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CONCEPT MAPS APPLIED TO MARS EXPLORATION PUBLIC OUTREACH

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Abstract. This paper describes CMEX Mars, an effort to create a comprehensive set of concept maps to describe all aspects of Mars exploration. These concept maps, created using the CmapTools software developed by the Institute for Human and Machine Cognition, are available on the Internet at http://cmex.arc.nasa.gov/CMEX and are linked among themselves as well as to resources on the Internet. The work described took place mainly between 1998 and 2001 and combined the goals of: 1) developing a library of concept maps for educational outreach, while also 2) refining the capabilities of the software used to create the interactive maps, and 3) making them available on the Internet. Here we focus on the library of Mars exploration concept maps that has been created.

1 Motivation

Space exploration programs are by their nature highly interdisciplinary. Many advanced technologies are brought together in space flight projects to achieve a range of interrelated science goals, usually in several disciplines. As public interest in the recent Mars Exploration Rovers attests, Mars exploration wins a wide audience by virtue of its extraordinary technical challenge, the exotic nature of its targets, and the profound importance of its astrobiology goals. The public information project described here was motivated by a belief that concept maps (CMaps) would be an effective way of satisfying the needs of members of the general public who might wish to penetrate more widely and deeply into the subject than is generally provided by an individual website.

The phrase "*not* rocket science" is a colloquialism used in the United States to describe a task that does *not* require extraordinary skills. The implication is, of course, that "rocket science" is beyond the understanding of

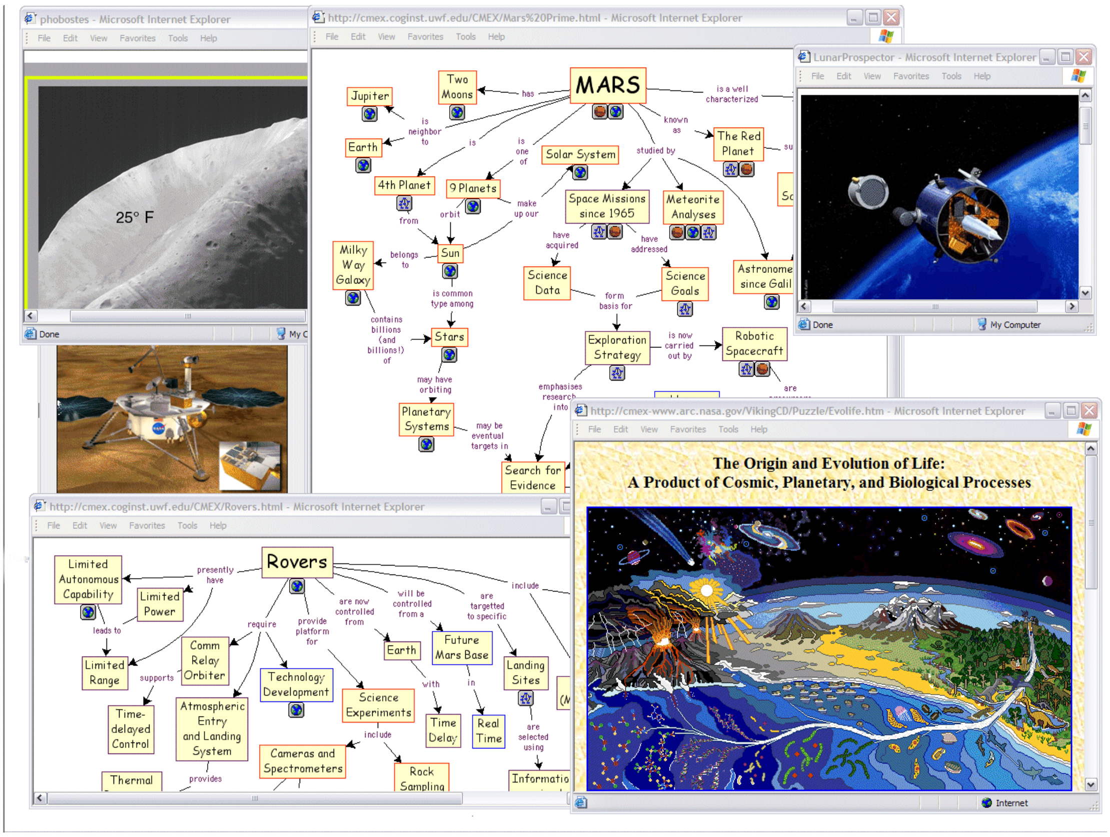

Figure 1. Most elementary Mars concept map (MARS) and associated resources.

mere mortals—an endeavor that approaches magic in its execution. Obviously this isn't true but, indeed, space missions are unusually complex and do require a considerable range of skills in many technical and scientific disciplines. It is through disciplined organization and experience developed over many decades (and which clearly still has room for improvement) that the necessary skills are brought together toward an end result that is frequently a source of great pride to the immediate project team and to the wider interested audience.

Because the now worldwide space exploration program addresses questions that attract keen interest far beyond the ranks of the participating scientists and, also, because the science disciplines and enabling technologies are so diverse, it is clear that the potential for educational outreach is large. This is especially so in the United States where scientific literacy is seriously lacking; as witnessed by the organized opposition to the teaching of biological evolution in schools. Although there is a mass of information about individual space missions and different aspects of space exploration available on the WWW, this information is not organized to allow an interested teacher or student to gain more than a shotgun perspective of the broad interdisciplinary field. Using the concept mapping software CmapTools (Cañas et al., 2004), a group from the Center for Mars Exploration (CMEX) at NASA Ames Research Center, in collaboration with the Institute for Human & Machine Cognition (IHMC), have sought to change this situation by creating "CMEX Mars," an ever-broadening tree of concept maps (totaling more than 100) on the subject of Mars exploration. This tree allows users to work their way from the most basic information to a level of detail that is intended to fully satisfy their interest. In principle, concept maps alone could provide unlimited detail but, because the Internet is now so rich in information it is much more efficient to supplement the concept maps with links to the most informative sites on the Internet. Thus, the concept maps are intended to provide summary information at different levels of detail as well as an organized list of Internet links to allow further penetration.

Mars Exploration Concept Map Contents

Exploring Mars	Science	Geology	Geologic Processes	Climate
Mars Introduction Planet Mars Mars Exploration Meteorites from Mars Myth & Science Fiction	Science Goals Comparative Planetology	Geologic History Geochronology Gravity Field Magnetic Fields Earth's Moon Gamma Ray Spectroscopy Recent to Current Water Activity Surface Chemistry Surface Layer	Impacts Volcanism Tectonism Valles Marineris Polar Caps Outflow Channels Valley Networks Paleolakes Recent to Current Water Activity New Martian Landscapes	Climate History Mars Atmosphere Earth's Atmosphere General Circulation Dust Storms Polar Caps Ozone Long Term Changes in Orbital Spin & Dynamics
History of Water	**Search for Evidence of Life**	**Life**	**Where to Search**	**Candidate Landing Sites**
History of Water Ancient Groundwater Modern Groundwater Ancient Surface Water Outflow Channels Paleolakes Valley Networks Long Term Changes in Orbital Spin & Dynamics Water Functions Water2 Water Molecule	Search for Evidence of Life Planetary Protection Mars Meteorites Astrobiology: The Study of Life in the Universe	Life on Earth Essential Requirements Life Tree of Life Unity of Life Limits of Life Water Functions Microbial Fossil Record Micro-organisms	Modern Groundwater Recent to Current Water Recent Volcanism Subsurface Exploration Deep Access	Site Selection Landing Site Hazards Gusev Crater Terra Meridiani Apollinaris Eos Chasma
Robotic Missions	**Orbiters**	**Landers, Rovers, Sample Return**	**Other Missions**	**Human Missions**
Interplanetary Spaceflight Mars Space Missions Deep Space navigation Robotic Outposts Planetary Protection Post 2003 Mission Plans	Orbiters Mariner 9 1971 Viking Orbiters 1976 Mars Observer 1992 Mars Global Surveyor 1996 Mars Climate Orbiter 1998 Mars Odyssey 2001 Mars Express 2003 Post 2003 Plans	Landers Rovers Sample Return Viking Landers 1976 Mars Polar Lander 1998 Pathfinder 1996 Sojourner 1996 Mars Exploration Rovers 2003	Airborne Platforms Airplanes, fixed wing Mars Aerodynamics Subsurface Exploration Deep Access Post 2003 Plans Robotic Outposts	Human Exploration Eventual Habitation Habitability Goals Cultural value Economic Value NAS Committee Report
Technology	**In Situ Resources**	**Other Considerations**		
Technology Development Aerocapture Power Surface Mobility Autonomous & Adaptive Operations Autonomous Control "Remote Agent" Biology-based Technologies Image Processing Pixel Array	In Situ Resource Utilization Atmosphere Rocket Propellant Surface Chemistry Minerals Ores Building Materials	Earth Analog Studies at Haughton Crater Practical Calendar for Mars		

Figure 2. A full listing of all the Mars concept maps.

2 Approach

The CMEX Mars concept maps are structured in a hierarchical form with the most general map, the MARS concept map shown in Figure 1, at the apex of the pyramid. An index to the set of concept maps is provided as a simple listing, shown in Figure 2, because the set of concept maps far exceeds the number that can be displayed in the form of a high level concept map sized to fit on a typical computer monitor.

2.1 Single Map Display

In principle, the entire set of concept maps could be linked into one giant concept map but this is a problem when working in two dimensions and with the display capabilities of a computer monitor. In creating the concept maps using an ordinary desk top computer (a Mac) with a modestly sized monitor (17 inch), the scope of an individual map is constrained to contain no more than about 30 concepts. This assumes that one wishes (as the author of the Mars concept maps does) to be able to see the entire concept map without the need to scan beyond the borders of the screen.

Typically, each concept map is linked to a number of others so that the total number of paths that may be followed according to the particular interest of the user is *very* large. Links are activated by clicking on an icon attached to the concept in question.

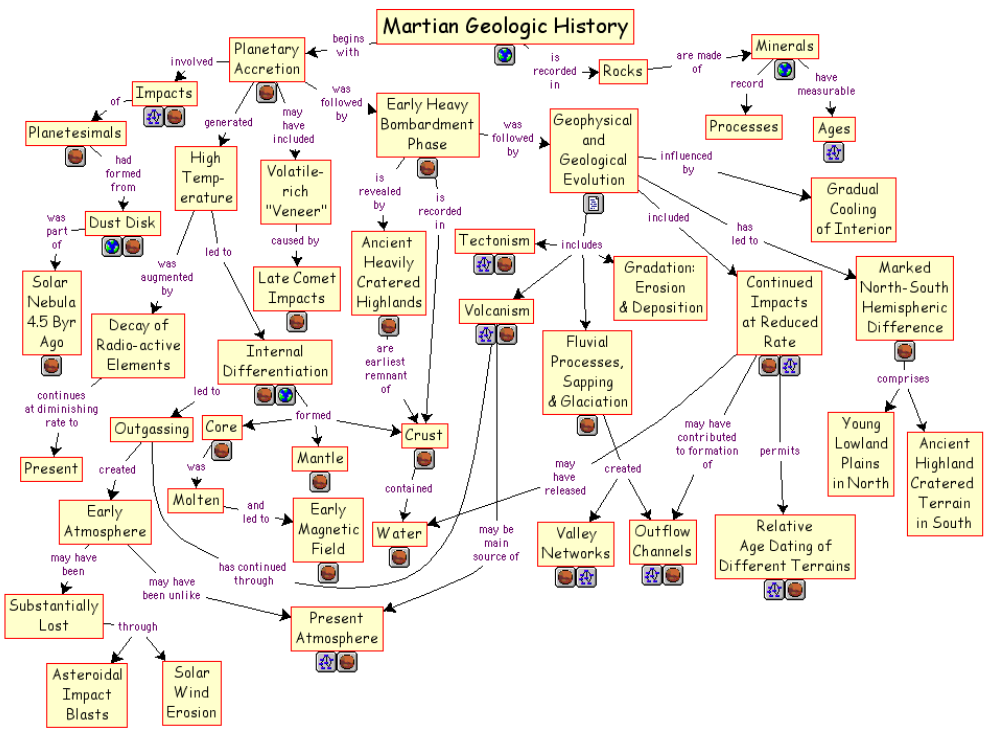

Figure 3. Geologic history (example of detail-level 1 science).

Figures 3 and 4 show examples of the increasing levels of detail that are provided by the concept maps. Thus far, the concept maps have been made to cover three levels of detail (Figure 5). The information content of a given map at the greater levels of detail is similar to what would be contained in the abstract to a science paper, that is, a basic summary that in most cases is expected to meet the interest of a general user.

As a practical matter, in order to maintain the legibility of the concept maps, the links between concepts (i.e., the linking phrases on the concept map itself, *not* the link between concept maps) are limited to the most important, and the layout of the maps inevitably tends toward a tree-like form. Figure 6 shows such a concept map. Figure 7 shows one that is less tree-like, capturing the inherent strength of the concept mapping form of information presentation. To some extent legibility issues may limit the value of the concept maps because, of course, it is the linkages that make a concept map more powerful than a simple PowerPoint-like listing. This

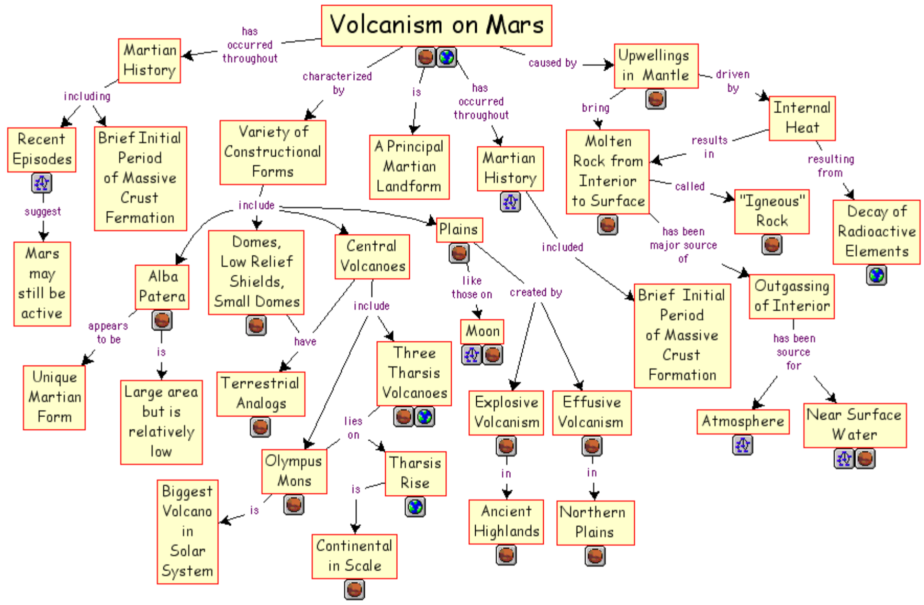

Figure 4. Volcanism on Mars (example of detail-level 2 science).

limitation is offset by the software links that are provided by clicking on the icons attached to concepts. These links effectively introduce a third dimension to the otherwise two-dimensional concept maps.

Also, toward providing visual ease in using the concept maps, a lot of thought and trial and error went into the colors and fonts used in their design. In principle, color can be used to provide additional information but we have decided to forego that opportunity for the sake of overall simplicity. Whether we were successful in our choices is a matter of individual taste.

We have also considered the use of images as an integral part of the concept maps both to provide information and to add visual interest to the maps. Thus far, given that we have already taken advantage of most of the 'real estate' available on each map, we have not been able to add images in a way that avoids clutter. Images associated with the concepts, therefore, have to be retrieved by clicking on the icons.

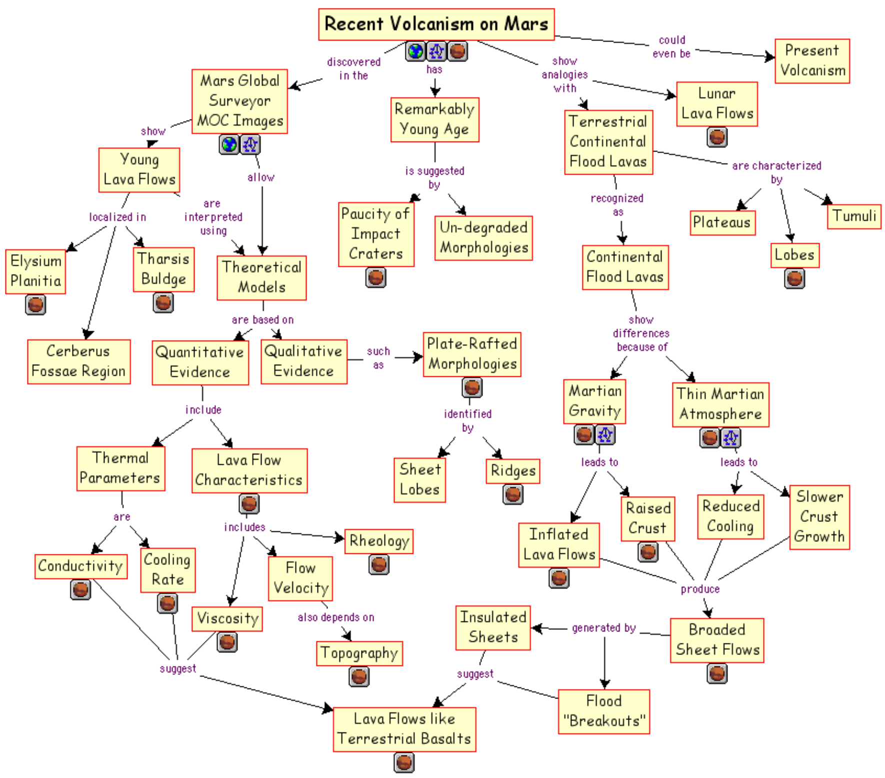

Figure 5. Recent volcanism on Mars (example of detail-level 3 science).

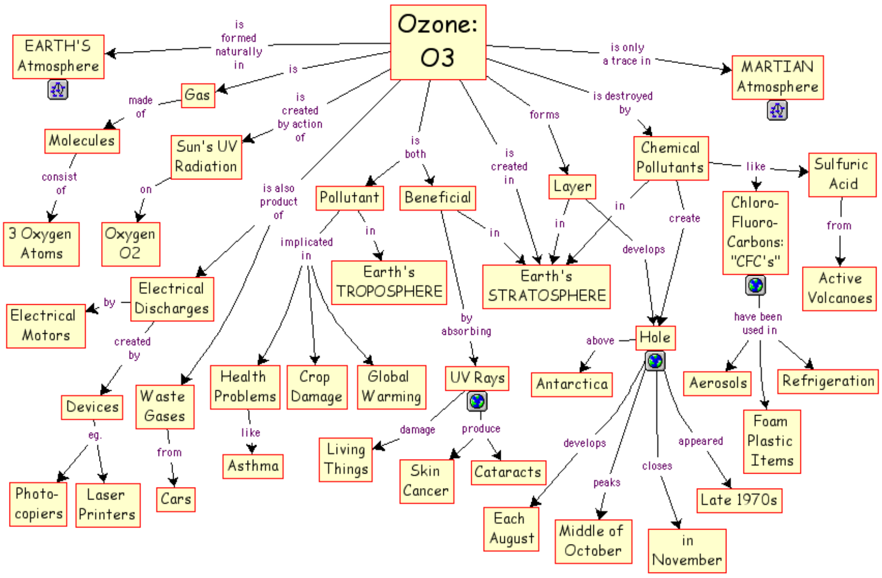

Figure 6. Ozone (concept map that is generally tree-like in structure).

2.2 *Live Web Reflections*

As this work was part of an international educational outreach, we had little knowledge of the end user (the students and teachers) computer speed, or even platform. This also meant we could not assume that a school would have any access to the World Wide Web (WWW) or that it could support infrastructure to connect via an intranet. Conversely, if a school *did* have the networking resources, we wanted to enable them with as much concept mapping tools as possible.

To facilitate this, we created an HTML application that could be distributed as a set of web pages on a CD-ROM. A thin client allowed the creation of a single, multiplatform, shared partition CD-ROM. The CD

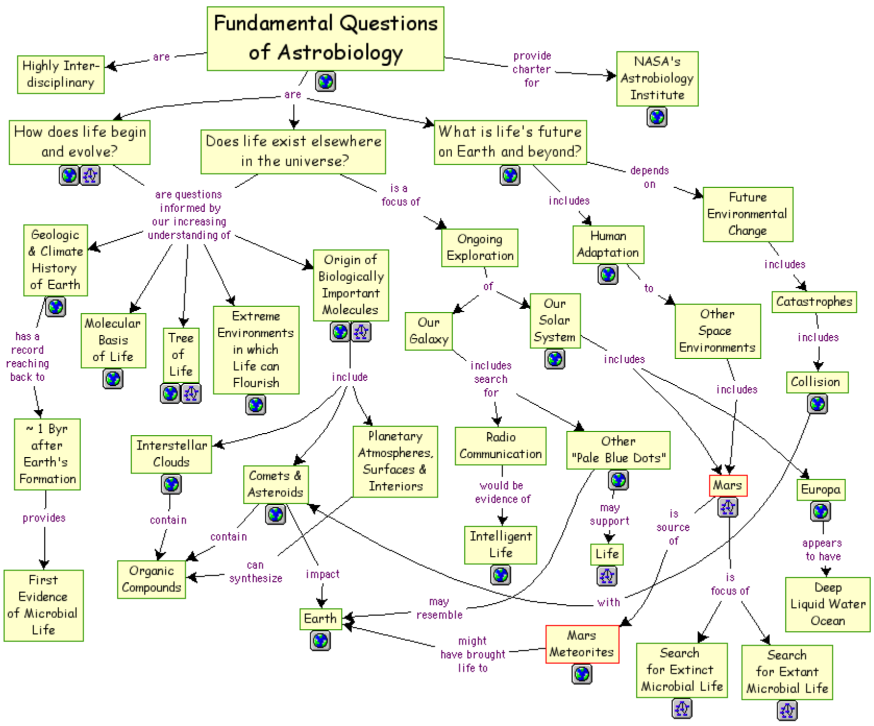

Figure 7. Fundamental questions of astrobiology concept map that is less tree-like in structure.

contained some 500 MB of Mars Orbiter Camera (MOC) images as well as several QuickTime Movies. With the concept maps as a thin client, we could easily share the maps and supporting multimedia on a single CD-ROM.

With maps being built in the modeling toolkit, we designed a special module for the toolkit in order to prevent concurrency problems. Map builders work and build maps in the same environment while web content is synchronized automatically by the tool. Deploying the CD itself was simply, and quite literally, distributing the website on a CD. Auto-start functionality launched the 'home' page when the disc was inserted into the computer.

3 Internet Links

A key feature of the IHMC CmapTools software is its ability to allow concepts to be linked directly to relevant sites on the Web. There is no limit to the number of sites that a single concept may link to; these sites are identified in a drop-down list after clicking on the Internet icon attached to a given concept (Figure 8). The Internet icon pictures the Blue Planet Earth. (The CMap in Figure 7 shows many such icons.) Each concept map has many Internet links (~1000 in total for this project) to sites where yet more detail is available on the subject (i.e., concept) in question. In this way the Mars concept maps are intended to provide access to a complete library of information to satisfy many nonprofessional needs.

3.1 Local and Remote Links

In addition to Internet links, the concept maps incorporate many links to material contained on the same server as the concept maps themselves, and that were included in the CD to allow students to build new maps from them. This material includes a variety of NASA reports, video clips, and an *interactive* Martian calendar. (Many have been proposed over the years—we, of course, like ours best.) The icon for these links pictures the Red Planet Mars. (The CMaps in Figures 3, 4, and 5 show many such icons.)

The Mars exploration concept maps are available on a server located at the NASA Ames Research Center in California. The CmapTools software used to generate the concept maps automatically saves a version of the new concept map in HTML format so that it can be accessed, in effect, as an interactive image. This allows users to browse the concept maps and directly link to the many websites to which the maps provide a portal.[1]

One of the challenges of establishing a web-based concept map library covering an active research area is the need to keep it up-to-date in light of new discoveries from data acquired by the various spacecraft orbiting and landing on Mars. The concept maps themselves require relatively infrequent updates because most provide basic information that changes relatively slowly. Given how much new data about Mars is being returned by spacecraft and how avidly the planetary science community devours that data, discoveries are made and new insights developed at an impressive rate. Some of these new developments lead to the need to amend one or more of the concept maps but, more generally, the new information can be incorporated by adding a new link to a site on the Web.

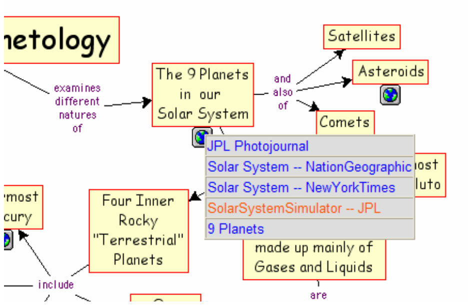

Figure 8. A close up of a set of links. Icons provide a menu of links to other concept maps and resources.

3.2 On Searching and Indexing

Concept maps provide a top-down browsing tool through the knowledge model. It has been shown that subjects can browse through these well-formed maps with less difficulty when compared to standard web pages (Carnot, Dunn, Cañas, Graham, & Muldoon, 2001).

The act of web browsing has been replaced lately with large scale search engines. That is, many web users rely on the large scale server farm indexing billions of web pages for them. Toward this end, the average search query, from a recent study, is 2.2 words (Spink, Wolfram, Jansen, & Saracevic, 2001). Google's popularity emerged largely due to their ranking system. Google's PageRank (Page, Brin, Motwani, & Winograd, 1999) is based on counting the number of hyperlinks pointing to the search candidates. The more links pointing to a website, the closer to the top of the search result list it appears. For example, the search in Google for "Mars Exploration" returns 1.3 million pages at the time of this article. The CMEX home page appears at the top, second to the Jet Propulsion Lab. The problem with the approach of most of the large scale search engines is they return the global maximum and are not built to return context specific relevant pages. Large search engines reflect the general familiarity of people across all ages and education levels (Shamma, Owsley, Hammond, Bradshaw, & Budzik, 2004); and as a result of their specific nature, many of the concept maps are ignored.

The maps represent a knowledge model; a well-formed set of linked concept maps and associated resources (Cañas, Hill, & Lott, 2003). Much work has progressed on how to link, index, and establish ranking for searching concept maps as well as the links to media, web pages, and documents they contain (Carvalho, Hewett, & Cañas, 2001; Leake et al., 2003). In particular, we continue researching how to leverage the topology and semantics of concept maps to index the maps and to search for information relevant to a map. This work is available in CmapTools and we are actively exploring its introduction into the HTML content.

4 Knowledge Modeling by the Expert

A characteristic of the CMEX set of concept maps and associated resources is that navigation takes place by browsing the CMaps constructed by an expert on the domain. Successful capture and sharing of human expertise depends on the ability to elucidate the experts' understanding of a domain, to represent that understanding in a form that supports effective examination by others, and to make the encoded knowledge accessible when it is needed in the future. This knowledge elicitation process is usually carried out by a knowledge engineer interviewing the expert, and is such a daunting challenge that it is referred to as the "knowledge acquisition bottleneck" (Buchanan & Wilkins, 1993; Hayes-Roth, Waterman, & Lenat, 1983) within the expert systems

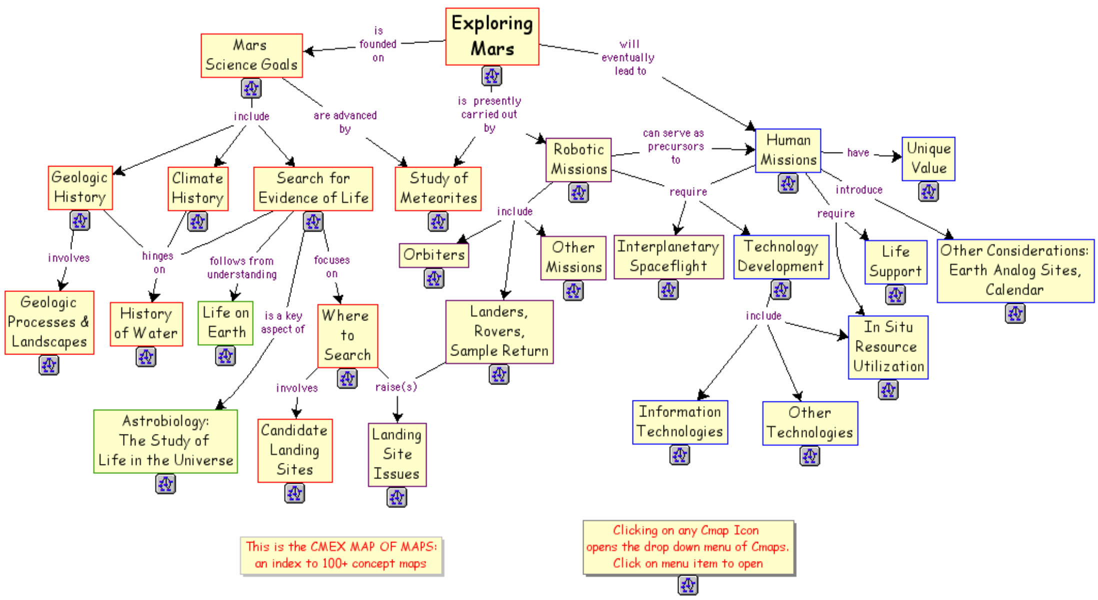

Figure 9. A map of maps.

[1] The maps are available at http://cmex.arc.nasa.gov, and mirrored at http://cmex.ihmc.us.

community. Even though the set of CMEX concept maps were not intended to be used as part of an expert system, the fact that they are based on the knowledge of an expert and were created by the expert himself without the aide of a knowledge engineer, speaks favorably of concept mapping as a knowledge elicitation and representation technique that is accessible to the expert, and of the CmapTools as a medium to carry on this knowledge modeling.

5 Conclusions

When this project got underway high speed access to the Internet was not common and so we chose to make the material available on a CD-ROM as well as via a server. More than a hundred requests for the CD have been received through the mail, almost all from high school teachers.

One clear conclusion we *have* reached is that a single concept map is not a good way to provide an index to a library of concept maps once the number exceeds about 30. Figure 9 shows the “Map of Maps” (MoM) in its original form. This concept map/index links more than two dozen subject areas that represent (this is, of course, subjective) the principal areas of science, technology, and mission information. As a practical matter it is difficult to incorporate more than about 30 concepts in a single map that can be viewed on a typical computer screen. So, it is not practical for the MoM to include (in the form of a separate concept) all 100+ concept maps that are available. Thus, each of the two dozen MoM concepts must serve as the portal to an average of five concept maps. Some of the MoM concepts serve as a portal to 20 concept maps. These can be accessed by clicking on the small icon associated with each concept. Figure 8 shows an example. In practice, a lot of hunting and pecking may be required to find the concept map that is of interest, and we have concluded that the index approach described earlier (Figure 2) is the preferred approach.

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