GIS 101 FOR PLANETARY RESEARCH

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ABSTRACT: Geographic Information Systems (GIS) are computerized systems for the storage, retrieval, manipulation, analysis, and display of geographically referenced data (Mark et al., 1996). The components of a GIS project fall into three categories; computer hardware and software, spatial data, and trained personnel. A GIS can also be considered a visual language that allows the user to visualize and easily interact with digital data. This paper will discuss the basics behind defining and assembling a planetary GIS project.

I. WHY USE A GIS?

1.1. Introduction

GIS-like tools have existed in the computer age since scientists have been displaying images or comparing digital datasets. Whether it was a program on a mainframe to draw a satellite image to screen, or a piece of FORTRAN code to gather statistics from, all were similar to GIS. The difference now is that nearly all the tasks necessary in a digital mapping project have been merged under one umbrella. A good GIS system should be able to handle a digital mapping project from start to finish. This would include data ingestion, storage, creation, manipulation, multi-layered analysis, visualization, and data output (whether it is digital or hard-copy), through an easy to use interface.

1.2. GIS in Planetary Research

GIS has been used in planetary projects for a number of years (Hare et al., 1998). Because GIS is just an expansion of cartography and mapping, the use of the technology fits naturally into planetary research. GIS software uses any data that can be tied to a spatial location, including tabular or other information associated with that location. But like other related technologies such as remote sensing, photogrammetry or image processing, commercial software is usually written for terrestrial applications, thus using these applications with planetary datasets has sometimes proven difficult or impossible. For this reason, those in the planetary community are accustomed to writing their own software applications. But with the advent of powerful and inexpensive computers and the advances in extremely robust and easy to use software applications, it is becoming harder to justify the cost of creating and maintaining these homegrown applications.

Another reason planetary mappers have begun to rely on GIS technology is that they offer one the ability to overlay multiple datasets. This was not as much an issue during previous mapping projects because there was potentially only one base to use. For Mars there are now dozens of global datasets available, for example: multiple global image mosaics, topography, and mineral maps.

1.3. Benefits of a GIS

Benefits of investing in GIS technology can sometimes be shrouded by the initial expense and learning curve. Planetary investigations are also generally considered to be pure research, not commercially-sold services or products, so a cost-benefit analysis for a research facility can be difficult to determine (Wilcox, 2000). However, by investing in GIS technologies, a research facility can expect to benefit in these major ways. They will be able to:

1. Provide up-to-date maps
2. Perform spatial queries and easily display the results
3. Conduct complex spatial analyses
4. Make better decisions
5. Easily improve and update digital datasets
6. Employees will become more efficient and effective

Item six will likely have a large impact on the overall objectives of any mapping project. But like any new technology, money will need to be spent on computer hardware, software, and above all, training. Although GIS software has come a long way from its cryptic command-line driven applications to GUI applications, a learning curve still exists. The technology also changes so quickly, it is a good idea to budget for yearly training (Webster et al., 1999).

II. BUILDING A GIS

1. Define the goals
2. Assemble equipment and facilities
3. Train the personnel
4. Locate existing digital data / hardcopy data
5. Design methods and database
6. Data - do the work
   - 6.1. Data creation
   - 6.2. Data conversion
   - 6.3. Data updates
7. Analyze

70 - 80% cost of entire project (6.1–6.3)

Figure 1. This list describes the chronological steps needed for a complete GIS project, large or small.

2.1. Define the Goals

The principle investigator should define the goals of the project based on the needs of the user community. GIS specialists should help the principal investigator determine feasibility of the project and help define the tasks. This step should also determine if a GIS system is even necessary to complete the project's goals.

2.2. Assemble Equipment and Facilities

2.2.1. Hardware and Operating Systems

Desktop computers have become so powerful in the last decade that most GIS software will easily run on them. Most packages are also able to run on centralized servers using Microsoft Windows and UNIX variants, including LINUX, although support for LINUX is still not extensive. The current trend in GIS software is to primarily support Windows. ♦

2.2.2. Software

There are hundreds of GIS software packages currently available, from simple viewers to advanced all-in-one integrated systems. Many of these packages are now able to handle each other's file formats, thus data compatibility is not as large an issue as it use to be. When choosing an application, planetary researchers should at the very least make sure planetary spheroids are supported in the package before purchasing (Hare, 2001, Digital Mapping).

At the USGS in Flagstaff, AZ, we currently use and support the major software packages from Environmental Systems Research Institute (ESRI). These software packages include Arc/Info, ArcView 3.x, and ArcMap products. Arc/Info and ArcView 3.x capabilities and limitations are well known and we have many examples and tools for each. We are currently learning the newer ArcMap product and so we still do not understand all the problems a planetary researcher may come across, but it does support setting planetary projections.♦

An article that describes many of the free GIS viewers available can be found at the website: http://spatialnews.geocomm.com/features/viewers2002/ "GIS Viewing Tools You Shouldn't Be Without!" This will give users an opportunity to test drive some rudimentary GIS functions before actually investing in the technology.

As a GIS project grows, an underlying database management system (DBMS) for storage and management of the geographic and attribute data may be necessary. This can be a large investment in hardware and administration, but it should not be essential for small or medium-sized projects. If the project plans to support more than ten users and potentially terabytes of data, then this will be a task that will eventually be necessary to explore.

2.3. Train the personnel—5 Distinct Roles

Personnel Roles

1. **Project Manager**
   - Defines goals
2. **GIS Manager**
   - Defines necessary people, procedures, database, and quality control
   - Should know what software can/cannot do
3. **System/Database Administrator**
   - Maintains hardware and software
   - Maintains database software
4. **GIS Analysts**
   - Implement procedures and database creation
   - Write programs and interfaces to help with automation
   - Possess very good knowledge of software
   - Perform GIS analysis
   - Train personnel
5. **GIS Technicians**
   - Collect data
   - Enter tabular data, digitize, attribute features
   - Print and output

Figure 2. List of employees necessary for a strong GIS project. This is extremely important for large projects. Unfortunately for smaller projects, it is not uncommon for one person to wear several of these hats, or even all of them.

♦ Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Personnel Training

- ❖ **Project Manager**
  - ➢ Should have GIS training but not necessary
- ❖ **GIS Manager**
  - ➢ University undergraduate degree coupled with advanced technical training and experience
- ❖ **GIS Analysts**
  - ➢ University undergraduate degree coupled with advanced technical training
- ❖ **GIS Technicians**
  - ➢ Several weeks of computer and GIS training.

Figure 3. Recommended minimum training times for each employee type. A system administrator needs to support hardware and software installation, including potential DBMS setup and administration.

2.4. Locate Existing Digital/Hard-copy Data

2.4.1. Satellite Base Maps

Planetary mappers rely on remotely sensed imagery as their main mapping base. GIS systems need these base images spatially registered and map-projected. However, getting the data into a form that is spatially located can be a difficult process unto itself, especially for planetary datasets. The advent of Global Positioning System (GPS) allows for Earth imagery to easily, almost automatically, register spatially. Planetary datasets must be converted from a raw space to a map-projected space using specialized image-processing software like ISIS (Integrated Software for Imagers and Spectrometers) and VICAR (Video Image Communication and Retrieval) (see figure 4.; Hare et al., ICC 2001; Gaddis et al., 1997). Fortunately, much of the data planetary mappers need are eventually map-projected and released to the PDS (Planetary Data Systems) nodes.

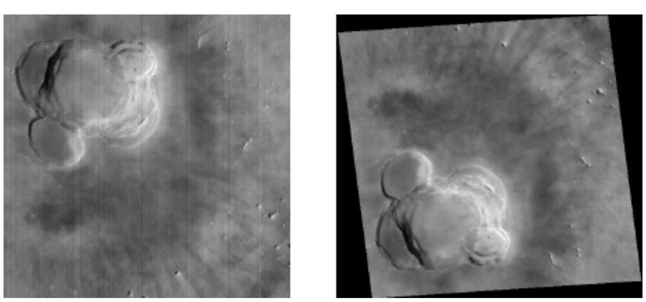

Figure 4. The image on the left shows a raw Mars Orbiter Camera (MOC) frame of the Ascraeus Mons caldera. The image on the right has been radiometrically and cosmetically corrected and projected to a sinusoidal projection.

The PDS archives and distributes scientific data from NASA (National Aeronautics and Space Administration) planetary missions. While much of the data is saved in its original uncorrected form, there are many datasets available that have been spatially registered and map-projected. PDS formatted images are not compatible with most GIS or image processing packages, but they can be converted into a GIS format. The PIGWAD (Planetary Interactive GIS on the Web Analyzable Database) project, as one of its funded tasks, has generated many tutorials and tools to help make this data conversion easier (Hare et al., LPSC 2001). PDS may also look into the viability of GIS compatible formats like Geotiff. It should be noted that PDS also supports many other data types besides data that can be spatially registered, like astronomical observations and laboratory measurements.

2.4.2. Registration Errors

Of course, by just map-projecting a dataset does not mean it will register perfectly. Every instrument used to collect satellite imagery has limitations in horizontal accuracy. This is especially true for planetary datasets. Satellites can slightly lose track of their position or the camera may be slightly calibrated wrong, the number of potential problems is overwhelming. Spatial accuracies are also affected as our knowledge grows about the size and shape of the planets and moons (Seidelmann, 2000). Recently, this has become a large problem in dealing with Mars (Hare, 2001, Digital Mapping). Many of the older martian datasets, which are registered to out-dated control and an older definition of the size of the planet, can be kilometers off from the newer datasets. Researchers must recognize these errors or go back to the original data and reconvert them to the newer system (Archinal, 2002).

2.4.3. On-line Data

There are currently many excellent planetary on-line mapping sites. These applications allow the client to make use of the spatially co-registered data without the need to purchase commercial software or download large datasets. Each site also has a suite of specialized tools used to query the data. Some of the facilities producing these applications are PDS, NASA AMES Research Center, Arizona State University (ASU), Observatoire Midi-Pyrénées in France, and the USGS. Listed below are some websites, and when available, the applications' names.

- **PDS**:
  - http://pds.jpl.nasa.gov
- **NASA AMES,** Mars Landing Site Analysis:
  - http://marsoweb.nas.nasa.gov
- **ASU,** JMARS:
  - http://mapserver1.la.asu.edu/jmars
- **Observatoire Midi-Pyrénées,** SPINS:
  - http://www.geotexel.com

- **USGS,** Map-a-Planet:
  - http://pdsmaps.wr.usgs.gov
- **USGS -** PIGWAD:
  - http://webgis.wr.usgs.gov

To use these datasets in your GIS, the data must usually be downloaded and converted into a compatible format. An ultimate goal for all these facilities to strive for is interoperability for their served datasets. That will allow the end-user to load different co-registered layers from different facilities into a single application. The OGC (Open GIS Consortium, website: http://www.opengis.org/) consists of over two hundred companies, universities, and government agencies whose goal is to bring this to reality. A term used on the OGC website that describes this process is to "geo-enable" the Web.

PIGWAD currently has technology installed to allow users of ESRI's ArcMap or their free viewer, ArcExplorer, to load its on-line mapping services. PIGWAD supports multiple datasets on Mars, the Moon, and Venus, and the Galilean satellites are to be added soon. The software solution used, ArcIMS (Internet Map Server), also supports the open-source OGC protocols, although this has not been tested (Hare et al., LPSC 2001)

2.5. Design Methods and Database

The project manager and GIS manager usually define the methods, although the other personnel should be involved with the process. The methods may be as simple as defining the need for geologic and structural maps, to generating advanced techniques for automatic feature extraction.

The database design may change over the course of the project but it should be tied down as much as possible. This would include defining what data layers are going to be created (point, line, polygon, raster, etc.), and what the attributes for those layers will be. For a geologic and structural mapping project, types of layers would include polygon geologic layers and linear structural layers. But it may also include layers like points that define craters or a layer that defines channels. Attributes (for example unit descriptions or structural types) for each layer should also be well established. These of course will evolve as more feature descriptions are added, or previously defined descriptions are grouped or subdivided.

2.6 Data

2.6.1 Data Creation

Data creation is the heart and usually the most expensive portion of a mapping project. "Geographic data, which is comprised of geographic features and their corresponding attribute information, is entered into a GIS using a technique called digitizing" (PASDA). Digitizing is the process of tracing the location, path or edge of a feature. When older hard-copy maps need to be converted into a digital format, the maps can be scanned and digitized directly on the screen, or the maps can be attached to a digitizing tablet. As the features are digitized, the attributes should also be assigned.

Automatic feature extraction is an exciting field that is also growing by leaps and bounds. There are many interesting techniques currently being developed for use on planetary data also (Brumby et al., 2003; Garvin et al., 2001; Kim et al, 2003)

For planetary geologic mappers, there are many good resources (mapping guidelines, symbols) available on the USGS Planetary Geologic Mapping Home Page: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/

2.6.2 Data Creates Data

The idea that data creates more data is especially true when using a GIS. By using standard GIS tools, existing data can be used by itself or intersected with other datasets to generate new layers. For example, topographic layers can be used to generate slope and aspect maps, contours, hillshades, watersheds, drainage delineations, or viewshed layers (line-of-sight analysis). Datasets, when combined together, can generate almost unlimited combinations of new layers. For example, combining a slope map with a thermal inertia map can help generate a landing site hazard map.

2.7 Analyze

The stage of data analysis is always the most interesting and stimulating stage in a GIS project. GIS analysis lets the user ask: where, why, and how. Some general questions may look like: where are distinct features coincident, why do these structures exist at this latitude range, or how does this process affect another?

For some direct examples of GIS being used in planetary projects, please see some the papers listed here: Barlow et al., 2003; Dohm et al., 1999; Maurice et al., 2003; Roddy, D. J. et al., 1998; Tanaka et al., 2001; Shingarev et al., 2003; Skinner et al., 2003 .

III. CONCLUSION

The future will continue to see the emerging uses of GIS technologies and spatial analysis in planetary research. As technology filters across facilities and via on-line applications, the more efficient we will become as a community.

REFERENCES

Archinal, B. A., T. R. Colvin, M. E. Davies, R. L. Kirk, T. C. Duxbury, E. M. Lee, D. Cook, and A. R. Gitlin, 2002. A MOLA-controlled RAND-USGS control network for Mars. *Lunar Planet. Sci. XXXIII*, abstract 1632 (CD-ROM).

Barlow, N. G., C. W. Barnes, O. S. Barnouin-Jha, J. M. Boyce, C. R. Chapman, F. M. Costard, R. A. Craddock, J. B. Garvin, R. Greeley, T. M. Hare, R. O. Kuzmin, P. J. Mouginis-Mark, H. E. Newsom, S. E. H. Sakimoto, S. T. Stewart, and L. A. Soderblom, 2003. Utilizing GIS in Martian Impact Crater Studies, *International Society for Photogrammetry and Remote Sensing Working Group IV/9: Extraterrestrial Mapping Workshop*, "Advances in Planetary Mapping 2003". This volume.

Boyce, J. M., D. J. Roddy, L. A. Soderblom, and T. Hare, 2000. Global distribution of on-set diameters of rampart ejecta craters on Mars: Their implications to the history of martian water. *Lunar Planet. Sci. XXXI*, abstract 1167 (CD-ROM).

Brumby, S.P., C. S. Plesko, and E. Asphaug, 2003, Evolving Automated Feature Extraction Algorithms for Planetary Science, *International Society for Photogrammetry and Remote Sensing Working Group IV/9: Extraterrestrial Mapping Workshop*, "Advances in Planetary Mapping 2003". This volume.

Dohm, J. M. and K. L. Tanaka, 1999. Geology of the Thaumasia region, Mars: Plateau development, valley origins, and magmatic evolution, *Planet Space Sci*., 47, 411-431.

Gaddis, L., J. Anderson, K. Becker, T. Becker, D. Cook, K. Edwards, E. Eliason, T. Hare, H. Kieffer, E. M. Lee, J. Mathews, L. Soderblom, T. Sucharski, J. Torson, 1997, An Overview of the Integrated Software for Imaging Spectrometers (ISIS), *Lunar Planet. Sci. XXVII*, abstract 1226 (CD-ROM).

Garvin, J. B., S. E. H. Sakimoto, J. J. Frawley, and C. Schnetzler, 2000. North polar region craterforms on Mars: Geometric characteristics from the Mars Orbiter Laser Altimeter, *Icarus*, 144, 329-352.

Hare T. M., K.L., Tanaka, 2001, Planetary Interactive GIS-on-the-Web Analyzable Database – PIGWAD, *International Cartographic Conference, Beijing, China*, abstract (CD-Rom). website: http://webgis.wr.usgs.gov

Hare T. M., K.L., Tanaka, 2001, Digital Mapping, Planetary Mappers Meeting, abstract, website: http://webgis.wr.usgs.gov/publications.htm

Hare T. M., K.L., Tanaka, 2001, PIGWAD – OpenGIS and Image Technologies for Planetary Data Analysis. *Lunar Planet. Sci. XXXIII*, abstract 1365 (CD-Rom). website: http://webgis.wr.usgs.gov

Hare, T.M., J.M., Dohm, and K.L., Tanaka, 1998. GIS and its Application to Planetary Research. *Lunar Planet. Sci. XXVIII*, abstract 515 (CD-ROM). website: http://webgis.wr.usgs.gov

Kim, J. and J. Muller, 2003, Automated impact crater detection on images and DEMs, *International Society for Photogrammetry and Remote Sensing Working Group IV/9: Extraterrestrial Mapping Workshop*, "Advances in Planetary Mapping 2003". This volume.

Mark, M., N. Chrisman, A.U. Frank, P.H. McHaffie, J. Pickles, 1996, The GIS History Project. Website: http://www.geog.buffalo.edu/ncgia/gishist/bar_harbor.html

Maurice, S., C. Angleraud, L. d'Uston, F. Aumonier, S. Chevrel, Y. Daydou, and T. Levoir, 2003, A Virtual Observatory of Planetary Surfaces, *International Society for Photogrammetry and Remote Sensing Working Group IV/9: Extraterrestrial Mapping Workshop*, "Advances in Planetary Mapping 2003". This volume.

PASDA (Pennsylvania Spatial Data Access system), website: http://www.pasda.psu.edu/tutorials/gisbasics

Roddy, D. J., N. R. Isbell, C. L. Mardock, T. M. Hare, M. B. Wyatt, L. M. Soderblom, and J. M. Boyce, 1998. I. Martian impact craters, ejecta blankets, and related morphologic features: Computer digital inventory in Arc/Info and Arcview format. *Lunar Planet. Sci. XXIX*, abstract 1874 (CD-Rom).

Tanaka, K. L. and E. J. Kolb, 2001. Geologic history of the polar regions of Mars based on Mars Global Surveyor Data. I. Noachian and Hesperian Periods. *Icarus*, 154, 3-21.

K. B. Shingareva, K.B. and S. M. Leonenko, 2003, Specialized Planetary Cartography Data Base, *International Society for Photogrammetry and Remote Sensing Working Group IV/9: Extraterrestrial Mapping Workshop*, "Advances in Planetary Mapping 2003". This volume.

Seidelmann, P.K., Abalakin, V.K., Bursa, M., Davies, M.E., De Bergh, C., Lieske, J.H., Oberst, J., Simon, J.L., Standish, E.M., Stooke, P., and Thomas, P.C., 2002, *Report Of The IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets, and Satellites*: 2000, in Celestial Mechanics and Dynamical Astronomy, v. 82, p. 83-110.

Skinner, J.A., Jr. and K.L. Tanaka, 2003, How Should Planetary Map Units be Defined? *Lunar Planet. Sci. XXXIV*, In Press.

Webster, Avis L. and Lombard, Kristi. 1999. GIS Implementation: Measuring the Value of Lifelong GIS Learning. Available online from 1999 ESRI Conference proceedings on the ESRI website: http://gis.esri.com/library/userconf/proc99/proceed/papers/pap496/p496.htm

Wilcox, Darlene L. 2000. GIS Implementation. Available online from the GeoWorld website: http://www.geoplace.com/gw/2000/0200/0200wlcx.asp