CMAPTOOLS: A KNOWLEDGE MODELING AND SHARING ENVIRONMENT

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Abstract. Concept maps are an effective way of representing a person's understanding of a domain of knowledge. Technology can further help by making it easy to construct and modify that representation, to manage large representations for complex domains, and to allow groups of people to share in the construction of the concept maps. CmapTools is a software environment developed at the Institute for Human and Machine Cognition (IHMC) that empowers users, individually or collaboratively, to represent their knowledge using concept maps, to share them with peers and colleagues, and to publish them. It is available for free for educational and not-for-profit organizations, and public servers have been established to promote the sharing of knowledge. The client-server architecture of CmapTools allows easy publishing of the knowledge models in concept map servers (CmapServers), and enables concept maps to be linked to related concept maps and to other types of media (e.g., images, videos, web pages, etc.) in other servers. The collaboration features enable remote users to asynchronously and/or synchronously collaborate in the construction of concept maps, and promote comments, criticism, and peer review. Public CmapServers have resulted in a large collection of knowledge models publicly available, constructed by users of all ages in a variety of domains of knowledge and from a large number of countries.

1 Introduction

Concept maps are a result of Novak and Gowin's (1984) research into human learning and knowledge construction. Novak (1977) proposed that the primary elements of knowledge are *concepts* and relationships between *concepts* are *propositions*. Novak (1998) defined concepts as "perceived regularities in events or objects, or records of events or objects, designated by a label." Propositions consist of two or more concept labels connected by a linking relationship that forms a semantic unit. Concept maps are a graphical two-

Figure 1. Concept Map about CmapTools (from http://cmap.ihmc.us)

dimensional display of concepts (usually represented within boxes or circles), connected by directed arcs encoding brief relationships (linking phrases) between pairs of concepts forming propositions. The simplest concept map consists of two nodes connected by an arc representing a simple sentence such as 'grass is green,' but they can also become quite intricate. Figure 1 shows a concept map about the CmapTools software. 'IHMC CmapTools facilitates the manipulation of Concept Maps' is one of the propositions in this map. By convention, links run top-down unless annotated with an arrowhead. The vertical axis expresses a hierarchical framework for the concepts. More general, inclusive concepts are found at the highest levels, with progressively more specific, less inclusive concepts arranged below them.

Concept maps have been demonstrated to be an effective means of representing and communicating knowledge. When concepts and linking words are carefully chosen, these maps can be useful classroom tools for observing nuances of meaning, helping students organize their thinking, and summarizing subjects of study. From an educational perspective, a growing body of research indicates that the use of concept maps can facilitate meaningful learning (Coffey, Carnot et al., 2003). Concept maps have also been shown to be of value as a knowledge acquisition tool during the construction of expert systems (Ford, Coffey, Cañas, Andrews, & Turner, 1996) and performance support systems (Coffey, Cañas et al., 2003), and as a means of capturing and sharing experts' knowledge (Coffey, Hoffman, Cañas, & Ford, 2002).

Technology facilitates the construction of concept maps in the same way that a word processor supports the task of writing text. However, more powerful tools enable better management of large representations for complex domains, and facilitate sharing by groups of people in the construction of the maps. This paper describes CmapTools, a client-server based software kit developed at the Institute for Human and Machine Cognition (IHMC) that is designed to support the construction of concept maps by users of all ages, and to enable collaboration and sharing during that process. We begin by providing background information on CmapTools, proceed to list the objectives that led the design of the software, and then describe the software by expanding on these objectives.

2   Background

At IHMC, research efforts on concept mapping have two separate and distinct roots. The first has its origins in the use of concept mapping for knowledge elicitation. ICONKAT (Ford, Cañas, Jones et al., 1991), a toolkit for knowledge acquisition and the development of expert systems, had a concept mapping component. During the development of the nuclear cardiology expert system NUCES (Ford, Cañas, Andrews et al., 1991; Ford et al., 1996), the use of concept maps was extended beyond knowledge representation, to serve as the browsing interface to a domain of knowledge. NUCES used a concept map-based browser as the interface for the explanation subsystem of the expert system, as reported by Ford, Cañas, and Coffey (1993). This concept map-based interface provided a unique way of organizing and browsing knowledge about any domain (Cañas, Ford, & Coffey, 1994). Icons located right below some of the concept nodes provided access to auxiliary information to explain the concept in the form of pictures, images, audio-video clips, text, or other concept maps related to the topic. (The web had not yet been developed when this concept map-based browser was implemented.)

The second root has its origins in Quorum, a joint partnership between IHMC and IBM Latin America (Cañas, Ford, Hill et al., 1995). In Quorum, IBM's corporate computer network enabled collaborative projects between students throughout Latin American countries. (The Internet had not yet arrived to these countries when the Quorum network was implemented.) During Quorum we confronted a lack of software with a constructivist foundation needed to facilitate collaboration among students. We developed the Knowledge Soup (Cañas, Ford, Brennan, Reichherzer, & Hayes, 1995), which provided a unique type of collaboration among a group of users, usually students, each constructing a concept map on the same topic. The program automatically converted the concept map under construction to a list of propositions. The users selectively published propositions (we called these published propositions *claims*) to an aggregation or database of propositions from all students (and teachers) working on a particular topic –the Knowledge Soup— which resided on a server. It is through these Knowledge Soups that collaboration and sharing took place. Published claims were seen by other students and could be utilized in their own map-building process, but a student couldn't see *all* claims published by other students, as this would often be cognitively unmanageable. The only claims a student saw were those directly related to the ones he/she contributed to the Soup. As a student published more, a wider range of other related claims became visible. This strategy was intended to encourage and reward students for participation. A student could query or question a claim submitted by another student, if he/she disagreed with it or found it puzzling, and the originator of the claim could respond.

The lessons learned from these two efforts, together with the potential impact we envisioned a powerful software tool for the construction and sharing of concept maps could have in education and organizations, led to the development of the CmapTools software.

3 Objectives of CmapTools

CmapTools was developed with key objectives in mind:

1. *Low Threshold, High Ceiling*
   Myers, Hudson, and Pausch (2000) referred to the "threshold" as how difficult it is to learn how to use a system, and the "ceiling" as how much can be done using that system. Most systems have either a low threshold and a low ceiling, or a high threshold and a high ceiling. Our aim was to combine a low threshold (a system that can be learned in a few minutes and does not have an intimidating interface e.g., filled with icons surrounding the canvas, so that the user is able to concentrate on concept mapping), together with a high ceiling (an environment that supports the construction of large sets of concept maps by experts).

2. *Extensive Support for the Construction of Knowledge Models*
   Concept maps enable users to graphically express their understanding of a domain of knowledge. This representation can consist of a small concept map constructed by a child, or, in the case of a detailed representation of a domain, a large collection of related maps. In CmapTools, we refer to a set of concept maps and associated resources about a particular domain as a knowledge model (Cañas, Hill, & Lott, 2003). Our objective was to provide an environment that supports the development of knowledge models of all sizes, without limitations on where the resources and maps physically reside.

3. *Extensive Support for Collaboration and Sharing*
   The WWW was conceived by Tim Berners-Lee to be a global system to assist collaboration through hypertext (Berners-Lee & Fischetti, 2000). Unfortunately, it has turned out to be an environment where it is easy to browse (although not necessarily easy to find what one is looking for), hard to publish, and much more difficult to collaborate. Berners-Lee envisioned a system that would facilitate collaboration among scientists. We share this vision and believe that the best use of the Internet in education is to enable and foster collaboration among students. However, there continues to be a lack of constructivist-based collaborative learning environments. Similarly, scientists and other professionals have few tools with which to share their knowledge and inquiries. Our goal was to develop an environment where users of all ages and from all domains can collaborate and share in their knowledge construction efforts.

4. *Modular architecture*
   CmapTools was designed based on a modular architecture, in which components can be added or removed as needed from a Core module. This facilitates the development and evaluation of modules in a research environment without affecting other parts of the program. It also allows different ideas to be tested concurrently and independently, as well different versions of the program to be tailored to the needs of different users. On the server side, the various components are services that can be added or removed from the program, or started and stopped, as needed.

In the next sections we expand on the first three objectives listed above to describe CmapTools. Discussing the fourth objective is more technical and beyond the scope of this paper.

4 Low Threshold, High Ceiling

The user interface of CmapTools was designed to be nonintrusive, allowing the user to concentrate on the task of constructing the concept map without distractions. Figure 1 shows the canvas window on which the user builds (and browses) concept maps. The interface is model-less (e.g., there is no "concept" mode or "link" mode), and the map components (concepts, linking phrases, connecting lines) can be put together by direct clicks of the mouse on the canvas. This allows the user to concentrate on building the map as opposed to moving the mouse around to select boxes, lines, and so forth, as in drawing programs. Note the lack of intimidating collections of "icons" – we aim to provide a clean, simple interface. Style options (e.g., fonts, colors, curved lines, etc.) are provided via a style palette that can be hidden at any time. Constructing a simple map is straightforward, and new users are up and "mapping" after just a few minutes. At the other end, the style palette

allows the creation of graphically more sophisticated maps, as is demonstrated by the concept maps that form the websites for both CmapTools itself (http://cmap.ihmc.us, e.g., Figure 1) and the CMC2004 conference (http://cmc.ihmc.us). At these websites images and colors are combined to provide visually more appealing designs while preserving the strong communication characteristics of concept maps.

The user interface and functionality of CmapTools was designed to be simple enough to be appropriate for children and naïve users without much technical expertise, but powerful enough to support the advanced needs of expert knowledge engineering users. As a result, thousands of users from over 150 countries are using it to construct knowledge models based on concept maps. They range from preschoolers in Italy (e.g., Giombini, 2004), to professionals in a variety of organizations who have applied CmapTools to a broad range of applications (Beirute & Barahona, 2004; Dumestre, 2004; Moon, 2004; Peacock, Schaffer, & Zelik, 2004).

5   Construction of Knowledge Models

CmapTools has a number of features intended to support the development and publication of collections of interlinked concept maps and associated resources. The program supports both the constructing and browsing aspects of publishing and navigating: At the same time it is the editor and the browser. Alan Kay, recipient of the 2004 Turing Award, "decries what he sees as a fundamental failing of the web—it is primarily an environment for displaying information, not for authoring it. 'You can read a document in Microsoft Word, and write a document in Microsoft Word. But the people who did web browsers I think were too lazy to do the authoring part.'" (Kirkpatrick, 2004) Tim Berners-Lee (2004) considered that "There are many parts of the original dream which are not yet implemented. For example, very few people have an easy, intuitive tool for putting their thoughts into hypertext." Although it could be argued that most people are more interested in searching for information than in creating it, this distinction has a potentially huge impact in the educational arena, where there is a gigantic difference pedagogically between students as knowledge constructors and students as information (web) consumers.

To show the relationships among concept maps in a set, CmapTools facilitates the linking of concept maps through simple drag-and-drop operations, enabling the navigation from one map to another. Additionally, the user can establish links to all types of resources (e.g., images, videos, sound clips, texts) that are related and complement the information in the map, and can reside anywhere on Internet. The links are depicted as icons underneath the concepts (or linking phrases). The icon itself portrays the type of resource targeted by the link, and labels are displayed explaining each link when the icon is clicked. Figure 2 shows several opened windows, the result of navigating through a knowledge model that includes possible landing site craters on Mars (Briggs et al., 2004). The "Mars (Root)" concept map is the top-level map, the entry point to this knowledge model. Some concepts in the "Mars" map have small icons underneath them. After clicking on the "concept map" icon underneath the "Space Missions since 1965" concept, from the list of concept maps displayed the user can select and open, for example, a "Space Missions" concept map (not displayed in Figure 2). The "Gusev Crater" map window in the figure was opened after navigating through several maps, starting at the concept "Space Exploration" (not shown) in the root map. The other images displayed were opened by similar navigation through the icons in the maps. Briggs et al. (2004) provided a detailed account of the construction of a large knowledge model that includes over 100 concept maps and over 600 MBs of resources. Using concept maps as a browser for navigation through a large domain has been found to be particularly effective, as discussed by Carnot et al. (2001).

CmapTools provides a rich collection of additional features that aid users in the manipulation of knowledge models. The Views window (see Figure 3) allows the user to create a hierarchy of folders in the user's computer or at a server to organize concept maps, images, videos, or URLs, all resources associated with a project. Through drag-and-drop operations, resources and knowledge models can be moved around or copied to servers (as explained in the next section), while links are preserved or updated. Among other features we cite: importing and/or exporting as images, web pages, outline, Topic Map format, XML, and so forth; recording for playback the steps in constructing a map; a full-screen presentation module; and a concept suggester that mines the web for relevant concepts (Cañas, Carvalho et al., 2004).
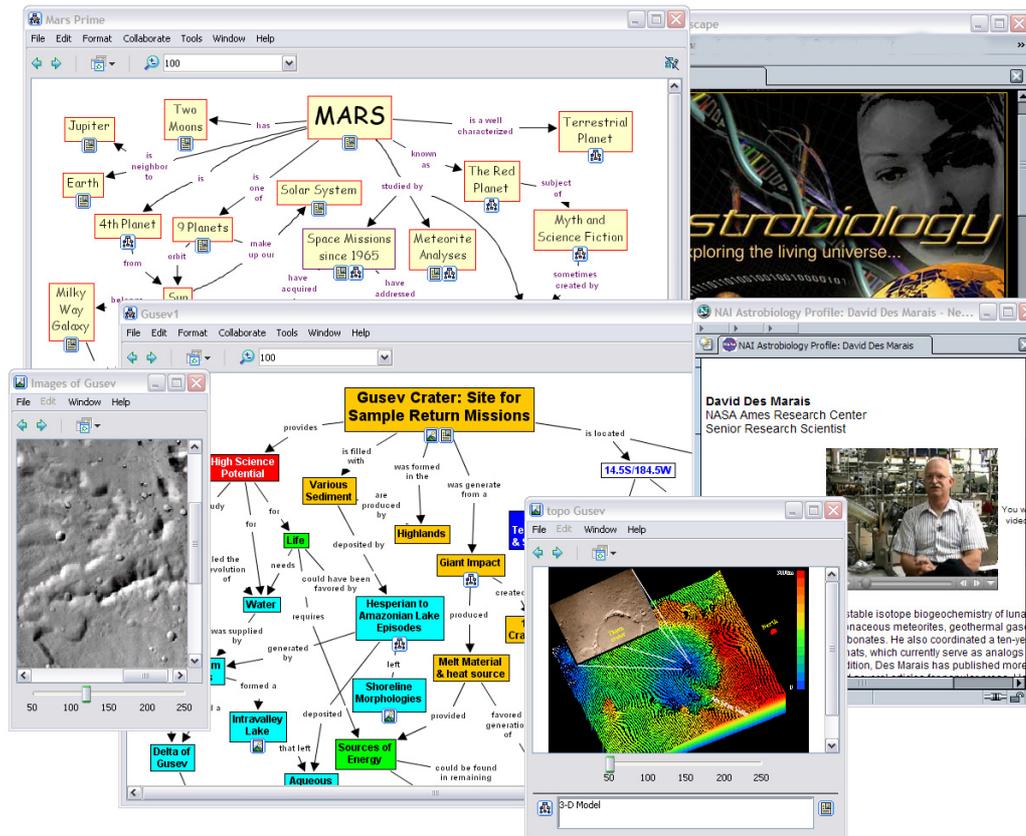
Figure 2. A knowledge model proposing the Gusev Crater as a possible landing site in Mars

6   Collaboration and Sharing

The CmapTools program works well as a stand-alone tool, allowing the user to construct concept map-based knowledge models and store them on his or her computer's hard drive, establish links among maps and to resources in the hard drive, and print the maps. However, the ease with which knowledge models can be shared, and collaboration can be established through shared Places, is what makes CmapTools unique. Physically, a Place is a server computer running the CmapServer software. From the user's perspective, a Place is a shared location, accessible through the Internet or an Intranet, where he/she can construct knowledge models collaboratively with colleagues or peers, where these knowledge models can be shared with others, and where he/she can access, browse, and comment on others' knowledge models.

The purpose of the CmapTools network is not limited to allowing users to share in the construction of their knowledge models. The network is designed to encourage and facilitate *public* sharing of knowledge. To achieve this, two key features were included in its design:

a) The CmapTools program must be able to automatically locate new Places that are installed in the network, so that new knowledge models are available to all users, and
b) Public Places must be available on the network so that anybody can publish and share their knowledge models, even if they are not associated with an organization that has a CmapServer.

To automatically locate new Places, every time the CmapTools program is launched it automatically contacts a Directory of Places: a special-purpose server with which Places register periodically (Cañas, Hill, Granados, Pérez, & Pérez, 2003). Figure 4 shows four Places (Public Cmaps, KM Cmaps, Science Cmaps, and History Cmaps) that periodically register with the Directory of Places, letting it know their network location and what services they can provide. It also shows a CmapTools user whose program has contacted the Directory of Places and thereby located the Places available. The CmapTools program continues contacting the Directory of Places periodically, making sure it is aware of any new Places that are made available. The window on the left of Figure 3 shows the list of Places available to a user at a particular point in time. Some of these Places appear
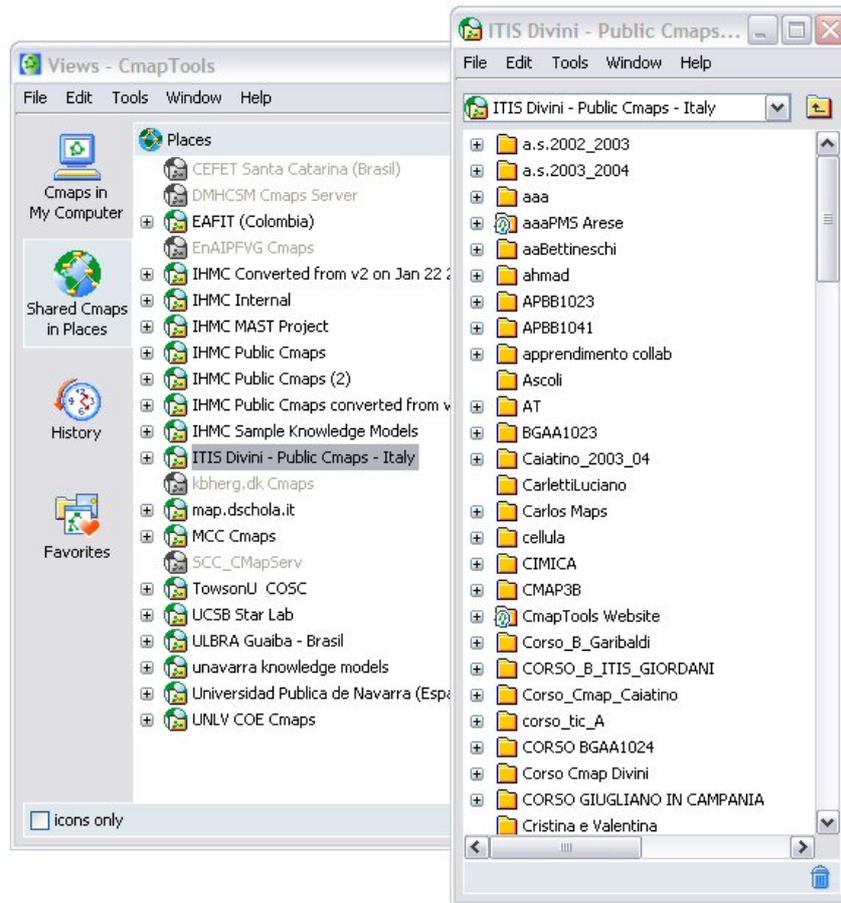
Figure 3. The Views window (left) showing available Places, and a partial view of the IT IS Divini Public Place in Italy (right).

grayed out, either because they may be behind a firewall or because CmapTools is aware that they were recently registered, but for some reason are not reachable at this moment. As new Places are installed on the network, the CmapTools program discovers them automatically and adds them to this list.

The Public Places are computers running the CmapServer program, configured in such a way that any user on the Internet can create his/her own folder, construct concept maps in it, copy knowledge models from his/her computer to it, and share that knowledge with others. Certain permissions are set on these Public Places such that *any* user on the Internet, without *any* prior authorization, is able to create a new folder. The permissions also make the user the *Administrator* of the folder and any subfolders that he/she creates under it. The user determines who has permission to read, modify, or annotate the resources in the folder (Cañas, Hill, Lott, & Suri, 2003). For example, the annotate permission allows a user to add comments (annotations or post-it notes) or discussion threads to concept maps in those folders, without having permission to modify or delete the maps. This way, a user can publish his/her concept maps and set permissions such that others can comment on them and provide feedback, without being able to modify the maps. This Public Places network, together with the permissions scheme, is particularly suited for peer review and collaborative projects where users, whether students or scientists, can easily share and collaborate in the construction of their knowledge models.

Collaboration through shared folders, annotations, and discussion threads is asynchronous: Users don't need to be working on the maps at the same time. CmapTools also supports synchronous collaboration: If two or more users located anywhere on the Internet attempt to edit the same concept map located at a Place, the system confirms with the users that they want to collaborate and begins a synchronous collaboration session. During this session, users can simultaneously modify the map, and changes are reflected on the screens of all participating users. Each modification made on the map is identified on the screen by the userID of the user performing it, and a chat window is available for text communication among participating users. Also asynchronously, users can collaborate at the 'knowledge level' through the Knowledge Soups described earlier in this paper.

The window on the left in Figure 3 has the Place "IT IS Divini – Public Cmaps – Italy" selected. Teachers and students of all ages from schools throughout Italy and from other countries take advantage of the public availability of this server to collaborate and share in their knowledge model construction. The window on the right shows a partial view of the folders available at the root level of that Place. The list of Places in the Figure also includes Public locations in Spain, Brazil, and Colombia. Thousands of users are sharing their knowledge models in these Public Places. As of June 2004, approximately 20,000 concept maps were being shared on these servers. Of course, additional maps are stored in the users' personal computers and Places that are not public.

The growing number of Places and the increasing number of concept maps and resources stored in them makes it impossible to "browse" through the folders for maps and information of interest. Each CmapServer keeps an index of the content of all concept maps and resources stored in it (and of web pages linked to by the concept maps), which makes searching through the Places easy and fast. In addition, all of these indexes are copied to an IndexServer, making searching through all servers just as easy. Users can also refine the search by indicating where to search, and what type of resources to search for.

CmapTools also offers the capability of searching the web for information that is relevant to a concept map. Users can select a concept within a map, and ask the system to search through the web for information relevant to the concept within the context of the map. The program takes advantage of the structure and semantics of concept maps to construct a query, send it to Google, rank the results, and present them to the user. (For more details, see Carvalho, Hewett, & Cañas, 2001; Leake et al., 2004).

The web is the best medium to offer information to the largest possible number of users. The objective of making knowledge models publicly available would be incomplete if the concept maps were not accessible on the Internet using a web browser. CmapTools facilitates publishing through the web by automatically converting concept maps saved on Places to HTML (web pages) that can be browsed immediately using an Internet web browser (e.g., Internet Explorer, Safari, Netscape). The concept map in Figure 1 has a URL at the bottom of the window that is the HTML version of the map's web address. The CmapServer includes a web server that delivers HTML versions of the concept maps it stores, and as such can support concept map-based websites. The concept maps in the CmapTools and CMC2004 websites (http://cmap.ihmc.us, http://cmc.ihmc.us) are all stored in CmapServers. Alternatively, the user can explicitly export a concept map or a knowledge model as web pages that can then be uploaded to a website for publication (Cañas, Carvajal, Carff, & Hill, 2004). Thus, any user can publish on the web the concept map-based representation of his/her understanding of a domain by constructing the concept maps in a Public Place, or constructing them in his/her computer and copying the maps to a Public Place.
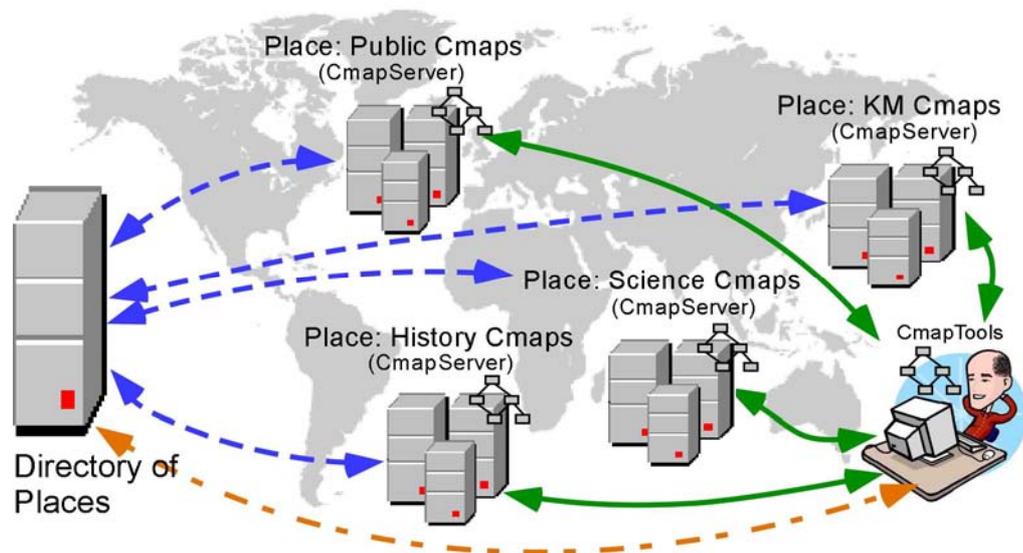

Figure 4. The CmapTools program locates Places that are registered with the Directory of Places.

7   Summary

The CmapTools software toolkit was designed to support constructing and sharing concept map-based knowledge models. Emphasis was placed on implementing a software program that is easy to learn, but powerful enough to support sophisticated uses. Based on lessons learned from previous research efforts, tools to enable the construction of concept map-based multimedia systems and strong support for collaboration are key components of the toolkit.

The software is available in many languages, and has enabled tens of thousands of users throughout the world to share and collaborate through a network of Public Places where any user, whether a student, a teacher, or a scientist, can create their own space and publish their knowledge models.

Acknowledgements

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