can make a group for a club, a place, or even a private group for just your friends. You can talk in the group forum, search all group members' libraries at once, or check out the Group Zeitgeist to spot shared books. With Talk, the forum system, you can see the conversations happening in all groups, or just your groups. You can also find just the topics that mention your books. ” (http://www.librarything.com/tour/7)

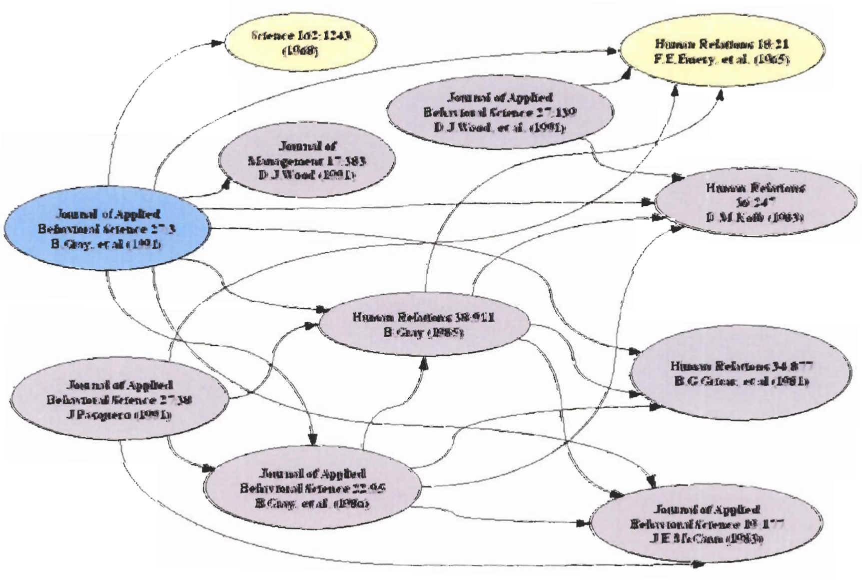

Figure 2-3 **A citation map generated by Sage Publications’ online library**[3]

In a digital library, a user’s catalogs specify one kind of exhibition. The readings notes and reviews the user writes are the annotations. Apart from that, there is another

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[3] Reproduced based on screenshot from Http://jab.sagepub.com (HighWire Press, Stanford University) by permission)

EAR structure. Figure 2-3 shows a citation map generated by Sage publication's digital library for a journal article by Gray et al's in 1991. Its citation list can be recognized as an exhibition of ten other journals. From the map, we can find nine papers being directly cited and five papers being both directly and indirectly cited. There is one article (Robert et al. 1991) sharing a citation with Gray et al. In such a paper, we can treat the paper as an exhibition, the citations as collected resources, and the content as the annotation.

2.2.4 In Open Access System - Wiki

Open access (OA) is the subject of many current discussions among academics, librarians, university administrators, and government officials. It is the free online availability of digital content. It is best-known and most feasible for peer-reviewed scientific and scholarly journal articles, through which scholars publish without expectation of payment. OA has taken an important role in scholarly research. One of the most successful systems supporting OA is Wiki (Cunningham and Leuf 2001).

A Wiki system is a hypertext system. It is a class of server software that allows users to create and edit Web page content freely through any Web browser. Wiki supports hyperlinks and has simple text syntax for creating new pages and crosslinks between internal pages. Wiki is unusual among group communication mechanisms because it allows the organization of contributions to be edited in addition to the content itself. Like many simple concepts, "open access" has some profound and subtle effects on Wiki usage. Wiki is a successful OA system for several reasons. For example, users are able to browse and contribute freely, and rich linkages make a Wiki site engaging and useful. There are many different types of Wiki software; some are very simple, others have been enhanced with specific advanced features. No matter what type of system it is, a Wiki system contains EAR structures.

The Wiki system can be seen as an exhibition, uploaded files and links are resources. Users interlace text and links to compose Wiki pages. These Wikipages are annotations. WikiWords[4] inside the Wikipage create new wikipages (annotations). Furthermore, the editing time sequence table generated by the system is also an annotation for that exhibition. In the Wiki system, the EAR structure may be complex, the graph of the relations is no longer a tree, and it may contain cross links and loops to become a more general graph.

2.2.5 More Digital Environment Examples

There are many other domains in which we can observe EAR structures. People collect and contribute resources into exhibitions in different forms and leave explicit or implicit annotations. A website itself could be an exhibition that collects multimedia files (such as images, video or audio) and web page(s). These multimedia files are resources, and the web pages are annotations that reference images and files in the page. Different variations of websites such as blogs, discussion forums, and the Wiki system discussed above, can all be seen as EAR form.

Computer programming also has the structure of EAR. In JAVA programming, a class is an exhibition, methods and variables are resources, and documentation and comments are annotations created by the programmer. In a digital environment, a user's act of collecting resources is easier than the physical world – objects can be easily cloned

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[4] A WikiWord is a way of writing compound words where the words are joined without spaces, and each word is capitalized within the compound. A WikiWord is used to create a link to a new wiki page in Wiki systems.

by copying. It is even simpler since links can be created to point to the real objects. When the original resources change, all exhibitions get a fresh view of the resources simultaneously. Consciously or not, users create digital exhibitions by creating and collecting resources, and making annotations of them.

2.3 Human-centred Issues of EAR Structure

After analyzing the elements in four distinct types of systems, I find evidence of EAR structures in all of them. These EAR structures were not consciously created by the system designers. Instead they are naturally created from human users' needs. While reviewing the state of the art of content-based multimedia information retrieval researches, Lew et al. uses the term "human-centred system" to highlight the consideration, the behaviour and the needs of the human users (Lew et al. 2006). In this research, I chose the EAR structure to discover a new general approach to support user preferences and to design human-centred systems. Compared to standard hierarchy structures, the EAR structure uses annotations as users' intentional commentary, which may provide much more human-centric information.

2.3.1 Understand and Support User Preferences

Dealing with data relations and user preferences is becoming a widespread issue in novel data-intensive application domains, such as digital catalogues, real estate listings, e-commerce systems and multimedia databases. Many contemporary applications face the problem of managing massive data according to users' personal interests. For example, there are 34 product categories in Amazon.com's website. Just under the section of Amazon Grocery, there are more than 14,000 non-perishable food and household items on sale. Effectively supporting users' searching and browsing over such large repositories entails the problem of properly understanding user needs, filtering out irrelevant items, helping the user to formulate the most appropriate queries, and presenting results ranked according to their presumed relevance. Similar issues arise in multimedia databases when the user is looking for files similar to or related to a given one. For example, The ISI Web of Knowledge provides access to current and retrospective multidisciplinary information from approximately 8,700 of the most prestigious, high-impact research journals in the world. In this case, the problem is that the notion of relevance can be a subjective one, thus the system has to "learn" it and then exploit the acquired knowledge about user preferences to retrieve the most relevant objects (Bartolini et al. 2001).

If we regard a user as a collection of preferences, having (or sharing) similar preferences between users indicates an important relation between them. By using such information, collaborative filtering recommender systems in e-commerce applications provide advice to users about products or services in which they might be interested (Shardanand and Maes 1995). The goal is to offer an enhanced solution for each individual user that meets his or her needs more effectively and efficiently.

2.3.2 Collaboration Experience as the Annotation

Collaboration refers abstractly to all processes where people work together applying the work of individuals as well as larger collectives and societies. In a project context, instead of learning to manage information between disparate software products, staff can use their valuable time to create more innovative products, services and workflows, and to help accomplish the project more effectively. Asynchronous collaboration is very common in many digital systems: buyers appraise the qualities of one product, audiences evaluate a new movie, scholars discuss a published journal or travellers sketch a new tourist route. Trust, knowledge sharing, and collaboration are central elements of effective digital relations (Black et al. 2002). Such collaborations help individuals to make decisions and share knowledge.

In EAR structures, some annotations are produced enthusiastically by "collaborators" (other audiences, buyers, scholars, etc). However, if a system is still in the beginning stages or users are not active enough to leave notes, it would be a problem for later users to have enough annotations to consult. To enrich this "collaborative information," the system can automatically generate annotations based on other "collaborators'" navigation experiences (clicking and refreshing) and activities (purchases or subscriptions). Collaborative filtering enables such automatic annotations.

2.4 Summary

This discussion has identified several elements that motivate my study. First, a simple but appealing triangular structure of Exhibition, Annotation and Resources (EAR) is described from the perspective of a digital gallery. Second, analogues to the EAR structure are found in various kinds of digital applications, such as e-commence systems, digital repositories, and open access systems, where retention of its inherent logic is demonstrated. Finally, I identify this structure as an approach to consider the needs of users because of the analysis of two human-centred issues: supporting user preferences and referring to collaborative advice.

Because of the similarities of its appearance in different systems, I argue that EAR structure is a general device that provides a foundation to organize, analyze, visualize and understand navigational issues in applications with large databases. Before describing an implementation, I will outline data properties and relation hierarchies in next chapter.

3 CONCEPTUAL JUSTIFICATION (PROPERTIES OF EAR STRUCTURE)

3.1 Hierarchy of Relation: Data Structure in EAR

As described in the last chapter, there are three kinds of primitive objects: exhibition, resource and annotation. The relations among these objects are described in Figure 3-1. In this figure, nodes represent objects, edges stand for inclusion or link relations, and the arrows are the directions of the inclusion or link.

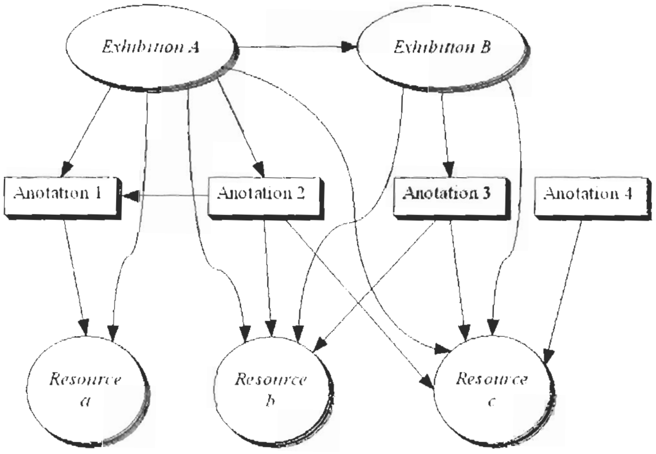

Figure 3-1 Data structure of objects in EAR[5]

In this data structure, the inclusion relation can be complex and iterative. It is not only direct for example exhibiting resources and annotating resources, but also transitive. For example, an annotation may be annotated by other annotations. An exhibition may include other exhibitions, and exhibitions can also be annotated. The inclusion relations may contain loops, trees and cross links. Indirect relations can be inferred from direct

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[5] Copyright: Yingjie Chen, 2006.

inclusion, fro example, co-citation, bibliographic coupling and similarity. From simple to complex, direct to transitive, these relations form a hierarchy. The following sections will discuss this hierarchy in detail.

3.2 Foundation Level of Hierarchy: Inclusion (Link) and Been-Included (Back-Link)

In EAR structure, the most basic relation is the inclusion relation: an exhibition includes one or more resources, an exhibition includes one or more annotations, and an annotation refers to one or more resources through referencing the resources in its content. In other domains such as web pages and e-commerce applications, inclusion relations can be applied to connections such as "reference," "linkage," "attributes" or even user behaviours such as "purchase" or "register." More generally, we can say that two objects are "connected" to form the relations like "inclusion," "reference" or "purchase."

Exhibition use inclusion to gather resources, and such an exhibition often has its own theme in which all included resources participate. In some cases, the theme can be very explicit such as "17 inch wide screen laptops". However, when you look at a favourite link a user stores in his/her web browser, the theme gets fuzzy and blurred.

"Being included" can be described as the reverse of inclusion. One resource can be included into multiple exhibitions. "Being included" also assigns multiple attributes to a resource. Since different exhibitions that include the same resource(s) can have different themes, the overlapping resources are used to support those different themes. For example, consider an image showing the entrance to a granite-structured Gothic church built in the Victorian period. If we include the image in an exhibition of religious history, it would demonstrate the religious influence on the building. If we place the image in an architecture exhibition of stone structure, it would exhibit the carving techniques used to build and sculpture granite. If it is included in a representation about entrance design, the image may illustrate how to arrange the entrance spaces to form a sacred atmosphere.

In web pages, links and backlinks (also called incoming links, inbound links or inward links) are similar to the relations of including and being included. Backlinks can be described as links received by a web node from other web nodes. The quantity of backlinks is an indication of the page's popularity and may also indicate the importance of that page. Most commercial search engines provide a mechanism to calculate the number of backlinks recorded on a particular web page. In Google.com, a search on "link:wikipedia.org" will list all the web pages that link to wikipedia.org. These links are defined in the original HTML definition. However, currently there is no mechanism to keep track of backlinks – although it naturally exists. At present, backlinks are internally supported by some web applications such as Blogs (trackBacks between blogs), Wikis and some content management systems (CMS).

In the digital world, inclusion (link) and included-in (back-link) form complex relations, which can be transitive, looped, one-to-one, one-to-many, many-to-one and many-to-many. For example, a web page can be linked from different pages while several pages can contain the same image or link.

Some visualization technologies have been developed to represent link and backlink relations between Internet nodes. CZWEB (Collaud 1995) treats the web as an information space and represents the complex link structure as a map, automatically constructing a dynamic visual network of browsed websites according to the paths that the user has traveled. User studies show that CZWEB successfully increased users' experiences of navigating, gathering, filtering, managing and retrieving information from the web by giving them a geometric layout of the Internet's information space.

3.3 Second Level: Co-Citation and Bibliographic Coupling

Extending the relations of inclusion (link) and included in (back-link), co-citation and bibliographic coupling are two key concepts from citation analysis research. They have been studied since the 1960s in information and library science.

Historically, citation analysis methods have been used to trace relations among citations in an academic journal. As early as 1961, the Science Citation Index began to apply citation analysis to publications. Data from citation indexes can be analyzed to determine the popularity and impact of specific articles, authors, and publications. For example, the analysis can gauge the importance of a faculty member's work as a part of the tenure review process. Information scientists also use citation analysis to quantitatively assess the core journal titles and watershed publications in particular disciplines, interrelations between authors from different institutions and schools of thought, and related data about the sociology of academia.

The concept of bibliographic coupling dates to 1963 (Kessler 1963). If two papers refer to the same paper, they are bibliographically coupled. Kessler found that if two recent papers are published in the same or similar research area, a bibliographic coupling pattern is very likely to be found in their local citation graph. The number of references two papers have in common can be used to measure these documents' similarity. Kessler showed that a clustering based on this measure yields related groupings of papers by finding a number of papers that bear a meaningful relation to each other.

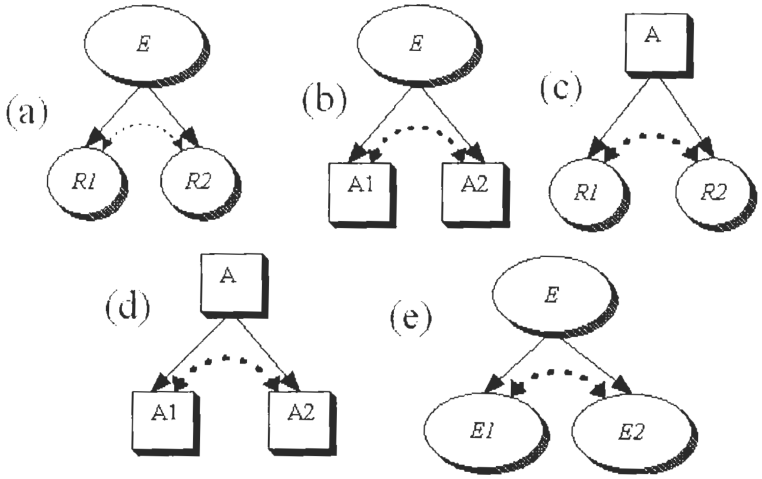

Figure 3-2 Different circumstances of co-citation among EAR objects.[6]
In each triangle, bottom two objects are co-cited by the top object. The thickness of the curved edge indicates the strength of the relation bought up by the co-citation.

In contrast to bibliographic coupling, if two papers are cited together by the same paper, they are related by co-citation (Small 1973). Small has studied the co-citation pattern among research papers and highlighted its importance in computing similarity of papers. He claims that, the greater number of times they are cited together, the closer the two papers are related.

In EAR structure, bibliographic coupling and co-citation relations are very common by extending its inclusion and being-included relations. Shown in **Figure 3-2** (a), two resources are co-cited if one exhibition includes them or if one annotation refers to them. However, due to the different roles exhibitions, annotations and resources play, the strength of these relations may be different. Since an annotation may likely take more

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[6] Copyright: Yingjie Chen, 2006

human effort to create, relations created or carried by annotations may be stronger than the relations through exhibitions or resources. If we think of an annotation as an academic paper, all the referred resources in the annotation can be treated as figures. Each annotation is written by users with some intention or from a certain perspective. The resource inside an annotation is strongly connected to the annotation to support the subject. In another words, the annotation assigns some meaning to the resource. Hence if several resources are co-cited by means of annotating (c), their relations would be stronger. In EAR, annotations can also be annotated. In such cases the two annotations would be very close (d). Two resources can be co-cited by exhibitions (a), in these cases the strength of the relation between the resources could be weaker than being co-cited by annotations (c). An exhibition could be organized by different kinds of subjects. For example, a collection of photos that are taken by the same photographer may not have obvious common features in appearance except for some indescribable style of photography. But, if some of the photos were selected in an annotation to introduce a subject, the connections among them could be stronger.

Figure 3-3 demonstrates different circumstances of bibliographic coupling among EAR objects. Two exhibitions or annotations may include the same resources. Similar to co-citation, due to the different roles played by EAR objects, the relations also have different meanings.

Here is a typical scenario of how one exhibition becomes bibliographically coupled with another exhibition. When a user browses an existing exhibition, he/she may find resources and annotations that appear related or appropriate to his own existing exhibition (or increase his interest in making a new exhibition) and references them

(Figure 3-3 a and b). The relation between exhibitions might not be strong if they are bibliographically coupled by the same resources (a). However, if the two exhibitions are coupled by the same annotation (b), since the annotation specifically links its contents and it is the user's own decision to capture and include the annotation, this scenario indicates that these two exhibitions may have a stronger relation. The relation is even stronger if two annotations are coupled by a resource (c) or another annotation (d). These annotations may either address different aspects of the resource, or act as the information supplement (or critique) of each other.

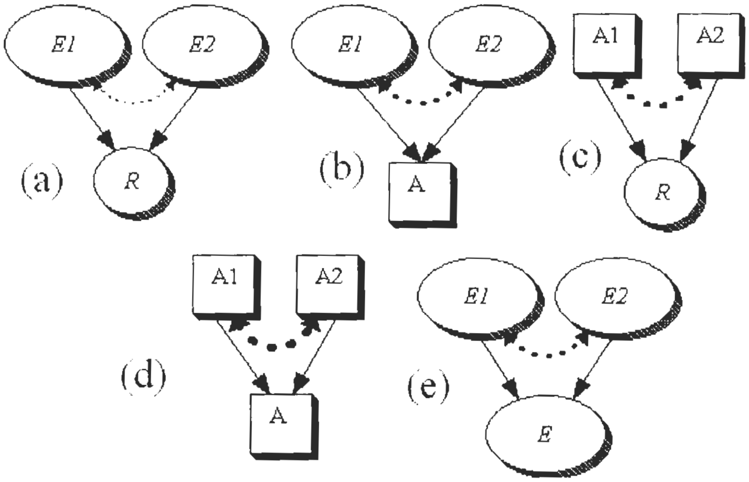

Figure 3-3 Different circumstances of bibliographic coupling in EAR. [7]
The top two objects are bibliographically coupled by the objects under. The thickness of the curved edge indicates the strength of the relation bought up by the coupling.

Except the effect of human involvement, the number of co-citing objects or coupling objects is another key factor determines the strength of the relations. The more the objects, the stronger the created relation. In Figure 3-4, the co-citation relation between R3 and R4 is stronger than the relation between R1 and R1 because there are

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[7] Copyright: Yingjie Chen, 2006

more objects co-citing R3 and R4. Similarly, the bibliographic coupling relation between E3 and E4 is stronger than the relation between E1 and E2.

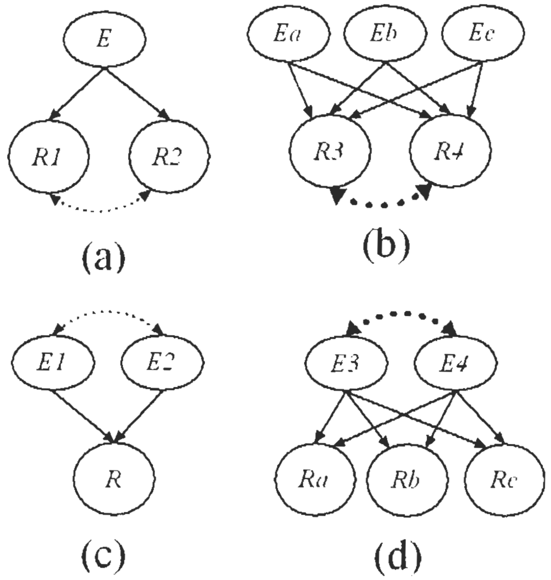

Figure 3-4 Number of co-citing or coupling objects determine strength of the relations. [8]

3.4 Third level of hierarchy: Measuring Similarity and Collaborative Filtering

The measurements of similarity and collaborative filtering are composite relations in the EAR structure.

3.4.1 Measurement of Similarity

Many applications require a measurement of similarity between objects. An obvious example is "find-similar-document" on the Web (Baeza-Yates and Ribeiro-Neto. 1999). Generally, a similarity measurement can be used to cluster objects. Similar users and items can be grouped and anchored in the users' preferences for collaborative filtering in recommender systems (Shardanand and Maes 1995; Konstan et al. 1997). Bibliometrics studies the citation patterns of scientific papers (or other publications), and

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[8] Copyright: Yingjie Chen, 2006

relations between papers are inferred from its cross-citations. Most noteworthy results from this field are the methods of co-citation (Small 1973) and bibliographic coupling (Kessler 1963). These methods have been applied to cluster scientific papers according to topic (Popescul et al. 2000) or cluster web pages (Larson 1996).

In 1998, Giles et al. proposed a similarity measurement based on common citations to judge the similarity between papers (Giles et al. 1998). Since citations of other works are handpicked by the authors as being related documents, it is intuitive to use citation information to judge the relatedness of documents. The metric is called "Common Citation x Inverse Document Frequency" (CCIDF). To find documents related to a given paper, all of the papers that have at least one reference in common with that specific paper are listed by assigning a weight to each paper, which is equal to the inverse of citation frequency in the entire database. The CCIDF metric is used by the automatic citation indexing system "ResearchIndex". To calculate the relatedness of all documents to a document A in the citation database and choose the Best M documents, Giles described the algorithm as follow:

1. Assign a weight (w_i) to each citation of A, equal to the inverse of the frequency of the citation in the entire database. The more counts a citation appears, the less weight it is.
2. In the database, find a set of documents that share any citation(s) with A.
3. For each document in step 2, determine the relatedness of the document Rj as the sum of the weights of the citations shared with A.

$$R_j = \sum_{i \in A \cap i \in B_j} w_i$$

4. Sort the Rj values and return the documents Bj with the M highest Rj values.

CCIDF algorithm assumes a very un-common citation has higher weight than a citation made by a large number of documents. This algorithm is found to be useful and perform well when retrieving similar documents.

SimRank (Jeh and Widom. 2002) is a research on comparing the similarity between object pairs. It studied the basic transitive intuition of "two objects are similar if they are related to similar objects." More precisely, objects A and B are similar if they are related to the same object C, or objects C and D, respectively, when C and D are themselves similar. SimRank developed mathematical equations to formalize the recursive notion of structural-context similarity, and defined similarity scores in terms of these equations. SimRank treated an object as maximally similar to itself with the similarity score of 1. Similarity scores of other objects are calculated recursively based on their neighbourhood (the next directly connected object). In similarity or relativity measurement fields in digital environments, much research has been applied in commercial systems such as Internet search engines, e-commerce systems and digital libraries (Lu et al. 2001; Bianchini et al. 2002; Xi et al. 2005).

EAR structures can be measured in a similar way. Consider the graph in Figure 3-1. Exhibition *A* and exhibition *B* both include resource *b* and resource *c*, therefore exhibition *A* and *B* are similar based on co-citation information (Small 1973). Correspondingly, annotation *3* and *4* would be similar since they both co-cite resource *c*. The strongest similarity is between resource *b* and *c*, since both resources are included in exhibition *A* and *B*, and are referenced by annotation *2* and *3*. Thus, they are closely related by the relation of bibliographic coupling.

A more complex situation takes place between annotation *1* and *3*. Although they do not co-cite any information, some level of similarity still exists. Annotation *1* cites resource *a*, and annotation *3* cites resource *b*, and resource *a* and *b* are similar (because they are co-cited by exhibition A), so annotation *1* is similar to *3* at some level. However, this similarity strength is much weaker than the similarity between annotation *2* and *3* (according to SimRank) because it is an in-direct co-citation. As mentioned before, annotations carry the subjective meanings of the annotator to intentionally present his/her idea and may take more human effort to create, thus the strength of relation between resources in the same annotation may be strong.

3.4.2 Collaborative Filtering

In EAR structure, users organize exhibitions to demonstrate collected digital materials, or write annotations to note or explain the exhibiting resources that interest them. Such activities show users' preferences over the objects. Similarly, a user click on a resource or look into the details of an exhibition or annotation may also show the users' preferences of the selected items.

Collaborative filtering has been widely used in recommender systems including e-commerce systems such as Amazon.com (Linden, Smith and York 2003). Recommender systems apply knowledge discovery techniques to make personalized recommendations for information, products or services during an interaction. In the process of decision making, people tend to make use of the advice of others who have made decisions earlier

(Schotter and Sopher 2001). Based on building a database of preferences of users or item-item matrix, collaborative filtering (CF) is one of the most promising technologies for recommendation. The main idea is to automate the process of "word-of-mouth" by which people recommend products or services to one another (Shardanand and Maes 1995). The underlying assumption of the CF approach is that users tend to have similar or close preferences if they select the same thing.

There are two common types of CF systems: user-based and item-based. A user-based CF system usually takes two steps: look for users who share the same rating patterns with the user who needs the prediction, and then use the ratings from like-minded users to make the recommendation for the active user. This method has been widely used in systems that recommend research papers (McNee et al. 2002) or movie databases (MovieLens and IMDB.com). Another type of CF system is an item-based system in which items are rated and used as parameters instead of users. A typical example is the recommendation system used by Amazon.com (Linden, Smith and York 2003). This kind of system initially creates an item-item matrix determining relations between pairs of items, then uses the matrix and the data of current users to infer his/her preferences. In Amazon, the Item-Item matrix is built based on a user's shopping experience: some users who bought item *X* also bought item *Y* – hence a relation between *X* and *Y* is built up. If a new user bought item X, the recommendation system could tell him that he may also need to buy item *Y*.

CF technologies have been proven to be very useful. In a big system, a large numbers of items may be included in one single category, making it an impossible task for a single person to review all of the items and select the relevant or interesting ones.

Traditional scoring or rating system only get the average evaluation score across all the users, and ignore the special demands of an individual. Such systems perform poorly in tasks where there is a large variation of interest – such as music or movie recommendation. CF systems accommodate user preferences, which are important in a large online gallery – there are so many different exhibitions with different subjects and themes. The problem of guiding the visitor to the most attractive area (for the visitor) is a similar problem that may be addressed by collaborative filtering.

In the past decade, much research has been done to create a wide variety of collaborative filtering algorithms, such as "user-item relevance model" (Wang et al. 2006), "mixture models" (Kleinberg and Sandler 2004), "item based" (Sarwar et al. 2001) and "item-to-item" algorithms (Linden, Smith and York 2003). However, it is still difficult to properly evaluate a CF recommendation system (Herlocker et al. 2004). Algorithms designed for data sets that have many more users than items (e.g., the MovieLens data set has 65,000 users and 5,000 movies) would be entirely inappropriate in a domain where there are more items than users. The goal of different systems may vary as well. Some algorithms may only focus on improving the recommendation accuracy, and some systems may be more focused on how to avoid mistakes.

When a system is designed for recommending decisions, it may be more essential to measure how often the system leads to wrong decisions. This fact suggests that maybe simply laying the recommending list in front of the user is not the only solution. There is an old Chinese proverb: "public clamour can confound right and wrong." In the process of decision making, people tend to rely on the advice of others who have made the decision before (Schotter and Sopher 2001). The results of CF generated from greater numbers of users is convincing. However, the "filtering" may also filter out a lot of useful information. The opinion of the majority has been considered in the CF, but the minority has been ignored. If we can visually represent all the relations drawn from collaborative filtering among objects by taking advantage of users' cognitive systems, it may lead to another approach to help users look at the object at a new level, to let him/her examine the target more completely, to consider opinions from both the majority and minority, and to improve the decision making process of navigating or retrieving data in the massive information space.

3.5 Information Retrieval and Browsing

With a good understanding of EAR relations, we can potentially improve users' information retrieval and browsing experiences over the Internet. The World Wide Web can be seen as an overwhelming, unstructured but ubiquitous database. How to efficiently manage, retrieve and filter information in the Web is a recurring topic. If the information is not able to be found, it will be useless. Due to this basic demand, search engine companies such as Google have achieved tremendous commercial success. Clearly, one central problem regarding information retrieval systems is the issue of predicting which documents are relevant and which are not. Based on the previous discussion of relations between EAR objects, we can conclude some principles that will not only improve user information retrieval experiences, but also allow the user to amplify the search dimensions.

Generally, there are two types of information retrieval on the World Wide Web: browsing and seeking (Ricardo Baeza-Yates 1999). Modern digital library and web interfaces attempt to combine the two tasks to provide improved retrieval capabilities. In the section, I will discuss human behaviour in information retrieval activities.

3.5.1 Multimedia Information Retrieval

For data retrieval, users usually have relatively clear goals. Some sample data retrieval activities include: looking for literature to support an argument in a research paper, searching for a photo or video clip to be used in a webpage of a tourism site, reviewing features and prices of a Hoover vacuum cleaner in different online stores. The quantity of information on the web is extremely large. The main question for today's information retrieval is no longer "is there any information related to this subject?", but "how can I locate the most relevant information about this subject in the shortest time?"

Apart from text information, the hypertext system contains a great quantity of images, audios, videos, and different kinds of files stored in binary form that can not be analyzed as text. This fact has led researchers to expand information retrieval into multimedia domains. Multimedia information retrieval (MIR) is about the search for knowledge in all its forms, everywhere (Lew, Sebe, Djeraba and Jain 2006). It is about "making capturing, storing, finding, and using digital media an everyday occurrence in our computing environment"(Rowe and Jain 2005). There are two fundamental necessities for a multimedia information retrieval system: 1) searching for a particular media item and 2) browsing and summarizing a media collection (Lew, Sebe, Djeraba and Jain 2006). While progress has been significantly made in research, there has been little progress in the development of applications for widespread use (Jaimes et al. 2005). Currently, much research in multimedia information retrieval is focused on content-based retrieval of multimedia data, such as using computer vision algorithms to do feature-based similarity searches over images, video and audio. Other research attempts are also effective. For example, one recent research is to use information visualization to retrieve TV news (Luo et al. 2006) in large-scale news video collections and provide more valuable information to the users.

Using keyword (text) is still the most direct way to search multimedia information content. Most current commercial systems use text to search for web pages, images, videos and other pieces of information. However, studies have shown that most users have difficulty using the query interface, especially when queries need to be specified in Boolean format. Users often misjudge what the results will be (Boyle et al. 1984; Young and Sheneiderman 1993). Many English-speaking users reverse the meaning of the English words AND or OR. Some inexperienced users may expect the search result of "term a AND term b" will result in the combination of results "term a" AND "term b" instead of the intersection of the two results.

The primary goal of a multimedia retrieval system is to provide effective browsing and searching tools for the user. It is clear that the design of such systems should be human-centric. Rodden did a study in 2001 trying to find if organization by similarity assists image browsing (Rodden et al. 2001) and helps designers to seek design materials. The study performed an experiment asking users to choose photographs to illustrate a set of "destination guide" articles for a new "independent travel" website. Images were arranged based on similarities (visual or caption). The visual content similarity view was compared with a text caption similarity view, and a randomly arranged view was compared with a visually similar view as well. The study shows that arranging a set of thumbnail images according to their similarity is indeed more useful to designers than arranging thumbnails in random. Caption-based arrangement helped to break down the set according to meaning, which was rated significantly higher (3 out of 4, 4 as strongly agree) than visual similarity (2 out of 4). This research reminds us that text annotation is still the most valuable information to help people search for media content on top of content-based methods. For example, in an online learning object repository, an instructor will look for a learning object of a specific topic. In such a case, the user might carefully define his/her querying terms (keywords, metadata etc.) and narrow down the searching range until the object is retrieved. Here the annotation is even more important. Since there are no other evaluations or comments, it is hard to determine whether the content is really suitable unless one reviews all the contents.

In many systems, the search result is simply a list sequenced by its relevance scale to the searching term. A joint eye tracking study, conducted by search marketing firms Enquiro and Did-it, and eye tracking firm Eyetools, has shown that the vast majority of eye motion activity during a search happens in a triangle at the left top of the search results page, which indicates that the areas of maximum interest create a "golden triangle" (Hotchkiss 2005). Visibility drops quickly with lower rankings: starting at a high of 100% for the top listing, dropping to 85% at the bottom of the "above the fold" listings (the section of a web page that is visible without scrolling), and then dropping dramatically below the fold from 50% at the top to 20% at the bottom. In other words, in a ranked list, only the top three draw the maximum attention. Attention to any items listed beyond top ten will drop dramatically. This traditional list layout will cause the majority of the information to be ignored by users. This is not fair for similar information pieces as a very tiny difference on the “ranking” score may cause a big difference of user perception. This research result reminds us that a good system should represent information in a fair and complete way. Condensing such information and placing it into a compact space may give users better visibility of all the information.

3.5.2 Neighbourhood and Amplified Navigation (neighbour exhibition or neighbour resources)

If a user has an interest that is either poorly defined or inherently broad, the user might use an interactive interface to simply look around the collection of documents without a specific search. In this situation, the user is browsing. A similar situation happens when people visit a gallery or museum (physical or online). Such visitors may be attending generally to expand their knowledge. Since there is no clear objective, a visitor might be attracted by one point and ignore others. Therefore, different visitors might have different navigation paths even though they started at the same point. Apart from that, all humans look for novelty. When something special shows up, the visitor is easily attracted and wants to discover more.

Proposed by Bates (Bates 1989) and supported by several observational studies, the "berry-picking" model of information seeking illustrates two main characters of human search activities. First, as a result of reading and learning from the information encountered throughout the search process, users shift both information needs and their queries. Information encountered at one point in a search may lead in a new, unanticipated direction. The second characteristic is that users' information needs are not satisfied by a single, final retrieved set of documents, but rather by a series of selections found along the way. Thus a user interface for information access should allow users to reassess their goals and adjust their search strategy accordingly, as well as help users to keep to a particular search path.

The neighbourhood of a webpage is defined as the set of web pages that are reachable by a path of hypertext links within a maximum predefined distance. In EAR structures, the neighbourhood of an object can be any objects that have relation within a predefined distance. As discussed at the first half of this chapter, the distance and these neighbourhoods are transitive. Direct relations such as inclusion, being included and links define close and direct neighbours, like the attached room in a physical gallery. Examples of transitive relations are co-citation, bibliographic coupling, or certain stages of similarity - they are non-direct neighbours. It is hard to access these directly in a physical gallery context, but they could be easily accessed in the digital world. If the neighbourhood information can be well presented and the user can easily jump from one place to another, shifting needs could be satisfied, and these neighbour objects may yield new ideas and new directions.

In a physical gallery, people visit exhibits located in different rooms by following a path. In the digital world, the user's browsing history also defines a path. CZWeb (Collaud 1995) maps a user's visitation history of the web space to automatically generate a flexible map for websites as they are visited. When a user navigates through direct links, for example, from one exhibition to another similar exhibition, or from one resource to another resource, he may need to go through exhibition → resource → new exhibition (back linked from the resource), or through resource → exhibition → other resources. It may take more effort for the user to remember the navigation path. In contrast, the indirect neighbourhood enables user access to a similar object directly as exhibition→similar exhibitions or resource → similar resources. When the indirect neighbourhood and the direct neighbourhood can both be represented to the user and can be directly accessed, the user's searching results are enriched and navigation paths are amplified. Thus the "berry-picking" information seeking model may be well supported.

Annotations also play an important role in the browsing experience. For instance, users can learn much from the clear explanations made by the curator or comments left by previous visitors in a gallery. They can also be encouraged by the comments made by others to write down more notes for future references.

3.6 Summary

In the pervious chapter, I discussed the existence of EAR structure in different domains. This chapter emphasizes what is inside the EAR structure, why it is important, and how it can be used to improve information retrieval. Among EAR objects, there are different kinds of relations that form a hierarchy from simple to complex and from direct to indirect. Direct relations are link, inclusion and been-included. These direct relations can form transitive relations such as co-citation and bibliographic coupling, which also can be used to analyze similarity among objects and make recommendations to users.

In the later section of this chapter, I discussed users behaviour in the processes of information retrieval, and the possibility of using EAR relations to improve users' experience of information retrieval and browsing. We suggest that human commentary and annotation may have the potential for making multimedia content analysis and retrieval easier and more efficient. Also the indirect relations can potentially amplify the user's searching, leading him to a "new" area to explore more deeply.

Based on the relations among EAR objects, and issues around information retrieval and browsing, I suggest that a direct presentation of the EAR relations (visualization) is an efficient approach to support user information retrieval. In the next chapter, I will discuss how to utilize the relations among EAR objects by using different kinds of visualization and interaction techniques to provide better support for the user experience.

4 QUALITIES OF VISUALIZATION AND INTERACTION

4.1 Introduction

As the saying goes, "a picture is worth of a thousand words." Humans are highly attuned to images and visual information (Tufte 1983; Larkin and Simon 1987; Kosslyn 1989). If well designed, pictures and graphics can be captivating and appealing. The use of computer-based visual representation of data helps users enhance their cognitive capabilities in understanding such data (Card et al. 1999). Varied visualization techniques can be used to represent aspects of the information. Aside from using icons and colour highlighting, techniques of visual representation include brushing and linking, panning and zooming, focus+context, magic lens and animations, along with many graph visualization methods. In an EAR structure, these techniques may help users to access information and data dynamically, interactively and smoothly.

4.2 User Interface and Visualization

In his book "Designing the user interface," Ben Shneiderman states that "well designed, effective computer systems generate positive feelings of success, competence, mastery, and clarity in the user community. When an interactive system is well-designed, the interface almost disappears, enabling users to concentrate on their work, exploration, or pleasure" (Shneiderman 1997). To achieve the above goals, there are several principles for designing a user interface based on years of research: First, the interface should offer informative feedback - this is especially important for information access interfaces. It should provide feedback on relations among retrieved objects and have "internal locus of control" to allow users to take control of how and when feedback is provided. Second, the interface should reduce working memory load. Since human working memory is limited, the interface should provide a mechanism to keep track of, for example, a user's navigation path (click history). The system should also be able to provide browsable information that is related to the current object. Another challenge of interface design is to keep the balance between simplicity and power – although simplicity does not necessarily imply reduced power. In addition to the popular interface design tools such as windows, menus, icons and dialog boxes, information visualization could be used in the interface as an attempt to provide visual depictions. It is often useful to employ an information visualization strategy to provide overview and details (Plaisant et al. 1995; Green et al. 2000). A visualization graph could be put in the overview window, providing a "large menu" of the overall information space. Mouse clicks on this overview window open chosen detail in a new window.

Bertin (Bertin 1981; Bertin 1983) describes a display primitive classification model dividing the output primitives into four categories: *networks* (including trees and path connections); *diagrams* (including bar charts, scatter plots, histograms and schematics); *maps* (including geographical maps and diagrams of "real life" object positions; and Symbols (including signs and icons). Bertin also describes representation methods, named retinal variables, of shape, orientation, colour, texture, value and size. In EAR structures, a symbol (more precisely, an icon) can be used to represent individual objects, and the network can be used to show the relations.

4.3 Icon as Glyph

An icon is an image, picture, or a representation of an object. It is like a sign that stands for an object by signifying or representing it, or making an analogy to it. The function of an icon is to act as a symbolic representation, which shows essential characteristics or features of a data domain (Post et al. 1995). The main purpose of icons is to replace the original data by a symbolic representation that is clear, compact, and meaningful. An individual EAR object, that is, an exhibition, an annotation or a resource could be visualized by icons.

Icons have been studied extensively in many fields, for example, the theory of signs or semiotics and pictorial information systems (Chang 1989). In 1994, Hesselink and Delmarcelle made the first attempt to relate the meaning of icons to classic sign theory (Hesselink and Delmarcelle 1994). In scientific visualization, the icon concept is related to "Abstract Visualization Objects" (Haber and McNabb 1990). The term "glyph" is frequently used (Ribarsky et al. 1994), which is similar to the term icon as it is used here. This term connotes nonverbal information in the symbol or figure.

While using icons for scientific or feature visualization, an important aspect to consider is the degree of freedom, or parameters, that can vary for the icon and separately bounded data quantities(Post, Post, Walsum and Silver 1995). The parameters can be divided into three groups: spatial parameters (which decide the position and orientation), geometric parameters (which control the shape of the object) and descriptive parameters such as color, texture, transparency, and sound. Orthogonality of parameters is important in enabling the user to distinguish among several different attribute.

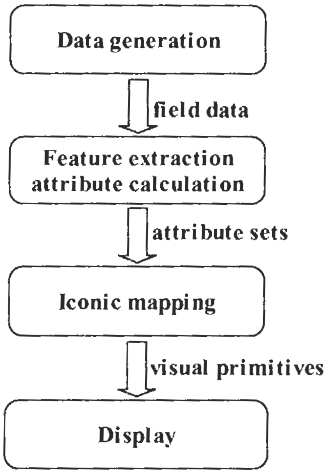

Figure 4-1 Iconic visualization pipeline[9]

Harber and McNabb proposed a visualization pipeline to describe the path from data acquisition to picture generation (Haber and McNabb 1990) through filtering and mapping. Derived from the visualization pipeline, Figure 4-1 presents the summarization of an iconic visualization processes. The goal of this iconic representation is to convey a summary visualization. The first step is to find the attributes that need to be represented in a summary, that is, features that are important and relevant. The next step is to determine how the characteristic parameter values of the features are calculated. The result is a set of "vectors"[10] that characterize the features. This step is also referred to as *feature extraction* or *attribute calculation*. In the next step of iconic mapping, each attribute is mapped onto parameters of icons to display the characteristics of an object in a clear and understandable way. Iconic appearances are determined by the way attributes are mapped onto icon parameters. The purpose of this process is to visualize features by objects that display the characteristics of a feature in a clear and understandable way. This stage determines the final appearance of the icon.

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[9] Reproduced based on Post et al., © [1995] IEEE

[10] "Vector" is used in an informal sense here.

Individual EAR objects, Exhibitions, Annotations and Resources, can be visualized by icons. Some evident features of Exhibitions are size (number of Resources and Annotations included in the Exhibition), time (when the Exhibition was created or modified), popularity (measured by clicks through the exhibition), strength of relations (strength of bibliographic coupling relations with a specific Exhibition). Similarly, Annotations and Resources all have features that can be parameterized and mapped to iconic visualization.

Icons are a compact method of representing individual objects in EAR structure. To represent the relations among these individual objects symbolically, I use graph visualization techniques.

4.4 Graph Visualization Models

Graph visualization is a useful way to represent relations among data elements. Objects can be represented by the nodes of a graph, with the edges representing the relations. Some familiar domains include: file hierarchies in a computer system, hierarchical illustrations of an organizational chart, web site maps (Collaud 1995), evolutionary trees in biology, and entity relation diagrams (UML and database structures). Graph visualization can also demonstrate relations among EAR objects. The basic graph drawing is simple: Given a set of nodes with a set of edges (relations), calculate the position of the nodes and the curve (line) to be drawn for each edge. There are several key issues in graph visualization: scalability, predictability, time complexity and aesthetics.

Scalability, the size of the graph, is a major problem in visualization (Herman 2000). It is well known that comprehension and detailed analysis of data in graph structures is easiest when the size of the displayed graph is small. If the number of elements is large, it can compromise performance or even reach the limits of both the viewing platform and human perception.

Predictability (Herman et al. 1998) can be referred to in the literature as "preserving the mental map" of the user, that is, two different runs of the algorithm, involving the same or similar graphs that should not lead to radically different visual representations. If the layout has been adjusted due to changes to the grapch, the new layout should preserve the relative spatial relationships of the previous layout.

When the visualization system has to provide near real-time interaction, **time complexity** needs to be addressed. Visual updates caused by the interaction must be done in very short time intervals to avoid the user from noticing delay.

Aesthetic rules also constrain the graphic layout. Planarity is one of the most important issues – "reducing the crossings is by far the most important aesthetic, while minimizing the amount of bends and maximizing symmetry have a lesser effect" (Purchase 1998). Other aesthetic rules include questions such as how to position the nodes properly and what is the suitable shape of the edges. Different graph layout (such as shape and colour) will produce different perception due to the nature of human perception systems. "Following perception-based rules, we can present our data in such a way that the important and informative patterns stand out" (Ware 2004).

In addition to such general rules, in the next section I will examine and evaluate several graph visualization models to help understand possible models for representing EAR structures.

4.4.1 Classic Tree Layouts

The tree is one of the most popular and basic data structures that represent relations among objects. A classic tree layout positions child nodes below their common ancestor. In Figure 4-2, the Reingold and Tilford algorithm is probably the most popular tree layout technique (Reingold and Tilford 1981). It can be top-down or adapted to bottom-up, left-right layout or grid-like positioning. This layout is planar – no edges cross. It can also obey certain aesthetic rules – nodes and edges can be evenly distributed, edges have the same length and be linear, nodes with the same depth can be placed on the same horizontal (or vertical) line, and the distance between siblings can be fixed. However, scalability is a problem. When the number of nodes increases, the horizontal space will expand accordingly, or the space between nodes will shrink. Eventually, the leaf will become too crowded to be read and understood meaningfully.

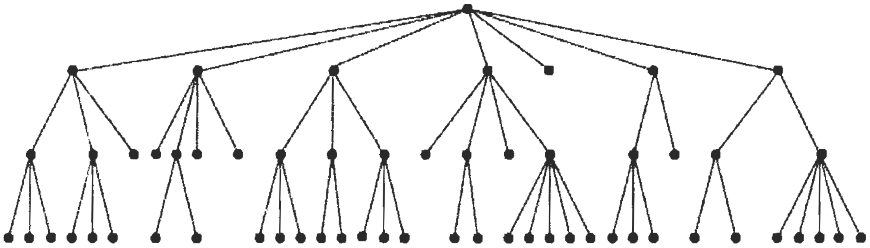

Figure 4-2 Classic view of tree layout[11]

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[11] Copyright: Yingjie Chen, 2006.

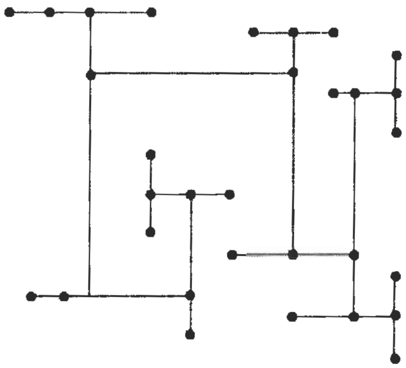

Figure 4-3 H-Tree Layout[12]

Classic tree layouts have different forms, such as H-tree, radial tree, balloon view, tree-map and onion notations. Figure 4-3 illustrates an H-trees, which performs well on balanced trees (Shiloach 1976). However, it does not clearly distinguish the root of the tree, and thus may lead users to explore the graph in a less hierarchical fashion. Figure 4-4 shows the balloon view which puts the sibling sub-trees in a circle around the parent node. It can be produced by a 3D cone tree projected on a 2D plane (Carriere 1995), or be computed directly (Melancon and Herman 1998).

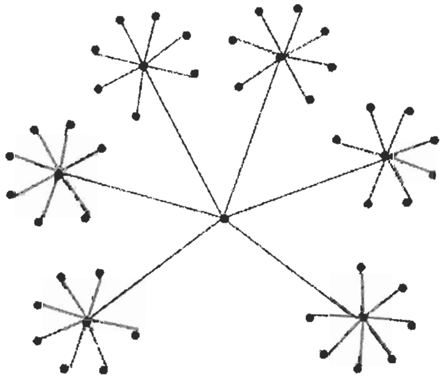

Figure 4-4 Balloon tree[13]

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[12] Copyright: Yingjie Chen, 2006

[13] Copyright: Yingjie Chen, 2006

The radial tree positioning put nodes on concentric circles according to their depth in the tree (Figure 4-5). Concentric circles can be used to represent temporal information (tree ring). A sub-tree is laid out over a sector of the circle and the algorithm ensures that two adjacent sectors do not overlap. Theron (Theron 2006) uses a similar Tree-ring layout to visualize both timing and structure in a single diagram and demonstrates how his "treevolution" system provides visualization and browsing over the history of computer languages.

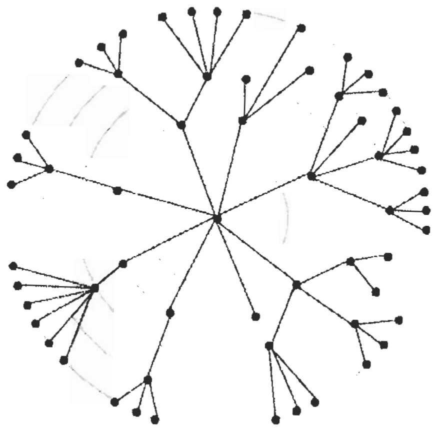

Figure 4-5 Radial tree[14]
Concentric circle can represent depth or temporal information

4.4.2 Treemaps and Onion Graph

Some graphic layouts do not look like a tree, but can also present tree-style information efficiently. Onion graphs represent trees through sequences of nested boxes. They are not limited to represent nodes and edges - the closed curve of the graph can also give the topological notions of enclosure, exclusion, and intersections. The onion notation graph in Figure 4-6 can be seen in several cases of inclusion, disjointedness and

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[14] Copyright: Yingjie Chen, 2006. Based on Theron 2006.

intersection of sets (Harel 1988). The right graph of this figure shows a more general graph that has intersection information.

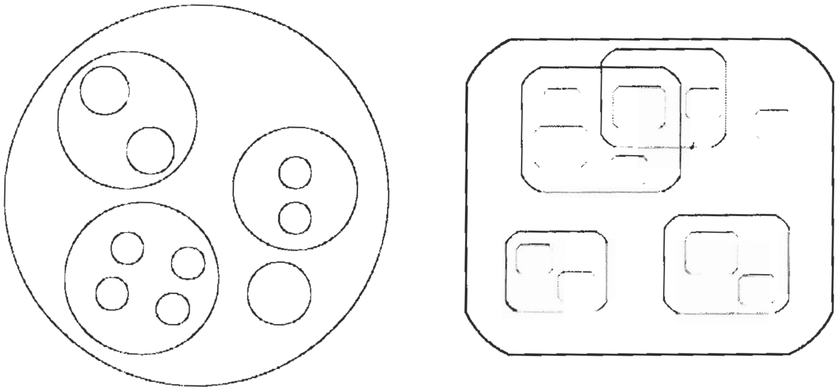

Figure 4-6 Examples of onion graph[15]

First designed by Shneiderman during the 1990s (Shneiderman 1992), Treemaps visualize hierarchical structures in a space-constrained layout (Figure 4-7). Treemaps transform a tree into a planar space-filling map. By using size and colour coding, attributes of leaf nodes can be effectively represented. The size of individual rectangles is significant and is effective in showing the size of the node. Treemaps enable users to compare nodes and sub-trees even at varying depths in the tree, and helps them spot patterns and exceptions. Variations of Treemaps have been developed and applied to different domains such as visualizing stock markets (www.smartmoney.com), computer file systems, oil production data, threaded discussion forums, project management (Cable et al. 2004) and discovering business intelligence (Shneiderman 2006). However, Treemaps present difficulties in perceiving the hierarchical structure of the information. Also, due to constraints of the space and the sole use of rectangles, the aspect ratio of rectangles is hard to control. Some rectangles may be too slim to see, select and compare

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[15] Copyright: Yingjie Chen, 2006

in size (Turo and Johnson 1992). Cushion Treemaps (Wijk et al. 1999) are an attempt to overcome this problem. They use shading of a curved surface to provide a cue for the hierarchical structure so that substructures can be identified.

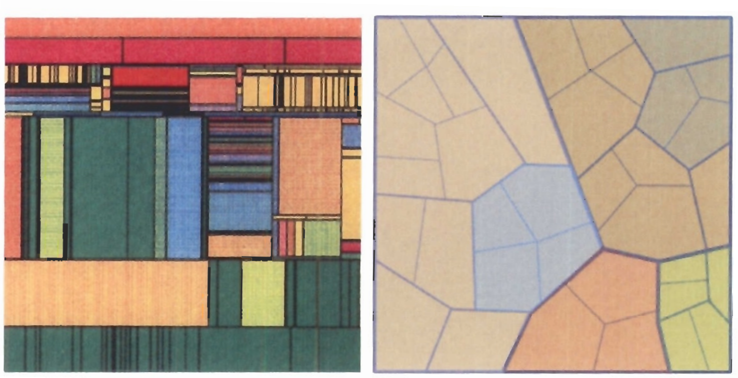

Figure 4-7 Treemaps[16]

Treemaps can also be displayed in forms other than rectangles to overcome the aspect ratio problem. Voronoi treemaps (Balzer et al. 2005) use Voronoi tessellations (a polygon-based subdivision algorithm) instead of rectangular shapes. They avoid the problems with the aspect ratio of the rectangles and also better visualize hierarchical structure.

4.4.3 Sugiyama Layout

Relations among EAR objects are more complex than trees. Due to co-citation and bibliographic-coupling, there are cross-links in the graph that make it no longer a tree but a general graph. Simply adopting a tree-layout and linking all the nodes may create too many cross edges that will reduce readability. Especially when dealing with small and sparse graphs, it is important to check for planarity.

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[16] Left image under permission from copyright holder. Right image based on Bazler 2005, copyright: Yingjie Chen, 2006

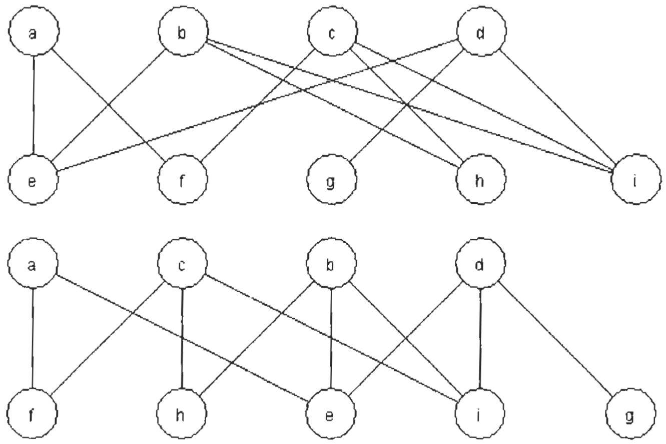

Figure 4-8 **Two level example of Sugiyama graph layout**[17]
Top: original messy graph with many edge crossings
Bottom: simplified graph after processed by the Sugiyama Algorithm

In 1988, Sugiyama et al. developed the Sugiyama layout (Figure 4-8) to produce readable diagrams by balancing the graph and reducing edge crossings (Sugiyama et al. 1989). The goals of the layout are: hierarchical layout of vertices, minimal crossing edges, straight and balanced layout of edges, and proximity of connected vertices. There are four steps in the algorithm:

- Adding dummy nodes (injecting) to form a proper hierarchy;
- Permute vertices on each level to minimize crossing edges, sort levels by barycentres, then consider two levels at a time with one fixed, another adjusted according to the fixed one;
- Assign horizontal positions to achieve straight lines, close vertices and maximize edge balancing – that is, to iterate up and down to assigned position of nodes on a level of priority order assisted by assigning dummy

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[17] Based on Sugiyama Algorithm. Copyright: Yingjie Chen, 2006.

    nodes, and order the remaining nodes by fan-in or fan-out. When positioning the node, move it to its barycentre; and
  - Remove dummy nodes and output the graph.

This algorithm is effective, easy to implement and has been widely cited and used.

4.5 Representing the Context

4.5.1 Preview and Overview in Context

The size and heterogeneity of digital libraries presents difficult problems for information retrieval. Users demonstrate a range of actions. Some roam the aisles scanning jackets for titles and authors, and flip pages on a whim. Others search for specific authors or subjects. Scholars follow reference and citation trails. In emerging digital libraries, designers often fail to provide appropriate views of materials that give an overall sense of the structure and materials. Green et al (Green, Marchionini, Plaisant and Shneiderman 2000) present a design framework for information representations in term of previews and overviews. Previews and overviews are graphic or textual representations of information abstracted from primary information objects. If used properly, previews and overviews allow users to rapidly discriminate objects of interests and more fully understand the scope and nature of digital libraries. Green et al. define preview and overview as follows:

A preview is extracted from, and acts as a surrogate for, a single object of interest.

An overview is constructed from, and represents, a collection of objects of interest.

Information retrieval is a dynamic and iterative decision-making process in which users are engaged in changing their knowledge state (Marchionini 1995). This view holds that except for known-item searches, information seekers initiate search through a query or by browsing in a subset of the digital library. Users scan objects rapidly to determine whether to examine them more closely or move on to a new object. This process continues until the information need is satisfied or the search is abandoned. Therefore, the system design is expected to provide multiple levels of representation for information objects. Directed by such an information retrieval view, Green suggested a design strategy to provide users with overviews of collections that are used to select more detailed overviews or specific previews. Where appropriate, an overview can also provide direct access to primary objects that directly appear in the overview.

Previews are analogous to bibliographic records and overviews are analogous to a catalogue. In EAR structures, an exhibition can be seen as the overview of collected resources and annotations, and thumbnails or icons can be seen as previews of resources. When a user enters an exhibition, he/she will see the overview of the included resources, annotations and sub exhibitions. Inside such an overview, the user can examine the previews of all collected resources to decide if he/she wants to spend some effort to look at them in detail.

4.5.2 Focus + Context

Many physical domains can be represented as node-link graphs. Visual depictions of graphs and networks are external representations that aim to exploit human visual processing to reduce the cognitive load of many tasks that are required in the understanding of global or local structure. *Focus+context* graphs are designed to relieve the load on working memory by linking context information. When there are many objects and many relations among these objects, visually representing all information in detail may create a complex graph that is impossible to read. With the focus+context technique, only some key information is present to make the graph simple. When the user is focusing on specific object, detailed contextual information around the object could be shown, so that the user needs to remember just the local relations but also has the ability to see the whole space.

A well-known problem with zooming is that if one zooms to a specific area, contextual information is lost. Some systems' solution is to keep a separate window open in order to keep the context visible, but the connection between contexts is often weak. Such loss of context can become a considerable usability obstacle. *Focus+context* techniques allow the user to focus on detail without losing the context.

Focus+context displays the most important data at the focal point in full size and detail, and displays the contexts in the area around the focal point to help make sense of the important information in the data structure. Regions far from the focal point may be displayed smaller or selectively omitted. This technique does not replace zoom and pan, but rather complements them. The complexity of the underlying data might make pure pan+zoom an absolute necessity.

Focus+context techniques include fisheye distortion (Sarkar and H.Brown 1992), polyfocal display (Kadmon and Shlomi 1978), bifocal lens (Apperly et al. 1982), perspective wall (Mackinlay et al. 1991), and cone tree (Robertson et al. 1991). After decades of exploration and development, the most popular approach for focus+context is still fisheye distortion. It imitates the well-known fisheye lens effect by enlarging an area of interest and showing other portions of the image with successively less detail. Focus+context techniques have been implemented and explored by researchers in different directions. Jayaraman and North (Jayaraman and North 2002) proposed a radical focus+context visualization for multi-dimensional functions in engineering disciplines. It can scale smoothly from two dimensions to 10-20, with a 1000 pixel range on each dimension. CZWeb (Fisher et al. 1997) provides fisheye views to visualize and navigate the web by using a light-weight focus+context technique. It is also a good example of combining continuous zoom with fisheye views.

4.5.3 Visualizing Large Image Database with Context

In most image database systems, image data are put into categories related to metadata and keywords. The result of a query in the image database systems is usually a set of images, displayed in an Image Browser or shown in a two-dimensional grid of thumbnails (Ogle and Stonebraker 1995). For document browsing, the Document Lens (Robertson and Mackinlay 1993) uses a focus+context technique to display the document of interest in detail while compressing the rest of the document space. Image browsing systems also display the entire space of images either without hierarchies (the default for most file managers) or with some structural information provided by annotations (Kang and Shneiderman 2000). Apart from giving an overview of the entire document/image space, recent projects such as Concentric Rings (Torres et al. 2003) and MoiréGraphs (Figure 4-9) (Jankun-Kelly and Ma 2003) highlight the relations among documents/images. However, in their detailed examples, images are overlapped and relation lines are entangled with each other. It seems that the design issue of visualizing large sets of resources remains open.

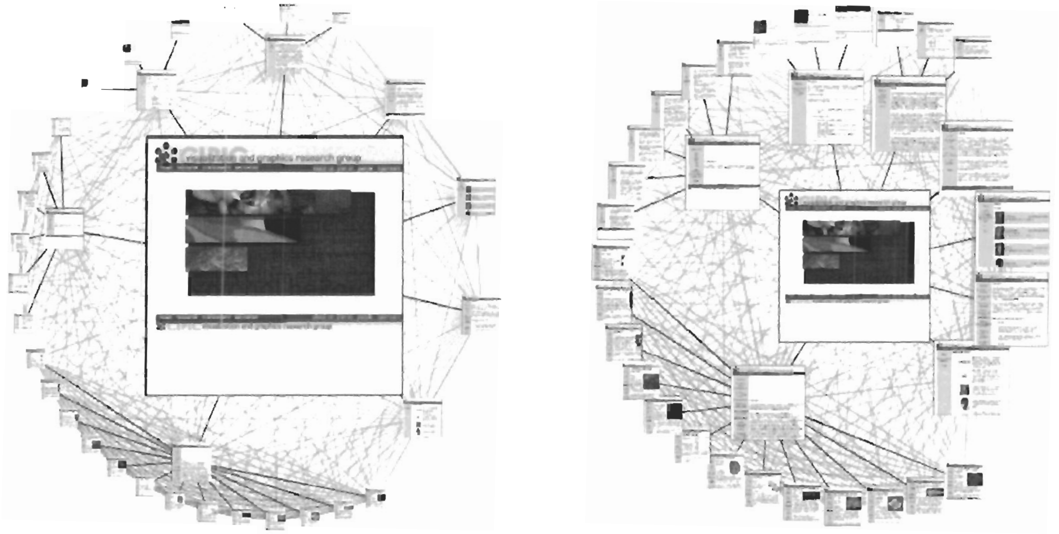

Figure 4-9 MoiréGraphs with different focus length [18]

4.6 Compact Visualization with Rich Information

Understanding can be improved if the user can see the whole picture at a glance while still retaining the detailed context. To make sure the user can see the whole picture, the visualization should be small. A small-scale compact visualization embedded into an application can dramatically increase a user's experience of the application.

4.6.1 Useful field of view

"Useful field of view" (UFOV) is a concept developed to define the size of the region from which we can rapidly take in information (Ware 2004). When we are reading fine print, we can read only the words within the fovea view, but we can see the overall shape of a larger pattern at a single glance. From being as narrow as one degree to as large as 15 degrees, the UFOV varies with target density to maintain a constant number of targets in the attended region. With the greater target density, the UFOV becomes smaller and the attention is more narrowly focused. With a low target density there is a

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[18] (Jankun-Kelly and Ma 2003) By permission.

larger UFOV. Compared with modern computer monitors, the UFOV occupies a relatively small portion of the whole screen. Condensing information into a compact space within the UFOV might be a useful strategy.

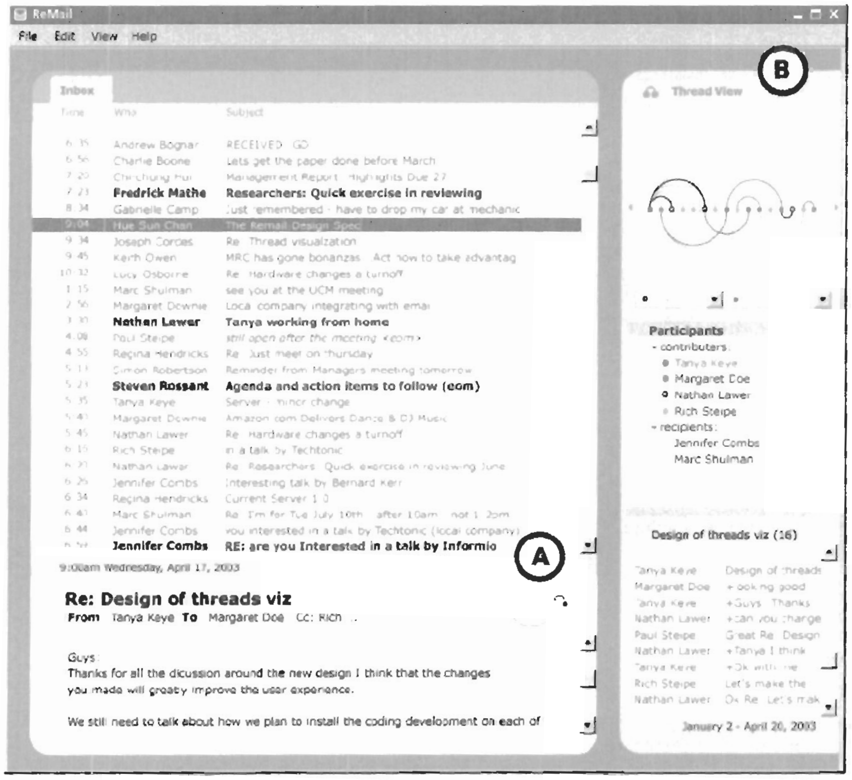
4.6.2 Thread-Arcs email visualization

Thread-Arcs email visualization is a novel interactive visualization technique designed to help people make use of threads found in emails (Figure 4-10) (Kerr 2003). Thread-Arcs combine the chronology of messages with the branching tree structure of a conversational thread in a stable and compact visualization panel. Visually it remains simple with nodes and connecting arcs, allowing users to find messages and see trends in the thread easily. By quickly scanning and interacting with Thread Arcs, people can see various attributes of conversations and find relevant messages in them.

The exchange of emails (such as reply-to) constructs tree-style conversation threads. Relations in such threads are simple. The first email of a conversation is called the "root," any message that is being replied to is called the parent of the message, and any replies to a message are called children of that message. Inspecting these threads gives users the context of the messages they are reading, reminds the users that a conversation is ongoing, records the state of discussion, automatically collates related messages, and allows users to perform actions such as reading or deleting a group of messages (Kerr 2003).

Chronology, relations and message attributes are basic information that needs to be visualized. Chronology is the arrival sequence of the messages in the thread. Users should easily locate the root message, following messages and the most recent message.

"Reply-to" relation tells users the direct relations between messages in the thread. Other message attributes such as messages sent by a particular person or in a particular day, and unread messages are all important characters that should be easily recognized in the visualization.



Time	Who	Subject
6:35	Andrew Bognar	RECEIVED GO
6:56	Charlie Boone	Lets get the paper done before March
7:20	Chi-chung Hui	Management Report Highlights Due 27
7:23	**Fredrick Mathe**	**Researchers: Quick exercise in reviewing**
8:34	Gabrielle Camp	Just remembered - have to drop my car at mechanic
9:04	Hue Sun Chan	The Remail Design Spec
9:34	Joseph Cordes	Re Thread visualization
9:45	Keith Owen	MRC has gone bonanzas Act now to take advantag
10:32	Lucy Osborne	Re Hardware changes a turnoff
1:15	Marc Shulman	see you at the UCM meeting
2:56	Margaret Downie	Local company integrating with email
3:30	**Nathan Lawer**	**Tanya working from home**
4:08	Paul Steipe	*still open after the meeting <eom>*
4:55	Regina Hendricks	Re Just meet on thursday
5:11	Simon Robertson	Reminder from Managers meeting tomorrow
5:23	**Steven Rossant**	**Agenda and action items to follow (eom)**
5:35	Tanya Keye	Server - minor change
5:40	Margaret Downie	Amazon com Delivers Dance & DJ Music
5:45	Nathan Lawer	Re Hardware changes a turnoff
6:15	Rich Steipe	in a talk by Techtonic
6:20	Nathan Lawer	Re Researchers Quick exercise in reviewing June
6:25	Jennifer Combs	Interesting talk by Bernard Kerr
6:34	Regina Hendricks	Current Server 1.0
6:40	Marc Shulman	Re I'm for Tue July 10th after 10am not 1 2pm
6:44	Jennifer Combs	you interested in a talk by Techtonic (local company)
6:50	**Jennifer Combs**	**RE: are you Interested in a talk by Informio**

9:00am Wednesday, April 17, 2003

Re: Design of threads viz
From Tanya Keye **To** Margaret Doe CC: Rich ..

Guys:
Thanks for all the dicussion around the new design I think that the changes you made will greatly improve the user experience.

We still need to talk about how we plan to install the coding development on each of

Participants
- contributers:
  - Tanya Keye
  - Margaret Doe
  - Nathan Lawer
  - Rich Steipe
- recipients:
  - Jennifer Combs
  - Marc Shulman

Design of threads viz (16)

Tanya Keye	Design of threads
Margaret Doe	+ ooking good
Tanya Keye	+Guys Thanks
Nathan Lawer	+can you change
Paul Steipe	Great Re Design
Nathan Lawer	+Tanya I think
Tanya Keye	+Ok with me
Rich Steipe	Let's make the
Nathan Lawer	Ok Re Let's mak

January 2 - April 20, 2003

Figure 4-10 Thread Arcs integrated into email client prototype. [19]
A: the preview pane of email client. B: The thread view pane. (Kerr 2003)

Kerr's project addresses several visualization principles: chronology, relations, stability, compactness, attribute highlighting and scalability. For easier cognition, the visualization should be small-scale, compact and stable.

The threads are only meaningful when they are accompanied with message contexts. Users should see the thread visualization and the content of the message in the

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[19] © [2003] IEEE. By permission.

same screen simultaneously. Therefore, it is better to imbed the visualization into the personal email client. Compactness is important. At one glance, the user should be able to see the contextual information of the email. Compactness will also enable the visualization to compete with other spaces required for email functionality.

To reduce cognitive load, stability needs to be considered so that different runs of the visualization algorithm yield similar layouts. The appearance of each message (especially locations relative to each other) should be kept consistent in the visualization so that users can easily return to the message and its thread, and find the same message or see new messages if the thread grows.

When dealing with dynamic data, scalability is always a concern. If the email conversations involve many people and occur over long periods, the threads become large and complex, but the visualization should remain clear and interpretable. However, since the vast majority of email threads are typically between 2 to 20 messages, it does not need to scale to handle hundreds or thousands of messages.

The threads are visualized in a node-link graph. Message nodes are linearly distributed from left to right connected by arcs. The positions of the nodes represent the chronology of the messages. The first message (root) is at the far left end and the most current message is at the other end. This format also makes the visualization stable and compact. Reply relations are represented by connection arcs. Since the horizontal length of the visualization is determined linearly by the number of messages, further limiting the size vertically, then once the arcs reach a certain height, they are flattened out at the top, thus the visualization only grows horizontally.

In Thread Arcs, different colours and shading (grey or colour scale) are used to represent message attributes such as highlighting personal, and distinguishing contributor, generation, and time. When certain email is selected, the node is changed to a circle instead of a dot. Interaction allows users to examine threads and emails in detail. Thread Arcs also have an interaction to allow users to highlight and inspect thread and message attributes dynamically. It allows one to decide which attributes are relevant to the task and display them when needed.

Evaluation of Thread-arcs shows that they are well suited for the size and type of conversations found in user email. With such a compact visualization, users are able to see, at a glance, the size of the thread and the number of responses to any specific message. Attributes encoded in the Thread-arc also allow users to find important messages or predict the types of conversations. Thread Arcs thus comprise good example of compact visualizations with rich information.

4.7 Immediacy and direct manipulation

Media present both themselves and the external events they depict to users. Users interact with a medium and so are indirectly interacting with the event. Principles of immediacy and direct manipulation need to be addressed in a good system design. Immediacy is the perfection, or erasure, of the gap between signifier and signified, such that a representation is perceived to be the thing itself. It is a consequence of what Kenneth Burke calls "naive verbal realism" (Burke 1968) whereby the symbol is simply perceived to be a window to reality. The desire for immediacy is the desire to get beyond the medium and get to the objects of representation themselves. A good user interface should bring the user face-to-face with whatever is being manipulated and experienced.

David Ungar shows how the experience of immediacy can be conveyed in a programming environment to draw a programmer closer to the program (Ungar et al. 1997).

In an interactive system, the designer should attend to at least three kinds of immediacy that are important for users experience in the design process, as follows: temporal immediacy, spatial immediacy and semantic immediacy. These three qualities bridge the gap between the cause (user interaction) and effect (system response) in three dimensions: time, space and semantics (Ungar, Lieberman and Fry 1997).

Temporal immediacy links cause and effect. Humans recognize causality without conscious effort only when the time between causally-related events (latency) is kept to a minimum. If there is a delay between a change in a steering wheel and the response of a car, the steering is "mushy": the delay destroys the feeling of immediacy in controlling the car. During a user's interaction, the delay between cause and effect strains short term memory while waiting for the system to catch up. In a visualization system, this issue is called *time complexity*. The updates must be done in a very short time frame in order to escape the notice of the user.

Spatial immediacy means that the physical distance between causally related events is kept to a minimum. The reason is the same as temporal immediacy – objects that are widely separated by space on the screen force the user to devote more conscious effort to link them, forcing the user to shift attention and strain short-term memory. Spatial immediacy is important because it maintains visual context. Seeing two related pieces of information next to each other fosters semantic connections in the mind between those pieces. If objects are spatially separated, "out of sight" becomes "out of mind."

Semantic immediacy means the conceptual distance between semantically related pieces of information is kept to a minimum. In interactive interfaces, the conceptual distance between two pieces of information is often represented by the number of operations, such as mouse clicks. In the hypertext world, users will easily get lost during the navigation if there are too many clicks between information pieces. Semantic immediacy is important to help the user maintain the navigation path in his mind to make the information retrieval process efficient.

4.8 Summary

Information visualization is useful in visualizing EAR objects and may help users understand them. In visualizing EAR objects, I am interested in representing object relations and context as well as the EAR objects themselves. Therefore, my focus is on representing the object and context, as well as reviewing the current theories, technologies and design projects.

In this chapter, I discuss several visualization methods and key qualities of how to create effective interactive systems. For a single object, I argue for the use of icons to represent features of the object. For visualizing relations between objects, node-edge graphs are an intuitive solution. I investigate classic tree algorithms such as H-tree, balloon view and radial tree, and some tree variations such as Treemaps and onion-graph. The Sugiyama algorithm is introduced to reduce cross edges in the node-edge graph, In a higher level of visualization system design, overview/preview and focus+context can benefit users in getting detailed information about the focused object as well as keeping the context in mind. In the later section, a compact visualization project of email threads (Thread-arcs) is analyzed and discussed in detail as one of the primary references for visualizing EAR objects. Finally, immediacy of direct manipulation is another principle for designing interactive visualization systems.

In the next chapter, I will introduce A•VI•RE, a general multimedia repository that implements the EAR structure. To better understand the relation between the EAR objects, a compact visualization panel "NEAR" is proposed to help users in "**N**avigating **E**xhibitions, **A**nnotations and **R**esources". Theories, technologies and design principles discussed in this chapter will act as guidelines for the design the NEAR visualization panel.

5 DEVELOPMENT PROCESS OF NEAR

5.1 About A•VI•RE

A•VI•RE (a Visual Rete, available at: http://www.AVIRE.ca) is a generic repository for visual material related to cultural disciplines. A•VI•RE is designed to be an online space where different users (such as curators, exhibitors, critics and viewers) play together to create a large social entity. Users upload new resources, organize exhibitions (by browsing other exhibitions' resources or by using uploaded resources), and annotate resources and exhibitions (in their own exhibitions or in public exhibitions) in the system. A•VI•RE uses Wiki technology as its main annotation device.

A•VI•RE began as an digital collection system, intended to be repurposable for such tasks as online galleries, academic slide collections, student work repositories and peer-reviewed collections of papers. The abstract components of A•VI•RE comprise the object types *Exhibition*, *Resource* and *Annotation*, and the roles of *Curator*, *Exhibitor*, *Critic* and *Viewer*. EAR structures abstract A•VI•RE object model by removing its gallery connotations and user roles.

5.1.1 Structure of A•VI•RE

Having three kinds of data elements (Resource, Exhibition and Annotation), the information structure of A•VI•RE was designed on the following principles:

- A resource can be any type of digital work, such as an image, a multimedia file, a paper, or a webpage.

- An exhibition is a collection of exhibitions, annotations and resources.
- An annotation is a mixture of text and references to exhibitions, annotations and resources.
- One resource, annotation or exhibition can be referenced in multiple exhibitions.
- Each exhibition or resource has metadata[20].
- Exhibitors can choose an annotation as the primary default view to represent the exhibition, or the system will generate a default annotation.
- Annotations can share information through a Wiki page. [21]

When a user visits A•VI•RE, he/she looks at three different types of objects: Exhibition, Annotation and Resource. The exhibitor may choose two different ways to represent the exhibition. By default, the system composes a webpage showing the first 20 resources of the exhibition. Or the exhibitor can choose one annotation as the default description (default view). An annotation is displayed as a standard webpage mixed with text and resources (images, multimedia files or icons for non-displayable files).

Although a resource can be any type of file, an image is still the most common file type in A•VI•RE. To make user access to the resources quick and easy, each image resource has four levels of size and detail for different situations. The levels are:

- 40 x 40 thumbnail. The image is resized and cropped to a 40 x 40 thumbnail. This size provides the quickest preview of many resources in a limited space.

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[20] In the future, annotations will also have metadata.

[21] Wiki is an open-source application to share information and support online collaboration through using WikiWord.

- 95 x 134 thumbnail. This size gives a better preview. The “resources” page of an exhibition uses this size to list all referenced resources.
- 800 x 600 image. In this size, most details of the photo can be seen by the user. The resource information page displays the image in this size as well as all the metadata of the resource
- Original image. The original file uploaded by the user which provides maximum resolution and detail, but also takes the longest time to download.

For other types of files, if it is playable inside the web browser, such as a Macromedia flash file or a Quicktime movie, the resource information page will play it directly. Files that are not playable in the browser are represented by file type icons adopted from popular operation systems (Windows and Mac OS X). For any resource, the user can download the original file from the link provided in the page.

The annotator does not need to know any HTML code to write the annotation (HTML code can be used for special layout and effects). In the annotating page, the user types in plain text, clicks on the resource thumbnails to insert the resource ID along with the text, and saves the page to create the annotation as a standard webpage with a mixture of text and image. Wiki technology is used to render the page. The user can use WikiWords to create and share Wiki Pages among annotations.

An A•VI•RE exhibitor usually interacts with the system in two steps: collecting favourite resources (creating an exhibition) and interpreting his collection (making annotations). Therefore, an exhibition and its annotations are the exhibitor’s interpretation of the collected resources. One exhibitor sets up an exhibition and writes annotations, while another exhibitor might collect the same resources but interpret from a different perspective. Thus, A•VI•RE provides views of an object from different perspectives to the users.

Users' activities such as uploading resources, writing annotations, creating exhibitions, referencing resources into different exhibitions, and revising annotations, are all recorded in the database with a timestamp. The timestamp information can be used to track the history of A•VI•RE objects.

5.1.2 Issues in A•VI•RE navigation

"Usability rules the Web. Simply stated, if the customer can't find a product, then he or she will not buy it"(Nielsen 2000). A•VI•RE shares similar issues with most online galleries on the usability of navigation, browsing and data retrieval. "The designers of museum Web sites often invest huge amounts of time and money in developing extensive Web sites with fabulous content. Not analyzing these Web sites for usability can mean users of the site will fail to discover and appreciate this rich content" (Marty and Twidale 2004) . Some usability flaws of museum Web sites pointed out by Marty are:

- Too much content. The large amount of content and choices may frustrate users, lead users to focus on only one area at the expense of others, and confuse people when looking for specific information if there are too many perspectives.
- Artistically designed graphical user interfaces bring confusion to the user who simply wants to know "what do I do now." Such interfaces may be disorienting and distracting to users trying to accomplish tasks, and may also be perplexing and meaningless to users trying to navigate the Website.

- Unguided “exploratory interfaces” provided by the Website may turn quickly into an exercise in frustration for the users who have specific interests. Such interfaces may lead to too much random browsing and discourage users interested in exploring specific topics. Such interfaces often require users to make choices without understanding the consequences of those choices. Websites need to support both guided and unguided exploration and to include tools that allow users to quickly locate specific known items.

In A•VI•RE, there are two ways to locate a resource: listing or searching. Lists post titles of exhibitions or thumbnails of resources page by page, normally in chronological or popularity order. In chronological order, the most recent visited item is first. If it is in popularity order, objects are listed by the number of clicks items received. The list is efficient in showing the most recent objects (chronological order) or the most popular objects (clicks order). Neither of the two methods scales, so it takes users much effort to locate any specific object through listings.

Searching by keywords is the most direct and common way to find specific information in modern applications. Search results are lists, typically ordered by relevance. As we stated in 3.5.1, users might have difficulty in formulating a query (define the searching term) especially when Boolean logic is used (Boyle, Ogden, Uhlir and Wilson 1984; Young and Sheneiderman 1993).

A list of all the objects line by line is not the best way to represent the information. Due to the nature of the human eye, “useful field of view” (UFOV) (Ware 2004) can only cover a small portion of modern computer display. Research on eye movement (Hotchkiss 2005) also tells us that the maximum visibility of the search result only happens on the "golden triangle" at the top left corner of the list. Most entries in such lists will be ignored.

Other usability issues in A•VI•RE include:

- **It is hard to provide a contextual view of a resource.**

  A resource can be referenced by multiple exhibitions and referenced by multiple annotations, so it naturally bridges different interpretations and connects interesting ideas. However, when a user looks at the information page of a resource, he/she only sees its original properties. For example, there is no indication that a resource is popular (having been frequently visited and used), and no indication if other exhibitions share the same resource. The system should provide a multiple views of a resource from different perspectives.

- **It is hard to see the relations between exhibitions.**

  An exhibition might share resources with other exhibitions or belong to other exhibitions. These relations are potentially valuable references for users. However they are not displayed.

- **It is possible to see a resource be referenced by multiple exhibitions and annotations and concepts across annotations, but hard to see the relations between annotations and exhibitions.**

  The annotation part was built on one kind of Wiki template: TikiWiki (Tiki Groupware 2004). Annotations in A•VI•RE can share resources and concepts through using WikiWords. It is unnecessary to visualize the map of annotation pages because it is designed to be an interpretation pool from which ideas grow. However, the user would want to see how an annotation can be made across exhibitions to connect interpretation perspectives. In the original version of A•VI•RE, this contradiction has not been solved.

- **It is hard to locate relevant resources, exhibitions and annotations.** Resources are organized in an exhibition by the exhibitor. It is easy to search one resource or exhibition by key words. However, sometimes a user may want to search for an object that is related to a known object. In such a case, the user may only have a vague idea of how the sought objects can be traced from some known objects. Although he can locate the known objects, searching for an unknown object is still difficult due to the lack of information about the direct keywords or metadata. If we can show users more hints about related exhibitions and annotations, searching for a specific resource among more than thousands of resources could be easier.

To solve the above issues, I propose a compact interactive visualization panel to help users visualize, analyze and navigate through EAR objects. The panel's name is called "**N**avigating **E**xhibitions, **A**nnotations and **R**esources" (NEAR). Based on the discussion in chapter 3 and 4, I believe a compact, small-scale, interactive visualization embedded into the interface of the A•VI•RE system can enhance the user's experience while browsing, navigating, understanding and using information in this generic multimedia repository.

5.2 Methodology

To make NEAR, I used the spiral model of software development as my methodology and work with circles of Design – Evaluate – Improve and Redesign.

In his 1970 paper, Royce (Royce 1970) proposed what is now popularly referred to as the waterfall model as a straw man for critique. He then explored how this initial model could be developed into an iterative model, with feedback from each phase influencing previous phases, similar to many methods used widely. The model adopted by this research, the *spiral model,* is a software development process combining elements of both design and prototyping-in-stages, in an effort to combine advantages of top-down and bottom-up approaches.

The spiral model was defined by Barry Boehm in his article "A Spiral Model of Software Development and Enhancement" (Boehm 1986) . This model was not the first model to discuss iterative development, but it was the first model to explain why iteration matters. Each phase starts with a design goal and ends with the client (who may be internal) reviewing the progress thus far. Analysis and engineering efforts are applied at each phase of the project, with an eye toward the end goal (Boehm 1988). A typical cycle of the spiral begins with the identification of the objectives of the portion of the product being elaborated (performance, functionality, ability to accommodate change, etc). Then the designer implements or alternates this portion according to the objectives and imposed constraints. The next step is to review and make sure that the objectives are achieved, and constraints have been satisfied. Such review also may set new objectives and discover new constraints.

Before the implementation of NEAR, I planned several spiral design circles to improve the design from the quality and quantity perspectives. On one hand, I tried to enhance the qualities of usability and recognizability for users in each cycle based on user feedbacks. On the other hand, to enrich the functionality and increase the visualization compatibility, some new functions were added and the performance was tuned.

5.3 Key qualities for representing A•VI•RE objects

In previous chapters, I discussed the relations among Exhibitions, Annotations and Resources and some key qualities for an effective representation of such objects. In this section, I relate these general concepts to the specific situation of A•VI•RE.

5.3.1 Key properties of A•VI•RE objects:

Outlined below are several important characteristics of resources, exhibitions and annotations, along with a brief discussion of their value.

1. **Relations** - These relations among resources, exhibitions or annotations give important context for user interpretation. These relations should be visible at a glance.
2. **Interpretation** - The process of collecting resources as exhibitions and writing annotations is the process of interpretation. One should be able to trace the interpretation history of an exhibition, an annotation or a resource and understand different perspectives around it.
3. **Popularity -** If one exhibition contains more resources and attracts much attention, or one resource has been annotated many times, they may be particularly interesting or useful. Users should be able to discern object popularity.
4. **History & Visit Status -** Users should be able to visually distinguish current, visited and unvisited items. User navigation is actually choosing a path to

explore the collection space. The awareness of such a path is helpful for a user to make the navigation decision and understand the consequence of his choices. [22]

5. **Change** - users should be aware of new or modified resources, exhibitions and annotations. New resources may be added to an existing exhibition and new annotations could be created to annotate old resources or exhibitions to provide additional support or commentary. Curators, exhibitors or annotators might also make modifications. These newly uploaded or modified items should be made known to users.
6. **Chronology** - Users should be able to see the evolution of an interpretation, so exhibitions and annotations would be sequenced by time of creation.

5.3.2 Key qualities of representation

The human perception system constrains the design of human computer interfaces. From these constraints, I argue several features of a visualization interface for EAR objects.

1. **Compactness** - Both eyes together provide a visual field of a bit more than 180 degrees, and detail is resolved at 10 degrees from the fovea (Ware 2004). For this reason, the graph's central area should be preattentive and information should be highly concentrated so that the user can see relations at a glance.

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[22] The information of removal (eg. A resource been removed from an exhibition) maybe worth discussing in future research.

2. **Preattention** – Preattentive processing of visual information is performed automatically on the entire visual field detecting basic features of objects in the display. Such basic features include colours, closure, line ends, contrast, tilt, curvature and size. These simple features are extracted from the visual display in the preattentive system and later joined in the focused attention system into coherent objects. Preattentive processing is done quickly, effortlessly and in parallel without any attention being focused on the display (Treisman 1985). The design should maximally take advantage of the human preattentive system to greatly improve intuitiveness of representations in a faster and more natural way of acquiring information.
3. **Immediacy** - The gap between the cause (user interaction) and effect (system response) exists in three dimensions: time, space and semantics (Ungar, Lieberman and Fry 1997). All should be kept to a minimum. The general design goal of immediacy, an unperceived gap between cause and effect, applies to all three domains.
4. **Simplicity & Consistency** - Similar relations should yield similar results. It is essential to keep the layout consistent as effective navigation is learned and to help a user to "preserve the mental map". In visualization algorithms, consistency can be referred to as predictability (Herman, Marshall and Malancon 1998). Two different runs of the algorithm involving the similar set of data should not lead to radically different visual representations.
5. **Recognizability** - Most of the current resources are image-based. The size of an image significantly affects the recognition of the image significantly (Ware

2004). This criterion directly conflicts with the first criterion (compactness) and implies a design compromise: the size of visualization graph nodes should be small but recognizable.

6. **Responsive & Communicative** – Node-link graphs can represent complex relations and users may wish to focus on particulars. Highlighting, or ephemeral display of relations from acts such as moving the mouse over an object, may make some information stand out from other information so as to draw a user's attention (Ware 2004).
7. **Orthogonality -** Users should be able to distinguish the different relations and attributes of data demonstrated in the visualization panel easily. The visual method used to visualize each attribute (size, popularity, etc.) of the data elements should be unique and easily recognizable.
8. **Scalability** – A•VI•RE objects are linked together by inclusion, co-citation and bibliographic coupling. The representation should accommodate a reasonable number of objects involved in such relations.

Scalability is always an issue to be addressed in visualization. In the EAR structure, it is about the number of resources included in one exhibition, the number of exhibitions that the one resource been referenced, the number of exhibitions that bibliographically couple and the number of resources co-cited by exhibitions (similar principles can apply to annotations vs. exhibitions and annotations vs. resources). In A•VI•RE, at the time of writing this paper (Oct 2006), on average exhibition includes 30.8 resources, standard deviation 52, with one exhibition having a maximum number of 179 resources. In contrast, on average each resource is included in 2.05 exhibitions, standard deviation 4.2, with a maximum number of one resource being included in 27 exhibitions. However, since A•VI•RE is a stand alone system, such numbers are not sufficiently representative enough to be generalized to other domains. More general statistics may be found in citation index research (Table 5-1)

Table 5-1 Descriptive statistics for the citation counts for year 2000

Service provider	Web of Science	Scopus	Google Scholar
Mean	7.6	7.6	12.1
Standard deviation	8.3	9.0	12.7
Min	0	0	0
Max	52	60	64

Data source: (Bauer and Bakkalbasi 2005)

The number of references in a paper or the number of papers being cited by other papers could have more practical meaning and such numbers are important. Most journal papers may reference between ten to twenty papers with an average of twelve or thirteen (Garfield 1976). The number of papers being cited can be used to determine the popularity and impact of specific articles, authors, and publications. Such numbers of citations can be found from service providers such as Web of Science, Scopus and Google Scholar (Table 5-1). In the year 2000, Google Scholar shows that an average number of citations is 12.1, while Web of Science and Scopus shows a relatively smaller number of 7.6 (Bauer and Bakkalbasi 2005). In CiteSeer, the overall average number of citations per publication is 46 (Rahm and Thor 2005). The number of objects involved in these relations are small, so the NEAR panel needs not scalable to accommodate huge numbers of objects.

5.4 Technologies used to build A•VI•RE and NEAR

A•VI•RE is a web application built on PHP/MySQL on a Mac OSX server. The system was originally built based on Tikiwiki. Tikiwiki is a full featured free Wiki/CMS/Groupware written in PHP and can use different kinds of databases as the backend data storage. A•VI•RE adopts some basic functions from Tikiwiki such as user management, content management and Wiki page editing. As an information repository, A•VI•RE extends and develops core functions of information management, such as managing hierarchies of exhibitions, annotations and resources, appointing metadata to objects, assigning different privileges to different roles, and handling multimedia file uploads.

Like most web applications, A•VI•RE uses a client/server structure. User input is sent from the client side (Internet web browser) to the server, the server runs the PHP script (accessing the MySQL database when necessary) and sends the outcome (the HTML file) to the browser to render and display the page. Interaction between the user and the webpage is through mouse over, click and double click on A•VI•RE objects. The interaction ion the client side is implemented in Javascript and dynamic HTML such as layers and Cascade Style Sheet (CSS).

To be consistent with A•VI•RE and get the maximum compatibility with different client Internet browsing applications, I decided to use the same technology as A•VI•RE to design the NEAR panel to support user navigation and interaction. With this decision, The NEAR panel could be a window in a floating layer above the main content of the webpage. The panel would be shown/hidden according to a user's request. The visualization could be arranged by standard HTML code and style sheet. Icons could be used to represent exhibitions, annotations and resources. As I discussed earlier in this thesis, these objects all have features of different dimensions. To reflect the differences, icons need to show a large number of variations. Therefore I proposed to PHP and its image library to create icons on the fly – using cache technologies in the server to avoid repeated execution of the same code. Such icons would be displayed in the browser by standard HTML tags[23]. Interaction and the result of interaction would accomplished through Javascript and CSS [24].

The development process for NEAR comprised three spiral cycles. Formative evaluation studies with small sets of users advised the next design cycle. In the next two sections I will demonstrate and discuss the designs of the first two cycles and their evaluation results.

5.5 Spiral Cycle 1 – the most abstract graphic

5.5.1 Design

Node-link diagrams are very common in representing the entity-relation model in the area of computer science and business modelling (Chen 1976). A•VI•RE can be described as an entity-relation model. Exhibitions, annotations and resources are different kinds of objects from the entity. Inclusion, reference are the relations. To form a node-link diagram, there are several general ways to express entities and relations which can be regarded loosely as visual syntax (Ware 2004).

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[23] The image tag looks like:

In the tag, features and values are sent by querying string, like "size=247&resources=13" in this example

[24] Each object in the webpage has its own ID. Relations among these objects are stored inside Javascript so that when an interaction occurs, the related objects can be highlighted by changing their appearance in the browser through changing its CSS without interfering with the server.

Since most of resources are photos and images, thumbnail icons are used to represent resources. Exhibitions are the primary relation-generating structure in A•VI•RE, so I chose the visualization of exhibitions and their relations as the starting point of the whole design and research process.

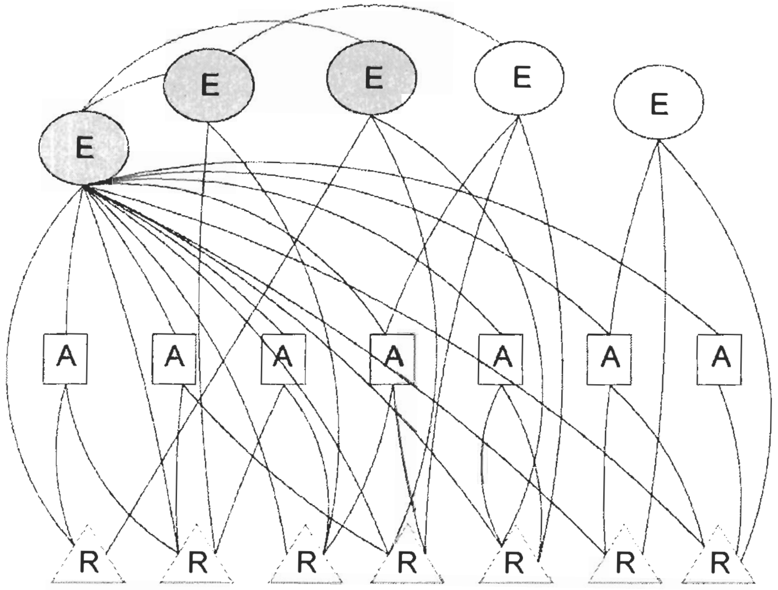

Figure 5-1 **The general graph of A•VI•RE objects and their relations** [25]
Circles: exhibitions; squares: annotations; triangles: resources; edges: inclusion relations

When a user looks at an exhibition, he/she needs to be aware of the contents and contexts inside the exhibition. For a typical exhibition, the main content includes some resources, several annotations and zero or more child exhibitions. The relations between this parent exhibition and included objects are direct and obvious. As discussed in Chapter 3, bibliographical coupling is observed by transitivity. Because these exhibitions include the same resources or annotations, crosslinks exist. An immediate graph that represents all the related objects and links might look messy (Figure 5-1). To make such diagrams easier to read and understand, more complex algorithms might be applied.

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[25] Copyright: Yingjie Chen, 2006.

When a user visits an exhibition, two kinds of information should be represented: One is the strength of the bibliographic coupling relation between other exhibitions and the current one, and the other is the relation between resources and the bibliographically coupled exhibitions. Since resources and annotations in the current exhibition are obvious, there is no need to draw the connecting edges. However, because other exhibitions reference resources in this exhibition, crosslinks exist that violate the planarity principle, making it difficult for users to read the graph. Therefore, I decided to use node-link graphs to represent the indirect relations (bibliographic coupling between exhibitions in the current version), and to hide the direct inclusion relations between exhibitions and resources. The direct relations will only show up at the user's request by interaction.

According to the principles and technologies discussed in Chapter 4, I considered the following criteria to achieve the goal of supporting easy cognition and navigation. This graph should be compact enough to display tens of exhibitions in a tiny portion of the screen. Spatial, semantic and temporal immediacy should be considered so that the user will not need to spend much effort to view and browse neighbour exhibitions. The visualization needs to be consistent and predictable. When a new exhibition is set up that has a bibliographic coupling relation with current exhibitions, it will be put at the far left side. The relations and positions of the rest of the nodes are kept the same. Some basic features of graphs such as colour, size and contrast should be used to take advantage of the human preattentive processing system. For example, different sizes of a round dot could give a good intuitive overview of the exhibition about its size. Different thickness of connection lines to the objects ("branch on a dot") could be clear to represent the strength of the bibliographic coupling relations between the exhibitions with the current one.

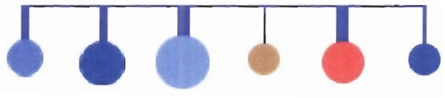

Figure 5-2 **The nodes designed to represent different type of exhibitions.** [26]
Different colours are used to represent Visiting Status and Popularity (see chapter 5.3.1)

I drafted the node-link graph to visualize the relations between the current exhibition with its bibliographically coupled exhibitions (Figure 5-2). My purpose in this design is to discover the possibility of visualizing the bibliographic coupling relations and the inclusion relations in a compact and clear way. Thus I did not include annotations at this stage.

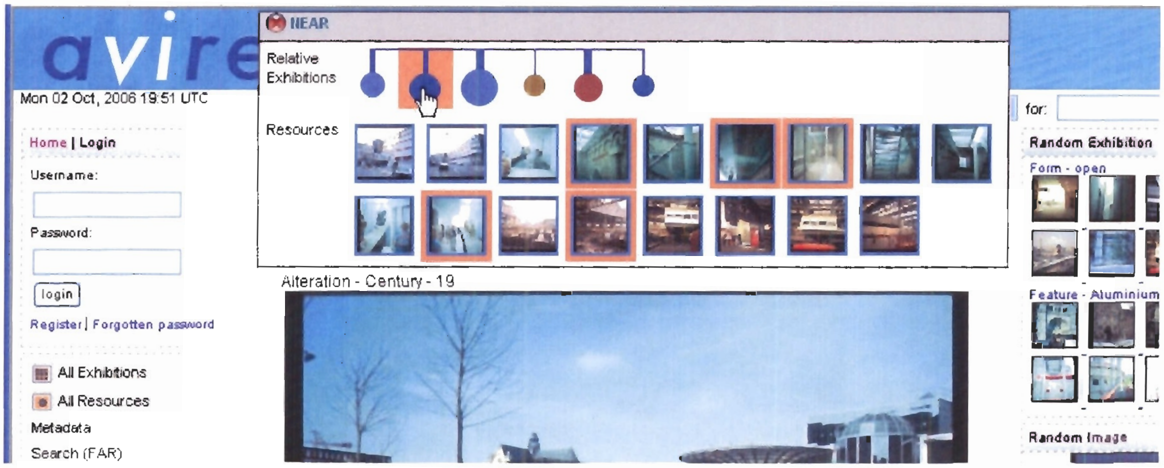

Figure 5-3 **Screenshot of the NEAR with mouse over interaction.** [27]
The hand symbol is the mouse cursor. Thumbnails with the orange border are included by the pointed exhibition.

The relations between resources and exhibitions are revealed though interaction. A user moves the mouse over an exhibition to highlight all included resources (Figure

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[26] Copyright: Yingjie Chen, 2006.
[27] A•VI•RE and its screenshots by permission from the copyright holder. Others by Yingjie Chen, 2006.

5-3). When the mouse is over the current exhibition, it and all resources will be highlighted since these resources are all included. When the mouse is moved over other exhibitions, only its co-included resources and that exhibition will be highlighted. When the mouse is moved over resource thumbnails, any exhibitions that include this resource will be highlighted as well.

In this graph, I tried to visualize the following information:

- Size of the exhibition: how many resources are included in the exhibition. The diameter of the node represents the number of resources it contains.
- Visitation status: the current exhibition and the just-visited exhibition. The red node represents the current one, and the brown node represents the last visited.
- The number of shared resources between exhibitions is represented by the thickness of the "fruit branch" connecting to the "cherry". The thicker the branch, the more resources it shares with current exhibitions.
- Chronology: nodes are ordered from left to right by the time of exhibition creation – the one on the right end is the "oldest" exhibition.
- Popularity: how people "like" these exhibitions. It is measured by the clicks on each exhibition. In the graph, the darker colour of the node, the more it has been clicked.

5.5.2 Discussion and Evaluation:

In this design, I visualize the bibliographic coupling relations in a compact limited space, and use interaction to reveal direct inclusion relations between resources and exhibitions. To find out whether or not this design is effective for people to understand, I invited three graduate students to discuss this graph.

Although the direct inclusion relation is not shown visually, these participants did not have any problem realizing the direct inclusion relation between exhibitions and resources through mouse move interaction. Also they thought the compact panel embedded together with the browser window was simple and clear. From these two points, the design intention was successful.

The main purpose of visualization is to enable people to understand complex data. If people cannot understand or still need detailed explanation, then the visualization is problematic. Unfortunately, this happened to this version of implementation, especially regarding the readability of icons. First, the meanings of the icons and the connections were not apparent. Participants thought the round dot shapes were too simple and abstract. The simple dots cannot reflect the meaning of an "exhibition" that it is a collection of multiple resources and annotations. Although people did notice the variation of colours and shapes (such as size of dot, thickness of branch), they can hardly relate these variations to the attributes or qualities I want to address. For example, I used the thickness of branch to represent the strength of the bibliographic coupling relations, but participants tended to think it represented something about "size" and mixed it up with the size of the dot. Another problem was the colour code in this graph. I used different shades of blue to represent the popularity, but overrode the blue colour by using red to represent visiting status (The red dot). It had two problems: one was that the popularity data could not be seen when the dot was red. The other problem showed that participants could misunderstand the red colour, wondering if it represented the same meaning as the blue colour. Apparently, some of the key qualities I mentioned before have not be represented in such an abstract graph or failed to work properly.

Since such visualization in workable to representing the bibliographic coupling information and the inclusion relations, I decided to focus on improving the icon design to acquire better readability in the next step of the design of NEAR. Changes to the design could be made to three aspects: first, make it look meaningfully close to the objects represented. Second, the icon should be able to show higher dimensions on the objects, avoiding problems such as visitation status (red colour) overriding the popularity information (blue colour). Finally, the thickness of the branch is not effective enough to represent the strength of links between objects. In the next stage, annotations should also be considered in the visualization design. The same principles of exhibition icons can be applied to design annotation icons.

5.6 Spiral Cycle 2 – A more vivid design

Considering the evaluation of the previous design cycle, following the principles discussed earlier, and keeping the effective part of the previous design, I started the second spiral (Figure 5-4).

5.6.1 Design

To reflect the direct inclusion relations among the EAR objects, the same interaction technology as the last design was adopted in this version. However, I extended it by adding annotations to accommodate the three types of objects. When a mouse is over an exhibition, all its included annotations and resources (and the exhibition itself) are highlighted (Figure 5-4). When the mouse is over an annotation, all referenced resources and any exhibitions including the annotation are highlighted. When the mouse is over a resource, all annotations annotating the resource and all exhibitions including this resource are highlighted.

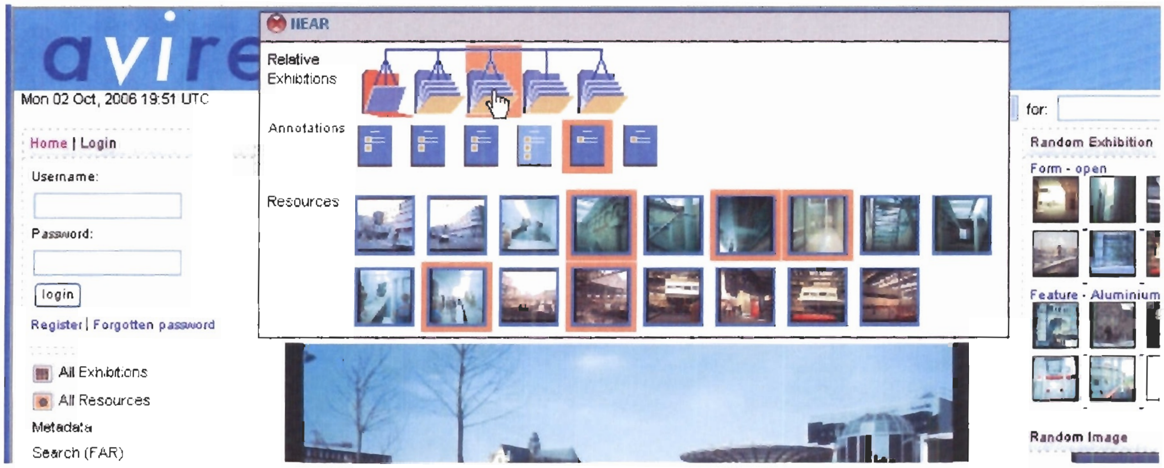

Figure 5-4 **Screenshot of NEAR (2nd version) with mouse over interaction.[28]**
The hand symbol is the mouse cursor, and all related objects are highlighted with orange background or borders)

In icon design, I decided to use the well-known folder metaphor to represent exhibitions and illustrate the meaning of "collection" (Figure 5-5). In most modern computer operating systems, files are structured as trees and put into containers called directories. Each directory may contain files and other directories. In the graphic interface of operating systems, an icon of a physical file folder is used to represent the directory. As we discussed in previous chapter 2.1 and 5.5.1, the EAR structure composes a triangle and connects as a general graph. In the EAR structure, exhibitions are containers, and should not be organized as trees.

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[28] A•VI•RE and its screenshots by permission of copyright holder. Includes public domain images from A•VI•RE image bank. Others by Yingjie Chen 2006.

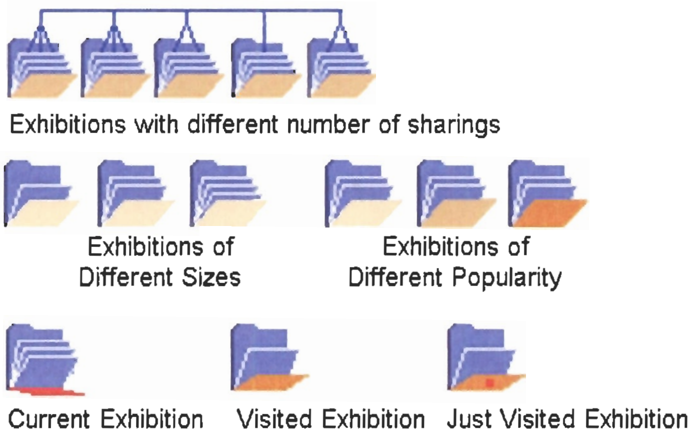

Figure 5-5 **Examples of exhibition icons** [29]

The folder-like exhibition icons represent the following types of information:

- Bibliographic coupling relations between exhibitions: Since the thickness of the branch does not give a clear demonstration of the strength of sharing between exhibitions, I used thin lines. There are three levels of sharing – a little (1 line), intermediate (2 lines) and many (3 lines).
- Size of the exhibition: the number of pages in the folder (1~3) shows how many resources have been collected in the exhibition (3 possibilities).
- Popularity: different cover shading colours show the number of times an exhibition has been visited by users (3 possibilities – few, moderate, many).
- Visitation history: the slightly opened folders are visited exhibitions by this user, and visited exhibitions with a red dot on the cover of a folder are just visited exhibitions. Totally opened folders show current exhibitions (3 possibilities, visiting, visited and not visited).

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[29] Copyright: Yingjie Chen, 2006.

- Exhibitions are ordered horizontally in the order of creation time (chronology) – the aim is to make it easy for a user to discover information such as which exhibition is the first one to collect these resources.

Figure 5-6 Examples of annotation icons[30]

Annotations are user commentary about resources and exhibitions. In A•VI•RE, an annotation is a mixture of text and referenced resources. While being displayed in the browser, it appears as a paper with figures. Thus I decided to use the paper metaphor to represent annotations (Figure 5-6).

These paper-like icons represent the following information about annotations:

- Content organization: number of words and figures in the annotation. The icons use different numbers of lines to represent the length of text, and small squares to represent the number of resources to which it refers. (Figure 5-6, content organization)
- Importance: an annotation may be set as the default view of the exhibition by the exhibitor. It can be seen as the main interpretation of the exhibition that

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[30] Copyright: Yingjie Chen, 2006

usually draws the visitor's attention. Such annotation has a red folded triangle on the right top corner.

- Popularity: similar to an exhibition, popularity of an annotation is also calculated based on the number of visiting clicks. Three possibilities are listed here (few, moderate and many) by using 3 different shades of brown in the folded triangle of the right top corner.
- Visitation history: Visited annotations have a bigger folded triangle to show that this piece of paper has been read and flipped.
- Chronology: icons are ordered from left to right according to their creation time. Since an annotation may be annotated, or may act as a supplement of previous annotations, the reading sequence may be important for users. This line-up gives users a hint of reading order.

In these icons for exhibitions and annotations, only three to four levels of each attribute of the objects are represented. Due to the limited capacity of human visual working memory (Ware 2004, p. 352), three to four options for each attribute seems to be the upper limit. Even though a quality may have tens or hundreds of variations, they are condensed into three or four steps.

5.6.2 Stage 2 design study

To study the effectiveness of the second design, the same three graduate students who discussed the first design and two new university students were invited to test and discuss this version. During the process, we found the following problems: the icons have too many details, and the users' ability to distinguish the difference has been weakened because their attention is drawn by the details of the icons. Also, unless the size of the icon is enlarged, there is no space to handle many attributes. To keep the primary goal of a compact visualization, the icon has to be small and elegant.

In terms of the high degree of details in these icons, there are some problems. First, most of space in the icon, along with the details, has been used to represent the size of the exhibition. This approach actually limited the space to demonstrate other information. Second, the number of variations is limited. For example, it is hard to have more than 4 pages inside the folder to represent a large exhibition without enlarging the icon. At the same time, there is not enough space to show the variety of visiting status by using the open folder. Also, this design violates the orthogonality rule. I intended to use the open folder to represent the visiting status, but due to the limited space of the icon, it is hard to represent four variations (including none-visited). The additional feature has to be added (the red dot on a half-opened folder) to represent the "just visited" exhibition. The different shades of brown on the folder cover represent the popularity of the exhibition. However, red is also used to represent the current status of an exhibition. This makes it hard to distinguish – two icon features represent one attribute, or one feature represents two different attributes. Another aspect I should improve is the appearance of links on the top of the bibliographically coupled exhibition icons. These links should join smoothly instead of joining stiffly at right angles. The human eye tends to follow smooth curves instead of shape angles (Ware 2004).

5.7 Summary

A•VI•RE is a general information repository utilizing the EAR structure. Visualization of EAR objects and their relations can effectively support users in information seeking, browsing and navigating.

In the first part of this chapter, I introduced the structure of A•VI•RE and issues around navigating and browsing A•VI•RE objects. Then, I outlined key properties of A•VI•RE objects, discussing key qualities of representing such objects, and proposing a compact visualization panel, "NEAR", to improve the information retrieval and browsing in the system. I adopted the spiral model of software development as my methodology and started to work on cycles of design, evaluate, improve, and redesign.

Apart from the basic technologies that support NEAR, in the later part of the chapter, I discussed the first two design cycles of NEAR. The first cycle was to discover the possibilities of a compact visualization of a cross-linked relation. The second cycle was to explore variations of icon design to represent EAR objects. In these two versions, interaction was used to reveal the direct inclusion relations among EAR objects. Two rounds of evaluation and discussion found that such interaction is effective.

In the next chapter, I will discuss the new implementation of the NEAR panel in detail. Users will be allowed to shift their focus on different types of objects, expand the relation views upon request, and use interaction to execute Boolean query visually.

6 CURRENT IMPLEMENTAION OF NEAR

Throughout the design process, selection remained a principal choice: visualization is local to the user's choice of a current exhibition. The objects shown are, in terms of data relation, near to current selection. I chose the name NEAR (Navigation Exhibitions, Annotations and Resources) to denote this choice. In this section, I will introduce the new (at the time of writing) design and implementation of NEAR. The new design summarizes differences from prior panel designs and improves icon, graph, and interaction.

6.1 Overview

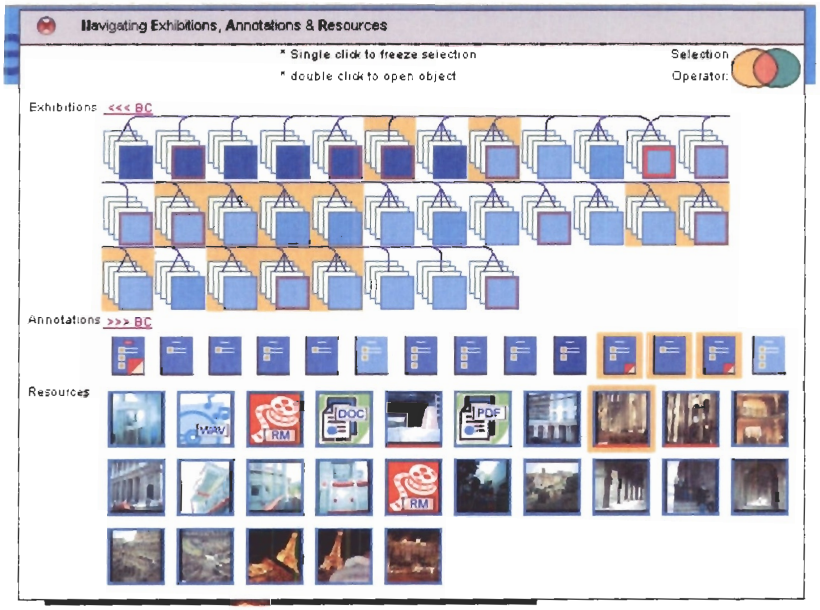

Figure 6-1 Screenshot of the NEAR panel in A•VI•RE[31]

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[31] Includes public domain images from A•VI•RE image bank. Others by Yingjie Chen, 2006

There are three parts in the design: icons are used to represent the individual objects of exhibitions, annotations and resources. Graphs represent the relations among objects and the interaction helps users to explore and reveal deeper relations.

Figure 6-1 is an expanded exhibition-centred view showing the following: all resources referenced in the current exhibition, all exhibitions that are bibliographically coupled with the current exhibition, and all annotations of resources in the current exhibition. Some of the annotations may not belong to the current exhibition. These external annotations were created in other bibliographically coupled exhibitions to annotate the resources that are referenced by both the current exhibition and the bibliographically coupled exhibitions. Individual objects of exhibitions, annotations and resources are represented by icons. To make the icons meaningful, content-based thumbnails are used to represent resources where possible[32], otherwise type-based icons are used. In the top right corner (at the right of text "selection Operator"), the dual circle Venn diagram is used to hint at the interactions (See section 6.4), with the colours showing different selection states. In this particular example, we can see that the current exhibition contains 25 resources, and has not been visited much by users (light blue cover, see section 6.2.2, Figure 6-3). There are 32 exhibitions sharing resources with this exhibition, and 6 of them have been visited by the user (shown by the thin red outline). The levels of bibliographic coupling with the current exhibition are indicated by the links on top of the exhibition icons. The annotation area shows 14 annotations of the current exhibition. Some users annotate many resources while others only annotate a few resources. The furthest left annotation is the default view of the current exhibition (the

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[32] Image thumbnail are used to represent images at the time of writing. In the future, content-based icons of other types of files (e.g. PDF, movie) maybe used to represent the file.

paper icon with a red square at the title area). The exhibition builder chose this annotation to represent the exhibition. It has been viewed many times as well (dark blue color). Also the big red foldout at right bottom indicates it is opening in the browser window (as the default view to represent this exhibition). Two other annotations have been visited by the user (small red foldout). One annotation received many visits (dark blue color), several received moderate visits and some have not been visited much. In the resource area, resource icons are displayed to provide a preview of each resource. Other than images, there are 5 other types of files including audio (.wav), video (.rm) and document (.doc and .pdf). Resource icons have a thin red edge at the bottom indicating that they have been viewed by the user. In the next section, I will discuss the icon design in detail.

6.2 Design of Icons

In NEAR, icons are designed to visually represent attributes of individual EAR objects. The icon is a tiny image denoting an object. Attributes of the object are mapped to the features (or degrees of freedom) of the icons. Due to the rich information carried by each EAR object, orthogonality is important in the icon design for users to distinguish every attribute of the object. One feature of the icon should only be used to represent one kind of attribute of the object, and one kind of object attribute should only be represented by one kind of feature of the icon. Due to the limited capacity of human visual working memory, only three to four variations for each attribute are represented in the design.

In these icons, different shapes and colours are used to represent different attributes of the objects. Using colour coding to label an object as nominal information is extremely effective (Ware 2004). Assigning distinctive colours to objects is often the best solution to classify objects into different categories. However, there are still several perceptual factors that need to be considered while choosing colour in this NEAR icon design. Some of these factors are (Ware 2004):

Unique hues. Red and green, yellow and blue, as well as black and white, are special in terms of the opponent process model. These colours provide natural choice when a small set of colour codes is required. Works on colour confusion also suggest not choosing two colours from the same hue. In the NEAR design, colours are carefully chosen among these unique hues. Considering the 10 percent colour-blinded users, Orange- red and blue-green are used instead of pure red and green.

Contrast with background. If the background colour changes much, simultaneous contrast with background colours can dramatically alter colour appearance, making one colour look like another. In NEAR, the main background is white which is neutral for colours. For colour blocks inside icons, to reduce the contrast effect, a thin white or black border around the colour-coded area is an effective method (e.g. white border around red and yellow squares on the blue background of Figure 6-5).

Number. Only a small number of codes can be rapidly perceived. Estimates vary between about five to ten codes (Healey et al. 1998).

Field Size: Colour-coded objects should not be too small. In general, the larger the area, the more easily colours can be distinguished.

Conventions: In different cultures, some colours have some common conventions, such as red=hot, red=danger, blue=cold, green=life, green=go. These conventions should be taken into account when using colours as coding.

6.2.1 Resource Icons

Resources in A•VI•RE could be an image, a multimedia file, a website or any type of document. To meet the qualities of compactness and recognizability, the scale of thumbnail nodes should be small but easily recognizable. A thumbnail (40 x 40 pixels) is used as the icon for image resources. For files other than images, we divide them into 4 categories: audio, video, document and other. The most popular file format has its own icon (Figure 6-2), such as .mp3, .wma, .wav format for audio, .mpg, .mov, .avi, .rm for video, .doc, .txt, .pdf, .xls for document [33], and .htm for web pages. Since there are so many different kinds of files, and it is impossible to list them all, a generic "other" icon is used to represent these unknown files[34].

Figure 6-2 Example icons of multimedia resources and image resources[35].
Left: Blue border - different borders represent the frequency of the resource, as cited
Right: Red border – visiting status, current visiting and visited

In this iconic visualization, the following attributes are considered: file type (e.g. image, text file or web page), number of citations and visitation status (visiting or visited). The number of citations is important because it is a measure of intentional popularity if it has been explicitly used in annotations or exhibitions. Showing the visitation status reminds users of where they have been and helps to avoid needless revisits. Blue borders

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[33] Content-based screenshot of other types of files (e.g. PDF, movie and web page) may be used as the thumbnail to represent the file in the future.

[34] File format has been continually added to the system. Each has its own icon.

[35] Icon images created by author, other images are public domain images from A•VI•RE.

are used to represent the number of citations (popularity of the resource). If it has been cited by many exhibitions and annotations, the icon will have a solid blue border. If it has only been cited a few times, it will have a dashed border. If the resource only appears once in a current exhibition, there is no blue border. Visitation status is represented by red border(s). A solid red border under the icon means this resource has been visited before (visiting status is stored in a cookie). The current resource will have two red borders both at the right side and bottom of the icon. Top and left borders are kept to show popularity. In this way, the two features of a resource can be represented simultaneously (bottom and right red borders for visitation, top and left blue borders for popularity). There are a total of nine different border combinations (three popularity with three visiting status)

There are two reasons I want to keep the resource icons simple (by only adding coloured borders around the icon to make variations): first, most of the resources in A•VI•RE are images. A thumbnail is the best way to preview an image. Anything inside the thumbnail would obscure part of the image and thus affect the readability of the image. Second, image manipulation is CPU-intensive work for the server. In A•VI•RE, on average, each exhibition has 31 resources. When a NEAR panel opens one exhibition and shows all its resources, directly manipulating the thumbnail could load the server excessively.

6.2.2 Exhibition Icons

An exhibition is a collection of resources, annotations and exhibitions organized and annotated by users. The following information is represented in exhibition icons (Figure 6-3): the size of the exhibition (the number of pages), popularity (different shades of cover colour), chronology (from left to right in the order of time of creation), and bibliographic coupling relation (number of resources shared, Figure 6-7), currency and visitation history (Figure 6-6). To set a scale of measurement for a particular quality, I dynamically analyzed all exhibitions and based ratings on a normalized distribution.

Figure 6-3 Examples of exhibition icons. [36]
Left Group: icons of different size (determined by number of resources).
Right Group: icons of different popularity (determined by the user visits).

The numbers of variations of exhibition icons are: 3 states of size, 4 states of visitation status, 3 states of popularity, and 2 states of including current resource. Variations multiply by the Cartesian product of the varying qualities. So there are 72 total variations of exhibition icons.

6.2.3 Annotation Icons

Annotations combine text and resources into a linear narrative – in essence, they are papers and their thumbnails display them as such. The qualities of content organization, chronology, and popularity are presented in Figure 6-4.

In this figure, the left three icons show several examples of the content arrangement – how many resources (none, few, several, many) have been referenced in the annotation and the length of text content (few, several lines and many lines). The middle group shows the popularity (number of clicks by users) in three levels (few, mediate and many) by different shades of blue. The less clicked, the lighter the shade. An

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[36] Copyright: Yingjie Chen, 2006.

annotation may be set as the default view of the exhibition, meaning that this annotation will appear automatically to represent the exhibition when a user opens this exhibition. Such annotation is important and may designate the exhibitor's primary interpretation of the exhibition. Hence a red square is placed at the title part of the paper icon (2nd icon on the right) to indicate its importance. When a user is visiting a resource, all annotations referencing this resource may be worth reading, so a red square in the figure area of the paper icon would be marked on such annotations (Figure 6-5). Visitation history is presented by the foldout of the right bottom corner of the paper (Figure 6-6). The big red foldout means it is the current annotation being read. A smaller foldout square means the annotation has been visited by the user.

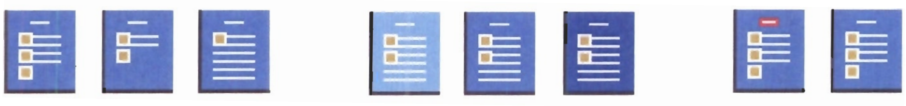

Figure 6-4 Examples of annotation icons. [37]
Left Group: icons of different organization (number of resources & amount of text).
Middle Group: icons of different popularity (user visits, darker colour means being more frequently visited).
Right Group: annotation as default view or not of an exhibition

The numbers of variations of annotation icons are: 4 states of figures inclusion, 3 states of text inclusion, 3 states of visitation status, 3 states of popularity, 2 states of default view, 2 states of inclusion of current resources. The Cartesian product yields a total of 432 variations of annotation icons.

6.2.4 Highlighting Relations

In A•VI•RE the main window displays detailed information of an exhibition, an annotation or a resource. NEAR expands this local view to adjacent nodes in the citation

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[37] Copyright: Yingjie Chen, 2006.

graph. NEAR icons are responsive to showing the direct inclusion relation between the represented object and the objects in the main window. For example, when the main browser window is displaying a resource, any annotation and exhibition including this resource will have a red square to remind the user of such information (Figure 6-5).

Figure 6-5 Examples of an exhibition and an annotation that references the current opening resource in the background browser. [38]

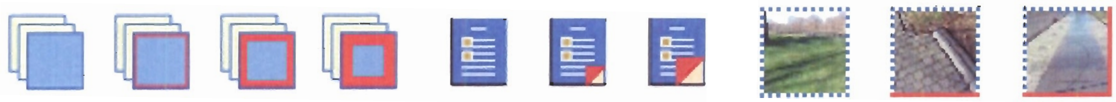

Figure 6-6 Examples of icons with different visit status.[39]
Left Group: Exhibitions: unvisited, visited, just visited and current.
Middle Group: Annotations: unvisited, visited and current.
Right Group: Resources: unvisited, visited and current.

Furthermore, to reduce unnecessary revisiting and make navigation smoother, NEAR changes icons to display the visitation history and visiting status (Figure 6-6).

6.3 Links and Relations

In NEAR, links are used to show the co-citation and bibliographic coupling relations among exhibitions, annotations and resources. As in Thread Arcs (Kerr 2003), smooth continuous contours are used to connect nodes. In NEAR, any exhibitions sharing the resources with the current exhibition are linked (Figure 6-7) with smooth thin lines. Similarly, annotations and resources can also be linked by such edges to represent bibliographic coupling and co-citation information when the user is focusing on an

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[38] Copyright: Yingjie Chen, 2006
[39] Icons created by Yingjie Chen, 2006. Includes public domain images from A•VI•RE image bank.

annotation or a resource respectively. The level of sharing is represented by the number of branches from the node. Since all the links are counted toward the current object, it is important for users to realize that there is a "root" in the graph representing the current object (Figure 6-7). The exhibition icon with thick red borders indicates the current visit, and all edges from other icons bend toward the current icon to emphasize such root information again.

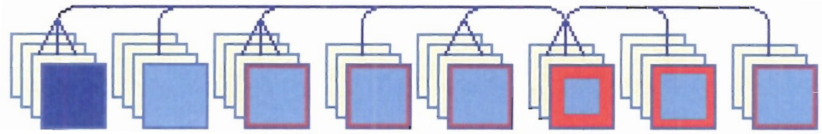

Figure 6-7 Bibliographic coupling relations between exhibitions[40]
Branches on the top of icons show the levels of sharing resources

6.4 Interaction

The NEAR panel uses interactions to support local navigation in the hierarchy and citation graph of A•VI•RE. There are three kinds of interactions in NEAR: cursor over (brushing), click and double-click. Ben Shneiderman gave a "mantra" to guide visual information-seeking behaviour and the interfaces that support it: "Overview first, zoom and filter, detail on demand (Shneiderman 1998)." In the static screen, the NEAR panel provides the overview of the visiting objects and its contexts. For example, when a user is viewing an exhibition, all its annotations and resources are displayed in the NEAR panel to provide the overview of this exhibition. Cursor over and click provides "filter" related objects by highlighting, and double-click leads users to view the details.

Brushing (Ware 2004) is adopted to enable visual linking of components of heterogeneous complex objects. More importantly, in NEAR, brushing avoids linking

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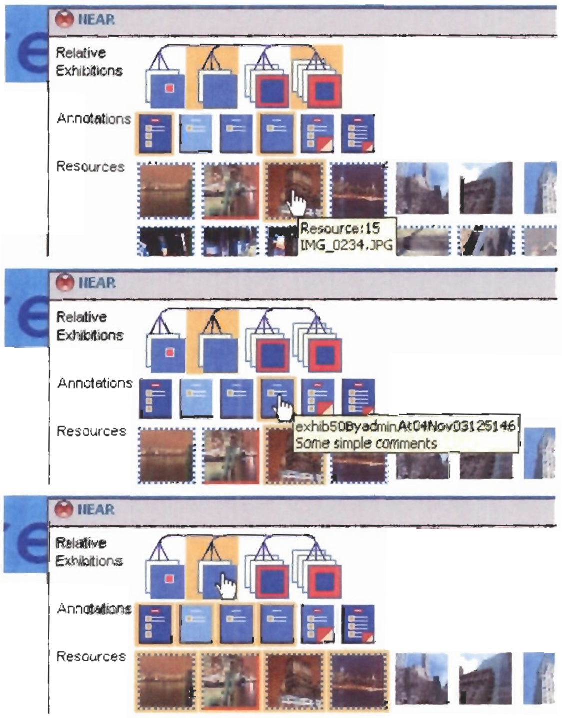
[40] Copyright: Yingjie Chen, 2006.

collision in the graph if large numbers of bibliographic coupling and co-citation relations existed within an exhibition. The relation among EAR objects is "web"-like (Figure 5-1), without brushing, to represent all the direct links among EAR objects, the 2D graph must have many cross edges or use other complex visualization forms such as 3D graphs.



Resource:15
IMG_0234.JPG

exhib50ByadminAt04Nov03125146
Some simple comments

Figure 6-8 Screenshots of NEAR panel when the mouse cursor is over.

Figure 6-8 shows instances of how NEAR works. Moving the cursor over an exhibition will highlight all the referenced resources and annotations with yellow backgrounds, moving over an annotation will highlight all quoted resources and related exhibitions, and moving over a resource will highlight all annotations and exhibitions that include the resource. Cursor-over also pops up a text box and shows property information of the object such as its ID, name, contributor and comments. When the mouse is moved over another object, new set of objects will be highlighted to reveal the direct relations dynamically and immediately.

When the mouse cursor brushes over an object, all the objects having direct relations (including or been included) with it would be highlighted by changing colour instead of using connecting lines. However, this will make the screen flicker if the user moves the mouse too often, and it could be difficult if the user wants to read the highlighted information carefully. To avoid such flicker, a click on the object will freeze the relation view, so that the user can freely move the mouse without changing the highlights. A click on an empty space will re-activate the mouse-over effect.

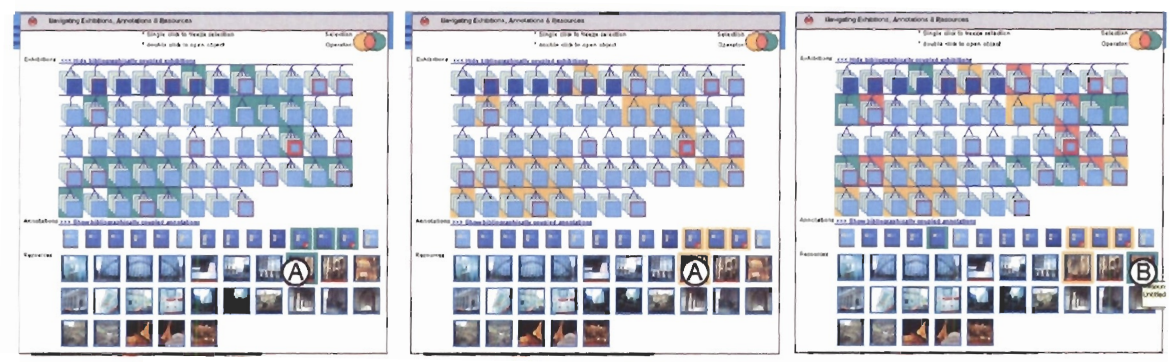


Figure 6-9 Click and mouse over for visual Boolean query
left: mouse over resource A to highlight objects with green colour
middle: mouse click on resource A to freeze view and highlight with yellow
right: mouse over on resource B highlights objects with green and pink.

Since many users have difficulty using Boolean logic to define their query (Boyle, Ogden, Uhlir and Wilson 1984; Young and Sheneiderman 1993), a simple method in NEAR allows user to do Boolean operations visually (Figure 6-9). As we stated above, a single click on an object freezes the view. In this frozen view, the user moves the mouse over other objects to show the union, difference, and intersection of two sets of highlighted objects (the clicking highlights and mouse over highlights). In the particular example of Figure 6-9, the user moves a cursor over resource **A** (marked as **A** in the figure), thus all annotations and exhibitions including this resource (and the resource itself) would be highlighted with green. A single click on resource **A** freezes this view and changes all highlighted colour to yellow (the middle screenshot). When the user moves the cursor over another object (resource **B** in the right screenshot), related objects would be highlighted with three different colours: green, yellow and pink. If we call the objects related to **A** "set **A**", the objects related to **B** "set **B**", all the objects in the current NEAR panel as the "global set," then the right screenshot represents the following information:

- Union of set **A** and **B** - all highlighted objects (green, yellow and pink)
- Intersection of set **A** and **B** – objects highlighted by pink.
- Difference of set **A** to **B** – objects highlighted by yellow.
- Difference of set **B** to **A** – objects highlighted by green.

The Venn diagram icon on the top right corner of the NEAR panel provides visual hints for the colours and meanings.

A mouse click on resource **B** will reset the screen to a static highlighting of all objects related to **B** only – in the above example, yellow highlights will be de-highlighted, objects highlighted by pink and green will be changed to yellow.

To support user navigation, similar to desktop applications, double-clicking opens the document in the main content part of the same window to display the full content of the object (providing details on demand).

6.5 Views

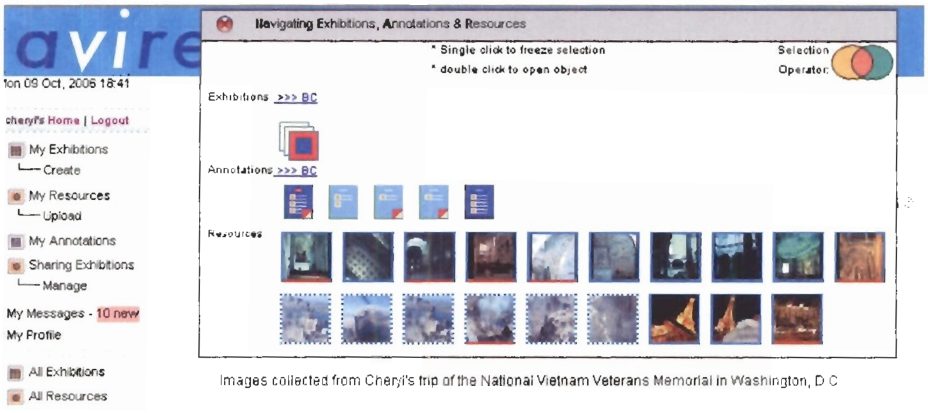
EAR objects have a hierarchical structure, that is, an exhibition includes annotations and resources, an annotation comments on resources, and an exhibition may include exhibitions. However, since resources can be included in multiple exhibitions, the link graph is not a tree, but rather a general graph. When we focus on one specific object, objects linked to it could be of interest. These objects can either be similar to the current object, or be supplemental information.

Just like the name "NEAR", when a user focuses on a specific object, the NEAR panel brings the related objects of the current selection "near" to the user. The NEAR panel provides three different views to reveal relations around each type of object according to a user's focus. Each view has two states: the simple state uses a simple layout to show the direct relations (inclusion and annotation), and the advanced state has multiple (2 ~ 3) complex views to show co-citation and bibliographic coupling information.

6.5.1 Exhibition Centric View

When a user is looking at an exhibition, the NEAR panel provides an exhibition-centric view. It shows all related objects around the current exhibition, including annotations and resources referenced in the exhibition, and can be extended to show all bibliographically coupled exhibitions.

The simple exhibition-centric view shows the most fundamental hierarchy structure of a current exhibition (Figure 6-10) – it can be seen as an overview of the exhibition. In the exhibition area, icons provide the general information. Annotations areas list all annotations and resources areas list all resources included.



Images collected from Cheryl's trip of the National Vietnam Veterans Memorial in Washington, D.C.

Figure 6-10 Exhibition-centric view – simple view

Clicking the ">>>BC" (BC stands for Bibliographical Coupling) link in the exhibition line expands the view to show all bibliographically coupled exhibitions (Figure 6-11), accordingly the link of ">>>BC" is replaced by "<<<BC".

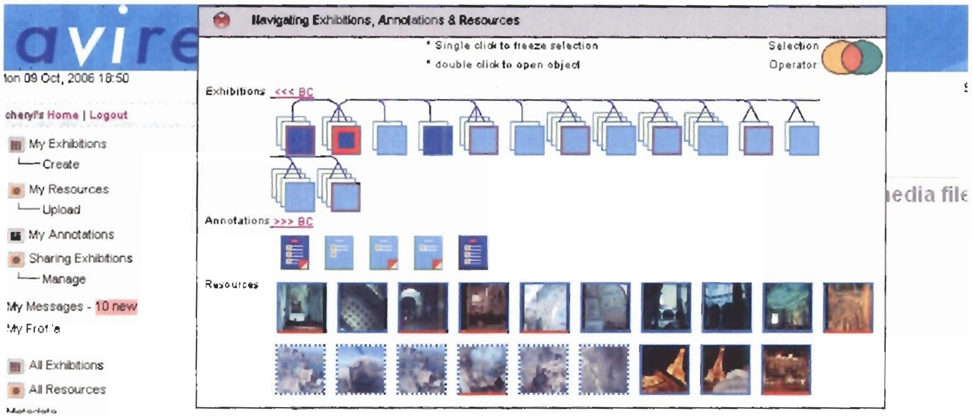


Figure 6-11 Exhibition-centric view – expand to show bibliographically coupled exhibitions

In this view, from the left to the right, exhibitions are placed in chronological order. Since there are many exhibitions bibliographically coupled with the current exhibition, it is impossible to fit them into one line. In this example, icons are arranged in two lines to show all related exhibitions. A current exhibition is indicated with the thick red border on the icon. Other icons also display their overview information: size, popularity and visitation status. Strength of the bibliographic coupling relations is shown by the edges (line and curves) on top of the exhibition icons. Exhibitions may share a few, several or many resources with the current exhibition. These different levels of sharing are shown as one, two or three edges respectively. Clicking "<<<BC" collapses the bibliographically coupled graph to change the view back to the simple state as in Figure 6-10.

In the annotations area of Figure 6-10 and Figure 6-11, the listed annotations all belong to the current exhibition. This area can also expand to show all bibliographically coupled annotations that annotate any resources under the current exhibition (Figure 6-12). These annotations may not be included in the current exhibition.

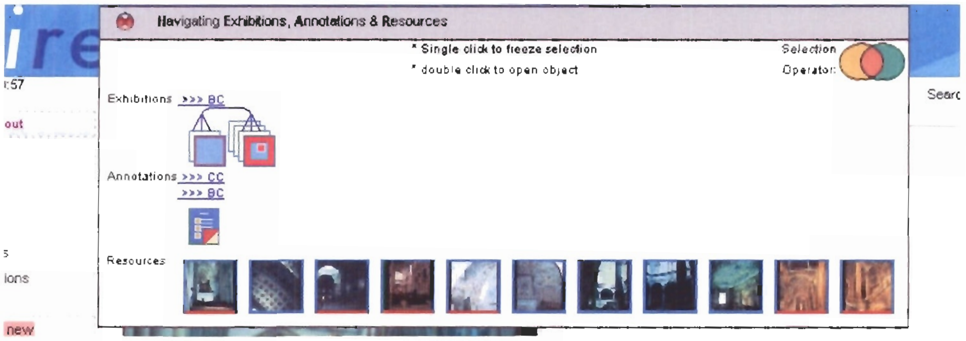
Figure 6-12 Exhibition-centric view – expand to show bibliographically coupled annotations

Comparing above figures (Figure 6-12 vs. Figure 6-11), there are two more annotations in Figure 6-12 that do not belong to the current exhibition, but are coupled with the exhibition's resources. These two annotations may interest the user because they reflect another user's intentional commentary and could provide views from different perspectives. Bibliographically coupled exhibitions and annotations can be expanded together in one screen (Figure 6-1).

Both in the simple view and expanded view, the resources area lists all resources under current exhibition.

6.5.2 Annotation-Centric View:

The NEAR panel switches to the annotation-centric view when the user is reading an annotation. This view focuses on the current annotation, listing all related exhibitions, annotations and resources around the annotation. Similar to exhibitions, there are two views with different levels of complexity – simple and expanded view.



* Single click to freeze selection
* double click to open object

Figure 6-13 Annotation-centric view – simple view

The simple view of the annotation-centric view (Figure 6-13) provides the overview of the current annotation. The centre annotation icon demonstrates information about the annotation in section 6.2.3. The top exhibitions area shows all exhibitions that are included in the current annotation. In A•VI•RE, an annotation is created by a user to explain or interpret resources collected in an exhibition, so each annotation has a primary exhibition. Other exhibitors may include this annotation in their exhibitions if they find this annotation interesting, which then makes two or more exhibitions bibliographically coupled by annotations. In the example shown in Figure 6-13, two exhibitions include the current annotation, and the icon with a white bordered red square in the centre represents the primary exhibition of the annotation. All resources that have been annotated are listed on the bottom of Figure 6-13. As described in section 6.2.1, thumbnails with a red bottom edge indicate that they have been visited by the user before, and the solid blue border around thumbnails indicate they have been shared by many exhibitions.

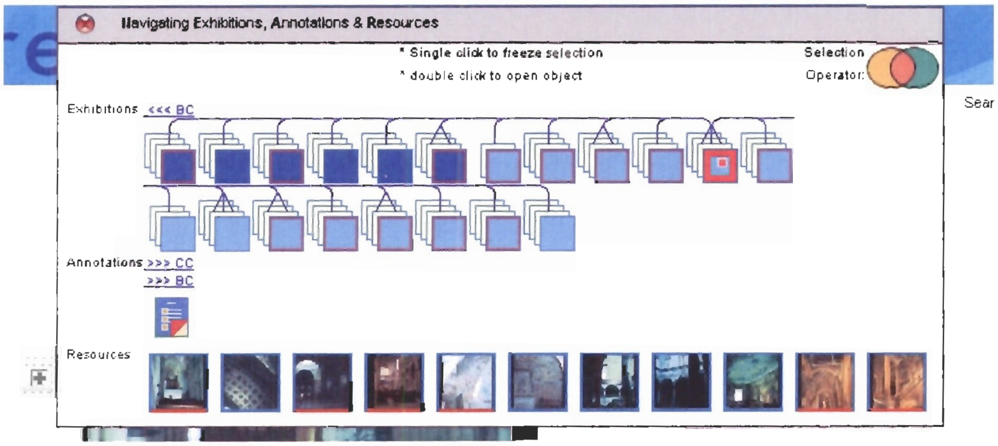


Figure 6-14 Annotation-centric view - expand to show bibliographically coupled exhibitions

There are three views in the annotation panel's extended state due to an annotation's special position in the EAR structure. Since an annotation may include several resources and be included in several exhibitions, the following situations exist: exhibitions may bibliographically couple with the current annotation by resources; bibliographically coupled annotations may exist by including the same resources; and co-cited annotations may exist by being included the same exhibitions. Hence I provide three links for users to explore these relations.

Clicking the ">>>BC" link in the exhibitions area expands and displays all bibliographically coupled exhibitions with current annotations (Figure 6-14). Clicking on the "<<<BC" will collapse the view back to Figure 6-13.

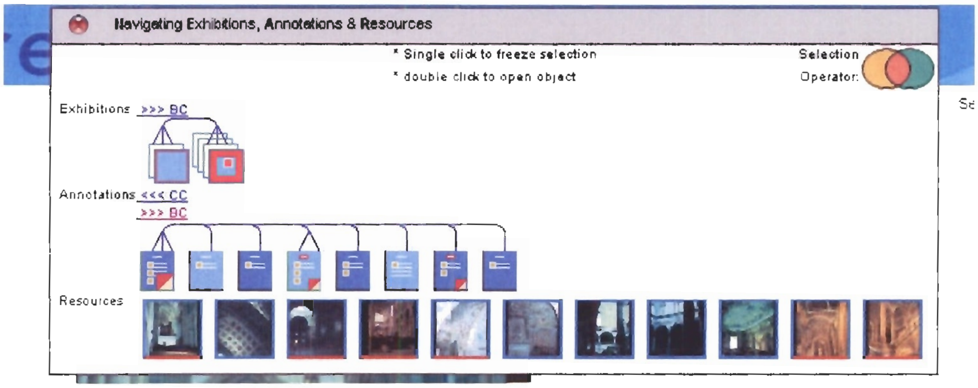


Figure 6-15 Annotation-centric view – expanded to show co-cited annotations

Clicking the ">>>CC" (CC stands for Co-Citation) in the annotations area expands the panel to display all annotations co-cited by the exhibitions (Figure 6-15). Icons are linked towards the current annotation to show the co-citation strength (how many exhibitions co-cited this annotation and the current annotation). Clicking the "<<<CC" collapses the view.

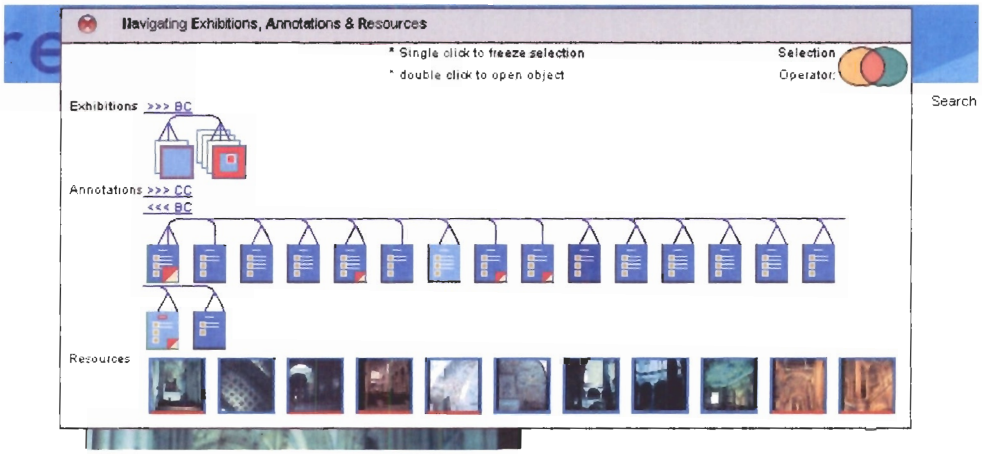


Figure 6-16 Annotation-centric view – expanded to show bibliographically coupled annotations

Clicking the ">>>BC" in the annotations area displays all bibliographically coupled annotations with the current annotation (Figure 6-16). Links on top of the icons indicate the level of sharing between the represented annotations with the current annotation (the paper icon with a big red foldout). Clicking the "<<<BC" collapses the view.

The three expanded views can be integrated with any combination. The user can choose to expand any two views or even three views together. For example, in Figure 6-17, all three relations are expanded to provide a full list of related objects around the current annotation.

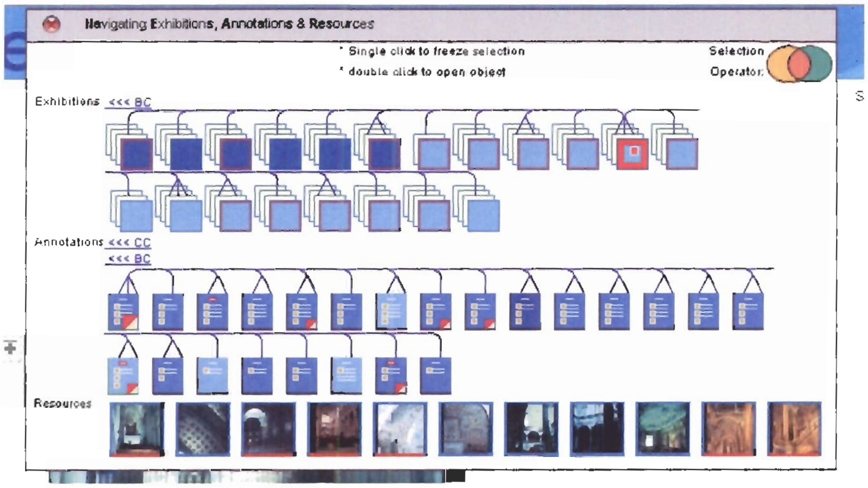


Figure 6-17 Annotation-centric view – expand all three relations

In the annotation-centric view, the resources area is kept the same to only display resources included in the current annotation.

6.5.3 Resource Centered View

Resources are the core data in the A•VI•RE system. Exhibitions are organizational structures to manage these resources, and an annotation is a commentary on the resources. When users seek information in A•VI•RE, they are actually looking at specific resource(s) through exhibitions and annotations. The resource-centric view provides views from different aspects by showing all related exhibitions, annotations and similar resources. It also has simple and expanded levels.

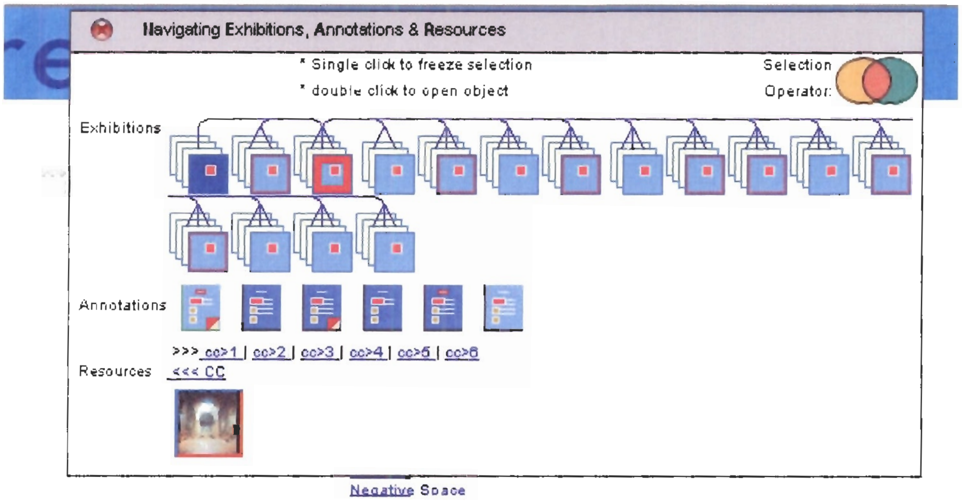


Figure 6-18 Resource-centric view – simple view

The simple view (Figure 6-18) shows the exhibitions and annotations that use the current resource. A resource has a primary exhibition, to which the resource is initially uploaded. Other exhibitions borrow (copy) this resource as part of their own. In the exhibition area, all exhibitions are linked toward the primary exhibition. The number of links represents the strength of bibliographic coupling relations between the represented exhibitions and the primary exhibition. The annotation area lists all annotations about the resource in chronological order.

Resources can be co-cited by one or more exhibitions. The expanded resource-centric view shows such co-cited resources (Figure 6-19). However, the links to open such an expanded view are different with the exhibition-centric view and annotation-centric view. The strength of co-citation relations between two objects is determined by the number of parent objects citing these two objects together. The more objects co-cited by the two objects, the stronger the relation. Therefore I provided six links to allow users to search for co-cited resources at different levels: co-cited by current, two, three, four, five, six or more exhibitions and annotations.

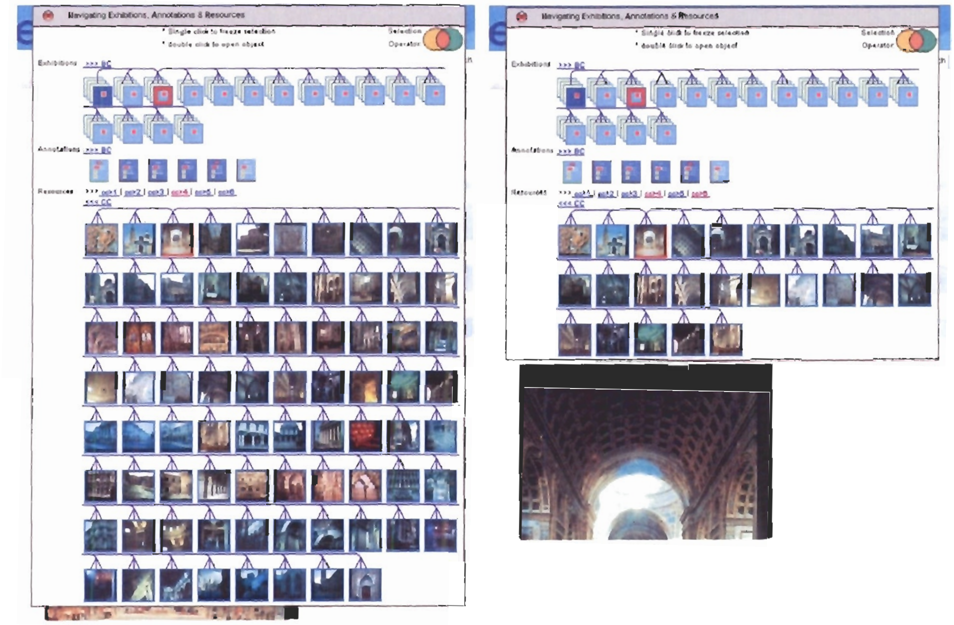


Figure 6-19 Resource-centric view – expanded modes
Left: co-citation > 4 right: co-citation > 6

The option of co-citation by only one exhibition (except current visiting exhibition) is not provided here. I made this decision because too many resources will be included if we list all co-cited resources under single exhibitions, which actually lists the union of all resources under these exhibitions and yields hundreds or even thousands of resources with weak co-citation relations. Since it generally takes more effort to create annotations than to make exhibitions, the co-cited resources by annotations tend to be more valuable than those through exhibitions. As a result, any resources that are co-cited by one or more annotations will be listed in the expanded views.

In A•VI•RE, the two most common methods for a user to locate a resource are: navigating through the EAR hierarchy (including through NEAR) to find a resource under an exhibition, and searching by keywords (or the exact name) to find the resource directly. The co-citation option of "current" is used to list all resources included by the current exhibition. In the scenario of navigating through EAR hierarchy, the current exhibition is the exhibition through which the user navigates to find the resources, so the user may be interested in the exhibition and go deeper to read all the resources in detail. In the scenario of searching by keywords, the current exhibition is the first exhibition uploading the resource, or we can say that it is the primary exhibition.

In the expanded view, the current resource is marked with a red border on the bottom and left sides. All visited resources are marked with a red border on the bottom. Edges and lines are put on top of the thumbnail to show the strength of the co-citation relation. These levels of strength are indicated by the number of links (one, two or more) on top of the thumbnails. Clicking the "<<<CC" link collapses the view to a simple state as in Figure 6-18.

6.6 Evaluation

There are two broad dimensions of measuring usability, one is *ease of learning by* novice and casual users, another is *ease of use* by frequent and proficient users after they have mastered the initial interface (Mayhew 1999). At the current stage, our design goal is to have most users understand the NEAR design (icons, graphs and interaction) and the evaluation will provide ideas for future improvement. Therefore our usability study is mainly focused on ease of use. We asked two groups of users to evaluate our current design. One group has three users who had participated in evaluating the first two versions of NEAR. The other group has three totally fresh users, having never seen the NEAR interface before.

In the evaluation process, we initially asked users to play with NEAR without any introduction and explanation, and we asked the users to guess the meanings of each component: meanings of icon variations, the link graph, interaction and clickable links.

After comparing the guessed meanings and our designed meanings, the evaluation found that prior users could easily grasp the meanings of the icons, links and interactions, and notice the improvements between the current version and previous versions. But new users had a hard time grasping the semantic meanings, especially for the icons. The old users could be considered as experts or trained users. The following evaluation summary is concluded from novice users.

Generally, all people found accessing NEAR easy and obvious. It is provided through a tab that appears at the top of a content object's display area, adjacent to the Annotations and Resources tabs. Clicking the NEAR tab makes a rectangular window area appear with the NEAR interface at the top of the page.

Through NEAR, evaluators were able to navigate the three primary repository object classes easily: Exhibitions, Annotations and Resources. These labels appear in the NEAR interface along the left hand side. Immediately right of the labels are navigational elements.

The semantics of the NEAR interface are difficult to grasp. Iconic representations are very detailed, and developed in subtle ways. A single Exhibition icon, for example, shows a set of rectangular elements layered one on top of the other, with the top rectangle colored either some solid color, or with a thick colored line along the edge. A small red square appears near the center of the icon. Branching lines emerge from the top of the icon, joining a horizontal line with similar branching lines from other icons. Sometimes branching lines are left oriented and sometimes right oriented. These subtleties are difficult to grasp at a glance, and the detail may be better rendered with text listings.

Similarly, when the user selects an Exhibition icon, for example, other Exhibition, Annotation and Resource icons are also highlighted. The meaning of this cross-class highlighting is not clear in the interface. Some inference may lead the user to conclude that there is some interrelation between these objects but this can only be speculation without further information.

After the process of "blind" guessing, we explained the detailed meanings of the icons, graphs and interactions to the participants. They relaxed after they understand those meanings and started to interact with the NEAR, navigated through the A•VI•RE objects and tried to find new functions. It seems a Help Page explaining the functionalities of NEAR might bridge the gap between users and NEAR.[41]

The NEAR panel can scale up to handle hundreds of objects. As we discussed in chapter 5.3.2, in the current A•VI•RE system, the largest exhibition has 179 resources (the average is 30.8 resources per exhibition, standard deviation is 52). In this specific exhibition, the NEAR panel expands to occupy the whole length of the screen, but it is still viewable by the user. To check the appearance of NEAR when large number of objects are involved, we made a test by setting up an exhibition with about 1000 resources. In this case, the screen has to be scrolled down several times to see all the objects. Interaction becomes fragmented, some resources are located several screens away from the exhibition icons, users can no longer see the colour changes of linked

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[41] But help is a poor substitute for good user interface design.

objects from the mouse over, and they are unable to execute the visual Boolean query. In future versions of NEAR, scalability needs to be improved.

6.7 Summary

In this chapter, I introduced a new implementation of NEAR in detail. Considering the evaluations, principles and qualities of the two spiral design cycles discussed in Chapter 5, the new implementation made improvements to different aspects. In the icon design section, I introduced a new design of exhibition icons to represent exhibition attributes in a clearer, more orthogonal way. The paper icons of annotations and the representations of resources have been improved as well. In this version, interaction is richer. In addition to highlighting the direct relations by mouse over, basic Boolean querying is enabled visually by using mouse clicks and mouse over consecutively.

Using a node-link graph to visualize bibliographic coupling relations among exhibitions has become more efficient in Chapter 5. In this new implementation, the visualization is enriched to follow a user's shifting focus, and reacts based on a user's demands. The visualization has three different views (exhibition-centric, annotation-centric and resource-centric) when a user focuses on the three types of objects. Each view has two states: the simple view is used to show the direct local hierarchy of the focused object, and the extended view(s) are used to reveal bibliographic coupling or co-citation information according to the user's request. Thus the NEAR panel makes visible the EAR structure and contexts such as bibliographic coupling and co-citation. It is a first step towards fluid browsing and resource discovery with such structures.

7 CONCLUSION AND FUTURE WORK

7.1 Conclusion

In this thesis, I propose and argue the existence of a culturally meaningful data structure of *Exhibitions*, *Annotations* and *Resources* (EAR), discuss the relations and influence of such relations that exist in EAR objects, and design a compact interactive visualization panel to help users navigate, understand and use EAR objects in a generic information repository A•VI•RE.

7.1.1 EAR objects

Inspired by the content organization and hierarchy of museum online galleries and many other applications, I examine the EAR structure in the following domains of digital space: websites, online galleries, e-commerce systems, academic repositories, digital libraries, Open Access Systems, and computer object oriented programming. In each of the domains, the EAR structure always exists (although in different forms) due to the involvement of users. In EAR structure, a *resource* is identified as a piece of information or an object in the digital environment. An *exhibition* is a public display of a collection of such resources. Annotations are created by users through intentional comments or interpretations of the resources or the exhibitions. The following is a summary of a basic EAR structure:

- Exhibitions include annotations and resources;
- Annotations annotate resources and exhibitions;

- An exhibition may include other exhibitions;
- An annotation may be created within other annotations;
- Resources and annotations may be included in multiple exhibitions.

With these direct relations, we can draw indirect relations like bibliographic coupling and co-citation relations. Bibliographic coupling happens between exhibition and exhibition via resources or annotations; exhibition and annotation via resources; and annotation and annotation via resources. Co-citation happens between annotation and annotation via exhibitions; and resource and resource via exhibitions or annotations. Integration of these relations can be used to compare similarities or used as collaborative filtering methods in recommendation systems. People author EAR structures and other people value these acts of authorship when attempting to understand a large collection. Since resources are selected and gathered by exhibitors based on certain purposes (preference, usage or convenience) and the emphasis is highlighted by annotations, information around an exhibition is much more abundant than a simple collection. Also, different annotations and exhibitions around one object may provide views from different perspectives to give users more understanding. Considering human factors, the EAR structure reflects user preferences and refers to collaborative advice. The hypothesis of our research is that recognizing, analyzing, prototyping and evaluating the EAR triangle can result in both generalizeable insights and the creation of new tools for information visualization and system design.

7.1.2 Navigation and Understanding of EAR objects

A•VI•RE is a generic multimedia repository carrying the EAR structure. In the system, bibliographic coupling and co-citation relations among EAR objects form a general graph. To help users understand and navigate these data, information visualization embedded in an interactive interface could be an effective solution. After reviewing several principles and techniques of information visualization, I proposed a compact interactive visualization panel to help users "Navigating Exhibitions, Annotations and Resources" (NEAR) in the A•VI•RE system. The visualization represents key qualities of objects like relations, popularity, visitation history and changes, and follows design principles such as being compact, responsive, consistent and recognizable.

7.1.3 Implementation of the visualization

After three spiral cycles of design, evaluation, and redesign, the current implementation of NEAR panel has three components: icons represent individual objects, node-link graphs represent bibliographic coupling and co-citation relations, and interaction components help users in exploration. Each type of EAR object has its own series of icons to represent its local attributes such as size, popularity and visitation status. An exhibition icon is a stack of layered squares to represent the idea of a collection. An annotation icon uses a paper metaphor to represent the mixture of text and resources. A resource icon uses the thumbnail for image resource or file type icon design based on popular computer OS systems.

A node-link graph is used to represent co-citation and bibliographic coupling relations. All related objects are connected towards the current object. The NEAR panel has three different views to match user focus when the user is looking at an exhibition, an annotation or a resource respectively. Each view has two states: the simple state shows the local hierarchy of current objects, and the extended view shows all bibliographically coupled or co-cited objects according to user demand.

Interaction uses mouse click and mouse over as input. Mouse over will dynamically highlight all direct related objects to reveal the inclusion or reference relations. Mouse click freezes the highlight so that the user can examine the information in detail. In the frozen view, mouse over will highlight another group of objects in different colours, so that the user can see the Boolean operation result (union, intersection and difference) of two sets of objects visually.

Evaluation shows that the system reaches some of its design targets. However, there is still much room for improvement. In the icon design section, since there are many attributes encoded in a 40 by 40 pixel icon, it is challenging to make it easily recognizable. There is so much information encoded into the subtly designed compact visualization that it would be difficult for new users to get all the information if there is no explanation or help.

7.2 Future work

This implementation is not the end of NEAR development. There are many more improvements and functions to be added that will further support users. I list several potential improvements below:

Graph: Currently the system shows related objects using co-citation or bibliographic coupling information. However, such relations are only part of all possible relations. A more complete version of NEAR would need a more complex algorithm like SimRank (Jeh and Widom. 2002) to calculate relativity between objects, or even find the opposite of the current object (objects with conflicting ideas).

Icon: Current icons (especially the exhibition icons) are not sufficiently intuitive. Users still need training or a help file to fully understand the meanings. The paper metaphor of an annotation icon is better, but still has potential for improvement.

Interaction: Visual query is clear and direct for most users. The NEAR system currently only supports simple single-step Boolean operations between two highlighted sets of objects within the current displayed objects. The next improvement would enable users to define fully functional Boolean operations in succession within the whole system..

Organizing, managing and authoring: The NEAR panel currently is only used to display information. During the interaction phase, users may have selected a group of interested objects and may want to create an exhibition or make annotations based on the selected objects. A function to enable such operations could simplify the authoring process in the A•VI•RE system significantly.

7.3 Generalization

As I discussed in chapter 2, the EAR structure can be found in many domains. Principles and technologies used in this thesis could be generalized to assist people in these domains. Deeper research in this topic area may also help people to explore the limitations of current applications, such as E-learning and digital libraries.

7.3.1 Online education applications

EAR structures exist in E-learning systems. A course can be seen as an exhibition set up by the educator. References, figures, and examples are resources of online education. The teaching texts can be seen as annotations created by an educator to help students understand the course. Student assignments (their own annotations to the course and materials) reflect student understanding of the course. In fact, the vGallery system (Woodbury et al. 2000), prior version of A•VI•RE, was designed to support online learning in design schools.

The scaffolding metaphor in learning science focuses on making information organized and easily accessible during the learning process. Principles used in this thesis may be helpful for creating these scaffolding tools to assist users. Quintana et al. (Quintana et al. 2004) organized the scaffolding design framework around three constituent processes:

Sense Making, which involves the basic operations of testing hypotheses and interpreting data;

Process Management, which involves the strategic decisions involved in controlling the inquiry process;

Articulation and Reflection, which is the process of constructing, evaluating, and articulating what has been learned.

Information visualization presented in the NEAR panel could be an effective tool for the sense-making process. The combination of graphs and icons in NEAR is not a simple visual representation of the objects, but rather an environment to help users become aware of the surroundings. By visually representing contexts of the objects, users can read the objects from multiple aspects to get an overall understanding. Furthermore, with enhanced interaction, the visualization could support process management, articulation and reflection. The following describes a simple scenario of using NEAR to support the learning process. A user is given a topic to study. Searching tools and a NEAR panel helps him/her to find a resource of the topic. Then the user looks at contexts of the object through NEAR, selects related or supporting objects through interaction, builds his own exhibition with the selected material, and creates his own annotations or interpretations of the resource. After he/she finishes the process, his or her work becomes part of the whole system, which can be seen in the NEAR visualization, and can be referenced by other educators or students.

7.3.2 Scholarly research

In chapter 2, I discussed the existence of EAR structure in digital libraries and scholarly repositories. Online research can be seen as interpretation in the digital space including two types of acts: reading and authoring (Qian and Woodbury 2004). Authoring is interpreting by creating artifacts, and reading is interpreting by experiencing artifacts. Reading, authoring and interpretation are not sharp concepts with clear boundaries. They construct the space in which user acts occupy uncertain locations within a reading—interpretation—authoring triangle. Distinct kinds of acts and expectations, including most of researchers' activities, cluster around points in this space. The EAR structure and NEAR approach may assist researcher on the reading – interpretation – authoring triangle. Many scholar systems provide citation links, so that researchers can easily identify which paper has been cited in the current paper (the references list of current paper is obvious) and see the citation relations among papers. However, for most recent or near simultaneous research, these publications will not be able to cite each other. This is a reason why citation index research is important. Bibliographic coupling and co-citation relations make the clustering of publications much easier. Similar to e-learning's scaffolding metaphor, researchers also need such a support to build their own research frame. Researchers need to know and understand the "cutting-edge" research outcome in their field, search and collect research outcomes (publications, systems), track the path of ideas from citations and references, make creations based on previous works, and publish the outcome. Consider a paper as an exhibition of research work: all references and figures collected would be resources, and the text on paper would be the annotation. A visualization of the context of a paper could be helpful to the reader. Researchers benefit from a combination of recommendation-like functions that make it easier to collect, discriminate and filter related data and build up understanding across data.

7.4 Summary

EAR structure encodes user understanding and interpretation. This structure exists in many domains. Users create exhibitions, annotations and resources individually or cooperatively, encoding their ideas and thoughts into the annotations, resources and exhibitions. At the same time, other users visit these objects, read, understand and interpret the information. This process also makes contributions to the objects. In this thesis, I argue that the EAR structure is a general device that provides the foundation to assist users in navigating, understanding, and using data in digital spaces. A single set of EAR objects provides an environment to enable user to understand objects locally. Since

EAR objects contain cross references, a visualization of the relations among EAR objects may provide views of the objects from different perspectives, which help users to further understand the objects and obtain richer navigation choices in digital space. Focused on the indirect relations under the surface of EAR objects, a compact visualization panel with interaction was proposed and implemented as a preliminary to exploring the rich information carried by EAR objects. Although the analysis, implementation, and evaluation were based on an individual multimedia repository system, principles and techniques from this research could be applicable to other domains. I would like to generalize this idea, and I believe such generalization and further research of the EAR structures will benefit people surfing the contemporary information.

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