Chapter 10 The Implication of Metaphors in Information Visualization

The use of metaphors as a means of organizing thoughts or ideas has a long history that dates back to the fifth century B.C. (Yates, 1966). Metaphor study is multi-disciplinary. It relates to psychology, cognitive science, philosophy, education, computer science, and, of course, linguistics. Metaphors are pervasive in linguistics. However, metaphors are not merely linguistic phenomena; they reflect a deep structure of thought (Lakoff and Johnson, 1980). Metaphors are ubiquitous in interface design. A passion for metaphorical interface design stems from the metaphorical tendency of human information processing and its fundamental and indispensable role in the human cognitive process. It is no surprise that the application of metaphors in a computing environment can be traced back to the invention of computers. When people realized that the process of human computer interaction is also the process of human cognition, it is natural to employ metaphors to shape a variety of models to facilitate human computer interaction. Visualization for information retrieval also embraces metaphors with enthusiasm. The complexity and challenge of visualization for information retrieval are far beyond ordinary human computer interface design in the sense of both system design and system use. Metaphors are desperately needed to establish a cognition-friendly visual environment where users can easily understand the internal working mechanism, intuitively comprehend the objects and their contexts, quickly learn operations and features, and effectively explore the visual environment.

10.1 Definition, basic elements, and characteristics of a metaphor

What is a metaphor? There are plenty of definitions, but the essence of a metaphor is understanding and experiencing one thing in terms of another experience (Lakoff and Johnson, 1980). Since a metaphor involves a comparison between different concepts, there are many definitions that emphasize the comparison. Metaphor is a comparison in which the tenor is asserted to bear a partial resemblance to the vehicle (Tourangeau and Sternberg, 1982). A metaphor hinges upon an unusual juxtaposition of the familiar and the unfamiliar (MacCormac, 1989). It is clear that the purpose of a metaphor is to use one concept to explain another concept, so some definitions focus on the characteristics of the comparing and compared concepts in terms of explanation. Metaphors bring out the "thisness" of that or "thatness" of this (Burke, 1962). A metaphor is an analogy (MacCormac, 1989), which uses one experience in the one domain to illustrate another experience in a different domain and thus to acquire a better understanding of complex and unfamiliar concepts. Metaphors are also defined as models that apply tangible, concrete, and recognizable objects to abstract concepts and/or processes (Baecker et al., 1995). A metaphor is a description of an object or event, real or imagined, using concepts that cannot be applied to the object or event in a conventional way (Indurkhya, 1992). In other words, metaphors explain usually abstract concepts by using more concrete concepts (Weiner, 1984). In summary, when using a metaphor, a familiar, simple, concrete, intuitive, well-known concept or object is employed to describe another new, complicated, abstract, unknown concept or object by juxtaposition of their similar attributes, which make the concept more easily recognized, communicated, understood, and remembered.

One of the distinctive characteristics of metaphors is exaggeration. The hyperbolic nature of a metaphor really enriches its expression and gives users an unbelievable imaginary space. It is this exaggerated nature of a metaphor that produces a sense of humor. Metaphors usually reveal the emotions of its producer, and these emotions may be transferred to users/readers. The use of metaphor possesses a strong cultural background because a metaphor is deeply rooted in its cultural and social context. The cultural aspect of a metaphor makes its application more challenging.

A metaphor basically consists of the following elements: target domain, target item, source domain, source item, and mapping/matching (See Fig. 10.1). The target domain is where a relatively unknown and unfamiliar target concept comes from. The target item, or target concept, or target referent, or vehicle, is what is to be interpreted and explained in a metaphor. The source domain is a one where a relatively well-known and familiar source item, or source concept, or source referent, or tenor, comes from. The source referent is metaphorically expressed to explicate the target referent. People are supposed to be quite familiar with both the source domain and source concept in a metaphor. According to structure-mapping theory (Centner and Markman, 1997), the mapping between the source referent and target referent in a metaphor is a process of establishing a structural alignment between two represented referents, which consists of an explicit set of correspondences between the representational elements of the two referents, and then projecting inferences. As a result, metaphorical representation is made up of the referents, their properties, relations between referents, and high-order relations between the relations. The mapping may happen at different levels from referent attributes, to higher-order relations, even to the related domains, and then integrates them into the overall alignment. The process of matching between two domains is also called blending (Fauconnier, 1997).

Unfortunately, the target concept of a metaphor may never exactly match the source concept in the alignment process. Metaphors possess both epiphoric and diaphoric properties which arise from the similarity and dissimilarity among the attributes of the two referents, respectively (MacCormac, 1989). It is understandable because of the domain deference and the referent deference. As a result, mapping between the two referents produces three parts: matched part, unmatched part in the target referent, and unmatched part in the source referent. Some features and attributes of a target referent may not be reflected in a source referent. And similarly some features and attributes of a source referent may not reflect in a target referent (See Fig. 10.1). Even for the matched features and attributes of the referents, the extent of the match may vary. These are the reasons for the mismatch phenomena in a metaphor. Attribute mismatches have significant impact on a metaphor because the projected inference depends heavily upon the alignment. The audience of a metaphor must be capable first of identifying the connection being posited, and second making the correct attribute linkages between the referents (Hamilton, 2000). A mismatch, if it is not handled properly, may cause confusion for the audience.

Matching between both the target and the source in a metaphor creates juxtaposition and an association between them. This association may sometimes seem counterintuitive or make no sense if the nature and scope of the two involved domains are significantly dissimilar. In other words, a metaphor results from a cognitive process that juxtaposes two not normally associated referents, producing semantic conceptual anomaly. However, it can be this lack of making sense that generates unexpected and surprising effects that may lead to an easy and more thorough understanding of the target. That is the power of a metaphor. A metaphor constitutes a violation of selection restriction rules within a given context, when in fact, this violation is supposed to explain the semantic tension (Johnson, 1980). It means that a metaphor may be contextually irregular if it is interpreted only literally. This arises from the application a concept from a domain to the context of an "irrelevant domain". That is, the two referents do not have to be within

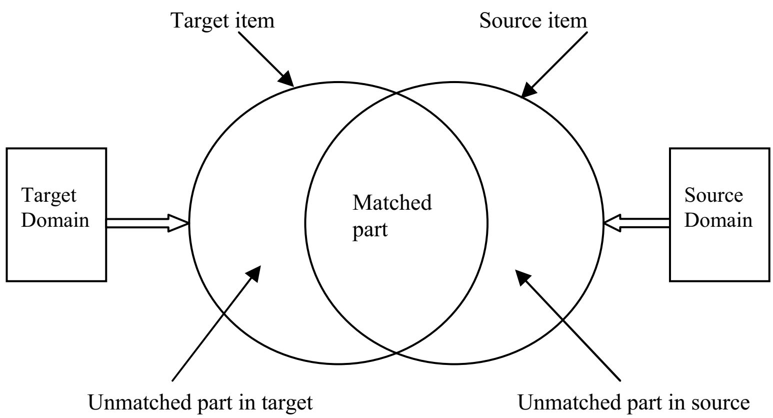

Fig. 10.1. Illustration of basic metaphor elements

similar domains, or species, or genus. As long as they share meaningful characteristics and these characteristics make sense in the contexts, one referent can analog the other.

The matching process is a one of integrating two domains. When the two domains map partially, a new domain in the metaphor is derived. Matching generates new features, relationships, and contexts which may not exist in either the target or the source. The new properties, relationships, and contexts are a result of the creative mapping. That is, matching between a target and a source is not simply a mapping process and it produces emotion and new attributes and characteristics belonging to neither tenor nor vehicle but the integration of both.

10.2 Cognitive foundation of metaphors

Cognitive science studies various human mental tasks, behaviors, and processes such as thinking, reasoning, planning, learning, memory, attention, and so on. In nature, the interactive process between a human and the information retrieval visualization environment is a cognitive one. Understanding of the relationships between metaphors and cognition at a deep mental level would help us to master the essence of metaphorical embodiment in the information retrieval visualization environment.

Metaphors, as proper cognitive devices (MacCormac, 1989), are essential to learning, development of thought, and a more holistic understanding of the domain. Use of metaphors affects perception of a concept, its interpretation and possible subsequent actions. The creation and explanation of metaphors have a close relationship with analogical reasoning and problem solving (Gentner and Gentner, 1983). In a landmark study, Lakoff and Johnson (1980) stated that our ordinary conceptual system is fundamentally metaphorical in nature in terms of how we both think and act, and human thought processes are largely metaphorical because the human conceptual system is metaphorically structured and defined. They claimed that the nature of metaphors is the nature of cognition. Johnson-Laird (1983) further confirmed that from the cognitive perspective, metaphors are regarded as examples of mental models.

Metaphors can play an extremely important role in understanding more abstract concepts. Lakoff and Johnson (1980) claimed that the reasoning we use for such abstract topics is somehow related to the reasoning we use for mundane topics. In other words, abstract reasoning depends upon concrete and simple facilities like metaphors. The more complicated a concept, the more a metaphor is needed to provide its explanation.

The cognitive metaphor theory (Romero and Soria, 2005) assumes that there is a set of ordinary metaphoric concepts around which people conceptualize the world. The concepts in the ordinary concept system contain the structure of what we perceive, how we get around the world, and how we relate to other people. People tend to solve problems by prior experiences and knowledge gained from similar situations. Cognitive models derive their fundamental meaningfulness directly from their ability to match up with pre-conceptual structures. Such direct matching provides a basis for an account of truth and knowledge (Lakoff, 1987). The pre-conceptual structures are a pre-existing knowledge system. They are built based upon long-term accumulated experiences and expertise. When people encounter an unfamiliar concept, the cognitive system looks for the best match between the unfamiliar concept and the pre-conceptual structures, and tries to understand it by relating the existing familiar concept, expertise, and experiences to the unfamiliar concept. Since metaphors are familiar and well-understood concepts, events, and objects, they are primary elements of the pre-conceptual structures. If metaphors in the pre-conceptual structures share common characteristics with a new concept, then they may naturally be used to explain the new concept. This theory is extremely important because it helps us understand the cognitive role of metaphors in learning and comprehending a new concept, especially complicated and abstract one.

10.3 Mental models, metaphors, and human computer interaction

10.3.1 Metaphors in human computer interaction

Metaphors have strong influences on computing, especially upon interface design. Of all the cognitive science concepts used in human computer interaction, metaphor has proved to be one of the most durable and accepted (Dillon, 2003). Interface metaphors act as a cognitive shortcut by helping users to build on already existing mental models of familiar concepts when learning new systems (Booth, 1989). If users work with a metaphorical interface, previously existing knowledge about the metaphor is bound to affect the perception of the interface and the interaction process. Well designed metaphors proved to be particularly robust as conceptual aids and were quickly adopted as part of the fabric of graphical interface (Hamilton, 2000). It is not surprising that the application of metaphors has become a basic guiding principle in general interface design.

It is interesting that both system designers and system end-users benefit from metaphors. System analysts and developers use metaphors in system design and programming such as states, data flow, task, activity, entity, object, overflow, traverse, tree, stack, and queue. On the user front they can easily find metaphorical embodiments in an application such as a window, drawer, folder, paper clip, bookmark, trash can, virus, quarantine, and hour glass. The information highway and Web are almost synonyms of the Internet; and navigation and surfing are equivalent terms to browsing.

10.3.2 Mental models

The theory of mental models was first introduced by Craik (1943). He believed that mental models of human beings are "small-scale models" of reality which are used to reason, anticipate events, and underlie explanation. Mental models are defined as a way that people solve deductive reasoning problems (Johnson-Laird, 1983). A mental model is the appropriate organization and representation of data, function, work tasks, activities, and roles that people inhabit within social organizations of work or play (Marcus, 1994). A mental model is an internal explanatory mechanism of human thought that dictates the way and method in which people perceive, understand, interact with, and make predictions about the real world.

10.3.3 Mental models in HCI

Mental models are extremely important for interface design. Users may not be aware of the formation of mental models and impact of mental models on their behavior when they interact with an interface. But people's thinking, behavior, and actions are guided by mental models in the interactive contexts. From the human computer interaction perspective, mental models tell people how a system works when people interact with the system (Norman, 1988). By understanding the users' mental model of an information system, designers may better know how users perceive the system, how users infer system features based upon the interface, how users react to the system, and what users expect for a response from a certain function or feature. Therefore, correct mental models may help people to avoid unnecessary loopholes in an interface design and make the interface design more user-centered.

The generation of mental models involves the aggregation of experiences and knowledge. Mental models are the result of categorization, classification, and abstraction of a complicated and sophisticated situation or phenomena by excluding some insignificant details and extracting the significant hidden structure. As a result, they simplify the situation or phenomena, present it structurally, and contain minimum detailed information about the situation and phenomena they describe to maintain the analytic, explanatory, and communicative power of a conceptual model.

Mental models vary among people because different people have different cultural and technical backgrounds, mental abilities, experiences with a system, and expertise in a domain. In this sense, mental models are subjective. Mental models are not fixed after they are established in the mind. Mental models can be updated and revised as users interact with new environments. They evolve based upon both successful and unsuccessful experiences with a system.

Users usually form their mental models about an interface from the following channels: training, user manual, user guide, system help file, and exploration of the system by themselves, and previous experiences with similar systems.

Types of HCI mental models

Mental models can be classified into three categories based on distinctive user groups in an information system: user mental model, design model, and system model (Norman, 1988 and Cooper, 1995 a). The user mental model of a system refers to the model that is established from the angle that users perceive and understand the system. The design/manifest model of a system refers to the description and explanation from the perspective of people who make theoretical contributions to the system. It is devised as a means for the understanding of system design. In other words, it is an initial conceptual model of the system. The system/implementation model refers to the model of the system from the viewpoint of system developers and implementers. A system model serves as an intermediate bridge between the users' model and the design model and directly influences the form of a user model. That is, users perceive and understand the design model through the system model.

In an ideal scenario, a design model should be correctly mirrored in an implementation model, and both the design model and implementation model should be correctly echoed in a user mental model. In other words, a well structured design model should be equivalent to its system model. And a user model should be consistent with both a design model and a system model. However, due to a variety of reasons, a user model has no resemblances to its system model and design model, which may lead to cognitive confusion and even frustration when users interact with a system.

Mental models can also be classified into a structural model and functional model from the perspective of system use (Preece et al., 1994). In this sense, they can be regarded as sub-categories of the user model. A structural mental model describes a deep internal working mechanism of a system/device and tells people how a system works and internal components are related. Knowing a structural mental model, users can understand the fundamental principle behind the screen, explain system reactions, predict about possible reactions and responses triggered by an operation, and therefore effectively interact with the system. A functional mental model describes how users operate a system/ device; it guides users in the operation of a system that it describes.

Implication of metaphors in mental models

The role of metaphors in effective interactions between users and information systems has been a focus in mental model studies for a long time. It is widely recognized that users, especially new users, try to understand information systems as analogical extensions of familiar activities and objects (Douglas and Moran, 1983). Metaphors embedded explicitly or implicitly in an application are powerful tools for the development of cognitive and conceptual models (Rubenstein and Hersh, 1984). These observations have inspired a variety of metaphorical interfaces ranging from pervasive metaphorical icons in interfaces, to a metaphorical paradigm for graphic controls, to a metaphorical interface design principle.

In nature, mental models are structural analogies of the world (Johnson-Laird, 1983). Therefore, it is very natural to employ metaphors to construct mental models. Metaphors can be embodied in a conceptual design model and be materialized in a system model so that the users' model may be easily and accurately formed and information of the design model can be conveyed to end-users by the system model in a more effective and efficient fashion.

For a variety of reasons, a system model may partially reflect a design model. User models can vary in different users for the same system because the generation of a user model is affected by user's knowledge, expertise, experience, and understanding of the system model. A poor design model definitely would result in an incorrect system model and a good design model does not guarantee a good system model. An improper system model would definitely produce a negative impact upon the generation of a correct user model. The role of metaphors in a design model, system model, and user model is to serve as an effective communication means. An appropriate metaphorical embodiment helps the system designer, system implementer, and system users to understand the system on the same cognitive ground. Metaphors make formations of both a design model and a system model within the same familiar contexts, which definitely would decrease the inconsistencies between the two models. In addition, metaphors enable users to bypass the system model and to directly communicate with the design model by the metaphors. As a result, it reduces a communication layer and eliminates possible "noise" created by the layer. Therefore, a metaphor embodiment facilitates the correct generations of the models; Maximizes the effectiveness of communications among designers, implementers, and end-users; And minimizes "noise" added to both a system model and a user model when a design model is transformed into a system model and shaped in a user model (See Fig. 10.2).

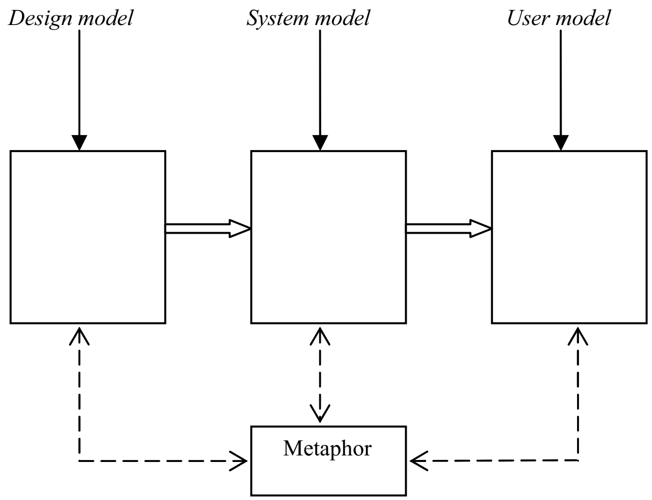

Fig. 10.2. Role of metaphors in the three models

The key point of metaphorical embodiment in mental models is to find the appropriate and applicable metaphor which fits a design model, and is conveniently and smoothly transformed to a system model, and easily help users to shape a correct user mental model.

10.4 Metaphors in information visualization retrieval

Metaphorical embodiments in information retrieval visualization environments are quite different from metaphorical applications in general computer interface design. That is because the former involves more variables and concentrates on not only analogy of each individual control, but also the analogy of an entire visual environment.

Metaphors have been applied at different levels of information retrieval visualization environments, ranging from an entire system such as a whole visual semantic framework, to a task such as a search and browsing, to a graphic icon design. Information retrieval visualization environments provide an ideal stage for metaphor application.

10.4.1 Rationales for using metaphors

Spatial, sophisticated, and abstract characteristics of information retrieval visualization

One of the most salient characteristics of an information retrieval visualization environment is its spatial presentation in a two or three dimensional space. Objects, abstract object relationships, semantic structure, and associated retrieval means have to be illustrated within the space for end-users in a meaningful fashion. It is a challenging task to come up with a visualization model which puts these elements together to establish a theoretical framework to make sense for information retrieval. The process may need complex mathematical reasoning, spatial imagination, and solid understanding of data characteristics and user information seeking behavior. But it is even more challenging for users to comprehend the information retrieval visualization environment. This is because:

1. Semantic relationships among objects and structures in a database are complicated, invisible, and abstract.
2. The high dimensionality of a database has to be reduced in order to present objects in the visual space. During dimensionality reduction some attributes of an object may have to be compromised to accommodate significant attributes in the visual configuration.
3. The objects, object relationships, or inherent structures which underlie the visualization environment may be “distorted” after they are projected on the visual space.

4. Semantic relationships of objects in the visual space may be expressed in a dynamic way rather than a static way.
5. An information retrieval visualization environment may contain multiple types of objects, for instance, documents, queries, reference points, links, retrieved results, browsing paths, and so on. These objects need not only to be distinguished but also to be understood and manipulated by users.
6. Furthermore, an information retrieval visualization environment usually offers more rich, dynamic, and sophisticated retrieval operations. For example, the search process may require the support of multiple reference points, browsing a visual space is no longer linear and users navigating in a visual space may become disoriented, reformulating a search strategy is affected by multiple factors, and selection of an information retrieval model requires more expertise in information retrieval.

In a broader sense, an information retrieval environment is an interactive interface. It should possess all of the basic characteristics of an ordinary human computer interface. In addition, these unique characteristics differentiate information retrieval visualization from ordinary human computer interface design. A design model of information retrieval visualization becomes much more complex due to these unique characteristics, the design model is less easily reflected and materialized in a system model, and establishment of a proper user mental model is even more challenging.

As a result, a visual configuration in a visual space is usually abstract and complex for users, especially users without an information retrieval background. If users do not understand the meaning of the visual configuration in a visual space, it is impossible for them to manipulate effectively and efficiently. Finding an effective way to simplify the abstract, sophistical, and complex visual configuration and make the abstruse visual configuration understandable without a huge effort is one of the high priorities for information retrieval visualization.

Metaphors as the solutions

As the levels of complexity are layered one atop the other in order to produce the high-level behaviors that are the actions we recognize while interacting with the computer, the possibility of talking or thinking literally about the computer's behavior vanishes. We deal with this complexity and this plasticity by speaking metaphorically about the computer (Hutchins, 1989). Purely intellectual concepts, the theoretical concepts in science, are often - perhaps always – based upon metaphors. Researchers found that spatial property and abstract property, which are basic properties of an information retrieval visualization environment, are inherently metaphorical. Studies showed that metaphors have a natural connection to abstract and spatial concepts. An abstract concept is intrinsically metaphorical (Lakoff and Johnson, 1980). Our comprehension of abstract domains is often shaped through spatial metaphors, a property which can be and has been directly exploited from a wide variety of interface designs (Kuhn and Blumenthal, 1996). The above analysis suggests that the complexity of an information retrieval visualization environment caused by its inherent spatial and abstract properties can be simplified by the metaphorical embodiment in the environment. In other words, metaphors simplify the complex design model of information retrieval visualization, smooth the progress of materialization of the system model, and facilitate the correct shaping of the user mental model.

Metaphors can help users to overcome the learning curve of information retrieval visualization environments. In fact, a metaphor has become the synonym of easy learning in human-computer interface design because it does not require technical knowledge, making an unfamiliar system look and act like a familiar system. As a result metaphors can not only minimize cognitive efforts to reduce the learning time of users, but may also result in long term memory about the system (Allbritton et al., 1995). Metaphors promise a considerable payoff in wide-ranging improvements in learnability and ease of use (Carroll and Thomas, 1982). It can improve the familiarity and predictability of an information retrieval visualization environment. Understanding of a visual semantic configuration in a visual space is not only important but also necessary. Users cannot effectively and efficiently interact with an information retrieval visualization system if they are thrust into such a complex environment with little background knowledge. This means that users have to understand its visual semantic configuration and learn its features before they can manipulate it. Metaphors help users to instantly grasp the essence of a visual configuration, quickly understand it, and effectively interact with it.

Another non-technical benefit of the metaphorical applications is to make a monotonous and tedious visual presentation and routine retrieval controls more vivid and interesting. An information explorative process may become an entertaining process in a metaphorical information retrieval visualization environment. For instance, if users navigate in a metaphorical information system where all elements of a library such as book, bookshelf, information reference desk, storage areas, rooms, check-in, and check-out are integrated, they feel comfortable and excited with the familiar setting and contexts. The fisheye technique maximizes an interesting area and immunizes its surrounding areas like a fish searching for food in the water. And the flexible control, dynamic focus, and dramatic exaggeration of the fisheye view can make information browsing great fun.

Metaphors also inspire new scientific ideas, and they are vital to scientific discovery. It is no exception for information retrieval visualization. In the Pathfinder layout algorithm, the spring theory was successfully applied to draw objects in a visual space based on mutual attraction strengths. Metaphors exist as a quite normal creative human cognitive process that combines unrelated concepts to produce new insight (MacCormac, 1989). The insight would definitely enrich information visualization environments.

10.4.2 Metaphorical information retrieval visualization environments

Metaphors are widely applied to visualization for information retrieval. Metaphors are used to illustrate different perspectives of information retrieval visualization, ranging from an individual document, to a hierarchy structure, to hyperlink structures, to citation linkages, to information retrieval controls and processes, to a customized dataset, and to an entire collection of databases. Applied metaphors include things such as a butterfly, river, disc, the galaxy, the solar system, geographic landscape, islands in an ocean, maps, library, book, bookshelf, fisheye, lens, wall, water flow, etc.

The application of metaphors in visualization for information retrieval can be categorized into the following three groups in general: metaphors for semantic framework presentation, metaphors for information retrieval interactions, and metaphors for solving theoretical problems. Most of the metaphorical information retrieval visualization environments are in the first category because a visual presentation is fundamental for the environment. Notice that in reality an information retrieval visualization environment may be classified into multiple metaphorical categories due to multiple embodiments in the visualization environment.

Metaphors for semantic framework presentations

One of the primary characteristics of an information retrieval visualization environment is the demonstration of object semantic relationships in the visual space. These objects are not randomly scattered in the visual space. Objects must be positioned and projected onto a meaningful framework to form a visual configuration where internal structure, semantic connections among projected objects, and other characteristics of projected objects are illustrated. Metaphors can be embodied in a visualization environment and provide intuitive structures for the display of these objects.

Map is a familiar concept and it is employed in metaphorical visual configurations like *Visual Net* (2005) and *WebMap* (2003). Important properties of a map such as location, area, neighborhood, distance, and scale can be used to express semantic relationships about a dataset. Location indicates the position of an object in the semantic context/map. An area includes a group of objects with the same semantic characteristics. A neighborhood shows two groups of objects which share some commonality and have some kind of semantic connections. A distance between two objects in a map implies the similarity degree between them. The closer they are in a map, the more relevant, and vice versa. A zoom feature allows users to observe interest area at different levels from a large-scale global overview to a small-scale specific local view.

Like maps, landscape is also used in metaphorical interface design. Landscape brings in a variety of physical geographic features like fields, valleys, mountains, paths, rivers, etc. These properties, for instance in *SPIRE* (Wise, 1999) and *VxInsight*(Boyack et al., 2002), are used in expressing data relationships in a dataset.

WebStar (Zhang and Nguyen, 2005) uses the solar system as its visualization configuration metaphor. We know that in the solar system, celestial objects such as planets and asteroids have their own orbits and move at a constant speed. These objects revolve around the sun in the universe and pull at each other due to gravity. It is gravity that determines the orbit and moving speed of a planet or asteroid. *WebStar* emulates the solar system. In the *WebStar* visual space, the defined central (focus) point, or a selected start Web page, is regarded as the sun, scattered subject icons which represent users' interests and Web page icons which are outgoing Web pages of the selected start Web page are perceived as planets and asteroids. When a subject rotates, all related Web pages revolve around the central point, the sun. The rotation speed of each Web page icon is determined by the semantic strength between the moving subject and the Web page. Scattered outgoing Web pages are gravitationally affected by the central point. The gravity in the visual space here is defined as the semantic strength between the central point and a scattered Web page. The closer to each other, the more relevant they are, and vice versa.

Ryukyu ALIVE (Access Log Information Visualizing Engine) (Wakita and Matsumoto, 2003) presents the *Information Galaxy* metaphor. Stars within the galaxy represent Web pages. A browsed Web page would jump towards the outermost rim of the galaxy for further review. Un-browsed Web pages would gradually be drawn towards the center of the galaxy, and eventually disappear. Users browse Web pages by observing the moving galaxy system. Another galaxy metaphor is introduced in *SPIRE Galaxies* (Wise, 1999), where documents as stars are clustered based on their interrelatedness.

In the *Topic Islands* interface (Miller et al., 1998), islands represent topics. The location and size of an island depend upon the relationship among involved topics islands and the number of documents associated to the island respectively. Oceans separate the islands and provide the browsing platform.

File Pile (Rose et al., 1993) is designed to support the casual organization of documents. All items/documents in a database can be automatically classified into several meaningful piles on a table. Each pile indicates a certain subject/category where users can put in or pull out items from it. If the number of items in a pile is large enough, it can be subdivided into several related sub-piles upon request of users. Items in a pile can be selected and browsed by users.

A library can be utilized as a metaphor to organize documents because library's elements are very similar to the structure of directories and a library's basic functions are also similar to directories. The mapping of the virtual entities of directories on the structure of a library is very natural and straightforward. The library rooms are a rendition of directories while the books in it are files. Bookshelves represent different subjects. Doors separate the rooms or subjects (Chudý and Kadlec, 2004).

A bookshelf as an independent metaphor provides a natural framework to organize data in the *Visual Net* system (2005), Forager (Card et al., 1996), and *LibViewer* system (Rauber and Merkl, 1999). Book icons in the bookshelf can present categories and classifications, or different book types such as reference books, periodicals, non-reference books, or electronic books. The size and thickness of a displayed book icon can be associated with the number of books within a category or book type. Location of a book icon in the bookshelf can indicate the status of a book such as whether it is reserved, or available, or currently borrowed. The color of a book icon can also be used to show its publishing time.

Hierarchical structures are widely used to organize information. The parent and children relationship, sibling relationship, and level relationships of a hierarchical structure need to be metaphorically presented. The *Disk Tree* visualization method (Chi et al., 1998) selects a disc layout to display a complicated tree structure. Multiple levels of a hierarchy are illustrated by successive concentric circles sharing the same center (the root of the tree). The nearer to the center a circle is, the higher the level the circle represents. The angular area size of a slice, which is a category within a circle, corresponds to the number of leaves in that category. The vertex of a slice is the parent and all children are located on the arc of the slice. Within the same category all sibling elements are located on the same edge of a circle. In this manner, a hierarchy structure is visualized in a two dimensional space. *WEBKVDS*(Web Knowledge Visualization and Discovery System) (Chen et al.,2004) chooses a similar disk tree structure to visualize Web visits, Web usage statistics, average access time per page, and access possibility of the links.

Multiple attributes of a single document rather than a set of documents can be metaphorically demonstrated in a butterfly structure. The *Butterfly Visualizer* (Mackinlay et al., 1995) uses the head and two wings of a butterfly to illustrate the relationships between a retrieved document and its citing documents and cited documents. The head of a butterfly as an entry point indicates basic bibliographic information of a retrieved document, the left and right wings of the butterfly comprise all references of this document and citers of this document, respectively.

Time, sometimes, is a crucial factor for certain data. It is used as a browsing thread to organize the data to guide users through a series of events. Time is metaphorically presented in many visualization systems for this purpose. *Perspective Wall* (Mackinlay et al., 1991) is a three dimensional wall metaphorical configuration. One dimension (the horizontal dimension) of the visual space is reserved for the time variable, and the vertical dimension is used to visualize data layering for its information space. Detailed textual data is organized as small grids (cards) posted on the wall. The position of a textual grid (card) is determined by the two important parameters: publishing time of the data (horizontal location) and the types of data (Vertical location). When the wall moves, users browse events that happened in a continuous time period. In this way the large amount of linear structural data can be effectively displayed. *ThemeRiver* (Havre et al., 2002) applies a river metaphor to visual demonstration of topic changes in a database as time passes. The horizontal flow of the river represents the flow of time. That means that each horizontal point indicates a certain time. Since the flow is continuous, a horizontal section of the river flow represents a period of time. Each point of the horizontal flow corresponds to a vertical section which indicates a topic or theme. This vertical section is equally divided by the horizontal line. The width of the vertical section means the number of related documents to the related topic or theme. All vertical sections consist of a dynamic current of the river. The wider the river, the more documents address the topic or theme at that certain time. The narrower the river, the lesser documents there are that address the corresponding topic in the time. *Presence Era* (Viégas et al., 2004) uses the geological layers in sedimentary rocks to present the time factor in its interface. Geologically speaking, the accumulation of geological layers over time can reveal the detailed evolution of geological changes. Users can look into the history by examining various layer patterns. The geological formation of sedimentary rocks is significantly impacted by time and geological environments. Geological properties such as number of the rock layers, location of a layer in rock, and thickness of a layer are utilized to metaphorically present time period, time, and the amount of data respectively to visualize a time-sensitive data set such as e-mail files, online news group discussion archives, the Internet traffic logs, and citation chains in such a geological information visualization environment.

Metaphors for information retrieval interaction

The interactions between users and an information retrieval visualization environment are vital and sophisticated. Searching, browsing, judging relevance, and other activities are done by interactions.

Browsing in an information visualization environment is a necessary and crucial means to find information. A lens is a special reading tool that allows readers to focus on a special interest area in a visual space and exclude other irrelevant areas during a browsing process. A visualization space can provide many interest points and complicated contexts. A special tool like a lens can help users narrow down to a focus area during navigation and avoid overwhelming non-relevant information. For this reason a lens is employed in many visualization applications like *VIBE* and the previously discussed *Perspective Wall.* A bifocal lens was used to support the perception of a sequence of messages and the focal area is magnified to emphasize it (Spence and Apperley, 1982). The fisheye view technique can be regarded as a special lens. Fisheye perceives objects around it in a quite unique way. The focus area of fisheye is magnified to show very fine details of the area while other areas are intentionally minimized but are not totally eliminated to maintain a context. Fisheye can smoothly and gradually transfer from the focus area to another focus area so that all areas are naturally connected. Both the size of focus area and degree of the details in the focus area can be controlled at will. It is obvious that the focus area is dynamic. As its interests change, the focus area changes accordingly. These properties of fisheyes can be analogized to an information retrieval visualization environment to facilitate browsing. In addition, the fisheye view technique maximizes use of a limited visual display space to demonstrate more data, and illustrates richer and more specific information without losing the context in the visual space. For these reasons, the fisheye technique has been used in a wide spectrum of information visualization environments such as fisheye map (Yang et al., 2003), fisheye menu (Bederson, 2000), and fisheye hierarchy (Schaffer et al., 1996). Notice that since the non-focus areas are "distorted" to some degree, the distorted areas may lead to the confusion of users.

The walking metaphor (Mackinlay et al.,1990) simulates a browsing operation by using the way that human body movement such as motion forward, backward, turning left, turning right; human head rotation such as left, right, down, and up; and the plane motion of the human body such as left, right, up, and down. These motion combinations enable users to make a flexible exploration in the visual space like walking in a physical world.

Turning a page, skipping pages, and ruffling pages are common reading behaviors of a reader. In *WebBook*(Card et al.,1996) these behaviors of a reader are animated in a vivid way. Users can browse next or previous page by clicking on the right or left page of a metaphorical book. As a page is turned by users, its contexts gradually appear to users as if they are leafing through real pages. A user can also click on the right or left edge of the book. Then relative distance from the current page position to the selected position on that edge indicates how many pages to skip. The system even allows users to ruffle through the pages to have a quick glance at all pages.

Boolean search is implemented in almost all information retrieval systems. But the correct understanding and proper use of the Boolean search is not a simple task. The visualization of Boolean operations may shed light on the problem. *Filter/Flow* (Young and Shneiderman, 1993) attempts to simplify the complex Boolean query formulation process by using pipelines and water control. Documents of a database are metaphorically depicted as water in a pipeline system. Water is controlled by a series of control valves. A valve is usually connected by two pipelines. Each valve, which consists of a group of search terms selected by users, serves as a filter to control the amount of the document flow. Valve combination way can form a normal Boolean operator like "AND" or "OR", depending on valve position in the two dimensional visual space. In other words, the positions of valves in the visual space determine nature of the Boolean operation. If two valves are connected by pipelines in parallel in the visual space, it suggests there is an "OR" operation between the two valves. If two valves are connected by pipelines in a serial order, it implies that there is an "AND" operation between the two valves. The diameter of a pipeline corresponds to the amount of flow in the pipeline. Document flow starting from a dataset finally reaches a result pool as final search results after a series of filtering processes.

In a traditional manual punch card retrieval system, a card represents a topic or subject and it has a grid system. Each grid cell corresponds to a document. The position of a document is the same in all cards. If a document is related to the topic or subject that the card presents, then the corresponding grid cell of the document is punched. Retrieval processing is simple: selecting a group of interest cards, putting the cards together, and checking grid cell status. If users can see through a grid cell, then the corresponding document is retrieved. That is because that the document is related to all selected topics/subjects. The *Semantic Filter* (Fishkin and Stone, 1995) simulates this retrieval processing successfully.

Metaphorical search strategies are embodied in *Book House* (Pejtersen, 1991). *Book House* looks like a familiar library which integrates a library building, rooms, and people. Each of the rooms is equipped with bookshelves and books. Users can seek information by navigating in the visual library setting. Users can enter the library building and roam any available rooms freely, guided by people icons and room titles. Upon entering a room, users may choose four different search strategies: search by analogy, browse pictures, analytical search, and browse book descriptions. These four search methods are visualized by four metaphorical figures in the certain contexts of a room. A classification scheme, which is represented by iconic display, can be selected by users to narrow down their search topics.

Metaphor for solving theoretical problems

The implication of metaphors on visualization for information retrieval is not only to establish interactive interfaces to facilitate understanding, learning, and manipulating the system for end-users but also to help solving theoretical problems behind the screen for system designers. The spring theory for an optimistic object layout in a visual space is a good example of this category. After semantic relationships among objects are clearly defined by a certain approach, these objects are positioned or drawn in a low dimensional visual space based on their existing relationships. This is the so-called graph drawing issue. It has been proven to be a difficult task because the drawn objects have to be evenly distributed in the visual space to achieve a spatial balance for display, mutual attractions of the objects have to be considered, and unnecessary edge crosses should be avoided. The aim can be reached by applying the spring embedder approach (Eades, 1984). Observe that when in a physical system, the ends of different springs are connected by rings and randomly positioned in an initial status, the positions of all connected rings would automatically be adjusted by the forces of connected springs and ultimately reach their equilibrium. In this case, if rings and springs are replaced by objects and semantic strengths between objects respectively, all objects can achieve an optimum display status in the visual space.

10.5 Procedures and principles for metaphor application

10.5.1 Procedure for metaphor application

The previous discussion has mentioned that there are five basic elements in a metaphor: source domain, source items, target domain, target items, and mapping/matching. In fact, the application of a metaphorical information visualization environment must include these basic elements. The essence of metaphor application rests on finding a source domain and source items and mapping them to the target items in a meaningful way. In this case the target domain is information retrieval visualization and target items may be the information retrieval environment and/or its components. The source domain can be open to any meaningful domains. Both finding an appropriate source domain and source items and making successful matching between the source and the target require experiences and imagination, in addition to a solid comprehension of the working mechanism of an information retrieval visualization environment.

The procedure is listed as follows.

1. Identify the target domain which is information retrieval visualization; it is obvious.
2. Identify the target items in the domain. The application of metaphors in an information retrieval visualization environment may occur at multiple levels. The entire visualization environment can be a target item, or a task of the visualization environment can be a target item, or a control of a task can be a

target item. If the entire visualization environment is defined as a target item, its sub-elements can be further broken down into target sub-items.

3. Identify the source domain. Potential candidates are user familiar fields, which share commonalities in some degree with the identified target items, or any domains which may trigger an association to the identified items.
4. Identify source items in the source domain. All possible items sharing the common attributes with the target items, associated and related objects of the identified target items, the context of the selected target items, and relationships with other items should be taken into consideration.
5. Match or map the target and the source. Be aware that the match between the target and the source may be partial. Make sure that the important attributes of the target are matched to the salient attributes of the source. Analyze the matched parts between the target and the source and the implication upon the visualization environment, the unmatched part of the target and the implication, and unmatched part of the source and the implication, respectively.
6. Evaluation of the metaphorical environment. Develop a prototype of the metaphorical visualization environment, conduct a pilot experimental study about the visualization system, and revise it based upon user feedback. Revision may occur in any step, changing the source domain, replacing the target items within the source domain, and adjusting matching. First-hand feedback from users is important for a successful metaphorical application in an information retrieval visualization environment.

10.5.2 Guides for designing a good metaphorical visual information retrieval environment

Metaphors hold a lot of promise for visualization for information retrieval. The application of metaphors to an information retrieval visualization environment is a complicated process. A good metaphorical visualization environment design requires guidance to avoid the improper application of metaphors. Poor metaphorical embodiment is regarded in interface design as not only unhelpful but also harmful (Cooper, 1995 b). Improper use of metaphors can cripple the interface with non-relevant limitations and blind the designer to new paradigms more appropriate for a computer-based application (Gentner and Nielson, 1996).

The proposed guides attempt to assist in the design of a metaphorical information retrieval visualization environment which should be appropriate and suitable to information retrieval, intuitive and easy for users to learn, applicable to system implementation, and extensible for future expansion. Let us discuss these in depth.

Be aware cultural differences

A metaphor contains two types of representations: explicit representation such as models and artifacts and implicit representation, such as associated background, role, and culture (Benyon and Imaz, 1999). Without a doubt, cultural factors affect design, implementation, functionality, and use of a metaphorical interface. Metaphors are deeply rooted in a cultural context and the cultural impact of metaphors on metaphorical embodiment and use is inevitable. People should be fully aware of the cultural impact. Cultural differences in application and understanding of metaphors goes beyond the simple shape and color of metaphorical icons, metaphorical embodiment in an interface. Deeper and more fundamental conflicts are rooted in culturally different cognitive, emotional, behavioral, and social processes and structures which constitute the network of relationships on which metaphors operate in any given culture (Duncker, 2002). For instance, in the Chinese culture a calculator concept would be instantly associated with an abacus rather than an electronic calculator because the abacus has been used as a calculator for more than thousand years. It is natural and widely acceptable to use an abacus as a calculator icon. In a library metaphorical setting an automatic check-out machine which people from a developed country are familiar with may be a mystery to people from a developing country.

Smoothly bridging the target and the source

Cognitive dissonance (Festinger, 1957) is created by mismatch between the source and the target. In a human-computer interaction metaphorical context, cognitive dissonance occurs when user's expectations for the system conflict with his/her metaphorical beliefs. In that instance, users may lose trust in the metaphorical interface and become confused during the interaction with the interface. Cognitive dissonance would definitely degrade system performance, if not cause a complete failure. Properly matching important attributes of the target and salient attributes of the source, minimizing unmatched attributes of the source, and maximizing the matched attributes between the source and target can avoid possible cognitive conflicts. This would also facilitate the smooth transition from one referent to the other and therefore alleviate discomfort. For instance, a search feature can be represented by various metaphorical icons: a dog, or a pair of magnifying glasses, or a binocular, or a magnifying glass. A dog metaphor may mislead users because a dog as the source has too many possible attributes such as guiding, hunting, searching, racing, rescuing, etc. Users may associate a dog to any of these attributes, which can lead to cognitive dissonance if a wrong attribute is selected. In contrast, a magnifying glass or binoculars generates a better a match since the salient attribute of a magnifying glass or binoculars fully maps the search feature.

Emphasizing important attributes of the target

According to the influential salient imbalance theory (Ortony, 1979), metaphoricity arises from an imbalance in the salience of the common features such that high-salient attributes in the source domain are matched with low-salient features of the target domain. That is, important features or attributes of an information retrieval visualization environment should be mapped to eye-catching attributes of the source so that these attributes are easily perceived by users. The *ThemeRiver* visualization environment demonstrates a good match between high salient attribute of the source and low salient but important feature of the target.

The time line is an important attribute because all of the data is organized and presented against this time line. This important attribute must be emphasized in the metaphorical interface. Water flow in a river is the most salient attribute of the source, the best candidate for the metaphor. Furthermore, both of the attributes (time and water) share common characteristics such as dynamics and continuity. It is a perfect match which connects the two attributes.

Selecting a distant source domain

Selection of a source domain affects not only the further selection of the source items but also the success of a metaphorical embodiment. A good metaphor should involve two different domains and thus have high between-domain distance; and illustrate low within-space distance between the source object and target object in their very distant respective spaces (Tourangeau and Sternberg, 1982). This suggests that people should choose a metaphor with a high dissimilarity between the target domain and the source domain but a high similarity between the target object/concept and the source object/concept. The high dissimilarity between the domains may produce an imaginary room to derive new ideas in the metaphorical design and to create an unexpected click effect for users. But this dissimilarity of the two domains must be based upon the high similarity between the two items which would assure the accurate conveyance of structure and information from the target to the source and avoid mismatch. For instance, the source domains for an information retrieval visualization metaphor can be the solar system, or a galaxy system, or a geographic landscape, or a water pipeline system which have nothing to do with information retrieval. But the relationships among the sun, asteroids, and stars; connections among field, valley, mountain, and path; and associations among water, pipeline, and control valve resemble the semantic relationships among documents/objects in a database.

Considering the entire contexts of a selected source

When items from the source domain are identified and used in a metaphor, these items should not be isolated from their contexts. The contexts may provide rich and useful information. Its related objects, activities, connections with other objects, and the environment should be considered for possible use. In this sense, a designer should concentrate on not only the selected items from the source domain but also the content-rich contexts. The primary benefit of considering the entire context rather than individual items is that all elements of the source are naturally connected as a whole and their relationships are preserved. This achieves a better holistic effect for the metaphorical application. For instance, a fan as the source of a metaphorical application is usually used to describe and represent visually a hierarchical structure (the target) because its structure looks like a tree structure and it is a quite familiar concept. But if only this structure is used in the metaphor and its important contexts are ignored, the metaphorical application is not considered as a good one. Notice that a fan can have two distinctive statuses: closed and open. If the two statuses are used in the metaphorical hierarchy configuration, it would enhance the flexibility and effectively display a vast array of data. When users are not interested in certain sub-hierarchies, they can be set in a closed status and therefore more display room is saved for interest sub-hierarchies. When users interact with a sub-hierarchy in the closed status, they can activate it and the corresponding sub-hierarchy will be fully displayed in an open status. Another example is a book metaphor. When a book is identified as the source item, its associated concepts, contexts, and activities such as pages, cover, spine, size, color, series, bookshelf, index, classification, lens, turning a page, ruffling pages, etc. may be utilized for further exploration in the book metaphorical embodiment. *Information Landscape* (Weippl, 2001) is another successful example in which both the source item and its environment are fully used in a metaphorical interface. The metaphorical islands which represent categorized data are elegantly integrated with tide change to illustrate information. The tide is dynamic and tidal change can lead to a change in sea level. A high sea level can cover relatively small and low islands, and therefore make them invisible. A low sea level would make more islands visible. This feature can be used as a filter to hide unnecessary data in the visual space. Controlling the sea level in the visual space, users can visualize different scenarios in the information landscape at will. *Information Mural* (Jerding and Stasko, 1995), where information like pictures is drawn on a mural, uses two windows in its visual space to illustrate overview and detail information, respectively, for the long sequent messages. The lower window contains the long entire message set. Users can use a rectangle to select a section of the messages in the lower window. Then details of the selected messages are displayed in the upper window for users to view.

Expanding features of the source

The appropriate identification of the items in a source domain is vital to the successful application of a metaphor in information retrieval visualization environments. Identification and use of the source items should not be limited in the selected domain and may go beyond the domain by expanding new features based upon the domain. Feature expansion would make a metaphorical application more powerful. Take the same fan metaphorical interface as an example; any point of the arc in a fan represents a child node in a hierarchy and vertex is the root of the hierarchy. If the metaphorical application is limited to the original form, it can only display a one-level tree structure. But the metaphor can be expanded to display a multi-level tree structure if a point on the arc in a fan can derive a new fan which represents a new sub-hierarchy. Following the same generation rule, new levels can be generated at will. The original single level fan structure now becomes a multi-level fan structure that accommodates a more complicated hierarch structure.

Applying multiple metaphors

An information retrieval visualization environment is convoluted. Multiple metaphors may be applied to different levels. For instance they can be used in individual object icon, information retrieval control, semantic framework, and even visualization model design. If multiple metaphors are used, it is important to make sure that these metaphors are compatible and do not conflict in their meanings. In the *Visual Net* system, two different metaphors are integrated in an *OPAC* system.

All top categories of a classification system are organized in a bookshelf as an entry of the *OPAC* system, and book icons on the bookshelf represent different top categories. The size of each individual book indicates the number of books within the corresponding category. The second integrated metaphor is a semantic map where areas represent sub-categories and all documents within a sub-category are located in the area. Clicking a book icon on the metaphorical bookshelf, users can smoothly enter another metaphorical map where its sub-categories are displayed.

Understanding users

The motivation of developing a metaphorical information visualization environment is to help users to better understand, learn, and interact with the environment. Identification and selection of a metaphor should not deviate system designers from the ultimate aim of serving users. They must understand users and listen to their feedback about the selected metaphors, what their expectations are for the metaphors, what their interactive behaviors are in the metaphorical contexts, and what preferences they have. These questions would help designers make an appropriate decision on the identification and selection of the source and provide for a smooth match between the source and the target. This data can be collected from user surveys and interviews.

A designer should anticipate and predict that users may interpret the metaphorical interface design beyond the designers' own intentions and expectations. Select concepts or objects which are widely used and recognized by common users. Its definition and scope are well understood by users. A concept or object that requires another metaphor to explain its meaning should not be selected.

10.6 Summary

A metaphor is defined as a familiar and well-known concept to represent and explain an unfamiliar and complicated concept. A metaphor uses preexisting knowledge and experiences to understand an unknown concept. Since our ordinary conceptual system is fundamentally metaphorical in nature, it is no surprise that metaphors are regarded as effective cognitive devices which help people to generate an appropriate mental model for comprehending complex, abstract, and spatial concepts.

An information retrieval visualization environment is much more complex than a general user computer interface. It usually includes a semantic framework where semantic relationships are displayed and objects are positioned; diverse objects such as reference points, documents, information retrieval models, and so on; and sophisticated operations such as browsing an interesting area, query searching, and navigating the visual space, selecting and manipulating an information retrieval model, and customizing a visual configuration. Interacting with such a visualization environment, users rely upon a mental model to interpret the features of the environment. A mental or cognitive model created in a user's mind regarding the visual space significantly affects the way that they interact with the visualization environment. That is because a mental model guides users' response to the environment. Undeniably, metaphors can assist users to establish such a critical mental model.

A metaphorical information visualization environment simplifies the cognitive process of user mental model generation, and positions understanding of the visualization environment for system designers, system implementers, and system users on the same cognitive ground. Consequently it can effectively reduce misunderstanding and miscommunication among these three groups of people.

Metaphorical embodiment in an information retrieval visualization environment can be a double-edged sword. Improper use of a metaphor leads to the confusion and frustration of users. Therefore, guidance is needed to design a good metaphorical visualization environment which is appropriate, intuitive, and robust.