Expedition Memory: Towards Agent-based Web Services for Creating and Using Mars Exploration Data.

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Introduction: Explorers ranging over kilometers of rugged, sometimes "feature-less" terrain for over a year could be overwhelmed by tracking and sharing what they have done and learned. An automated system, based on the existing Mobile Agents design [1] and Mars Exploration Rover experience [2], could serve as an "expedition memory" that would be indexed by voice as well as a web interface, linking people, places, activities, records (voice notes, photographs, samples), and a descriptive scientific ontology. This database would be accessible during EVAs by astronauts, annotated by the remote science team, linked to EVA plans, and allow cross indexing between sites and expeditions.

We consider the basic problem, our philosophical approach, technical methods, and uses of the expedition memory for facilitating long-term collaboration between Mars crews and Earth support teams. We emphasize that a "memory" does not mean a database per se, but an interactive service that combines different resources, and ultimately could be like a helpful librarian.

Problem and Challenges: The most cursory observation of field expeditions reveals (Figure 1) that people use a wide variety of recording media to document their experience for different purposes [3].

Figure 1. Haughton-Mars Project 1998.

The media here include: photographs, video, written notes, temperature probe, ruler, and audio. Multiply these records over a dozen stops in perhaps hundreds of traverses, over several years. Then start accumulating expeditions in different areas on Mars, with a land surface as large as the Earth's. How can we use computer methods to store, organize, present, and find original raw data so it can be indexed in a standard way by publications, whose charts, graphs, and theories will interpret this data? Can the original data be annotated to record contextual information such as: 1) identifying data (e.g., place, time), 2) instrument settings or collection methods, 3) associated data, and 4) the activity context, e.g., purposes of the observations?

Philosophical Approach: To be clear, by "expedition memory" we mean something like a computer memory, a *database*, not human memory. In particular, the expedition memory is not where the "knowledge" of past work resides. Data become information only under interpretation, in which people conceive distinctions or "news" that makes a difference to their activities [4]. Knowledge—people's potential to perceive, frame situations, and coordination activities—does not reside in the database either. Different people will bring different knowledge to bear, perhaps in viewing the same data structures in different circumstances, to make novel interpretations and plans [5].

Thus, in considering the whys and wherefores of an "expedition memory" it is useful to consider the essential skills that can't be easily described or learned by reading manuals, viz, electronics technician, tool maker, surgeon. These skills require years of practice, hands-on learning, and hence cannot be conveyed in email or by diagrams and procedures. Records can be kept about repairs, inventions, and medical treatment, but it should be remembered that any tool complements human capability, and cannot replace it [6].

Technical Approaches: Fortunately, a variety of methods past and present are available for us to consider and adapt.

Written Journals/Logs: For example Stuster [7] surveys logs from historical missions of discovery, including Cook, Lewis and Clark, and Darwin.

Web-based Journals: The most extensive and relevant journal on the web is the Apollo Lunar Surface Journal [8], which integrates transcripts of the Apollo missions with checklists, photographs, and video in a format meaningful to the public. Many aspects of the tools, plans, and interpretations are interwoven through hyperlinks in this very usable and comprehensive record. Recent "web logs" (blogs) are useful for personal field notes, but should not be confused with databases.

Web-based Databases: ScienceOrganizer [9] hierarchically indexes data according to customized semantic relations (e.g., creator, purpose, rock type), allowing a datum to be referenced by single pointer (URL). The Mars Exploration Rover (MER) Analyst's Notebook [2] is another chronological-hierarchical data archive, relating rover commands to engineering and science data, and intended for use by researchers.

Agent-based Workflow Systems: Data created during an exploration "traverse" can be transmitted and stored automatically. Mobile Agents [1] is a toolkit that integrates sensors (including GPS), observation plans, and speech (e.g., voice notes) in a distributed, wireless system, automatically storing and relating data in Science Organizer.

Using an Expedition Memory: Referring to the known examples, we can consider how the Mars expedition memory (EM) will be used.

The EM will serve many teams across time and space. Astronauts in training will need to access past exploration data to understand current theories and to devise new investigations. During the mission, the EM will facilitate the collaboration with the crew, as well as with distributed Earth teams (like the MER mission). Astronauts in flight will refer to ongoing robotic missions to adjust their plans and tools. Engineers designing the next generation of instruments, habitats, etc. will look for ways to make life on Mars more productive by automating routine communications and data transformations (e.g., creating charts and interpreting trends).

Despite the examples given above, an EM could not be one large database, any more than everything we know on Earth is or could be integrated. In particular, legacy systems (e.g., obsolete media like videotapes today [10]) will still be in use when yet more efficient digital (holographic?) methods will be introduced. Eventually, the EM will be distributed over many different data sources on Earth and on Mars. People and software systems will also need to access expedition memory in a variety of ways. Today's best web search systems use many different types of interfaces, including natural language (e.g., text we type into search engines), graphical displays, Web browsers, and software application interfaces (APIs). More generally, an agent-based approach could attempt to interactively understand a person's interests and carry out a search like an informed travel agent or librarian [11].

Next Steps: We have surveyed different architectural levels pertaining to an expedition memory for Mars: 1) creation, 2) storage (including copying to new media to preserve records), 3) organization, and 4) interpretation. Today research is beginning to emphasize integrating different kinds of data (e.g., instruments, commands, and measurements) with scientists' original intentions (including multiple-day exploration plans) and publications. Emphasis is increasing on developing model-based services (often called "artificial intelligence"), namely a system that can automate at least part of the process of informing people about the existence of relevant data. Much more work remains to be done in integrating planning tools with databases, as well as automating how data are arranged for easy browsing (e.g., customizable "home pages").

Keeping track of all the images, sensor data, interpretations, and conjectures during an extended exploration mission will be a powerful challenge, especially since so many individuals will be involved (on Mars and on Earth) and the missions will be running one after another. We (hopefully) won't have the luxury of a 20 year gap like the one that followed Viking for digestion to take place.

To be sure, the use of the internet and web representations for personal and scientific investigation is one of the most dynamic and inventive areas of our society today. Just as a space exploration plan from 1990 is obsolete today for not mentioning the web browser (though of course the internet has been widely used for communication and file storage since the mid-1970s), any design we imagine today will be potentially greatly changed by innovations in the years before the first Mars mission.

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