Comprehensive Mapping of Knowledge and Information Resources: The Case of Webster

Sherman R. Alpert

IBM T.J. Watson Research Center, PO Box 218,
Yorktown Heights, NY 10598, USA
salpert@us.ibm.com

Abstract. To maximize the representational and pedagogical effectiveness of computer-based concept maps, such maps should be able to incorporate any sort of media that can be represented in the computational environment. This chapter proposes cognitive and educational rationale for this thesis, and discusses an instantiation of these ideas in the form of a Web-based concept mapping tool named Webster. Webster permits broad flexibility in terms of the kinds of knowledge and information that may be represented and the structuring of their visual presentation. One result of this approach is the integration of knowledge visualization and information visualization in a single representational medium. These facilities also make Webster a convenient tool for personal knowledge management, facilitating individual organization of knowledge and external knowledge and information resources for reference and learning purposes.

1 Introduction

Many tools have been created to allow learners to visualize the content and structure of knowledge of a domain (Jonassen, Beissner & Yacci, 1993). Among the most useful and widely used of these are concept map tools (Novak, 1999). A concept map consists of nodes representing concepts, objects, events, or actions, connected by directional links defining the relationships between and among nodes. Graphically, a node is typically represented by a shape (such as a rectangle or oval) containing a textual name, and relationship links are textually labeled lines with an arrowhead at one or both ends (note that in some concept map representations, textual labels are disallowed for links, resulting in an arguably semantically inferior representation). Together, nodes and *labeled* or named links define propositions, assertions about a topic, domain, or thing. For example, a directed line labeled "can" beginning at a node labeled "birds" and pointing to a "fly" node represents the proposition "birds can fly" and might be a portion of a concept map concerning *birds* (see Fig. 1).

Concept maps have evolved from paper-and-pencil to computer-based tools. Extant software tools have been adapted for creating concept maps (e.g., HyperCard adapted by Reader & Hammond, 1994; NoteCards adapted by McAleese, 1992). Many research-based computer-based concept mapping tools have also been reported (for example, Fisher, 1992; Flores-Méndez, 1997; Kommers & DeVries, 1992; Kozma, 1992; Novak 1999). And there now exist commercial products for this endeavor (e.g., Inspiration®, Axon Idea Processor, Decision Explorer®, Semantica®). Many concept

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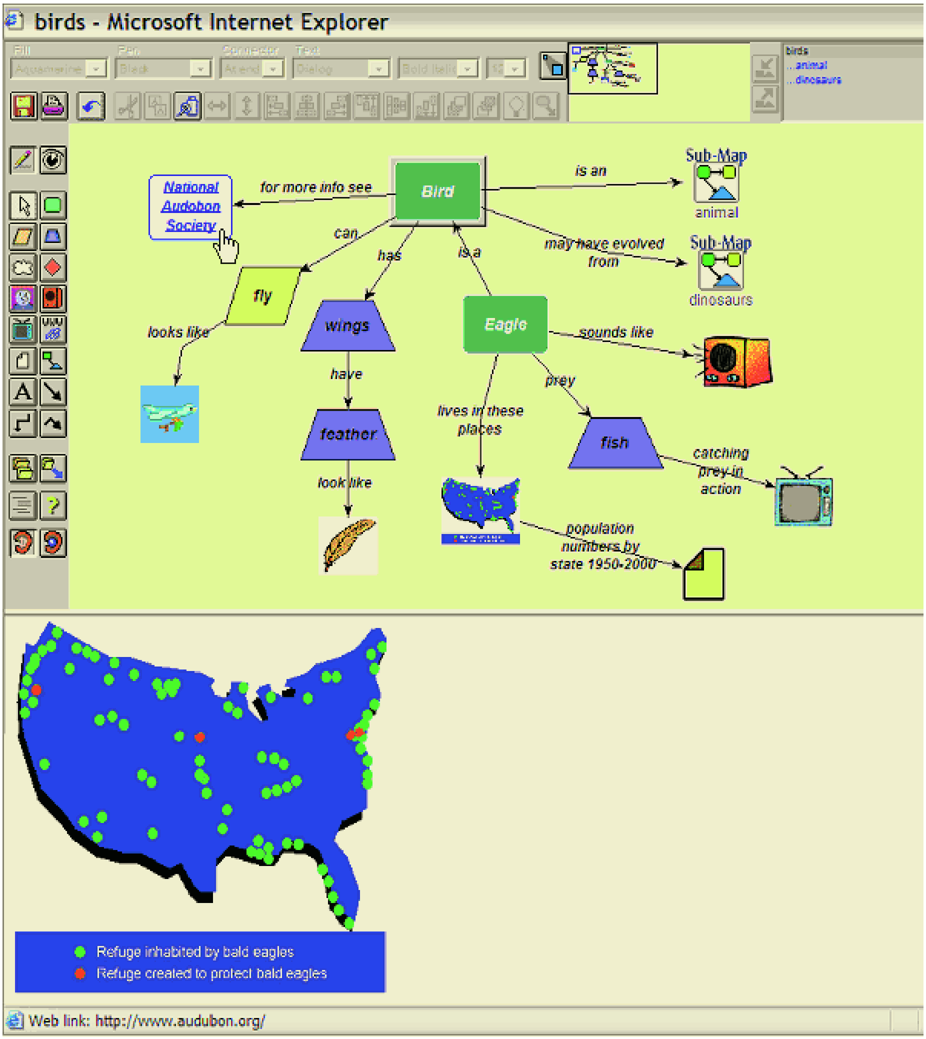

Fig. 1. Webster in a Web browser. The upper pane contains the main concept map tool; the lower pane contains a full-size information visualization that appears as result of the user clicking the corresponding image node near the bottom of the concept map (the node that looks like a map of the US). "Television" nodes represent videos or animations. "Radio" nodes represent audios. On the left side of the map is an animated image: the bird flaps its wings in-place in the map. Submap nodes (here, *animal* and *dinosaurs*) represent other layers of the overall map, which can be brought into view by clicking on the corresponding submap node. A document node at the bottom of the map references a spreadsheet with eagle population data

mapping tools focus exclusively on conceptual and (in most but not all cases) propositional knowledge, accommodating only a linguistic, text-based representational format. However, not only should concept map tools allow for the representation of other types of knowledge but they also ought to permit the inclusion, in an integrative manner, of information resources associated with the knowledge. Knowledge visualization and information visualization are, individually, powerful tools for learning and the integration of the two should synergistically contribute to enhanced learning.

This chapter is based on the simple premise that concept maps are ideal vehicles for organizing and integrating both elemental knowledge of a domain and associated information and information visualizations; this premise, however, relies on the equally simple assumption that computer-based concept maps should be able to incorporate any knowledge or informational artifacts in any medium that can be digitally represented. This includes static, passive, and interactive graphics and animations, written and spoken text, video, audio, and so on. Such media of course thereby include static, passive, and interactive information visualizations. This chapter describes a concept map tool with such capabilities, named Webster (Alpert, 2003; Alpert & Grueneberg, 2000, 2001).

Webster is a Web-based concept map application that permits broad flexibility in terms of the kinds of knowledge and information that may be represented as well as the structuring of that knowledge and information. With regard to structure, Webster simplifies the construction and navigation of multi-layer maps representing multiple abstract levels, permitting maps to possess representational, visual, and cognitive perspicuity which should support understanding and therefore learning. With respect to representation, Webster offers expressive power for the representation of *core knowledge* of a domain as well as external knowledge and information *resources*. The essential mechanism supporting representational breadth is the notion of permitting digital media of any sort to be incorporated directly into concept maps. Thus, maps may include semantically labeled links to and among audio, video, animations, as well as information resources such as external Web sites and spreadsheet, text, and slide presentation files; the ability to incorporate any form of digital media allows information visualizations, in the form of static graphics, animations, audio, or video, to become integral parts of a concept map. Thus Webster maps can represent the core, fundamental, essential knowledge of a domain - externalized implicit knowledge and visual and auditory imagery integral to a domain - as well as external knowledge and information resources that support a deeper understanding of the domain. These facilities also make Webster a convenient tool for personal knowledge management, facilitating individual organization of knowledge and external knowledge and information sources for reference purposes, as well as supporting sharing of these elements for learning.

The bulk of this chapter describes the facilities in Webster for representing and structuring knowledge and information resources, including the ability to integrate a broad range of types of knowledge and information. The cognitive and pedagogical rationale and implications of these facilities is discussed. The chapter also briefly discusses the use of concept maps for knowledge management purposes.

2 What Representations Should Concept Maps Provide?

A concept map consists of nodes representing concepts, objects, or actions, connected by directional links defining the relationships between and among nodes. Assuming relationship links may be textually labeled to describe the semantic relationship between the connected nodes, together nodes and links define propositions, assertions about a topic, domain, or thing. For example, a directed link labeled “produces” pointing from a node labeled “green plants” to another node labeled “oxygen” represents the proposition “green plants produce oxygen” and might be a portion of a concept map about photosynthesis.

Representing knowledge in this fashion is similar to semantic network knowledge representations (e.g., Quillian, 1968) and one view of concept maps is strictly as a knowledge representation mechanism, a means to make internal, tacit knowledge of a domain explicit and scrutable (e.g., McAleese, 1992). Others support the notion that concept maps are (or can be) accurate reflections of their authors’ cognitive structures (e.g., Jonassen, 1992). On the other side of the argument, the notion of concept map as direct mirror of cognitive knowledge representation has been challenged (Fisher, 1992). Nonetheless, whether concept maps provide a representational scheme that is identical or isomorphic to cognitive representations, a concept map *is* an external and visual representation of knowledge of a domain.

Jonassen (1992) poses what is therefore a crucial question: “What constraints does the software impose on the product?” (p. 20). In other words, what limitations do concept map tools impose on the knowledge that may be expressed using those tools? For example, if one can express only textual propositions using a particular tool (as indeed is the case with some concept map tools), then clearly only a subset of knowledge about a domain may be expressed. Because people possess a broader range of cognitive knowledge representations than simply language-based propositions, concept maps ought to offer a concomitantly broad range of representational facilities. By capitalizing on the capabilities of modern personal computers and the Internet, we can provide for much richer knowledge representation and greater flexibility of expressiveness in computer-based concept map tools. And such enhanced flexibility of expressiveness may extend to enhanced learning (Heeren & Kommers, 1992).

2.1 Imagery and Dynamic Media

At the least, concept maps ought to incorporate static visual imagery because unmistakably people possess this sort of knowledge about the world in addition to verbal or language-based propositional encodings (Kosslyn, 1980; Paivio, 1986; Johnson-Laird, 1983; Baddeley, 1982). From a pedagogical perspective, intuitively, being able to see something of visual importance or interest offers a learning experience qualitatively distinct and superior to simply reading a textual description - no matter how well organized into nodes and links (for example, see the incredible photographs of cranes dancing on the water’s surface, flying silhouetted against a sunset sky, and others at http://magma.nationalgeographic.com/ngm/cranecam/gallery01.html, or the staggering images of distant space phenomena created by the Hubble Space Telescope at http://heritage.stsci.edu/gallery/gallery.html; words cannot do justice to such imagery). Imagery can reify concepts described by textual means. Experiments have demonstrated that abstract textual information is better understood and learned when accompanied by illustrations, which serve to reify the concepts for learners (Moore & Skinner, 1985). There is evidence that memory for visual imagery is more robust than that for purely textual information (Shephard, 1967) and that information encoded both visually and verbally is more memorable than when encoded in either format alone (Paivio, 1986). Mayer asserts on the basis of numerous studies (summarized in Mayer, 2001 and Clark & Mayer, 2003) that students that learn from text and static illustrations perform better in subsequent tasks and tests than students who study text alone. Chandler and Sweller (1991) have further shown that procedural instructions are better understood when text is explicitly linked to images; when concept maps are capable of incorporating images, they can link specific textual nodes to particular images with meaningfully named links.

Going a step further, in order to more effectively portray knowledge, concept maps ought to include not only static images but temporally dynamic content as well, such as animated images, video, and audio. Again, humans cognitively represent memories for dynamic visual imagery (e.g., Johnson-Laird, 1983) and auditory information (e.g., Dowling & Harwood, 1986). For example, one's knowledge of horses might include not only what a horse looks like in a static sense, but what a race horse looks like when galloping full speed around a track amidst a field of thoroughbreds, how galloping and trotting differ in appearance - how they involve different coordinated movements of a horse's legs, what a herd of stampeding wild horses looks and sounds like, what a horse's neigh sounds like. An automobile mechanic diagnosing an engine problem relies not only on visual inspection of the engine but also on the sounds made by the engine - differing sounds, mapped onto specific engine problems, are part of his domain-specific memories. Dynamic media can also demonstrate how elements of a domain interact with one another, such as how lions in the wild behave cooperatively when attacking other wild animals, or how specific chemicals react with other chemicals producing visual and aural effects. Certainly such elements can be part of long-term memories for these respective domains: from a knowledge representation perspective some aspects of one's mental model of a domain may be expressible only via dynamic visual or auditory media. We ought to be able, then, to represent such elements in concept maps to demonstrate our own knowledge of those domains or to use concept maps as instructional resources.

From a pedagogical perspective, if, as a popular expression goes, a (static) picture is worth a thousand words (see Mayer & Gallini, 1990; Mayer & Sims, 1994; Larkin & Simon, 1987 for critical discussions of this notion), then a scene of multiple pictures in motion may be worth 10,000 words. One can explain with words how to perform a physical skill but a video *showing how to*, say, swing a golf club can be an invaluable tool for learning to perform the skill. One can explain in text how an eagle catches food, but a video portraying an eagle swooping down over a lake with talons flared, grabbing a fish just below the surface, and flapping off with a meal in its talons makes for a much higher impact and memorable learning experience. Returning to Mayer's work, studies of his have demonstrated a robust learning effect for instructional animations (Mayer, 2001; Clark & Mayer, 2003). Faraday and Sutcliffe (1999) have also demonstrated that multimedia documents with explicit co-references between text and dynamic imagery can result in better comprehension; concept maps' nodes-and-links format offers an extremely simple mechanism for clearly linking text and multimedia information.

With regard to audio, Faraday and Sutcliffe (1997) found better recall for propositions expressed by a combination of speech and imagery than those expressed by images alone. Lee and Bowers (1997) found superior learning effects when students listened to spoken text while viewing graphical images, far greater learning effects than for students reading text or hearing spoken text alone, and in fact better learning than students reading text while viewing the graphics. If studying the domain of blues music, a teacher can explain in words that the blues scale is a modified minor pentatonic scale and watch her students' eyes glaze over, or might explain that the scale is derived by flatting the 3rd, 5th, and 7th notes of a major scale, but also demonstrating the different scales by playing them on a piano will make the lesson more meaningful and memorable, and, further, without the student actually hearing and experiencing a performer playing the blues, he would really *understand* nothing about that musical form.

With regard to combining dynamic visual and auditory information, Mayer (2001; Mayer & Gallini, 1990) has repeatedly demonstrated in behavioral studies that students viewing an instructional animation while simultaneously listening to an explanatory narration are capable of generating many more useful solutions to subsequent problem-solving transfer questions than students who listened to the same narration but without viewing the animation.

Imagery (visual and/or aural) capabilities may also help to accommodate individual differences among students using concept maps to demonstrate their own knowledge or acquire new knowledge, thereby better supporting students with differential abilities, learning styles, and learning preferences or needs. For example, hearing impaired learners tend to prefer or require visually oriented learning materials. As a Teacher of the Hearing Impaired has told me, to explain textually-represented concepts "I spend half my time drawing pictures for my students" (Bomus, 2001). Concept maps that incorporate image-based nodes linked to text-only nodes should better suit the learning needs of such students.

In Webster, an individual node can *be* an image or may *reference* a media file containing dynamic imagery or audio. Static image and in-place animated image nodes may appear directly in the map, that is, the map node itself appears as an image (animated GIF89a images (CompuServe, 1990) or motionless graphics). For example, in Fig. 1 the bird image is flapping its wings (we must of course be judicious in the use of such *in situ* animations so as to not distract learners, especially from other knowledge elements (Faraday & Sutcliffe, 1999)). "TV" and "radio" nodes reference files with multimedia content: audio nodes appear as radio icons in the map, and dynamic imagery nodes look like televisions. In addition to traditional video, "TV" nodes may have associated with them any computational media that the user's Web browser is capable of playing - that is, any media type for which the browser has a plug-in. Concept maps may therefore incorporate VRML virtual reality scenes such as three-dimensional virtual walkthroughs, interactive Flash and Shockwave animations and games, and so on.

Dynamic media resources are thus integrated into the concept map as "first-class" elements of the map. Note that these media nodes are *visually typed*: imagery nodes appear as TV icons and audio nodes as radios, rather than having a uniform appearance for all nodes. This typing cues the user as to a node's medium; the user using a map as learning material can visually search the nodes of a concept map when specifically looking for video or audio related to the represented domain, and users know what type of medium to expect when "playing" such a node.

As mentioned earlier, incorporating such capabilities in a concept map tool enhances the tool's and its users' flexibility of expressiveness (Heeren & Kommers, 1992). Concept map authors can express, and learners can perceive from maps, a much richer set of knowledge and information, with concomitant pedagogical benefits. Concept maps can portray what the entities of a domain look like when in motion, what particular things sound like, how domain elements behave, react, move, and sound in specific contexts or situations, dynamic interactions between people and objects of a domain.

With static and dynamic imagery as first-class elements, concept maps can portray *essentially visual* elements of a domain per se (for example, in a map about wild animals, an image of a (difficult to discern) lynx in the wild against a natural backdrop, demonstrating how the lynx's spotted fur acts as camouflage in its natural environment) as well as *information visualizations* related to a domain (for example, a map of the United States annotated to indicate bald eagle refuges, see Fig. 1). In addition to static visualizations, *any* sort of information visualization can become part of a concept map. Our *birds* concept map could link to, say, an MPEG-encoded video showing the evolution of human population growth and concomitant eagle population decrease associated with urban expansion in a particular locale, or an animated-GIF image demonstrating population effects on wading birds of wet and dry seasons (e.g., see the animated visualizations at http://www.sfwmd.gov/org/wrp/wrp_evg/projects/birds/animations.html). An interactive programmatic visualization (encoded in, e.g., Flash, ShockWave, VRML) might demonstrate weather conditions, temperature variations, and bird migration patterns over time, in an area clicked on by the user, illustrating how and why birds navigate to widely distant locations at different seasons. Thus concept maps can naturally integrate both knowledge visualization - in the content and structure of the concept map per se - and information visualization - in the form of static, dynamic, and interactive imagery within or linked from the concept map.

2.2 Document Nodes

Concept maps ought to be able to reference external materials, including information and data associated with specific application programs or application categories (such as spreadsheets, graphs, slide presentations, databases, text documents). Thus textual and graphical information and data "stored" in, for example, Microsoft® Excel or Lotus® 1-2-3 spreadsheets, PowerPoint or FreeLance presentations, Word or WordPro documents, Access or Approach databases can become part of the knowledge and information integrated into any concept map. For example, Webster has been used by Chemistry students in an Ivy League university. Students used Webster to map their evolving knowledge of photosynthesis, incorporating newly learned information based on laboratory experimentation with their previously learned "book knowledge." In their concept maps, students linked scientific facts and experimental observations to lab-based data expressed in spreadsheets and graphs. Thus students were able to integrate external documents naturally into their maps, and later use those maps in laboratory reports and for studying for course examinations. Presentation-based applications that can, for example, visually portray data in tabular and graph formats, naturally support the notion of information visualization in concept maps as well.

To include documents associated with external applications in a concept map, Webster users create document nodes (see Fig. 1) and associate an application-specific file with such a node. When a user clicks on a node of this type, the document is displayed in a separate browser window. Webster provides this functionality in a Web-based application.[1] And, as above, in Webster document nodes are visually typed by their unique appearance within the map, providing users with an advanced notion of the node's content type. Thus, document nodes look like documents, rather than all nodes having a similar appearance.

2.3 Web Nodes

A more recent enhancement to the capabilities of personal computers is accessibility to the information and content available on the Internet. Firstly, the Web offers an unprecedented opportunity to educational technologists with regard to deploying instructional tools. No longer are we required to deal with the logistics of getting software applications onto individual computers so they can be used by students. Web-based concept map tools (or any educational application) offer the ability to reach greater numbers of students. Students are no longer constrained with respect to where or when they can access the tools. The Internet allows us to easily have a single centralized database so that all student maps reside in a single location on a server so that students can interrupt their work and continue to work on the same map later from a different location. Further, having applications - in Webster's case a downloadable client applet and a server-side servlet to access the centralized database - reside in a single location results in students always using the current version of the software. Bug fixes and tutor enhancements are immediately available to everyone, rather than again having to deal with the logistics of distributing and installing software updates. A centralized database of maps also opens the door for formal collaboration in map creation. For example, in Webster, students can import external maps created by others into their own maps.

Additionally, and more to the focus of this chapter, Webster concept maps also incorporate Web-hyperlink nodes that allow maps to "reach out" to the vast store of knowledge and information available on the Web. Webster provides Web-hyperlink nodes, in which a Web address (URL) can be specified. The node's associated URL may be hidden in the viewable concept map and its visible text may be something more meaningful than the URL itself (for example, see the hyperlink node labeled "National Audubon Society" in Fig. 1). Clicking on a Web-hyperlink node opens a secondary browser window to the associated site. This provides access to static and dynamic information incorporated into external Web pages, including live Web cams, and programmed facilities such as Java applets and other applications embedded in Web pages, which can offer rich and interactive information visualizations, and (see, for example, the live video of cranes in a wetland area at

[1] Because Webster runs in a Web browser, an application-specific document may be viewed if the browser can display the document, which sometimes means the browser must have incorporated a plug-in for the particular document type. Many applications provide such Web-browser plug-ins - for example, Microsoft Excel Viewer for spreadsheets, Microsoft Word Viewer and Adobe Acrobat Reader for text documents, Microsoft PowerPoint Viewer and Lotus Freelance Graphics Plug-In for slide presentations. There also exist third party plug-ins (e.g., Quick View Plus) that allow browser-based viewing of files associated with a broad range of applications.

http://magma.nationalgeographic.com/ngm/cranecam/cam.html, and the interactive climatology and atmospheric visualizations at http://ingrid.ldgo.columbia.edu/SOURCES/.LEVITUS94/.ANNUAL/html+viewer? and elsewhere on the ingrid.ldgo.columbia.edu site). Allowing concept maps to incorporate access to the Web can enhance further the expressiveness and learning potential of concept maps and Web-based knowledge and information resources can become “part of” concept maps. Secondarily, this sort of tool can foster a new type of student research involving mining relevant information sources from the Web.

2.4 Other Node Types?

While there are commercial and research applications of haptic and tactile computer interfaces, these are typically of the form of providing force feedback to a user’s hand when some distinguished event occurs, such as the cursor is over a button or a virtual object has been “grabbed” by the user (e.g., Oakley et al., 2000). The state of the art is not yet at the point where a computer can “output,” and a user experience, the feel of an object such as an animal’s fur. Other researchers are working on olfactory computer interfaces (e.g. Kaye, 2004). When sensory information of these types becomes widely available on personal computers, nodes representing such information should also be incorporated in concept maps. For example, the overriding distinguishing feature of the Rafflesia plant is its odor (it smells like decaying meat, thereby attracting insects which then become participants in the pollination process). A concept map about the Rafflesia should be able to “portray” this feature if we are to fully learn or “know” about them - a user should be able to experience the smell the plant to truly learn about the plant in a very real sense. A concept map about sharks should allow us to feel the texture of sharks’ skin to fully understand sharks more fully (sharks’ skin serves survival purposes and is made up of dental material that is very abrasive to the touch).

The point is, in order to fully represent and transmit knowledge, concept maps should be able to incorporate any information that can be represented in digital form and accessible via a computer. In fact, digital representations of sensory information allows users to learn by experiencing that which is dangerous or otherwise cannot be experienced in real life, such as the close-up sight and sound of a volcanic eruption or the tactile feel of a sting ray’s barb-tipped tail, which is not only extremely sharp but toxic when encountered in real life. This of course also includes “invisible” phenomena, such as the structure of atoms and temporally dynamic data such as weather-related temperature fluctuations, which can be made visible and observable through information visualizations.

3 Multiple Abstraction Levels

The ability to represent many types of knowledge and information enhances the expressive and educational power of concept maps; however if learners find particular concept maps confusing and difficult to use as learning materials due to visual characteristics of the maps, that power is deeply diminished. Concept maps that contain a large amount of nodes and links - geometric figures and lines - can become visually confusing and the knowledge and information within them opaque. One solution to this problem is to apply the same sort of clarifying mechanisms that people employ cognitively, that is the notions of chunking and abstraction as described below; in the case of Webster concept maps, this results in multiple layer maps that are easy to create and navigate.

Another fundamental characteristic of human cognition is the ability, and in fact necessity, to exploit knowledge abstraction. Abstraction implies the ability to represent a concept, action, or object by a single node at one level of detail while possessing the knowledge to expand that single node into an elaborated definition of its own. That is, a single knowledge element (or *chunk*) at one level of abstraction may subsume a number of lower level elements at a more detailed knowledge level (Anderson, 2000; Rich, 1983). This is to be differentiated from atomic nodes that have no underlying elaboration. This abstraction mechanism may be applied iteratively and recursively; that is any number of elements at a particular abstraction level may represent chunked knowledge and at a more detailed abstraction level, further chunks may appear as well. The resulting representation involves multiple abstraction levels that in a concept map are represented by multiple layers, each containing its own set of knowledge and information elements (nodes and links). Multiple-layer concept maps permit users to apply heuristics of visual and informational perspicuity and visual aesthetics.

Absent abstraction mechanisms, concept maps appear as a single diagram, that is, nodes and links representing all of the knowledge of a domain are drawn in a single network or layer. In such networks, a weak notion of abstraction can be represented only by generality-specificity relationships between nodes: a node representing a specific concept (say, *bird*) may have a link, labeled *is a* or *a kind of*, to a more general or abstract concept (say, *animal*). But the more abstract node might have additional links connected to other concept nodes (for example, portraying attributes of *animals*, such as *animals breathe oxygen*). There might also be relationship links and associated concepts connected to the *bird* node (e.g., a *bird has wings* and a *bird can fly*). This format can extend several levels of abstraction in either direction (e.g., a *goose is a bird*, a *lizard is an animal*, an *animal is a living thing*). Such a map does not reasonably mirror the cognitive representation of this knowledge that would exploit abstraction mechanisms to represent categories or concepts at differing levels of detail. More importantly for educational purposes, very quickly such a map can become visually crowded and confusing, and learning from such a map might be difficult.

Many concept map tools lack adequate visual or structural abstraction mechanisms altogether. While some tools do provide for the notion of submaps or child maps within concept maps, few do so in both an easy-to-perceive, easy-to-understand, and easy-to-use fashion. In Webster concept maps, a conceptual abstraction is visually represented by a single node in one layer of the map, and this single concept can be expanded into another (sub)map of knowledge elements representing the fuller, more detailed meaning and constituent parts at a more specific layer of the overall map. So for example, a concept such as *lizard* can be represented at one level of abstraction or detail by a single node, without cluttering that map level with all the detailed information about lizards, and yet those details are available in another layer of the overall concept map by "opening" the *lizard* submap node to view its "insides." We thereby gain the ability to portray the knowledge in a manner isomorphic to the way a person might cognitively represent it, and we further gain the benefit of making the knowledge representation more graphically parsimonious, thus easier to decipher, understand, and learn from.

For example, the concept map in Fig. 1 portrays knowledge and information about birds and, more specifically, about eagles. Without a great deal of knowledge elements, already this map is becoming visually noisy. And one might ask further, do the details specific to eagles really belong at the same knowledge level as those specific to (the more general concept) birds? In Webster, one may solve the visual and knowledge comprehension problems by simply selecting the eagle-specific elements and "pushing" them down (by a single button click) to a more detailed map layer. The result is shown in Fig. 2: a submap node - a visual abstraction - takes the place of the eagle-specific elements that had been in the original map layer, and a new "eagle" submap is created which may be opened to view those more detailed knowledge elements specific to eagles. Visual abstractions - submap nodes and their associated submaps - can be created in a variety of other intuitive and flexible ways, including importing an existing external concept map as a submap (see Alpert, 2003, for details).

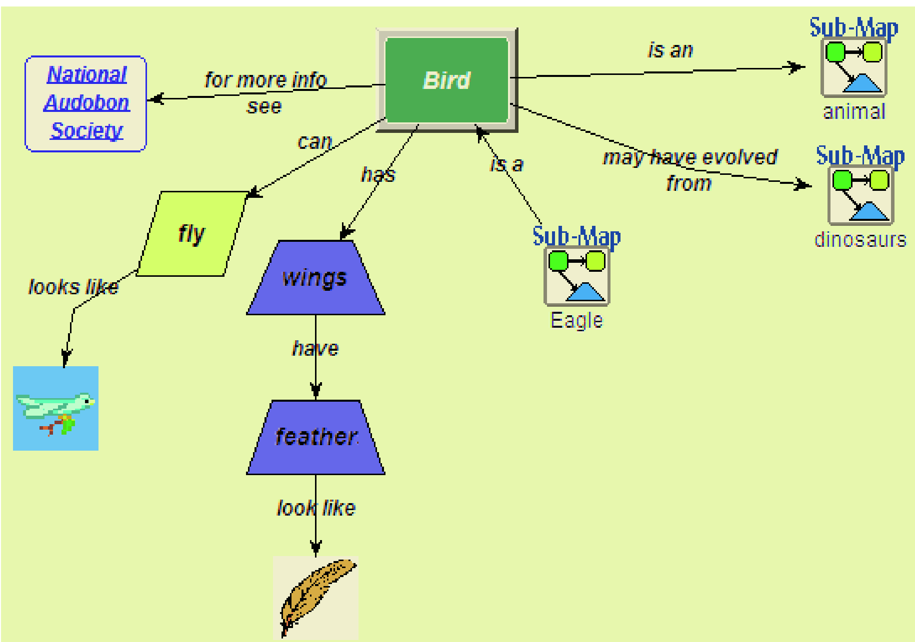

Fig. 2. The main level of the concept map shown in Fig. 1, now with an "Eagle" abstraction represented by a submap node. The corresponding submap layer can be opened to view the eagle-related elements that were formerly visible in this map layer. The abstraction/submap facility provides for visual perspicuity in the concept map

4 Outline Translations

Alternative representations support developing deeper understanding of a domain, and this may be particularly true when multiple representations of the same information are linked to one another in a learning environment (Kaput, 1989). A rational alternative representation for the information contained in a concept map is a traditional outline. Many students are comfortable with seeing their thoughts arranged in outline form. This may be especially true for students organizing ideas in preparation for prose composition. Outlines present concepts in a line-by-line numbered format

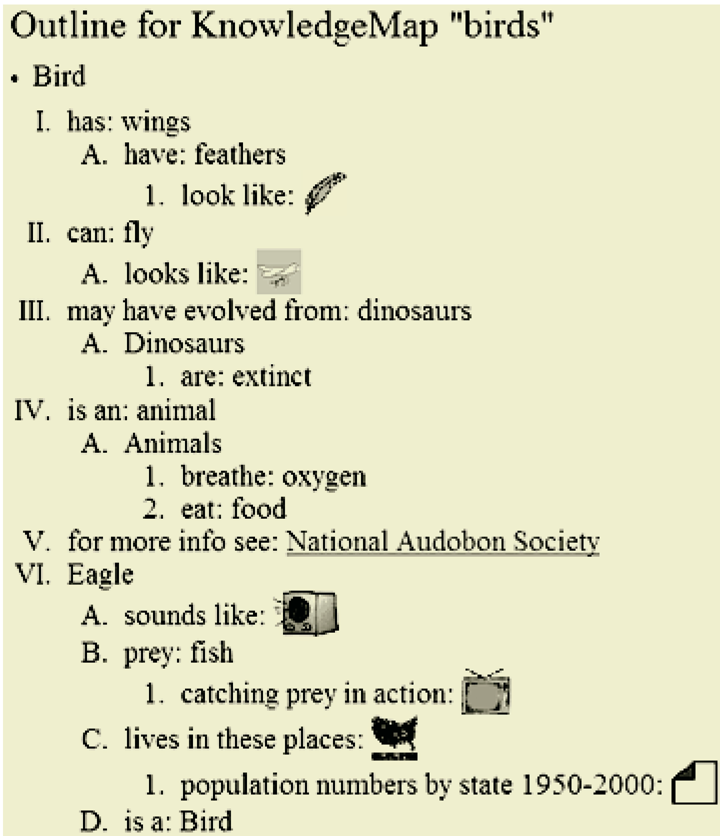

Fig. 3. The *birds* concept map partially shown in previous figures translated to a multimedia outline. The outline includes the information contained in all submap abstractions (Eagle, Dinosaurs, Animals) at the appropriate indentation levels. Webster presents the outline as a Web page; all nodes are translated to appropriate HTML objects. Radio and TV images are hyperlinks to playback audio and video files. The document image hyperlinks to a spreadsheet application. Thumbnails of the image nodes that had been in the concept map may be clicked here to view as full size images. The Web-link node in the map for the National Audubon Society appears as a normal hyperlink

with subordinate or associated terms in physically subordinate locations in the outline - subordinate terms appear indented below their immediately higher level concept - and this physical superconcept-subconcept scheme may repeat itself.

Webster, like several other concept map tools, offers automatic translation of concept maps into outlines. Based on Kaput's (1989) assertion regarding the pedagogical effectiveness of multiple representations, as well as common sense regarding a user's needs and expectations, outline representations should contain the equivalent semantic content as the corresponding concept map. As a counter-example, while other concept map tools, such as Inspiration®, may incorporate static and animated-in-place images in addition to textual nodes, the image nodes are absent in its outline translation of a map. Similarly, though Inspiration nodes may link to a video or audio file, its outline translation of a map with such nodes includes only the textual labels of those nodes. Further, the textual labels of all relationship links in a concept map are elided in Inspiration outlines. The knowledge elements in child maps are absent as well in the outline translation of a concept map. The only content present in a concept map to appear in the outline "translation" is the names of the nodes in the single level of the overall concept map that was visible when the "outline" button was pressed. These deficiencies may defeat users' goals in using the alternative outline representation.

In Webster, concept maps may be translated (also via a single button click) to outlines containing all of the map's knowledge and information resources. Static and animated images, videos, audios, interactive animations, Web hyperlinks, links to external data and information visualizations, relationship labels, all elements that are part of a concept map appear in the associated outline representation, as shown in Fig. 3. All of the information contained in all concept map abstractions (i.e., submaps) appears in a single outline at the appropriate indentation levels - thus, as we expect the user desires, the outline presents the organization of all thoughts and concepts in the overall map in a single place.

With regard to static and animated images, they are handled much as they are in concept maps: images (including in-place animated-GIFs) are embedded and visible directly within outline items. Images are displayed in the outline with a default thumbnail size and users may click them to view the images in their original size. Radio and TV nodes also appear in the outline and act as hyperlinks that reference and playback specific audio, video, or animation files: users click on embedded radio and television images to "play" them. Web-link nodes are translated into normal hyperlinks that when clicked open a second browser window on the associated site. External information resources, such as spreadsheets, textual and graphical documents, and slide presentations, appear visually as a small document (as they do in the concept map) which when clicked open the document's application.

5 Discussion

"Students studying self-regulated in e-learning scenarios are often overwhelmed by complex and ill-structured subject matters. In order to study effectively they often need to organize and represent information and knowledge in a manner that may help them to get quick and flexible access to relevant information and knowledge." Thus reads a portion of the rationale for this book and its associated Workshop. In response to this, another perspective on the use of concept maps is as tools for knowledge management.

For example, there is a vast amount of content available on the Web, and the Web has increasingly become a primary source for information. But for learning, users need that content organized in some fashion, focused on a particular topic or domain. Rather than a generic search engine to (hopefully) find relevant content and a resulting flat view of information, a concept map provides a centralized "place" to access knowledge and information, and one that visually organizes relevant content in lucidly structured ways while providing semantic links between knowledge and information elements. Concept maps can be the silver bullet to help the students described above by imposing order on the perhaps overwhelming amounts and complexity of knowledge of, and information germane to, a domain (especially when that knowledge and information is distributed across disparate locations on the Web). Concept maps can serve as "personal knowledge management" tools for students. To fully succeed in this arena, concept map tools must naturally incorporate and integrate external information such as Web sites and Web content, and act to filter vast amounts of knowledge and information resources to only those relevant to a specific domain.

As we've seen above, Webster provides for the representation of varied forms and sources of knowledge and information. Capitalizing on these facilities permits a Webster map to include *fundamental knowledge* about a domain as well as knowledge and information *resources*. That is, concept maps thus become tools for organizing core factual, conceptual, and sensory knowledge about a domain - facts and assertions about the central objects and concepts of a domain, fundamental visual and aural knowledge related to a domain, and the semantic relationships between them - along with nodes that reference external learning resources relevant to that domain - video files, audio files, any information and content available on the World Wide Web, text documents, spreadsheet data, slide presentations, databases, and so on, including the relationship links between one another and relations to fundamental knowledge elements. (Note that dynamic imagery can be a fundamental piece of knowledge, such as what a bald eagle looks like (which defines its being labeled "bald"), as well as an external information resource, such as a dynamic information visualization of the bald eagle population in a particular location, which deepens understanding of a domain but might not be considered a *core* knowledge element of the domain[2].)

We must also remember that the benefits of a representation are meaningless if we disregard the ease of *using* the representation. One aspect of a representation's usability and effectiveness is the ease of finding information therein (Larkin & Simon, 1987). Abstraction mechanisms enable the economical and visually lucid expression of knowledge in a concept map. Abstraction in concept maps is not important only because of it is analogous to cognitive knowledge representations, but it's also simply a *good idea* for organizing knowledge and information for any use, including learning or reference. Abstraction allows for visual and informational perspicuity in knowl-

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[2] The differentiation between *knowledge* and *information* may be quite subtle and difficult to adequately define. Certainly there is, however, a qualitative difference between tacit *knowledge* and various types of external knowledge and information *resources* (including information and scientific visualizations). The differences between knowledge and information are at the center of some debate as well in the knowledge management community (see, e.g., Tuomi 1999). At any rate, whatever the definitional differences may be, concept maps can serve as explicit, visual, organizational vehicles for both knowledge elements and knowledge and information resources.

edge renderings. Thus a student can learn from a map in a layered manner, studying the information at a single level without being overwhelmed by, and before tackling, too much or more complex information.

We thereby have a superlative knowledge management tool that, in a single place, visually portrays and provides access to the knowledge and resources about any particular domain. It appears that this brand of knowledge management is just the sort that ought to be useful in educational contexts.

6 Conclusion

The essential idea expressed here is quite simple, namely, for knowledge representation purposes, for pedagogical reasons, and for using concept maps as knowledge management tools, computer-based concept maps should permit the integration of *any* type

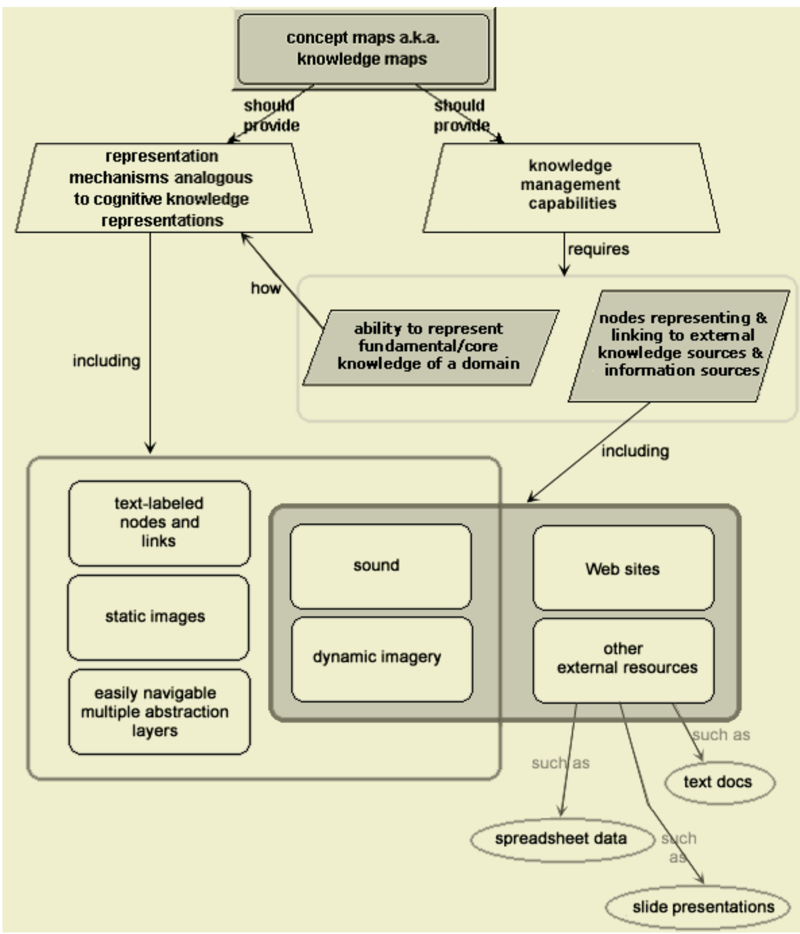

Fig. 4. Types of representations and functionality available in Webster

of information resource available in digital format. Such capabilities allow full integration into concept maps of external information and information visualizations, thereby coupling them with the knowledge visualization provided by the concept map itself.

Throughout this chapter I have deliberately used the term *concept map*; in previous work I have stated a preference for the term *knowledge map*, but now I believe this may be equally inadequate: maps visually and explicitly portray core knowledge of a domain, but also may incorporate external information sources that, while adding to a fuller understanding of a domain, might not be considered fundamental *knowledge* with regard to the domain - it is the combination of the two, knowledge and information, that maps can provide when appropriately designed and implemented. What then, however, should such maps be called? Knowledge and information maps? Wisdom maps? Comprehension maps? Learning maps? I leave this as an exercise for readers.

At any rate, integrating the capabilities presented here into concept mapping software provides the opportunity to:

- allow students to represent their knowledge more comprehensively;
- provide richer expressive power and representational choices, that is, enhanced flexibility of expressiveness;
- offer the illustrative and pedagogical advantages of dynamic visual imagery, audio, and (eventually) other sense-based information for students learning new concepts and domains;
- integrate knowledge visualization with information visualization;
- better accommodate individuals with differential learning needs or preferences;
- allow concept map authors to apply heuristics of visual clarity and perspicuity via multiple map layers and abstractions;
- perhaps provide for a more engaging student experience;
- offer engagement of the learner's senses for perhaps deeper and more intuitive understanding of a domain;
- perhaps, allow students to represent their knowledge in ways analogous to their own cognitive representations;
- support the use of concept maps for personal knowledge management.

Overall, enhancing concept maps by allowing them to access and incorporate any type of digitized information offers learners the opportunity to obtain a full and deep understanding of the domain of interest. It seems appropriate to sum up this chapter visually: Fig. 4 portrays the capabilities discussed in this chapter and their high-level rationale. This figure graphically portrays the types of knowledge and information concept maps should, and Webster does, make available to learners to capitalize on both knowledge and information visualization as educational tools.

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