Summary and Abstracts of the Planetary Data Workshop, June 2012

By Lisa R. Gaddis, Trent Hare, and Ross Beyer

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Conversion Factors

Multiply	By	To obtain
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)

Prefatory Note

Planetary Data: A Workshop for Users and Software Developers

A meeting for users and developers held at the DuBois Conference Center on the Campus of Northern Arizona University, Flagstaff Arizona, June 25 to 29, 2012

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NASA Planetary Data System (PDS)
PDS Imaging Node
PDS Geosciences Node
NASA Planetary Geology and Geophysics Program
NASA Regional Planetary Image Facility Network
U.S. Geological Survey Astrogeology Science Center, Flagstaff, Arizona

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Summary and Abstracts of the Planetary Data Workshop, June 2012

By Lisa R. Gaddis,[1] Trent Hare,[1] and Ross Beyer[2]

Introduction

The recent boom in the volume of digital data returned by international planetary science missions continues to both delight and confound users of those data. In just the past decade, the Planetary Data System (PDS), NASA's official archive of scientific results from U.S. planetary missions, has seen a nearly 50-fold increase in the amount of data and now serves nearly half a petabyte. In only a handful of years, this volume is expected to approach 1 petabyte (1,000 terabytes or 1 quadrillion bytes; fig. 1). Although data providers, archivists, users, and developers have done a creditable job of providing search functions, download capabilities, and analysis and visualization tools, the new wealth of data necessitates more frequent and extensive discussion among users and developers about their current capabilities and their needs for improved and new tools.

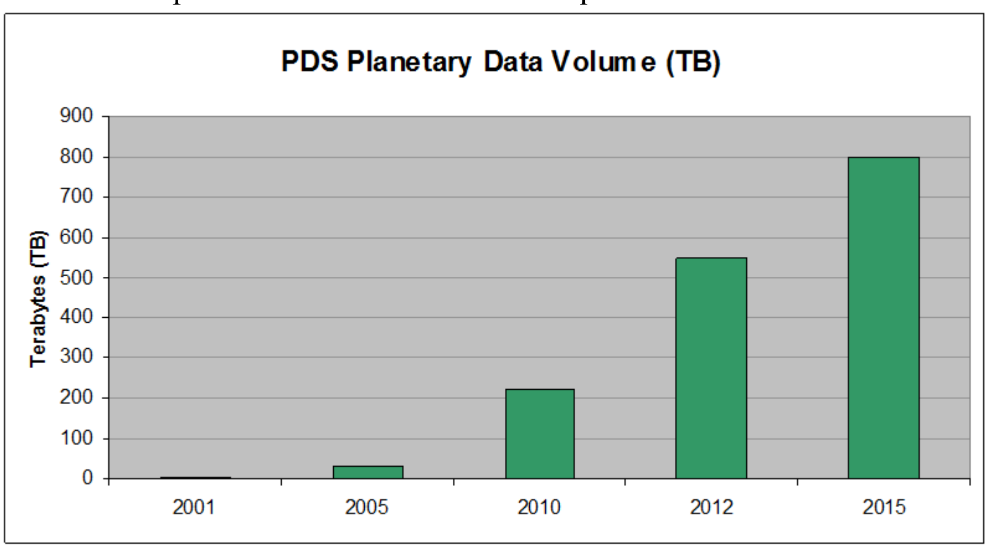

Figure 1. Approximate volume of data held by the NASA Planetary Data System (PDS) in the period from 2001 projected to 2015 (Gaddis and others, 2012).

A workshop to address these and other topics, "Planetary Data: A Workshop for Users and Planetary Software Developers," was held June 25–29, 2012, at Northern Arizona University (NAU) in Flagstaff, Arizona. A goal of the workshop was to present a summary of currently available tools, along

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with hands-on training and how-to guides, for acquiring, processing and working with a variety of digital planetary data. The meeting emphasized presentations by data users and mission providers during days 1 and 2, and developers had the floor on days 4 and 5 using an “unconference” format for day 5 (fig. 2). Day 3 featured keynote talks by Laurence Soderblom (U.S. Geological Survey, USGS) and Dan Crichton (Jet Propulsion Laboratory, JPL) followed by a panel discussion, and then research and technical discussions about tools and capabilities under recent or current development. Software and tool demonstrations were held in break-out sessions in parallel with the oral session. Nearly 150 data users and developers from across the globe attended, and 22 National Aeronautics and Space Administration (NASA) and non-NASA data providers and missions were represented. Presentations (some in video format) and tutorials are posted on the meeting site (http://astrogeology.usgs.gov/groups/Planetary-Data-Workshop).

Planetary Data Workshop: Meeting Overview

duBois Conference Center, NAU

Start Time	*Duration*	
Monday, June 25, 2012		
8:30	0:15	Welcome, Logistics, Opening Remarks
8:45	1:30	Opening Plenary Presentations
10:30	2:00	Theme: PDS4, Tools & Datasets
13:45	1:30	Theme: Tools & Datasets, Mission Examples
16:00	1:00	**Data/Tools Poster Session**
Tuesday, June 26, 2012		
8:45	1:30	Theme: Tools & Datasets, Mission Examples
10:30	2:00	Theme: Outer Planets and Surface Tools
13:45	1:30	Theme: Tools & Datasets, Mission Examples
15:30	1:30	Theme: Web Service Tools
Wednesday, June 27, 2012		
8:45	1:30	Keynote Presentations
10:30	2:00	Panel Discussion
13:45	1:30	Discussion Talks (15-min talks with 15-min discussion)
15:30	1:00	Discussion Talks (15-min talks with 15-min discussion)
16:30	1:00	Define Presentations for Friday (Unconference Day)
Thursday, June 28, 2012		
8:45	1:30	Developer Talks
10:30	2:00	Developer Talks
13:45	2:30	Developer Talks
16:00	1:00	**Developer Poster Session**
Friday, June 29, 2012		
8:45	1:30	Developer Talks
10:30	2:00	Developer Talks
13:45	2:30	Developer Talks
16:30	END	Adjourn, Safe Travels!

Figure 2. Overview of the agenda for the Planetary Data Workshop.

Summary

To facilitate planetary research, a wide variety of techniques are used across the planetary science and related communities to solve issues related to data access, calibration, cartographic processing, cross-correlation, and the creation of derived, typically more usable, scientific products. Such products can help scientists to portray characteristics such as surface or feature morphology, topography, and unit distribution and composition but tend to be even more valuable by bringing the observations into a common spatial and visualization system. Topics for the Planetary Data Workshop ranged from discussions of digital in-situ and orbital data integration, data processing methods, software development, data interoperability, visualization and analysis of multilayer data, cloud-based data storage, high-speed and high-volume cluster processing, cartographic and photogrammetric data processing, analysis procedures, and more. Examples of presentations given at the workshop include a summary of basic data search and retrieval tools from NASA research and archival programs and current planetary missions. Several tools for locating and downloading data were described and demonstrated, including the NASA Planetary Data System’s Planetary Image Atlas, the Orbital Data Explorers, Analysts Notebook, and Planetary Image Locator Tool (PILOT), Lunar Mapping and Modeling Project (LMMP) and Arizona State University’s Java Mission-planning and Analysis for Remote Sensing (JMARS), and non-NASA and commercial products such as Google’s Moon and Mars in Google Earth, Exelis’ ENVI, and Esri’s ArcGIS. Summaries of several data processing and visualization tools were presented also, and hands-on training was available for many of these tools (for example, the USGS Astrogeology’s Integrated Software for Imagers and Spectrometers (ISIS), JMARS, Moon/Mars in Google Earth, and NASA Ames Stereo Pipeline). Representatives of the PDS provided an introduction to the next-generation archive system called PDS4, and examples of how the system is being used for several currently developing NASA missions were presented. Several space missions summarized status and plans for their data archives, delivery services and products, and ancillary tools and facilities, such as the NASA Regional Planetary Image Facilities, were discussed. A poster session on the first night of the meeting provided an opportunity for one-on-one discussions on many of these tools and topics.

The early data users’ discussion was capped by keynote presentations by Dr. Laurence Soderblom (USGS, “Geometry: The ‘Drive Train’ of Planetary Data Analysis”) and Dan Crichton (JPL, “Cloud Computing and Big Data Challenges for Planetary Science”). Soderblom described the outcome of the first planetary data workshop (held in 1983 at NASA Goddard Spaceflight Center, chaired by Dr. Hugh Kieffer of USGS), discussed the disturbing findings of almost 30 years ago regarding the disorganized and unfortunate state of planetary data archiving, the creation of the NASA Planetary Data System in response, and a quick report card summarizing how far we’ve come in addressing many of the initial problems. Soderblom ended by noting several problem areas that need to be addressed now to improve the data user experience with finding and using planetary data. These are gathered with the workshop Outcomes and Observations for the Future listed below.

Crichton discussed the challenges posed by “big data” in the current and near-future environment, and he outlined the difficulties of storing, moving, and distributing big data. He also addressed the complexity and heterogeneities of not only the data themselves but how to serve the wide diversity of uses to which the data are often subjected. Crichton noted that PDS is addressing many of these issues with the PDS4 system architecture, with the result being a scalable system that is flexible and can respond to changes in user capabilities, current technologies, and user needs. Cloud computing and storage of planetary data are being investigated by NASA engineers, and current low-risk options include its use as an operational, secondary copy of digital data and a data access point. For example, the NASA Mars Exploration Rovers mission is effectively managing their datasets through use of

cloud-computing and data-storage mechanisms. Improvements in computation efficiency and speed using planetary data are also moving forward, and tools such as Hadoop Elastic Map-Reduce and hybrid solutions are being used to deliver data safely to users across the Internet. Efficiencies are also being sought in the online transfer of data, including use of parallel transfers and packaging-and-bundling of small files. Crichton's observations are also folded into Outcomes and Observations for the Future below.

A panel discussion followed in which panelists responded to comments, questions and suggestions from the audience. The audience was divided into several groups and given 20 minutes to discuss and compile a short list of their most pressing questions and concerns following the data users' and plenary presentations. Panelists included Dan Crichton (JPL), Lisa Gaddis (USGS), Dave Heather (European Space Agency, ESA), Randy Kirk (USGS), Mark Showalter (SETI), and Larry Soderblom (USGS). Topics were wide-ranging, with responses provided on the overlap between PDS and mission data delivery services, difficulty using existing search tools to find features on planetary bodies (for example, all long lava flows in the Solar System), a lack of extensive and cross-correlated metadata for archived products, plans for developing new tools or sharing existing ones outside mission teams, and current use of the "cloud" for big data storage by NASA centers. The common theme was that although data archiving, delivery, and search capabilities have undergone significant improvements in the past two decades, data users require more community support, including more communication between users, providers, and developers.

A major goal of the workshop was to bring researchers and technology experts together to discuss and exchange ideas to identify difficult planetary research issues that can be addressed with improved software. The developer presentations that followed were rigorously scheduled on Wednesday afternoon (day 3 of the weeklong workshop) and Thursday (day 4). On Friday (day 5) an "unconference" format was adopted in which presentations were suggested to promote discussion on "hot topics" based on earlier presentations. Topics in the developer sessions were also wide-ranging and included updates on existing software and tools, such as Geospatial Data Abstraction Library (GDAL), Python scientific libraries, MATLAB, and JMARS, that are used for planetary science applications. New software systems and methods were also presented and discussed, including tools for map-projecting image products, creating three-dimensional (3D) terrain maps, automated pattern recognition and panchromatic and multispectral image analysis, photogrammetric bundle adjustment, photometric corrections, and others. The unconference, held on Friday, evolved into much more of a round-table discussion or open forum for the remaining workshop participants. The group-defined topics, as determined on the previous day, were presented in a free-flowing, discussion-oriented manner, which allowed the entire group to actively engage across a range of topics. Many of the unconference discussions were excited—sometimes even very excited—underscoring the elevated level of interest and concern for topics under discussion.

Outcomes and Observations for the Future

All in all, the meeting was successful and was very well attended by both U.S. and international participants. Interest was high in the topics covered, and a wide variety of thoughts and opinions were brought forward. Here we summarize several common themes expressed by the meeting participants.

1. Progress on data archiving and delivery has been strongly positive since the last planetary data workshop in 1983,before the creation of the NASA Planetary Data System. Mission data archives are better documented, safer, more easily accessed than ever before.

2. There are a wide variety of tools available to deliver data to planetary scientists. No one tool is adequate to serve all users, and many tools are complex and require significant knowledge of the data to properly use. Better coordination among data providers, mission teams, and users is needed to clarify how capabilities can be improved, simplified, and streamlined for planetary data users.
3. Searching for planetary data is limited in part because of the lack of availability of extensive and high-level metadata. Generation of such metadata should be a priority of data providers, archivists and tool developers.
4. In part because of the complexity of planetary data, more training for users is needed to help them identify and use the data they need for research and analysis. This is especially true as PDS transitions to the new PDS4 archive structure, but also derives from a more general need to identify specific products from the large volumes of data now available.
5. Development and delivery of high-level, usable products (which may involve extensive processing and derivation from original mission data products) should be a high priority for missions, data providers and data archives.
6. Locating data of interest is of paramount importance to users. This is greatly facilitated if a unified or standardized planetary coordinate system is used for each planetary body. Often significant additional cost for using data is avoided if standardized coordinate systems and unified mapping parameters are used. To ensure the most cost-effective use of planetary data, the collaboration by the International Astronomical Union (IAU), PDS, and NASA that jointly shares the essential expertise and authority for recommending and upholding cartographic requirements must establish unified and clearly defined standards for planetary coordinates, publicize them widely and require their adoption by all NASA mission investigators.
7. Development of derived data products is also greatly facilitated by the standardization of sensor models for ingesting and processing planetary data. Currently, building sensor or camera models can be an expensive, time-intensive task because of the diversity of camera design and the frequent lack of documentation on instrument characteristics used for acquiring planetary data. The common use of NASA and PDS standards to describe and deliver sensor data would greatly simplify the development of camera models.
8. “Big Data” pose challenges end-to-end for NASA and its data users and developers. Cloud and Big Data technologies offer a great deal of support for these uses, but they must be tested and then applied appropriately to avoid problems with cost and ownership of data stored by commercial cloud vendors.
9. The development and deployment of PDS4 allows PDS and NASA to leverage Big Data technologies for storage, computation and data transfer, including several low-risk options and a general avoidance of proprietary approaches.
10. Many planetary data providers and users are engrossed in the challenges posed by the need to store and effectively deliver Big Data. Although the community is exploring (and in some cases taking advantage of) new services and technologies such as cloud storage and efficient data formats and data transfers, this process will be simpler and more cost-effective if we make sharing community knowledge and experiences a priority.
11. Software developers acknowledged that there are many facilities addressing and solving similar problems in data access, delivery services, and analysis methods. Using existing libraries and standards and sharing source code when possible would help to alleviate much of the overlap.

12. The use of best practices for software development and testing was also recommended so that software can be used more effectively on rapidly evolving hardware, including multithreaded machines, cluster- and cloud-based environments, and use of code sharing across many programming languages.

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List of Abstracts

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List of Presentations or Posters Only (No Abstract)

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An Update on SPICE

NAIF: Ideas for Extending or Improving SPICE

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LOLA primary topographic datasets, special products, and LRO combined data product

Beyer, R.

Non-NASA Supported Data and Tools

Costello, D.

Data Collection, Data and Information Storage Assists for New Scientific Method

Crichton, D.

PDS4: Developing the next generation Planetary Data System

Cloud Computing and the Big Data Challenges for Planetary Science

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Metadata Preserving Image File Format Conversion

Estes, N.

Lunaserv Web Map Service: History, Implementation Details, and Development

Gaddis, L.

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Kirk, R.

High-Level “Science-Ready” Products

Hare, T.

GDAL Updates and TB Virtual Mosaics

Heyd, R.

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Lunar Mapping and Modeling Project Infrastructure

Malaret, E.
Messenger Update, Quick-Map

McArthur, G.
HiWISH: HiRISE Online Target Submission Web Application

Mitchell, K.
Automated Stereogrammetry of Magellan SAR

Moratto, Z.
Continuous Software Integration

Patterson, W., B. Bussey, J. Cahill, C. Neish, and the Mini-RF Team
Mini-RF Update

Roatsch, T. and the DLR Experiment Team
HRSC Update

Sides, S., and the ISIS Team
What's New for ISIS 3

Soderblom, L.
Geometry: The Drive Train of Planetary Data Analysis

Williams, J.-P., D.A. Paige, and B.T. Greenhagen
Diviner Update

List of Demonstrations (On-Site Only)

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NAIF's WebGeocalc tool

Becker, T., J. Anderson, and L. Soderblom
Using ISIS for Processing Cassini Data

Bennett, K.
PDS Geoscience Node's Orbital Data Explorer

Blue, J.
Planetary Nomenclature Q&A

Castalia, B.
    HiView

Dickenshied, S.
    JMARS

Gordon, M.
    PDS Rings Node OPUS

Gorius, N.
    Systematic generation of spectral images from Cassini/CIRS data

Law, E.
    Lunar Mapping and Modeling Project (LMMP) Q&A

Moratto, Z.
    Ames Stereo Pipeline Tutorial

Pasek, V., D. Lytle, R. Watson, D. Moynihan, and R. Brown
    Data constraints for VIMS hyperspectral data mining

Sides, S., and S. Lambright
    ISIS Installation Help
    ISIS Tools: Qnet, jigsaw, blunder detection, qtie, qview, qmos

Stein, T.
    PDS Analyst's Notebook

Abstracts

Implementing the Map Projection Web Service Project (POW) for ISIS3. S.W. Akins, U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ, 86001. (sakins@usgs.gov)

Introduction: We will develop a Web tool that transforms a raw Planetary Data System (PDS) image to a map-projected image. This will be accomplished by providing a Web front-end to the Integrated Software for Imagers and Spectrometers (ISIS). The front-end will submit user jobs to a back-end computer cluster running ISIS.

Many users simply want to map-project images and then import them into other analysis tools (for example, ArcMAP, IDL, ENVI, and JMARS). The projected images, coupled with additional geometric images that can be produced in ISIS, such as phase, incidence, and emission backplanes, allow planetary researchers to perform a wide variety of analyses. However, one disadvantage of ISIS is that it is user intensive. That is, (1) it must be installed on a UNIX platform (for example, Linux or Mac OSX), (2) the user must be familiar with the UNIX operating system commands, and (3) the user must learn how to run ISIS commands and evaluate the results.

The Map Projection Web Service (POW) will eliminate much of this overhead by providing a Web-based tool for map- projecting images. Through a Web front end, a user will be able to (1) submit a list of PDS Engineering Data Records (EDRs), (2) select the desired output map projection (for example, Polar Stereographic, Sinusoidal) for individual images, (3) choose an instrument-specific suite of noise removal and radiometric calibration algorithms, (4) pick a set of geometric backplanes to be computed, and (5) select a geospatial output image format such as GeoTiff or JPEG2000.

Presentation: Here we will present how POW was built to:

- Connect to the image catalogs available from the PDS Unified Planetary Coordinates (UPC).
- Process planetary images on the Astrogeology clusters using Moab/Torque/ISIS3/GDAL Use XML to provide generic processing solutions.

Comparing Patch Orthorectification Algorithms in ISIS Based on Camera Type. J.A. Anderson, U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ. (janderson@usgs.gov)

Introduction: The creation of accurately orthorectified planetary images (orthoimages) is crucial for a wide variety of geospatial activities including cartography, change detection, landing site analysis, geologic mapping, rover traverse planning, and spectral analysis. Orthorectification, or projecting an image onto the three-dimensional (3D) shape of the target body, can be computationally time consuming [1]. Various patch orthorectification algorithms have been developed to improve the computational speed. We will compare processing speeds using a reverse patch orthorectification algorithm and a hybrid forward-reverse patch orthorectification algorithm [2]. Three different types of instruments, a framing camera, a pushbroom camera, and a pushframe camera, will be tested with each algorithm.

Background: The U.S. Geological Survey Integrated Software for Imagers and Spectrometers (ISIS) supports nearly 50 instruments from the older Apollo Metric, Viking, and Voyager cameras to the more modern instrument suites on Lunar and Mars Reconnaissance Orbiters. The support in ISIS for instruments includes rigorous physical camera models in conjunction with spacecraft orientation and positions (SPICE) from the JPL Navigation and Ancillary Information Facility (NAIF) [3, 4]. Both ISIS and SPICE provide the basis for examining the orthorectification speed variance among camera types for this study.

The process for creating an orthoimage (fig. 1) requires a camera model and map projection equation (for example, polar stereographic). In the forward direction, the camera model is given an image coordinate (sample, line) from the raw observation (fig. 2) and the model computes a ground coordinate (latitude, longitude, radius) on a digital terrain model (DTM). The ground coordinate is then given to the map projection equation, which computes an orthoimage coordinate. The entire process can be reversed starting with an orthoimage coordinate and working backwards through the projection equation and camera model to compute a raw observation coordinate. Often, the backward process is preferred as it allows for pixel interpolation using bilinear or cubic convolution resampling.

The computational challenges in orthorectification can be seen by the need to apply the reverse projection equations and camera model at each orthoimage pixel coordinate. For instruments such as the High Resolution Imaging and Science Experiment (HiRISE), which collects 20,000 sample by 50,000 line observations, the orthorectification on a pixel-by-pixel basis would take nearly a day in ISIS.

Patch-based rubber sheeting algorithms have been available in ISIS and it's precursors since the 1980's. The orthoimage is broken into $N \times N$ patches, and the camera model and projection equations are used on the corners of the patch. Those four sets of input/output coordinates are used to compute affine transforms from orthoimage coordinates to raw observation coordinates. The speed of the algorithm increases as N grows because fewer camera model and projection computations are required; however, as N becomes too large, the error in pixel placement for the orthorectification can increase.

Historically, ISIS has always used a reverse-patch orthorectification process. In May 2012, a hybrid forward-reverse patch algorithm was added to ISIS.

In this algorithm, the raw observation image is broken into $N \times N$ patches and the forward camera model and projection equations are used to compute the output orthoimage coordinates given the four raw image coordinates. Affine transforms are still computed from orthoimage coordinates to raw observation coordinates; hence the hybrid forward reverse patch algorithm still allows for bilinear or cubic convolution resampling.

In either algorithm, each patch is checked for its error. If the error is significant, the patch is broken into four equal-sized smaller patches, essentially a quad-tree error-handling mechanism, and new affine transforms are computed for each of the smaller patches. The subdividing process is repeated until the error condition is satisfied or until the patch size is two by two. The criteria for subdivision are applied when the coordinates at the center of the patch, using the affine transform, are in error by more than 0.1 pixels when compared to the coordinate computed using the camera model and map projection equations.

Analysis: A series of timed orthorectifications were run on the different camera types: the Dawn Framing Camera, Mars Global Surveyor (MGS) Wide Angle Camera (pushbroom), and Lunar Reconnaissance Orbiter (LRO) Wide Angle Camera (WAC)(pushframe). For the framing camera and pushbroom cameras, five orthorectification tests were run: (1) reverse pixel-by-pixel, (2 and 3) reverse patch with N=16 and N=4, and (4 and 5) hybrid forward-reverse patch with N=16 and N=4 (table 1).

Table 1	Framing	Pushbroom
Image size (SxL)	1024 x 1024	640x768
Pixel-by-Pixel	32 sec	731 sec
Reverse N=4	18 sec	451 sec
Reverse N=16	10 sec	48 sec
Hybrid N=4	360 sec	24 sec
Hybrid N=16	468 sec	15 sec

At first glance, the disparity between the two orthorectification algorithms was quite surprising. The Dawn Framing Camera image was an observation of the asteroid Vesta including the limb. The forward camera model, used in the hybrid algorithm, for intersecting the DTM is iterative and slows significantly for pixels near the limb. Conversely, the reverse algorithm for framing cameras is a direct computation; hence the faster execution times.

For the MGS pushbroom camera, the forward algorithm must still intersect the DTM using an iterative algorithm; however, the reverse pushbroom camera model is iterative and much slower when determining the correct time (spacecraft position and orientation) that a ground coordinate was observed.

The LRO WAC pushframe camera poses a different challenge. A pushframe operates much like a pushbroom but collects many lines instead of one. The LROC WAC collects 14 lines, and the patch size is therefore limited to that size or smaller.

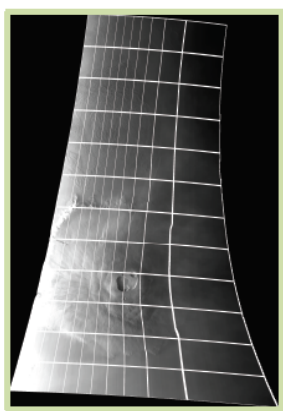
For a pushframe camera, we again see the hybrid algorithm to be faster because the iterative method to determine the time a ground coordinate was observed is slower than the forward DTM intersection algorithm (table 2).

Table 2	Pushframe
Image size (SxL)	704 x 3640
Pixel-by-Pixel	705 sec
Reverse N=14	358 sec
Hybrid N=14	11 sec

In all cases, a simple ratio between the truth image (that is, reverse pixel-by-pixel) and the two patch orthorectifications using different patch sizes was computed. Visual analysis of the ratio image showed little or no difference between truth and patch algorithms when *N*=4 with the exception of the hybrid algorithm at the extreme limb of Vesta. There was apparent visual differences when *N*=16 for both algorithms.

Conclusions: Computationally, pushbroom and pushframe cameras are well suited to the hybrid orthorectification algorithm, whereas the reverse orthorectification algorithm works better for framing cameras. Visually, smaller patch sizes produce better orthorectification, but results will need to be quantified in future analysis. The study of radar images and pushbroom observations of limb images are warranted, as well looking into improvements of the ISIS raster DTM intersection algorithm.

Finally, the analysis of pixel resolution of the DTM versus the observation image and how that impacts patch size should be investigated. Course resolution DTMs, such as those created by the Mars Orbiter Laser Altimeter (MOLA), when used in conjunction with HiRISE-scale images, may allow for larger patch sizes and hence faster run times.



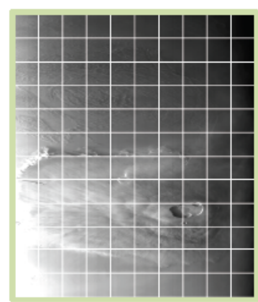


Figure 1: Left orthoimage
Figure 2: Above raw observation with grid lines representing 64x64 patches used in hybrid algorithm

Acknowledgments: The author wishes to acknowledge Frank Scholten (German Aerospace Center), developer of the hybrid orthorectification algorithm, for explaining his algorithm and Mark Robinson (Arizona State University) for supporting the hybrid algorithm development in ISIS.

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JMARS: Java Mission Planning & Analysis for Remote Sensing. S. Anwar[1], S. L. Dickenshied[1], D. D. Noss[1] and P. Christensen[1], [1]Mars Space Flight Facility, 201 E Orange Mall, Arizona State University, Tempe, AZ 85287 USA.

Introduction: JMARS (http://jmars.asu.edu) is a widely used mission planning and planetary-GIS software. Three active missions use it for targeting observations and thousands of users use it to view & analyze data from various missions.

JMARS was originally developed as a mission planning software for the THEMIS instrument aboard the Mars Odyssey Spacecraft. In order to properly target observations the mission planners needed contextual information such as topography, composition and prior coverage. THEMIS team members submitted their regions of interest (ROIs) along with their imaging parameters directly in JMARS. These parameters were taken into consideration while laying down observations.

Rendering of downlinked observation was added to JMARS as a visual verification method of data delivery as well as to gauge positioning errors between the planned vs. acquired observations. These features made JMARS the logical tool for participating scientists to do reconnaissance and basic analysis.

JMARS was formally released to the general public at the 34th LPSC in 2003 [2] with the aim to make it easy to disseminate Mars data to Mars enthusiasts and citizen scientists. One of the major success stories in this regard has been the Mars Student Imaging Project (MSIP), which allowed students to acquire observations and do basic analysis with them.

JMARS is a thriving product available for Mars, Moon, the Earth and a growing list of other planetary bodies.

In this presentation, we'll introduce JMARS, its basic architecture, the projection system it uses and how data is ingested and delivered through it.

At its core, JMARS is a multi-threaded client-server application written in Java. It allows data fusion across missions and datasets for research and analysis.

JMARS presents its data to the users in Oblique Cylindrical Projection. This allows the user to pick the point of least distortion anywhere on the map.

JMARS is backed by Web Servers, Web Map Servers (WMS Servers), Stamp Servers, Databases, Cluster Computers and a host of other support services. The back-end services are implemented in a variety of different languages and technologies. These services have a heavy reliance on Open Source technologies and tools, e.g. Postgres, PostGIS, GDAL and ISIS.

The WMS Servers and Stamp Servers perform the heavy lifting of slicing and dicing of data that can be presented to the users in a reasonable time.

New data from Planetary Data Systems (PDS), United States Geological Survey (USGS) and other sources is constantly integrated into the JMARS back-end. Availability of this data within days of its release is one of the major benefits of using JMARS. It relieves the scientist of the headache of dealing with disparate product types and delivery mechanisms, enabling them to focus on their research. It is the ability of JMARS to present disparate data in a uniform fashion that has most of our users use it as their primary reconnaissance tool for research.

A major design principle in this regard is to present JMARS users with the numeric data along with prettified graphical data. Thus, users can profile a transect across multiple datasets.

Work is in progress to produce publishing quality results right out of JMARS without requiring additional manipulation.

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Acknowledgments:

JMARS is partially supported by funding from the Mars Odyssey project and the Mars Program office.

The PDS Planetary Image Locator Tool (PILOT). M.S. Bailen; U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ (mbailen@usgs.gov).

Introduction: The Planetary Image Locator Tool (PILOT) is a Web-based interface (http://pilot.wr.usgs.gov) that provides a robust search interface for several Planetary Data System (PDS) image catalogs available from the Unified Planetary Coordinates (UPC) database [1]. The PILOT interface complements other PDS data search tools (for example, PDS Imaging Node's Planetary Image Atlas, http://pds-imaging.jpl.nasa.gov/search; PDS Geosciences Node's Orbital Data Explorer, http://ode.rsl.wustl.edu/) and takes advantage of recent PDS developments. PILOT includes (1) use of improved spatial and catalogued information for each image as derived by the UPC, (2) access to data from a powerful Geographic Information Systems (GIS) database, and (3) easy, quick access through a customized web portal and mapping interface.

Background: An enormous amount of digital image data has been collected recently for Mars, the Moon, and other planetary bodies [for example, 2, 3]. Historic photographic data such as those from Lunar Orbiter and Apollo are being digitally restored [4–6]. Ongoing missions deliver a constant flow of new data. And future planetary surveys promise to exponentially increase the amount of image holdings. In many cases, these data exist in a wide range of disparate coordinate systems, making it difficult for the scientific and mapping communities to correlate, combine, and compare data from different missions and instruments. The Unified Planetary Coordinates (UPC) database of the PDS Imaging Node was created to address these discrepancies [1, 7, 8].

The UPC is a database containing improved geometric and positional information about planetary image data, computed using a uniform coordinate system and projected onto the most current coordinate system [9]. Positional and instrument 'metadata' are extracted from PDS image labels and used to calculate detailed geometric data for a given image. The database is populated with up-to-date spacecraft pointing information (for example, SPICE kernels) that provides improved pointing for image corners, edges, and nearly every pixel in the image. The UPC also benefits from image positional refinements resulting from cartographic processing and map development at the U.S. Geological Survey (USGS). The USGS Integrated Software for Imagers and Spectrometers (ISIS [for example, 10, 11]) system is the primary tool for computing, maintaining, and continually improving the UPC database. An ISIS camera model [12] for a given imaging instrument is required for ingestion of image data into the UPC.

PILOT Improvements: The PILOT Web interface has been enhanced to reveal the percentage of images that successfully generated a footprint geometry. By indicating these amounts, the user will not only be aware of the completeness of the dataset, but also be given the opportunity to examine images that produced errors. In addition, a new search feature has been added which allows users to search through images based on bands. This feature is beneficial for science and cartography projects that rely on specific wavelengths for an instrument. Finally, a new interface has been developed to enable a more intuitive initial view of the data by providing access via both missions and targets.

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Mapping Mars in Detail: Contributions from Pattern Recognition and Image Analysis.
L. Bandeira[1], P. Pina[1], J. Saraiva[1], J.S. Marques[2], N. Benavente[1], M. Lousada[1], D.A. Vaz[1,3] and T. Statella[4], [1]CERENA/IST (Av. Rovisco Pais, 1049-001 Lisboa, Portugal; lpcbandeira@ist.utl.pt), [2]ISR/IST (Av. Rovisco Pais, 1049-001 Lisboa, Portugal), [3]CGUC (OAC, Almas de Freire, 3040-004 Coimbra, Portugal), [4]IFMT (95 Zulmira Canavarro 780025-200, Cuiabá, Brazil).

Introduction: Due to the huge and increasing amount of imagery collected with very high resolution on Mars, the need for automated tools capable of detecting ubiquitous geomorphological structures for mapping and characterizing its surface at large scale and in detail is clearly felt. Pattern Recognition and Image Analysis techniques provide a large set of tools for accomplishing these goals on planetary images, generating robust automatic methods that can identify and characterize some of the most common Martian structures (impact craters, sand dunes and ripples, polygonal terrains and dust devil tracks) and also analyze soil characteristics from images captured in-situ. This abstract presents a synthesis of the work originated at IST, Portugal, also developed with other colleagues, on the use of automated detecton methods applied to Mars features (craters, dunes and ripples, polygons, dust devil tracks and soils).

Impact Craters: Detection of craters is one of the most studied subjects in the application of automated methods to the analysis of planetary surfaces, since these features exist in all terrestrial planets in a wide dimensional range. Their densities, distribution patterns and morphologies can provide valuable data on the age and evolution of a landscape. Since the first publication on this matter by this team in 2004 [1], two crater detection algorithms were developed: one designed for medium-size craters based on the analysis of a similarity volume built from Template Matching techniques [2]; and another for small-size craters based on Boosting classification [3-4]. Both achieve high detection rates (> 80%) and are being used in catalogue production [5-6].

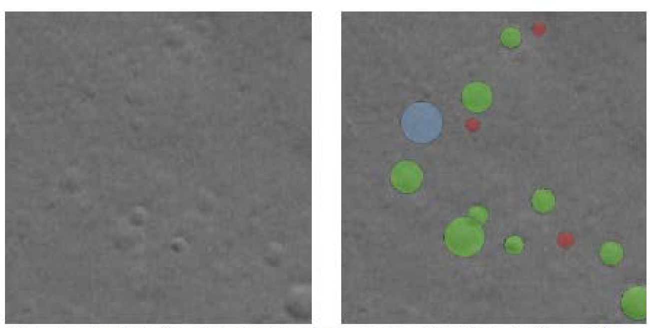

Fig. 1. Automatic crater detection on the Martian surface with a HRSC/Mars Express image (green denotes true positives; red, false negatives, and blue, false positives).

Dune Fields: The surfaces of all planetary objects with atmospheres show the presence of Aeolian features, whose characteristics, though varied, can be related to a number of parameters of interest in all cases (dimensions, wind intensity and prevailing directions, and others). Our team started working on this subject in 2010 and has since developed two pioneer methodologies for automatic dune field detection based on Learning strategies (single-scale [7-8] and multi-scale [9] approaches), with high detection rates (~90%).

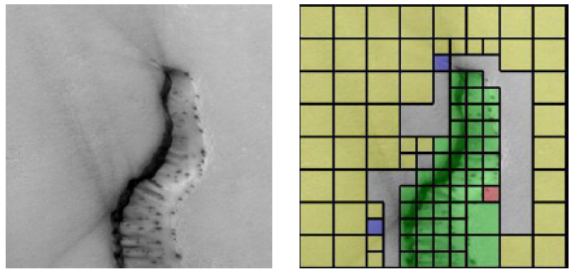

Fig. 2. Automatic dune field detection on the Martian surface with a MOC/MGS narrow angle image (green denotes true positives; yellow, true negatives; red, false negatives, and blue, false positives).

Ripples: These small scale sand features, clearly perceived on HiRISE images, are very adequate for analyzing the actions of current active Aeolian processes on Mars. An algorithm mainly based on directional morphological operations and hysteresis thresholding is able to generate a ripple marker matrix (the center of the illuminated side of the ripples), with a very good detection success [10].

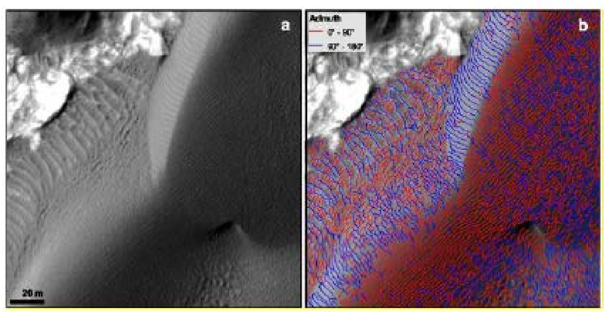

Fig. 3. Automatic ripple detection on Mars (Gale crater) with a HIRISE/MRO image, together with azimuth segmentation.

Polygonal Terrains: Under this heading a number of diverse features of this type of patterned ground of different origin can be gathered. In fact, those that raise more interest and have been most studied are related to the presence of ice in the ground, and thus limited to Earth and Mars. We have created a segmentation algorithm [8-9], based on the dynamics of watershed lines, that reveals the contours of Martian polygonal net-works (average detection rate of ~90%), allowing their geometric and topological characterization in a systematic and objective way [10, 11].

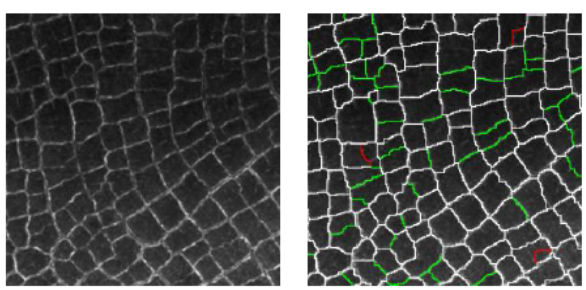

Fig. 4. Automatic detection of troughs of polygonal networks on the Martian surface with a MOC/MGS N/A image (white denotes true positives; green, false negatives and red, false positives).

Dust Devil Tracks: The direction of dust devils tracks can be used to get information on wind circulation. This can be done with success at large scale in very high resolution imagery of Mars by the image analysis method developed [15], mainly based on path closing operators from mathematical morphology, achieving an average detection rate above 90%. The method performs equally well on MOC and HiRISE images.

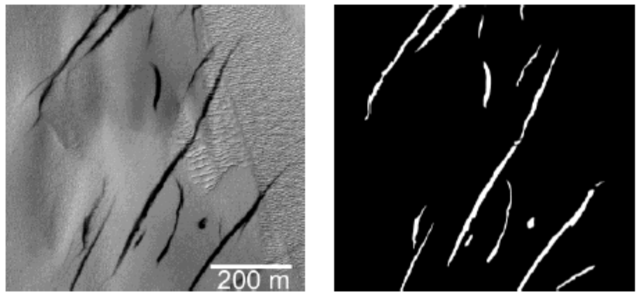

Fig. 5. Automatic dust devils tracks detection on a HiRISE/MRO image.

Grain size computation: The computation of full granulometric curves of the loose particles perceived on the images captured at the surface by the MI of the rovers Opportunity and Spirit was also achieved. A method based on morphological openings of increasing size, that simulates the sieving technique, was developed and directly applied to grey-level images with robust results [16].

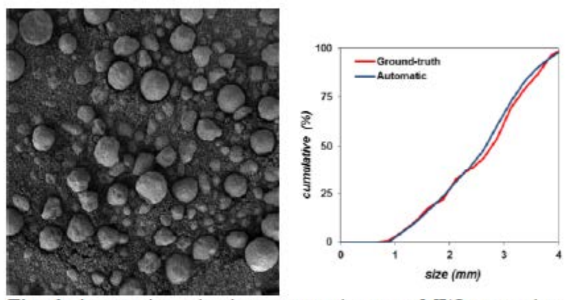

Fig. 6. Automatic grain size computation on a MI/Opportunity image.

Conclusions: All these automated approaches are being tested on a large diversity of conditions (different sensors and resolutions; different terrain ages; different illumination and acquisition periods of the Martian year) to intensively test their robustness. Globally, we are achieving very good performances with high true detections and low errors (false and misdetections), permitting each developed method to be used for glob-al mapping tasks. Yet, a number of improvements are still in progress, namely, to enlarge the training datasets with unknown patterns (especially important for the learning based strategies) or to fine tune the parameters of some algorithms.

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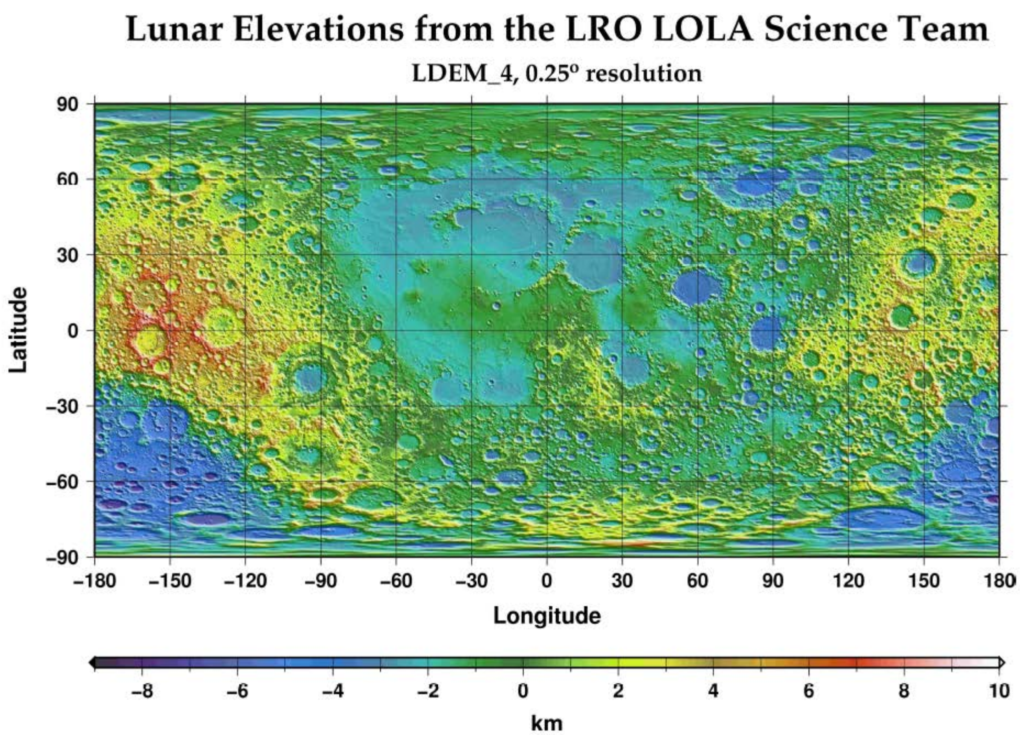
LOLA primary topographic datasets, special products, and LRO combined data products. M. K. Barker[1], G. A. Neumann[2], and the entire LOLA Science Team. [1]Sigma Space Corporation (michael.barker@sigmaspace.com), [2]NASA Goddard Space Flight Center (gregory.a.neumann@nasa.gov).

Introduction: The Lunar Orbiter Laser Altimeter (LOLA) aboard the Lunar Reconnaissance Orbiter (LRO) has been collecting topographic data for the Moon's surface since LRO entered lunar orbit in June 2009. In total, LOLA has collected over 5 billion measurements of surface height with a high vertical precision of ~10 cm, accuracy of ~1 m, and density of ~57 m (along-track spacing). This dataset is the current topographic reference for the Moon and is, thus, a key resource for the planetary sciences community. The primary LOLA objectives are 1) to produce a high resolution global topographic model and global geodetic framework that enables precise targeting, safe landing, and safe mobility on the Moon's surface, 2) to characterize the polar illumination environment at relevant temporal scales, and image permanently shadowed regions of the Moon on landform scales to identify possible locations of surface ice crystals in shadowed polar craters, 3) to identify the locations of appreciable surface water ice in the permanently shadowed regions of the Moon's polar cold traps, and 4) to assess meter- and sub-meter-scale features to facilitate safety analysis of potential future lunar landing sites. LOLA has two secondary objectives: 1) to establish a global geodetic reference system for the Moon and 2) to improve the model of the lunar gravity field to facilitate precision navigation and landing.

To achieve its objectives, LOLA operates a 1064 nm laser firing at a rate of 28 Hz that makes a five spot pattern on the Moon's surface. A telescope on the instrument receives the reflected signal, whose energy and arrival time are measured by the on-board electronics. The Moon’s surface height is derived from the timing of the outgoing and return pulses together with accurate knowledge of the LRO orbit from S-band tracking and one-way laser ranging to LRO from Earth-based ground stations. Cross-over analysis of LOLA ground-tracks performed by the LOLA Science Operations Center (SOC) at Goddard Space Flight Center further improves geodetic control by minimizing discrepancies between closely-spaced tracks. The 5 spot, 50-m wide laser footprint allows along-track and cross-track measurements of slope and roughness at scales as small as ~20 m while pulse-widths provide roughness information on scales the size of a single spot, ~5 m. After ~3 years of operation, the mean ground-track spacing at the equator is ~ 0.5 km while the maximum spacing is ~ 4.5 km.

LOLA data are released to the public online on a quarterly basis through the Planetary Data System Geosciences Node (http://pds-geosciences.wustl.edu/). The data archive is comprised of various products: raw telemetry, calibrated, reduced and resampled data, processed data, and software, all of which are generated by the SOC. The raw, calibrated, and reduced altimetric profiles are broken up into orbits with each ~2 hour orbit given its own binary Reduced Data Record (RDR) file. Each RDR file contains up to ~1 million data points (collected at the rate of 140 points per second). The RDR products undergo editing steps and pipeline processing, with subsequent analysis to validate their measurement accuracy. The RDR and higher-level products undergo monthly revisions after each orbit maintenance cycle.



Standard methods are used to create the higher -level products, which include gridded data (GDR) and spherical harmonic models (SHADR), whose revisions are associated with those of the cumulative RDR dataset. The GDR data products consist primarily of Digital Elevation Models (LDEMs) formatted as binary raster "IMG" images with detached labels. The images are also stored in JPEG2000 lossless compressed file format, which is compatible with many Geographical Information Systems. The global LDEMs use equidistant cylindrical map projections at resolutions of 4, 16, 64, 128, 256, and 1024 pixels per degree (ppd). An example of one LDEM (4 ppd) is shown in the figure above. As of March 2012, the total global coverage is 98% complete at a resolution of 16 ppd. Polar stereographic projected maps with resolutions of 400 meters down to 5 meters per pixel are included in the archive, as well. The SHADR data set contains spherical harmonic topographic and gravity potential models formatted as tables with detached labels. The data archive also provides software utilities, and their source code, to help the user convert the binary data files to human readable format. Finally, some additional products are included in the LOLA data archive, but unsupported by the SOC. These include maps of the lunar geoid, slope, roughness, and Hurst exponent (Rosenburg et al. 2011), permanently shadowed regions and sky visibility at the poles (Mazarico et al. 2011), and virtual textures for the 3-D simulator program, Celestia.

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Managing a Large Database for the Lunar Reconnaissance Orbiter Camera. J. S. Barnett[1], E. Bowman-Cisneros[1], N. M. Estes1; [1]Arizona State University, Tempe, Arizona.

Introduction: Supporting the Lunar Reconnaissance Orbiter Camera Science Operations Center (LROC SOC) with a database presents many challenges. Ensuring that adequate storage space is available, choosing the specific data to store, choosing software and hardware, and establishing backup plans are tasks common to all database projects. The LROC SOC database also needs to provide for the storage and retrieval of geographic data, and large amounts of instrument and spacecraft telemetry.

Storage: While ~44TB of compressed instrument data have been collected, and the LROC SOC has received and generated several hundred terabytes of experiment, calibrated, and reduced data products, only selected data are stored in the LROC SOC database: for example file and observation metadata, selected instrument and spacecraft telemetry, and geographic data in several formats.

As of April 2012, the LROC SOC database contains ~73GB of ancillary data in over 334 million records, with overhead (indexes and other resources) bringing total database size to over 115GB. Beginning with the launch of LRO in June 2009, the LROC SOC database has grown by an average of ~71MB and over 320,000 records per day, ~112MB including overhead. Overhead was initially estimated to be 100% of data size. Actual overhead is ~57%, meaning we require ~1.57GB of disk space for each gigabyte of data we store.

Software: PostgreSQL was chosen to store these data for reasons of cost certainty, enterprise-level features, and its reputation for stability and reliability.

PostGIS and PgSphere were added to PostgreSQL to handle geographic and spherical data. PostGIS was initially selected to satisfy several GIS needs: chiefly to supply data to WMS systems, to allow for geographic matching of data, and for the production of shapefiles. While we do use PostGIS to store data, it has some weaknesses when used for a global dataset, primarily in polar regions and along the 180°/-180° and 0°/360° boundaries. While originally created to store and retrieve astronomical data, we have found that PgSphere provides robust coordinate matching and does not suffer weakness at the poles nor along the boundaries.

Performance: Due to the size of the LROC SOC database, search performance can suffer. Identifying and pre-populating five-by-five degree geographic bins increases the speed of most geographic searches, and aggregated full text indexing improves searches against text. It was initially assumed that several database servers would be required to handle the loading and querying of these data. While we do place read-only subsets of the database on our publicly available Web sites, our nominal processing and science needs are met by one sixteen core machine. Our standby server is currently in place only to be used for recovery in the event of the loss of our main database server. As our processing cluster accounts for the majority of connections to the database, Pgpool is deployed on our processing hosts to remotely manage connections to the database, reducing the load directly applied to the database server.

Data retention: Data retention is achieved through a multi-pronged approach: point-in-time recovery is available through periodic archiving of full-database dumps and continual archiving of write ahead logs. These archives exist in multiple locations. Furthermore, streaming replication provides a standby server which can be quickly repurposed as the main database server in the event of the loss of the main database server.

GIS-Analysis and Mapping of Former and Future Lunar Landing Sites Using ArcGIS. M. A. Baskakova, A. Bystrov, A. S. Garov , I.P. Karachevtseva, **A. A. Kokhanov.** Moscow State University of Geodesy and Cartography (MIIGAiK), Gorokhovskiy per., 4, 105064, Moscow, Russia.

The Russian LUNA-GLOB mission, scheduled for launch in 2015, is to explore the Lunar subpolar areas. An associated research program was proposed by the LunaGlob science team from the Russian Space Re-search Institute of RAS [1, 2, 3]. The general landing area for a lander and a rover, as well as 3 specific coordinates of landing sites have recently been proposed [4]. Our team is providing cartographic support to the mission and assessments of these candidate landing sites on the basis of different types of data.

For the areas of interest, we have compiled a geodatabase containing vector data, orthoimages and DEMs with different resolutions. Using GIS techniques we carried out a various manipulations and cross-analyses of the spatial data. For characterization of the surface, we created some examples of maps: slope, roughness and hill-shaded reliefs in various scales. Slopes were classified in some groups to identify sites that would be safest for landing. The surface roughness was calculated using 5 distinct methods (Fig.1, one example). Hill-shaded maps were generated using two sets of illumination vectors 90° apart for unbiased studies of relief forms (Fig 2, one example).

Using data from LOLA tracks [5] we generated DEMs that matched the resolution of the global stereo terrain model "GLD 100" [6]. Comparison of topographic profiles from both data sets show general agreement along tracks, but across-track topography requires interpolation and has limited accuracy, so for characterization of the landing site entire area we need to use the DEM from stereo images.

Challenges, Encountered During Processing: Although all of smapping data have the same format «.img», each of the data types poses different problems and challenges when trying to make practical use of them. The first and the main problem is opening .img files in ArcGIS. While that PDS files can be used in ArcGIS in "read-only" mode, trying to open the LOLA Digital Elevation Model (LDEM) [7] we have only error message "failed to create raster object".

Another problem appears, when we use DEM "GLD-100"[8], provided by DLR. ArcGIS allows us open and visualize some tiles of the DEM. But correct spatial referencing is achieved for only one lunar hemisphere from 0 to 180 degrees. While GLD100 is stored on a 0 to 360 longitude system of PDS data, ArcGIS supports the -180 – 180 longitude system only. As a consequence tiles with central longitude larger than 180° E were situated in a wrong place.

We met the third type of problem when using the data from SELENE (Kaguya) [9]. Opening .img files with DEM in ArcGIS we get "reflected" image of surface: instead of eastern hemisphere images are situated in the western hemisphere (the same numerical of longitude, but with negative sign).

The problems we encountered also appear to depend on the version of PDS. However all of these problems were solved with conversion to the geotiff format. But each type of data conversion requires special tools or parameter sets:

For LDEM we can use a simple conversion from .img to tiff, using programs like GDAL Other conversion problems were solved with using converters with special algorithms, created in our laboratory on the base of GDAL functions.

So, the main difficulty with loading PDS data to ArcGIS is that we cannot use these data "as they are" but we must convert them to the working format, which takes time and disk space.

Summary: By means of these DEM we created several types of maps of the Moon's surface roughness. In our work we used 5 distinct techniques for the calculation of surface roughness. These methods enable to exercise geomorphologic analysis and help to find error in DTM. To create models are workflows we used ModelBuilder application. In this application we can run several processes simultaneously. This makes it possible to save time, when we create the maps of surface roughness.

Acknowledgments: This work has been supported by a grant from the Ministry of Education and Science of the Russian Federation (Agreement № 11.G34.31.0021 dd. 30/11/2010)

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[8]http://wms.lroc.asu.edu/lroc/global_product/100_mpp_DEM.
[9]https://www.soac.selene.isas.jaxa.jp/archive/index. html.en.

Introduction to PDS Geosciences Node's Orbital Data Explorer. K. J. Bennett, D. Scholes, R. Arvidson, J. Wang, S. Slavney, and E. A. Guinness, McDonnell Center for the Space Sciences, Washington University, 1 Brookings Drive, Campus Box 1169, St. Louis, Missouri, 63130, bennett@wustl.edu

Introduction: To facilitate access to orbital data the Geosciences Node of NASA's Planetary Data System (PDS) has developed a web-based tool, the Orbital Data Explorer (ODE), to access and download a variety of orbital imaging and other data sets.

Overview: ODE provides map and forms-based search, retrieve, and order functions for PDS-compliant archives from a variety of Mars, Mercury, Lunar, and Venus missions. Instruments from these missions are characterized in some cases by very high data volumes and complex observation strategies. ODE is designed to provide advanced search, download, integrated analysis, and visualization tools.

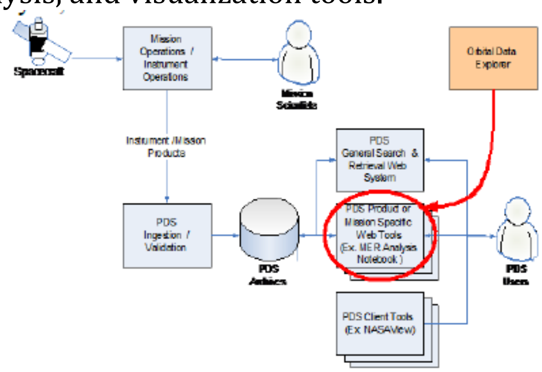


Figure 1 - ODE Relationships

ODE consists of a web site, a metadata database, and a background processor. The background processor extracts PDS product metadata from the selected PDS archives and organizes the information into a searchable database. The ODE web site provides a tool for searching and exploring these metadata as well as accessing and downloading the PDS archives them-selves. The primary audience of the website is the science community but use is not restricted and the public also uses the capabilities.

The ODE website complements the PDS Imaging Node's Atlas website (see Figure 4) by providing cross-mission and cross-instrument searches for imaging and non-imaging data products (e.g., MOLA laser altimetry).

PDS Data: A data product is a set of measurements resulting from a science observation, usually stored in one file. For example, an image, a spectrum, and a time series table of measurements are data products. A data product has a PDS label that contains metadata about a product such as when and where the data were collected, what the data contain, and as how the data are organized. These labels are either detached files or attached to the beginning of a data product file. Currently ODE works with PDS-3 formats but we will migrate to the new PDS-4 formats at the appropriate time.

ODE Features:

Product Search. ODE allows users to search for science data products via mission, instrument, product type, location, time, and product id. Users can search across multiple missions and instruments simultaneously. Search results can be shown in a table or on a map.

Product Details. Users can view the details of any product found in a search. Detailed information includes a table of metadata information and the product label. Product details also include a browse version of image-oriented products allowing the user to better understand the product before downloading it. This is particularly important as many of the orbital products are quite large. Product details may also include a map context and links to related products.

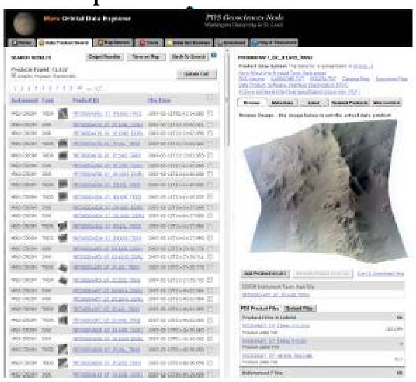


Figure 2 - ODE Product Details Page

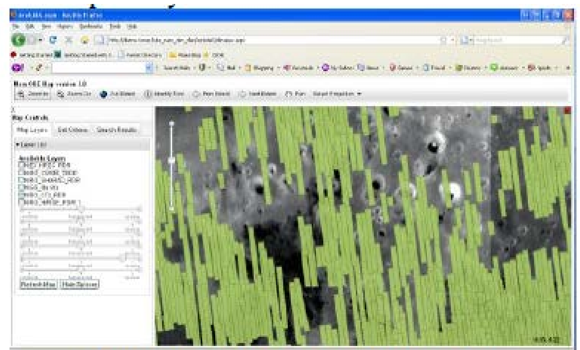


Figure 3 - ODE Map Query Page

Map Search. ODE also includes a map query tool that allows users to search, view, and download products in a visual map environment. The map query tool features include: multiple base maps; surface features; PDS product "footprints"; search-by-coverage; and filter by product type, product id, surface feature, time, and/or location. The interface includes typical GIS features such as map pan and zoom; layer ordering; and layer transparency.

Granular-Level Data Search. The primary purpose of ODE is to allow users to search and find single or multiple PDS data products. However, in many cases, users only want the science data for particular regions, which might be a subset of multiple products. This is particularly true for spatial data stored along orbit tracks in time-sequence chunks, such as the altimetry and other point measurement data sets. When a user makes a query, with the current PDS volume and data product structure, the standard ODE query tool would return far more data than actually needed (See Figure 4 - Granular-Level Data Search Example).

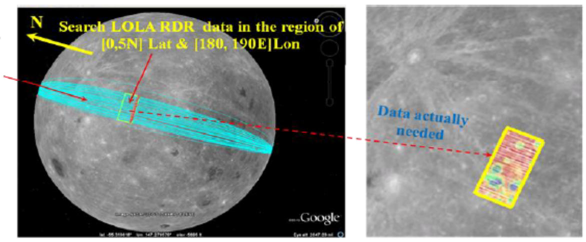
ODE includes a concept of "Observation Data-bases" together with specialized query tools for searching PDS science data. These tools help science users to find science data for a particular area of the surface or to search parameters that are not easily handled with the data product structure, which saves users time searching through the huge database and the effort of developing their own customized extraction tools. In addition, these convert the data into several formats including ASCII tables, shapefiles; and simple binned images. Currently ODE offers MGS MOLA altimetry, LRO LOLA altimetry, and LRO Diviner granular-level databases and tools.

Download. Users have several options for acquiring data products from ODE. First, ODE provides several places where the user can directly download individual files of selected data products or related documentation, browse images, or other supporting files. In addition, the user can select and order data products using a typical web-based "shopping cart" approach. As users search and review data products, they can add or remove selected data products to their shopping cart. They can request that these data products be packaged and made available via FTP. In addition to the selected data products, users may include in their delivery all related documentation and supporting materials. The time between submitting the order and receiving notification that the files are ready for download varies based on the size of the requests, and the number of other user requests in the queue.

Other Features. ODE includes several other features such as MRO Coordinated Observations; product footprint maps (KML and shapefiles formats); and a PDS archive browser.

Contact Information: The Geosciences Node welcomes questions and comments from the user community. Please send email to geosci@wunder.wustl.edu. Specific questions about ODE can be sent to ben-nett@wustl.edu.

E.g., a standard Lunar ODE query on the PDS metadata database returned 59 individual data products,
- each with about 0.2 million measurements,
- including many additional points outside of the search range,
- each file ~50MB.



A LOLA RDRs specialized query of the observation database returned ~2.6 million measurements that matched the selected criteria.

Figure 4 - Granular-Level Data Search Example

Table 1 - Web Address

PDS Geosciences Node web site	http://pds-geosciences.wustl.edu
PDS web site	http://pds.nasa.gov
Orbital Data Explorer	http://ode.rsl.wustl.edu/
Imaging Node's Atlas Tool	http://pds-imaging.jpl.nasa.gov/search/search.html

Table 2 - ODE Product Level Holdings

ODE Mars
MRO CRISM, HiRISE, CTX, SHARAD, MCS. RSS **ESA's MEX** HRSC, MARSIS, PFS, OMEGA **Odyssey** GRS **MGS** MOC, MOLA **Viking Orbiter** Camera
ODE Moon
LRO Diviner, LAMP, LOLA, LROC, LEND, Mini-RF **CLEMENTINE** A-Star, B-Star, HIRES, LIDAR, LWIR, NIR, RSS, UVVIS **Lunar Prospector** MDR, ER, GRS, MAG, NS, RSS **ISRO's Chandrayaan-1** M3, Forerunner **Lunar Orbiter** CDR
ODE Mercury
MESSENGER GRS, MASCS, MDIS, MLA, NS, RSS, XRS
ODE Venus - MAGELLAN RDRS, RSS

Working with Clouds and Supercomputers, Public and Private Ross A. Beyer[1,2] , Oleg Alexandrov[2] , Zachary Moratto[2] , Ara Nefian[2] and Ted Scharff[2] . [1]Carl Sagan Center at the SETI Institute, Mountain View, CA, USA, and [2]NASA Ames Research Center, Moffett Field, CA, USA (Ross.A.Beyer@nasa.gov).

Large modern data sets provide the raw materials for fantastic results, but also represent significant challenges. This talk will describe our experiences working with large data sets on a variety of cloud- and super-computing platforms, some of which are public services and some of which are private resources.

When your storage or computation needs outgrow a single machine, what are your options? There are several good examples in the planetary community of people building their own clusters, or leveraging computing infrastructure at their host institutions. There are also other resources out there that you might be able to take advantage of, depending on your needs.

We will describe some basics of beyond-a-single-box computing, discuss some of these community examples, and also describe our own experiences with NASA's Nebula cloud platform and Google's Cloud Storage system. We'll also talk about how we have used NASA's supercomputing facilities, a computation resource that you may not think of evaluating when you think you need a 'cloud' solution.

The data sets are only going to get bigger and more complicated, and knowing how to navigate these architectures may help us better manage the resources we have.

The Lunar Reconnaissance Orbiter Camera PDS Data Node. E. Bowman-Cisneros[1], M. S. Robinson[1], S.D. Thompson[1], N.M. Estes[1], D.W. Chandler[1], E. Malaret[2] and the LROC Team[1]
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The Lunar Reconnaissance Orbiter (LRO) was launched at 5:32 pm EDT on 18 June 2009, arriving at the Moon four days later. After an 83 day spacecraft and instrument commissioning period, the LRO primary mission began with all instruments operational [1]. The Lunar Reconnaissance Orbiter Camera (LROC) consists of four components: two Narrow Angle Cameras (NAC), which are panchromatic line scan imagers with a 0.5m pixel scale (from 50- km altitude); a Wide Angle Camera (WAC) 7- color push-frame imager with 75 m pixel scale; and the Sequence and Compressor System (SCS), which interfaces the NAC and WAC cameras to the LRO spacecraft [2]. The LROC instrument suite has been in continuous operation since 4 July 2009.

To date, the LROC Team has released 586,217 images (463,432 NAC and 204,140 WAC, totaling 81.6TB), as well as 7,692 map projected (RDR) mosaics (totaling 2.8TB) to the NASA Planetary Data System (PDS). The LROC Team delivers observations on a sliding three month window, at three month intervals. As the PDS Data Node for LROC products, the LROC Team at ASU developed a website to support exploratory and/or focused searching for NAC and WAC image data via the URL http://wms.lroc.asu.edu/lroc. The LROC PDS interface has three primary components: a WMS Browser; a Thumbnail Browser; and an Image Search. All three interfaces provide access to LROC NAC and WAC Engineering Data Records (EDR) and Calibrated Data Records (CDR) [3]. Each interface will be described in detail, as well as providing tips for finding data of interest, pitfalls to avoid and alternates to the LROC Data Node interface. The LROC Team also provides a simple menu interface for viewing published LROC Reduced Data Records (RDR), which are map projected NAC and WAC mosaics [4]. Currently, the LROC team has the following RDR products available for viewing and download: NAC Polar Mosaics; NAC Region of Interest Mosaics; NAC Digital Terrain Models; WAC Global Mosaics; WAC Polar Lighting Movies; WAC Regional Multi-band Mosaics; WAC Digital Terrain Models; and WAC Color Shaded Relief.

The LROC Team, in conjunction with Applied Coherent Technology (ACT), also developed an interactive interface to view NAC images, overlaid on the WAC global mosaic, allowing the user to seamlessly zoom from regional features down to the full resolution of the NAC. The QuickMap interface (ttp://target.lroc.asu.edu/da/qmap.html)has links to individual NAC and WAC products, to facilitate review of image meta-data and downloading the PDS product, as well as integrating additional lunar datasets (M3 spectra).

References:

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[2] Robinson, M.S. et al. (2010) Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview. Space Sci Rev, 150:81-124.
[3] Bowman-Cisneros, E. (2010) LROC EDR/CDR Data Product Software Interface Specification, http://lroc.sese.asu.edu/data/LRO- L-LROC-2-EDR- V1.0/LROLRC_0001/DOCUMENT/LROCSIS. PDF
[4] Bowman-Cisneros, E. and Eliason, E. (2011) LROC RDR Data Product Software Specification. http://lroc.sese.asu.edu/data/LRO- L-LROC-5-EDR- V1.0/LROLRC_2001/DOCUMENTS/RDRSIS.PDF

Digital Elevation Modeling of Key Lunar Science Targets with the LROC NAC. K.N. Burns, T. Tran, M.S. Robinson, E.J. Speyerer, D.G. Yates, T.N. Tran, H. Gengl, J. Banks, J.P. Jones, A. Martinez. School of Earth and Space Exploration, Arizona State University, Tempe, AZ, 85281. (knburns1@asu.edu)

Introduction: One of the primary objectives of the Lunar Reconnaissance Orbiter Camera (LROC) [1] is to gather Narrow Angle Camera (NAC) stereo observations to generate digital elevation models (DEMs). Although not designed for stereo observations, off-nadir slews of the spacecraft of ~20° enable stereo NAC observations acquired from adjacent orbits. Since off-nadir rolls interfere with data collection of the other instruments, LROC slew opportunities are limited to four per day. From an altitude of 50 km the NAC acquires images with a pixel scale of 0.5 meters and cover approximately 5 km cross-track by 25 km down-track. The low altitude was common during the nominal and first half of the science mission (September 2009 to December 2011). Images acquired during the commissioning phase and those acquired from the fixed orbit (after 11 December 2011) have pixel scales that range from 0.35 meters to 2 meters. In order to maintain a vertical precision of less than 1 meter and rarely above 2 meters, the convergence angle between image sets are ideally between 12° and 45°.

Method: A combination of USGS Integrated Software for Image and Spectrometers (ISIS) and SOCET SET from BAE Systems software packages are used to generate DEMs. ISIS routines ingest the images, perform a radiometric correction, and export the image data in SOCET SET data format. SOCET Set includes a NAC specific push broom sensor model to relate the image space to ground coordinates. A bundle adjustment is performed on the images to correct for offsets in camera pointing using a multi-sensor triangulation (MST) algorithm. Selected parameters, such as the position, velocity, and pointing angles of the cameras are adjusted so that the RMS errors for all the tie points are minimized. In order to improve accuracy between the images and ground truth, Lunar Orbiter Laser Altimeter (LOLA) data are used to define the geodetic reference frame for the DEMs. The images are shifted in relation to their original latitude, longitude, scale, elevation, and horizontal and vertical rotation, using a script in MATLAB, in order to better fit the LOLA data.

Once the images are adequately registered to each other, as well as the LOLA data, the process of extracting DEMs can begin with NGATE (SOCET SET- Next Generation Automatic Terrain Extraction). NGATE performs image correlation and edge matching for every pixel in the image to create a dense model. The DEM is then resampled to at least three times the ground sampling distance of the image (typically 2 meters for nominal phase images) [2].

Orthorectified images are created upon completion of the DEM using SOCET SET's Orthophoto Generation. Orthophotos are images that have had all distortion due to camera obliquity and terrain relief re-moved. An orthophoto represents what you would see if you were looking at the ground orthogonally from a distance above (every pixel is viewed as if nadir). In addition, a hill shade image, color shaded relief image, slope map, and confidence map are provided in GeoTIFF format. These products are made using the Geospatial Data Abstraction Library (GDAL) [3].

Application: The NAC DEMs are the highest resolution topographic resource of the lunar surface, and serve as a valuable tool to both the scientific and space exploration communities. Site selection is critical to the success of any future lunar mission. NAC DEMs will be crucial in manned or robotic attempt to land on the surface. Increased hazard avoidance capabilities in future missions will be able to pick landing sites with a greater emphasis on science return and less on engineering safety criteria [4]. NAC DEMs provide a reference for three-dimensional flight plans and provide meaningful hazard avoidance by locating steep slopes, rocks, cliffs, gullies and other landing hazards, which can be avoided by computing the local slope and rough-ness. A densely populated elevation model will aid on-board landing system that can autonomously and accurately determine spacecraft velocity and position relative to the landing site. DEMs draped with an orthophoto enhance site selection decisions with perspective views and 3-d flight simulations. Small craters, boulders, and hills can block communication with Earth for landed assists near the poles. Knowledge provided by NAC DEMs of these small obstacles reduce mission risk.

Such DEMs are also needed for traverse planning. Unnecessary movement across the surface wastes precious resources and therefore it is crucial that traverses are optimized in advance to follow a least work path.

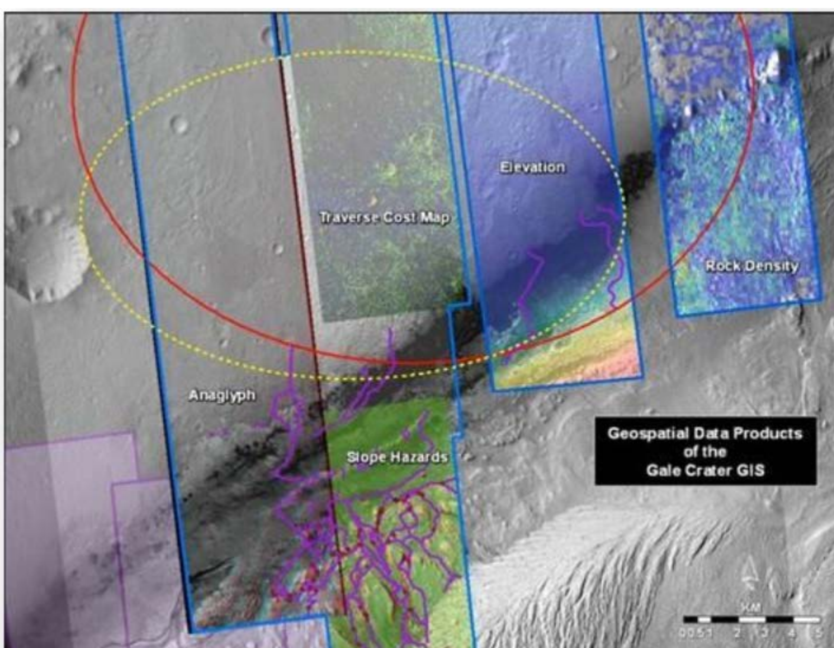
Release: The process of reducing NAC frames to DEMs has evolved to an efficient pipeline procedure with rigorous quality control checks. To date, ASU has processed 130 individual stereo pairs covering 11 CxP sites as well as 53 regions of scientific interest covering a total area of ~20,000 km2 (Table 1). The total coverage of the lunar surface is only 0.06%. The team at UA has processed approximately 40 stereo pairs, which include 5 CxP regions of interest. OSU has produced approximately 20 DEMs produced from NAC images. USGS has processed 20 DEM mosaics of CxP regions of interest that include multiple stereo pairs for each mosaic. ASU DEMs and associated products can be downloaded from http://wms.lroc.asu.edu/lroc/dtm_select. These DEMs are described in the following table. Additional DEMs (from USGS and UA) are available from http://lmmp.nasa.gov

References: [1] Robinson et. Al (2010) *Space Sci Rev, 150,* 81-124. [2] Tran, T. et al., (2010) *ASPRS/CaGIS 2010*. [3] Warmerdam, F. (2008). The Geospatial Data Abstraction Library. *Open Source Approaches in Geographic Information Science, Vol. 2, pp. 87-104*. [4] Johnson, A., 2005. Vision Guided Landing of an Autonomous Helicopter in Hazardous Terrain. Proceedings of the 2005 IEEE International Conference on 180-22 April 2005.

Constructing a GIS for the Final Four Mars Science Laboratory (MSL) Landing Sites. F. J. Calef III[1] M. P. Golombek[1] and T. J. Parker[1], [1]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109. (fcalef@jpl.nasa.gov)

Abstract: The engineering evaluation of the final four Mars Science Laboratory (MSL) landing sites relied on the integration of several multi-resolution and multi-product datasets. A geographic information system (GIS) was created for each site to manage and quantify the tens of gigabytes of geospatial information such as digital elevation models (DEMs), 0.25cm/pixel visible imagery, and cumulative fractional area (CFA) rock abundance maps. Mosaiced base layers were produced by georegistering progressively lower to higher resolution images for establishing the best horizontal and vertical geodetic control possible for entry, descent, and landing (EDL) Monte Carlo simulations and rover traverse analysis. These data products cover 80-85% of the landing ellipses at the time of selection with a meter-scale resolution that is unprecedented for any past lander mission. For the selected landing site, Gale crater, the GIS dataset will serve as a tactical and strategic planning tool during operations, as well as an important dataset for creating and evaluating new science during the mission.

Datasets: The MSL GIS consists of a pyramid of various visible and derived digital elevation models (DEM) from several sources: High Resolution Stereo Camera (HRSC) orthophotos (12.5 m/pixel) and DEM (50 m posts) [1], Mars Reconnaissance Orbiter (MRO) Context (CTX) visible (5 m/pixel) and DEM (25 m posts), and MRO High Resolution Science Experiment (HiRISE) orthophotos and associated DEMs (1m post) [2]. Several derived products were made from the HiRISE imagery including slope maps, cumulative fractional area (CFA) rockmaps at 150 m and 450 m cells (from Andreas Huertas/JPL), as well as traverse cost maps (from Paolo Belutta/JPL) for strategic planning. This would all server to test entry, descent and landing (EDL) scenarios for MSL to quantify landing safety at each MSL site (via Devin Kipp/JPL).



Methodology: HRSC data served as a base due to its excellent vertical and horizontal control to the Mars Orbiter Laser Altimeter (MOLA) global DEM. CTX visible imagery (and later resultant DEMs) were horizontally georeferenced to the HRSC orthophotography, followed by HiRISE orthophotos to the CTX. Each georeferencing step built on the previous to create a pyramid of data products at multiple scales. DEMs for each of these three datasets were registered based on the visible tie pointing of 30-100 points with a spline transformation in ArcGIS. Once georeferencing was complete, DEM products were horizontally rectified to the visible base (at JPL) and later 'equalized' vertically (at USGS-Flagstaff by Randy Kirk) to lessen differences in seams from image to image. Where offsets remained, detrending and re-interpolation after removing a buffer of DEM posts around HiRISE to CTX boundaries smoothed edge-to-edge vertical transitions.

Future Uses: For Gale Crater, the MSL Science Team will utilize the visible, DEM, and rock maps for traverse analysis, geologic mapping, as well as strategic decision making once Curiosity has six wheels on martian soil.

References: [1] Gwinner, K., et al. (2010), LPSC abs# 2727. [2] Kirk et al., (2011), LPSC abs# 2407.

Conductor and Kapellmeister: Managing Data Processing Pipelines

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Conductor

The Conductor (http://pirlwww.lpl.arizona.edu/software/Conductor.shtml) software provides a lightweight system for managing data processing pipelines defined in database tables. Conductor provides the management of the pipeline processes applied to a queue of source data files; it does not process the source data itself.

A database table provides a queue of source file records to be acquired in first-in-first-out order by a Conductor bound to the pipeline. Each data source is applied to each process specified in the record of a sibling database table. The process records define an ordered sequence of command lines with success criteria for each process. Conductor executes the command line for each process - any process will do, including simple scripts - with built-in parameter values, configuration file parameter values, and/or database field reference values used to fill placeholders in the command line specification of the pipeline process record. The process definition records, and/or their order, may be changed while the pipeline is active. Conductor logs all of the stdin and stderr output from the process, makes sure the process does not exceed a maximum runtime, and checks the exit status or scans the standard output for a pattern that the process record defines as completion success before proceeding to the next process or acquiring another source record. Each source record is updated with the location of its log file and the status of each process applied to it. If a process is not successful an on-failure or "branch" command, defined in each process record, is run instead of proceeding with the normal sequence of processing. The on-failure command will typically send an email notification to a list of appropriate recipients, or the command might queue the current data source as a new source record in an alternate pipeline.

Pipeline segments may be linked into data processing networks by having the last process in a pipeline queue the transformed data source into the next pipeline segment(s). Multiple Conductors may be bound to the same pipeline as needed to ensure that the data sources are processed faster than the queue is being filled. And the Conductors for a pipeline may be distributed on different compute hosts to distribute and parallelize the processing load. This is particularly valuable for compute intensive processes and/or heavy source data loads.

A source record is guaranteed to be acquired by only one Conductor regardless of how many Conductors are bound to the pipeline. A Conductor is typically run as a background service that periodically polls (at a tunable rate) its pipeline source queue for unprocessed records when all existing records have been processed. When a Conductor sees a new source record and acquires it and proceeds to run the sequence of processes. Source records might be entered in the first pipeline of a network by a watchdog process looking for the availability of data from a remote source. In this way large amounts of source data can automatically flow through a network of many linked pipeline segments that apply sophisticated processing sequences with little or no operator involvement.

External reporting tools, such as web applications, can track the progress of source data through their processing pipelines by querying the pipeline database tables and offering log files for inspection.

Kapellmeister

The Kapellmeister application is an uber-manager for profiles of pipeline networks. It uses an interprocess message passing mechanism to communicate with a Stage_Manager process on each host system that has been assigned to a set of Conductors, called a Theater. The Kapellmeister can request that the Stage_Manager start new Conductors or stop existing Conductors for specific pipelines to change the processing distribution across the pipeline network and the available compute hosts.

Each Conductor may be configured to maintain a message passing connection with the Stage_Manager for the pipeline network Theater on its compute host. More than one Theater with its Stage_Manager may be in operation on each compute host. The Conductor will report all its activities to its Stage_Manager, as they occur, including the process definition records it is using, the source records it has acquired, and which process is being run with the current source along with the output log stream and completion status for each process.

Utilities are provided to assist in instantiating the Stage_Managers for a Theater on a set of compute hosts. Each Theater typically operates independently of any other Theaters on the same compute hosts.

Because the Kapellmeister is intended for remote, real-time monitoring and control of Conductors in a distributed pipeline network, access is limited to authorized connections. A public-private key mechanism is used to authenticate all Kapellmeister-Stage_Manager and Stage_Manager-Conductor connections.

A Kapellmeister provides a GUI with a matrix of pipelines and compute hosts. Each matrix node lists the number of Conductors at that location in the network with their current processing status color coded. Source data can be seen to flow through the pipeline network of the matrix as linked pipeline segments become active while processing the source data. The Kapellmeister may open a monitor window for selected Conductors that provides details forwarded from the Conductor's Stage_Manager on all current processing activity, the current values of all configuration parameters, and the processing output log stream. The monitor also includes Conductor setting controls that will send messages to the Conductor to change its state. For example, a Conductor can be told to change its source record polling rate or the number of sequential processing failures to tolerate before suspending further processing, to gracefully suspend processing after the current source record has completed the processing sequence, to restart processing after having been suspended, or to quit managing the pipeline. Conductor start, suspend and quit messages may be sent to selected groups of Conductors or to the entire pipeline network.

A Kapellmeister can read Profile files that define a pipeline network distributed across numerous compute hosts and apply them to instantiate a complete set of Conductors for all the pipelines on all the compute hosts, or dynamically modify an existing pipeline network, however distributed, to conform to a Profile's specifications. A Profile file can also be generated to reflect the current pipeline network being managed so it can be instantiated again at a later time.

Characterizing Dehydrated and Dehydroxylated Phyllosilicates on Mars Using Thermal and Near IR Spectroscopy. C. Che[1] and T. D. Glotch[1], [1]Department of Geosciences, Stony Brook University, Stony Brook, NY11794 (cche@ic.sunysb.edu)

Introduction: Phyllosilicates are detected in a number of contexts on Mars, primarily associated with ancient Noachian terrains [e.g., 1-4]. These phyllosilicate deposits may have been altered by multiple processes. We hypothesize that dehydrated and dehydroxylated phyllosilicates may be present on the Martian surface as one of the consequences of widespread impacts and volcanism during the Noachian and early Hesperian. In addition, thermal IR (TIR) and near IR (NIR) remote sensing data give different perspectives on phyllosilicate mineralogy, crystallinity, and abundance on Mars [e.g., 5-8]. Among the potential reasons for this disconnect is the possibility that phyllosilicates on Mars have been modified by the effects of dehydration and dehydroxylation. Such effects could modify the mineral structures in such a way that their spectroscopic signatures appear different from various wave-length perspectives, and different instruments.

Under our previously funded MFRP grant, we have acquired NIR reflectance and TIR emissivity spectra of a suite of 14 phyllosilicates (coming from four structural groups: kaolinite, smectite, chlorite, and palygorskitesepiolite) and 2 natural zeolite minerals and their thermal decomposition products [9]. Results from this laboratory work show that phyllosilicates may lose all original spectral features in the TIR region while dis-playing familiar spectral bands of phyllosilicates in the NIR region in the same temperature range (Figures 1 and 2).

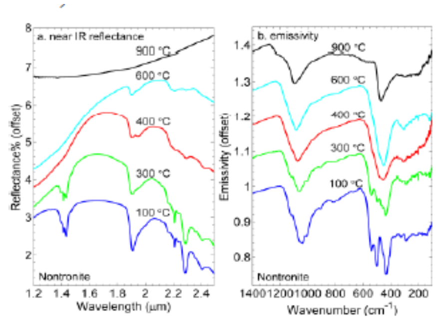


Figure 1. (a) Near IR reflectance and (b) TIR emissivity spectra of heated nontronite. At 400 °C, the triplet spectral feature in the Si-O bending region is replaced by a single absorption centered at ~450 cm^{-1}, while the nontronite sample maintains weak 1.9, 2.3, and 2.4 μm spectral bands in NIR region.

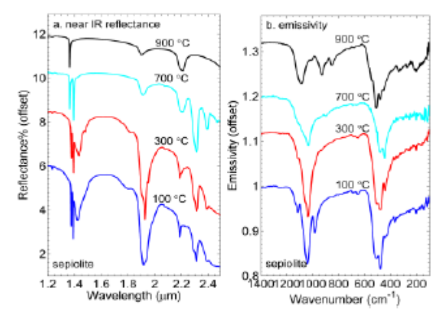


Figure 2. (a) Near IR reflectance and (b) TIR emissivity spectra of heated sepiolite. At 900 °C, sepiolite displays spectral bands at 1.9 and 2.2 μm that are diagnostic of phyllosilicates, while its TIR spectrum is already dominated by spectral bands of enstatite.

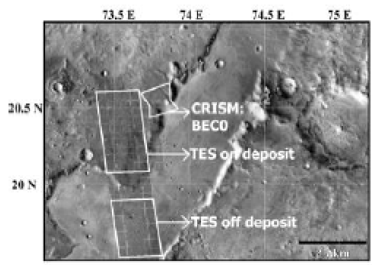
The objective of this work is to identify, map, and characterize these dehydrated and dehydroxylated phyllosilicates on Mars, using TES and CRISM data. The significant suite of our previous laboratory spectra will be the basis for our TES and CRISM data analysis. The identification of these phases on Mars would help provide insights into the role of post-depositional thermal alteration of phyllosilicates-bearing sediments.

Methods: We used a variety of spectroscopic methods, covering NIR to MIR wavelengths to map the distribution of dehydrated and dehydroxylated phyllosilicates on Mars. These include (1) global- and local-scale linear deconvolution of TES data using a spectral library that includes dehydrated and dehydroxylated phyllosilicates, (2) use of spectral ratios of TES data to determine the long-wavelength spectral character of phyllosilicate-bearing deposits, (3) global and local-scale spectral index mapping of dehydrated and dehydroxylated phyllosilicates, based on the unique TIR spectral properties of these phases, (4) factor analysis and target transformation (FATT) analyses of

TES data, to determine the independently variable spectral components in regions of interest, and (5) spectral index mapping and detailed spectral analysis of CRISM data.

Here we present the preliminary results using the above methods, contributing to a better understanding of nontronites in the Nili Fossae region.

Preliminary Results: *Preliminary Study Region: Nili Fossae (Figure 3):* Michalski et al. [2010] [10] analyzed the nontronite deposits in the Nili Fossae region using TES data, but did not detect the spectral features showing the occurrences of nontronite in the long-wavelength region. Instead, TES data consistently exhibited a spectral absorption located near ~450 cm-1 on the same surface where OMEGA and CRISM data identified the diagnostic NIR spectral bands (1.9, 2,3, and 2.4 μm) of nontronite [10, 11]. This leads us to investigate whether nontronites in this region were affected by post-depositional thermal alteration.



Mineral Group	On Deposit	Off Deposit
Altered Nontronite	19±8	5±6
Pyroxene	27±5	30±4
Plagioclase	18±5	26±4
Sulfate	6±3	7±2
Carbonate	5±1	6±1
Olivine	10±3	7±3
Phyllosilicates	8±4	13±4
Other	6±3	6±2
RMS Error (%)	0.1473	0.1608

Table 1. Modeled mineral abundances of TES spectra of "on deposit" and "off deposit". It appears that on deposit, the altered nontronite is largely substituting for the unaltered phyllosilicates and plagioclase.

Figure 3. Context image of the Nili Fossae region showing positions of TES and CRISM data presented below and shown in **Figure 4, 6, and Table 1.** The surface "on deposit" was determined to be nontronite-bearing based on CRISM and OMEGA data [10, 11], while the surface "off deposit" appears spectrally "neutral" in OMEGA data [10].

*Local Deconvolution of TES spectra (**Table 1**)*: We deconvolved TES spectra of the surface "on deposit" and "off deposit" in Figure 3. We used a 49 endmember spectral library composed of a range of silicates, carbonate, sulfates, and oxides that also included spectra of thermally altered nontronite (at 400 °C) acquired by Che and Glotch [2011] [9].

Index Mapping of TES Data at Regional Scales (Figure 4): We created a 450 cm-1 (spectral feature of 400 °C nontronite shown in Figure 1b) index map around Nili Fossae to identify small areas of interest.

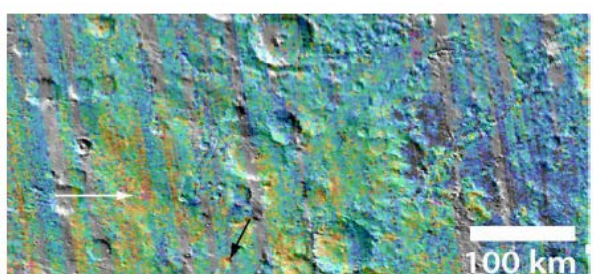
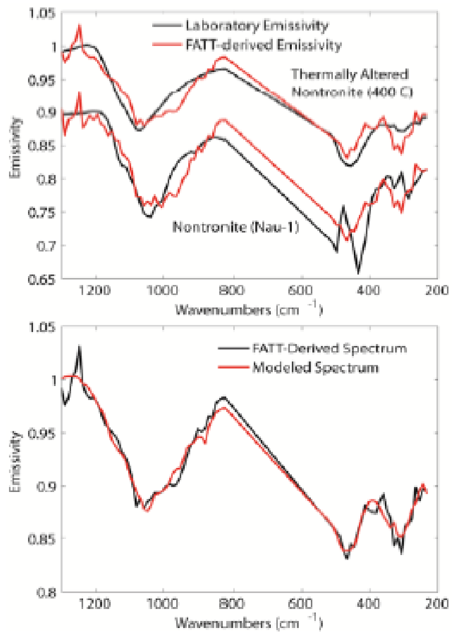


Figure 4: Regional-scale map of the 450 cm^{-1} index in the Nili Fossae region. The black arrow points to a high index value that corresponds to the TES spectra outlined in Figure 3. Index mapping and deconvolution results (Table 1) both suggest the presence of thermally altered nontronite in Nili Fossae region.

FATT of TES Data (Figure 5 and Table 2): We gathered 5616 individual TES spectral from the region shown in Figure 3. We used both our heated and unheated nontronite spectra as target vectors. FATT-derived spectral results are shown in Figure 5 and Table 2.



Mineral Group	Abundance
Altered Nontronite	46±6
Other Phyllosilicates	20±7
Olivine	8±4
Plagioclase	6±11
Amphibole	6±4
Pyroxene	5±6
Sulfate	4±2
Carbonate	4±1

Figure 5: a) FATT-derived spectra of heated nontronite and unheated nontronite. b) Linear deconvolution of our FATT-derived spectrum of heated nontronite. **Table 2**. Modeled mineral abundances of our FATT-derived spectrum of heated nontronite.

The TES data provide a much better fit to the heated nontronite. This FATT-derived spectrum is mod-eled as 46% heated nontronite, 20% other phyllosilicates, and <10% of all other phases.

Detailed spectral index mapping of CRISM data (Figure 6): At 400 °C, nontronite loses its 1.4 μm band completely while it still keeps a strong 1.9 μm feature (Figure 1), therefore we mapped the ratio of the 1.4 to 1.9 μm band depth indices in CRISM images to gain insights into the degree of thermal alteration of nontronite-bearing surfaced on Mars.

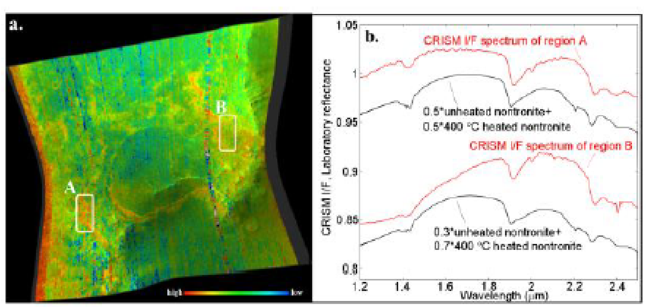


Figure 6. a) Ratio of 1.4 and 1.9 μm indices from CRISM image FRT0000BEC0 (Shown in Figure 3) overlayed on 1.3 μm reflectance. B) CRISM I/F spectra shown for each of the regions of interest and compared to spectra of mixtures of unheated and heated nontronite.

The spectrum of spot A displays a relatively higher 1.4/1.9 μm index value than spot B. One interpretation of this observation is that spot B has more thermally altered nontronite than spot A.

Summary and Future Work: Our preliminary results suggest the presence of thermally altered nontronite in Nili Fossae region. The results also suggest that mixing is occurring and the thermally altered nontronite may not exist as a pure phase on the surface. We will continue to use these spectroscopic methods to investigate the thermally altered phyllosilicates on Mars.

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In-Situ Mosaic Production at JPL/MIPL. R. G. Deen, JPL, Bob.Deen@jpl.nasa.gov.

Introduction: This poster will discuss how *in-situ* mosaics are produced by the JPL/MIPL team.

The Multimission Image Processing Lab (MIPL) at JPL is responsible for, among other things, the ground-based operational image processing of all the recent in-situ Mars missions: Mars Pathfinder, Mars Polar Lander, the Mars Exploration Rovers (MER), Phoenix, and the Mars Science Lab (MSL). Probably the most visible products to come out of this effort are mosaics.

Mosaics are generated for virtually every rover position for which a panorama is taken. They provide a much better environmental context than single images do, which is valuable to operations personnel, but they're also very important for public engagement.

Poster Content: This poster will describe the basics of mosaic creation – how single images are transformed to a single unified view using a surface model. Parallax will be described, which create uncorrectable geometric seams in non-orthorectified mosaics.

Mosaics are often in need of seam correction – both geometric and radiometric. Techniques used by JPL/MIPL to create these corrections will be described. These techniques preserve geometric relationships and provide explicit traceability of mosaic pixels back to their source image, something that commercial mosaic programs typically lack.

Mosaics can be created in several different projections – cylindrical, perspective, vertical, polar, a cylindrical-perspective hybrid, and orthorectified. Examples will be shown of different projections.

Open-Source Software from JPL/MIPL. R. G. Deen, JPL, Bob.Deen@jpl.nasa.gov.

Introduction: This poster will present the Open Source packages available from the Multimission Image Processing Lab (MIPL) at JPL. Each one will be described briefly with instructions on how to obtain it. The intent of the poster is to foster collaboration and reuse of these packages within the community, including contribution of modifications back to the authors. In this way, the authors hope to be able to evolve and maintain their packages more than limited budgets would ordinarily allow.

JadeDisplay: This is an image display component for Java, specializing in display of large images and graphics overlays.

JADIS: This is a Java interface that allows stereoscopic display of standard Swing components in Java. It supports both hardware stereo (if supported by OpenGL), and anaglyph (red/blue) stereo with no change to application code. It also works with JadeDisplay.

VICAR, PDS, and ISIS image I/O for Java: This is a package for image I/O of VICAR, PDS, and ISIS formatted images using Java. It supports low-level access as well as both Java high-level interfaces: Image I/O, and the now-deprecated Java Advanced Imaging (JAI) codec mechanism.

X-windows Image Widget: This is an Xwindows/Motif widget, written in C, for image display. It is a predecessor to JadeDisplay and also works with large images and graphics overlays.

Magellan Stereo Workstation: This is a Java-based stereo workstation built around JADIS and incorporating elements from a European collaboration (PRoVisG). It will display Magellan stereo data and allow the user to view and manipulate stereo match points. It is not yet complete and thus not yet available, but the task plan calls for Open Source release.

Software Reuse in the Planetary Context: The JPL/MIPL Mars program suite. R. G. Deen, JPL, Bob.Deen@jpl.nasa.gov.

Introduction: This talk will present a case study in how a planetary data processing software system can be architected to be reusable across multiple missions.

The Multimission Image Processing Lab (MIPL) at JPL is responsible for, among other things, the groundbased operational image processing of all the recent in-situ Mars missions: Mars Pathfinder, Mars Polar Lander, the Mars Exploration Rovers (MER), Phoenix, and the Mars Science Lab (MSL). Processing includes both tactical and strategic products, and encompasses stereo analysis, XYZ derivation, radiometric and geometric correction, slope and reachability maps, terrain meshes, mosaics, and more.

The processing is accomplished by a set of over 40 individual application programs. Each of these are completely multimission, with no changes necessary to support new missions.

This is accomplished via the Planetary Image Geometry (PIG) library. This C++ library hides all mission-specific aspects into subclasses behind reusable "model" classes. These models abstract concepts like Camera, Pointing, Label, Coordinate System, enabling applications to ignore most mission dependencies.

Presentation: The talk will present an overview of the software suite and its function. It will then show the architecture of the PIG library and how mission specific details are handled. Statistics on the sizes of the components will be presented, along with adaptation experiences for different missions and ways in which the library has been extended. Finally, a set of Lessons Learned will be presented on how to build such a library.

Terrain Generation from Stereo Imagery in the JPL/MIPL Pipeline. R. G. Deen[1] and O. Pariser[2], [1]JPL, Bob.Deen@jpl.nasa.gov, [2]JPL, Oleg.Pariser@jpl.nasa.gov.

Introduction: This talk will discuss how terrain data is derived from stereo imagery in the JPL/MIPL pipeline.

The Multimission Image Processing Lab (MIPL) at JPL is responsible for, among other things, the groundbased operational image processing of all the recent in-situ Mars missions: Mars Pathfinder, Mars Polar Lander, the Mars Exploration Rovers (MER), Phoenix, and the Mars Science Lab (MSL). A core part of this processing is the derivation of terrain data from stereo imagery.

This terrain data is used in operations throughout the Projects: rover planners (via terrain meshes in the RSVP tool), science planners (via range maps in the Maestro/MSLICE tool), and long-term planners. It is also used for science analysis.

Presentation: The talk will start with an overview of the products and how they are used. It will then discuss the pros and cons of linearization (epipolar alignment) of the imagery. It will next talk about the algorithms used at the various stages of production: correlation, creation of XYZ point clouds, surface normals. Recent work on error analysis of the results will be covered. Conversion of point clouds into mesh (geometry) triangles will be discussed, along with texture mapping. Pulling everything together into an automated pipeline will be briefly touched upon, as well as format conversions. Finally, applications of the techniques to two areas beyond the original scope will be presented: first, using them for orbital imagery, including rover localization; and second, use with the Block Island meteorite from the MER rover Opportunity.

Locating, acquiring, and working with planetary data in JMARS. S. L. Dickenshied[1], S. Anwar[1] , D. D. Noss[1] and P. Christensen[1], [1]Mars Space Flight Facility, 201 E Orange Mall, Arizona State University, Tempe, AZ 85287 USA.

Introduction: JMARS is a geospatial information system developed by ASU's Mars Space Flight Facility to provide mission planning and data-analysis tools for NASA orbiters, instrument team members, students of all ages, and the general public. Originally written as a mission planning tool for the THEMIS instrument onboard Mars Odyssey, JMARS has since been released to the science community and the general public as a free tool to quickly locate and view planetary data for Mars, the Moon, Earth, Mercury, and an expanding range of additional planetary bodies.

The public version of JMARS offers quick access to over 300 maps of Mars and millions of individual images collected from seven different orbital instruments. These images can be easily located by geographic area or filtered down based on any number of scientific parameters, then viewed in situ without excessively large downloads or extensive knowledge of planetary data formats.

Numeric data is preserved in JMARS whenever possible, allowing the user to draw a profile line to quickly plot elevation, mineral abundances, and temperature data, or project an entire scene over available topography to create a 3D image. Vector data can be imported or created on the fly, then combined with numeric maps to calculate and report separate values for each shape.
If the built in analysis features are insufficient, JMARS provides a quick link to the official repository for each image, allowing the user to download and process data on their own.

References:
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http://adsabs.harvard.edu/abs/2009AGUFMIN22A..06C

Acknowledgments:
JMARS was funded in part by the Mars Odyssey project, the Mars Program Office, and contributions from users like you.

Using DaVinci and JMARS for Processing and Visualization of Thermal Emission Spectrometer (TES) and Thermal Emission Imaging System (THEMIS) Data of Mars. C. S. Edwards[1] and P. R. Christensen[1], [1]Arizona State University, School of Earth and Space Exploration, Mars Space Flight Facility, PO BOX 876305, Tempe, AZ 85287-6305, Christopher.Edwards@asu.edu.

Introduction: Images of planetary bodies in our solar system are some of the most widely utilized data products available to the planetary science community. These data have been acquired from the beginning of NASA's exploration of the solar system to the present day. Imaging cameras and spectrometers such as the Viking Orbiter Visual Imaging Subsystems (VIS) [1], the Mars Orbiter Camera (MOC) [2] wide angle and narrow angle instruments, the Thermal Emission Imaging Systems (THEMIS) [3, 4] visual and infrared imagers, the High-Resolution Stereo Camera (HRSC) [5,6] visible imager, and the Mars Reconnaissance Orbiter's High Resolution Imaging Science Experiment (HiRISE) [7], Context Imager (CTX) [8], and the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) [9] have all provided new and unique views of the planet that have revolutionized the manner and detail in which Mars is studied. Additionally, high-resolution spectral data from the Thermal Emission Spectrometer (TES) [10] and CRISM have provided a wealth of mineralogical data which are widely used by the community to characterize the geology and planetary history of Mars.

Data Processing Tools: In this abstract, we present several open source tools developed by the Mars Space Flight Facility at Arizona State University, used to calibrate, analyze and visualize THEMIS and TES data. We briefly discuss their features and then provide examples of studies that make use of these tools to undertake geologic studies of the martian surface.

DaVinci: DaVinci (http://davinci.asu.edu) is an interpreted language that looks and feels a lot like C, but has additional vector oriented features that make working with large (>Gigabytes) blocks of data a lot easier. This makes DaVinci well suited for use as a data processing tool, allowing symbolic and mathematical manipulation of hyperspectral data for imaging spectroscopy applications. DaVinci provides support for importing and exporting current Integrated Software for Imagers and Spectrometers (ISIS, http://isis.astrogeology.usgs.gov) data formats, among a variety of other data formats including, Vicar, fully numeric GeoTIFF, CSV/ASCII and other commonly supported image formats (e.g. png, jpeg, bmp). DaVinci allows the end user to develop image-processing algorithms, query databases, directly download images and maps of Mars, the Moon, and other bodies all with an interactive scripting interface. Its plotting and image display capabilities let the user visualize the effect of data processing in real-time. Processing algorithms developed in DaVinci can be easily integrated with ISIS to provide a flexible compliment to the established ISIS routines. Additionally, DaVinci also allows the scientific user to mosaic hundreds to tens-of thousands of images together with various levels of normalization and processing [11].

JMARS: The Java Mission-planning and Analysis of Remote Sensing (JMARS, http://jmars.asu.edu) tool is also of great value for identification and correlation of various datasets and derived products from all the instruments listed in the introduction, as well as TES spectral data. Additionally, DaVinci and JMARS can directly interact, where data from the back-end of JMARS can be read into DaVinci, manipulated, and displayed in JMARS. The DaVinci-JMARS link is a straightforward way for end-users to directly and quickly input their data on a temporary, and if they choose, permanent basis. For example, spectral mixture analysis results of THEMIS data can be viewed in JMARS without saving a georeferenced file. Additionally, this link can likely be modified for users of ENVI/IDL or other image processing toolkits such as those developed for Python.

Application to THEMIS and TES Data: A large volume of literature has been published utilizing advanced image and data processing algorithms designed for the compositional analysis of THEMIS and TES data. These publications that utilize DaVinci explicity include: 1) TES atmospheric correction [12], 2) THEMIS atmospheric correction and instrument calibration [13], 3) THEMIS calibration, line correlated, and uncorrelated noise removal algorithms [11], and 4) mineral abundance determinations [e.g., 14, 15-24]. The data processing steps to both mosaic and utilize well calibrated, THEMIS data are presented by *Edwards et al.* [11]. Additionally the description of the method to remove atmospheric contributions to THEMIS data are presented by *Bandfield et al.* [13]. We have streamlined the processing steps required to atmospherically correct THEMIS data vicariously using TES data and requires the use of both JMARS and DaVinci, relying heavily on the contributions of many authors, including J. L. Bandfield and A. D. Rogers.

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High Performance Computing With Rector: Implementation, Operation, and Development. N. Estes, K. Bowley, K. Paris, E. Bowman-Cisneros, School of Earth and Space Exploration, Arizona State University

Rationale: In order to keep up with the ~450Gb of data that the Lunar Reconnaissance Orbiter Camera (LROC) Science Operations Center (SOC) receives each day, an automated batch processing system is required. This system is supported by the LROC SOC High Performance Computing (HPC) cluster that currently aggregates 466 CPU cores. Using the cluster to also support ad-hoc user jobs as a secondary priority was also desired. After evaluating existing solutions such as Conductor from HiRISE at the University of Arizona, Condor from the University of Wisconsin-Madison, and OpenPBS, the LROC SOC team decided to develop Rector as a custom solution tailored to our demanding operational needs.

Objectives: Rector's overarching requirement was to provide the batch processing framework to automatically ingest and process up to one thousand image files per day, ingest ancillary support files from the LRO Mission Operations Center (MOC) and other sources, report and handle exceptions, fully utilize the LROC SOC processing resources, and minimize manual operational overhead. Rector also allows additional ad-hoc processing jobs on a per-user basis on the cluster as a secondary priority.

Methods: Rector was developed in Ruby using the Rails framework for a web-based interface. The system is divided into a web-interface, command line interface (CLI), and backend daemon. A PostgreSQL database serves as a queue manager and log archive for all Rector processing.

Results: Rector has so far shepherded over 700,000 LROC images through the SOC pipeline to the PDS archive in the form of Experiment Data Records (EDR) and Calibrated Data Records (CDR). Rector is also being used to process scanned images from the Apollo Digital Flight Film Archive (a total of 8883 images so far). Additionally, Rector is used to streamline image mosaicking and other image analysis projects that are also archived as PDS Reduced Data Records (RDR). Over time Rector has evolved such that it can efficiently allocate resources and appropriately prioritize between tasks with little human intervention. Rector currently manages a cluster composed of 466 CPU cores operating at an aggregate speed of ~1.7 TFLOP/s as measured by the high performance linpack test. To date, Rector has processed > 2.5 million ad-hoc jobs and > 17 million nominal pipeline jobs.

The Rector web-based interface provides easy to use job tracking and exception management tools. Active procedures are listed on one side of the page with status columns across the top. At a glance, a user can see job status for any procedure. Processing exceptions and procedure output are clearly visible, and items can be resubmitted or cleared as appropriate with a single click.

Rector has proven to be time-saving relative to the other solutions (listed above) in that the backend daemon, together with the database, control the queue and what items will be run through what procedures based on memory, CPU utilization, and procedure priority. This queue control keeps the user from having to initiate and manage almost 100 procedures (for LROC and Apollo processing) across the LROC SOC HPC cluster (a nearly impossible task).

Conclusion: Rector has met or exceeded all of the original design objectives, and it has scaled from the original 16 cores to the current 466 cores.

Future Work: At the current cluster size of 466 cores, Rector is approaching a limit on the concurrency it can easily manage. This limit becomes more apparent when running more than 200 jobs concurrently that each complete in less than 10 seconds, and manifests as unallocated cores despite work being available. Given the success and usefulness of Rector in managing exceptions and handling priorities, work is underway to take the web and CLI interfaces and combine them using Torque, an HPC OpenPBS variant. This enhancement should allow scalability far beyond what Rector can currently handle without sacrificing any features.

Trajectory Browser Website, Cyrus Foster, NASA Ames Research Center, Moffett Field, CA, USA

The Trajectory Browser is a web-based tool developed at the NASA Ames Research Center to be used for the preliminary assessment of trajectories to small-bodies and planets and for providing relevant launch date, time-of-flight and ΔV requirements.

The site hosts a database of transfer trajectories from Earth to asteroids and planets for various types of missions such as rendezvous, sample return or flybys. A search engine allows the user to find trajectories meeting desired constraints on the launch window, mission duration and ΔV capability, while a trajectory viewer tool allows the visualization of the heliocentric trajectory and the detailed mission itinerary.

The anticipated user base of this tool consists primarily of scientists and engineers designing interplanetary missions in the context of pre-phase A studies, particularly for performing accessibility surveys to large populations of small-bodies. The educational potential of the website is also recognized for academia and the public with regards to trajectory design, a field that has generally been poorly understood by the public.

The website is currently hosted on NASA-internal URL http://trajbrowser.arc.nasa.gov/ with plans for a public release as soon as development is complete.

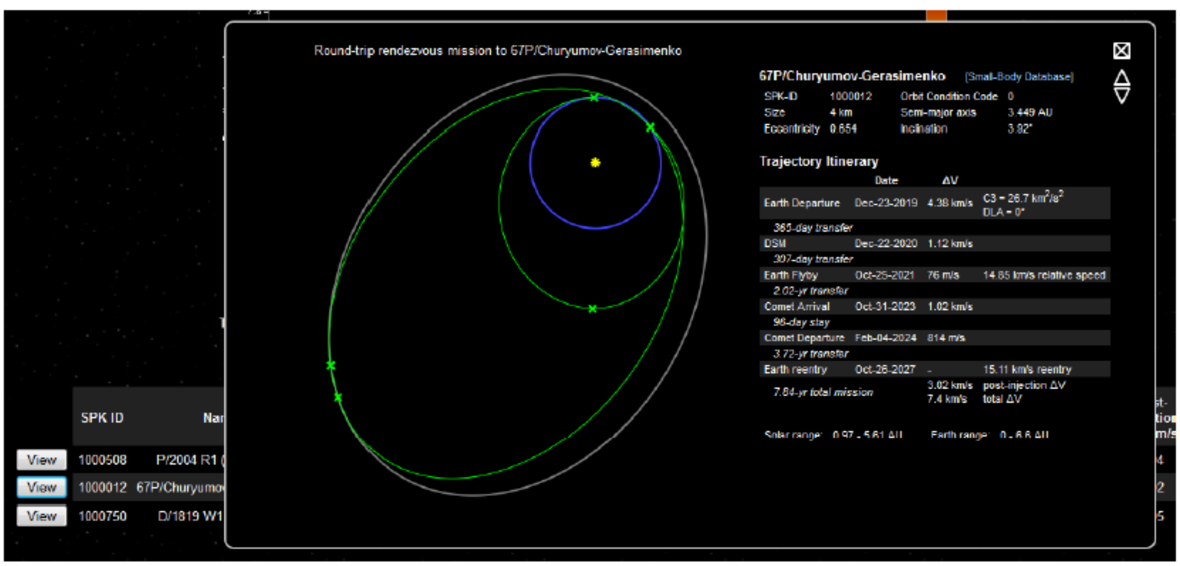

Figure 1. Screenshot of Trajectory Browser website

Using JMARS and DaVinci to Layer Diverse Image Sets and Collect Precision Measurements for Remot Sensing Analysis. S. L. Francies (steviefrancies@asu.edu)[1], C. S. Edwards, and P. R. Christensen[1], [1]Mars Space Flight Facility, Arizona State University, Mailing Address: PO Box 876305, Moeur Building, Room 131, Tempe, AZ 85287.

Introduction: With planetary datasets available from over three decades of orbiter missions to Mars, the possibilities for innovating data analysis techniques and making new discoveries are endless. Many software tools have been developed as platforms for planetary scientists to integrate Mars datasets. This abstract presents examples for how the Java Mission-planning and Analysis for Remote Sensing (JMARS, jmars.asu.edu) application can be used as a tool to apply such integration techniques.

Software Application: JMARS [1] is a geospatial information system developed at Arizona State University's Mars Space Flight Facility. This tool provides the user access to and allows for the analysis of data from instruments aboard various planetary missions without the arduous task of downloading, calibrating, geo referencing, and generating browse products for every instrument from every mission. This software tool gives viewers access to data acquired during NASA's missions to Mars including the Viking 1 & 2 orbiters, Mars Global Surveyor, Mars Odyssey, and Mars Reconnaissance Orbiter. Users are also able to analyze returned data from the European Space Agency's Mars Express orbiter. Every mission has built on its predecessor, providing higher spatial resolution, higher spectral resolution and higher surface and temporal coverage; JMARS is the only tool that allows users to easily access and analyze the data within a single application.

Methodology Overview: JMARS is currently used extensively as a tool for users to acquire thermal infrared data for the surface of Mars. With more recent high resolution imagery returned from HiRISE (High Resolution Imaging Science Experiment) [2], users are now able to select thermal data values from precise locations identified with visual references from the high resolution imagery (**Fig. 1**). The collected nighttime surface temperature data from THEMIS (Thermal Emission Imaging System) [3] can then be used to derive many surface properties at that precise location. Derived properties range from thermal inertia, size and sorting of sediment grains, to advanced compositional analyses.

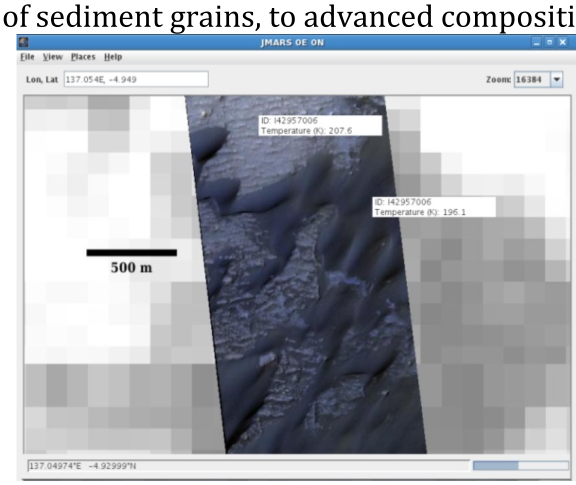

Figure 1. JMARS gives pixel values of thermal infrared data from THEMIS by hovering over image with mouse curser; HiRISE color image is superimposed for visual reference.

Layering and Integration: JMARS users can layer, toggle on/off, vary opacities, merge, and colorize all datasets within the application. One example of this functionality involves layering high resolution visible imagery over THEMIS colorized nighttime infrared temperature imagery in order to pinpoint and extract single pixel values of surface temperature. For this method, the THEMIS PBT (Projected Brightness Temperature) IR products can be set to appear completely transparent in the viewing window while the user locates the site of interest with HiRISE imagery. This technique has been extensively applied within Gale Crater; the locality hosts several sediment deposits that have been analyzed in this fashion in order to understand the origins of the deposits based on nighttime surface temperature.

Additional Tools: Used alongside JMARS, DaVinci (davinci.asu.edu) is a tool that allows for the loading of a variety of fully numeric data products and the straightforward manipulation of remote sensing image and spectral data. While it is capable of manipulating thousands of images and other planetary datasets at once, DaVinci is just as important in the analysis of single pixel values from remote sensing imagery. Users are able to perform complex functions within DaVinci to derive related surface properties. For example, in Gale Crater, or other locations on Mars, the user is able to input pixel values of the nighttime surface temperature with accompanying metadata provided by JMARS to calculate respective thermal inertia values and derive sediment grain size for aeolian materials [4][5][6].

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The Lunar Mapping and Modeling Project—The Application of Information System Technologies to Support Return to the Moon and Beyond. R. French[1], R, Haehnel[2], T. Hare[3], E. Law[4], S. Malhotra[4], K. Muery[1], M. Nall[1], and S. Talabac[5]; [1]Marshall Space Flight Center, [2]Cold Regions Research and Engineering Laboratory, [3]U.S. Geological Survey, Flagstaff, AZ, [4]Jet Propulsion Laboratory, [5]Goddard Space Flight Center.

Introduction: The Lunar Mapping and Modeling Project (LMMP)[1], led by NASA's Marshall Space Flight Center, has developed a Web-based Portal and a suite of interactive visualization and analysis tools to enable lunar scientists, engineers, and mission planners to access mapped lunar data products from past and current lunar missions; for example, Lunar Reconnaissance Orbiter, Apollo, Lunar Orbiter, Lunar Prospector, and Clementine.

The Portal allows users to search, view, and download a vast number of the most recent lunar digital products including image mosaics, digital elevation models, and in situ lunar resource maps such as soil maturity and hydrogen abundance.

The Portal also provides a number of visualization and analysis tools that perform lighting analysis and local hazard assessments, such as slope, surface roughness, and crater/boulder distribution. Through the Portal, users may also access two visualization and analysis software applications: Lunar Mapper (LM), a thin client Web-based Geographic Information System (GIS)[2] and ILIADS (Integrated Lunar Information Architecture for Decision Support), a rich GIS client that runs on a user-supplied desk side or laptop PC/Mac computer.

The data and tools available through the LMMP allow users to perform in-depth analyses to support lunar surface mission planning and system design for future lunar exploration and science missions. The combination of the Portal, LM, and ILIADS fosters detailed scientific analysis and discovery, and opens the door to educational and public outreach opportunities.

The LMMP's system infrastructure design uses a combination of custom software, commercial and open-source components, off-the-shelf hardware, and pay-by-use cloud computing services. Compute-intensive functions employ a workflow system that allows jobs to be outsourced to the cloud. Highly parallelizable jobs employ a Map Reduce framework to increase performance and lower latency. A system and data security layer allows the system to manage private, competition-sensitive, and public data and services. It also provides a transparent bridge to the Planetary Data System (PDS)[3] to allow users access to NASA archives. Other planetary data servers that adhere to the Open Geospatial Consortium (OGC)[4] Web-services protocol standards may also be accessed. Its Web interfaces, iPad and Android mobile platforms, and large screen Multi-touch with 3-D allow for a rich browsing experience.

The LMMP was targeted to support "Return to the Moon." However, the Portal and the client applications LM and ILIADS are designed to support other planetary bodies; for example, asteroids, and planets including the Earth. This system can easily be extended to support space exploration and Earth science.

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ISIS and GRASS GIS Integration—Overview and Updates. A. Frigeri[1], T. Hare[2], M. Neteler[3], C. Federico[4], R. Orosei[1]; [1]Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, via del Fosso del Cavaliere 100, 00133 Roma, Italy (e-mail: alessandro.frigeri@ifsi-roma.inaf.it); [2]U.S. Geological Survey Astrogeology Science Center, Flagstaff AZ; [3]Fondazione Edmund Mach, Research and Innovation Centre, S. Michele all'Adige, Trento, Italy; [4]Geologia Strutturale e Geofisica, Dipartimento di Scienze della Terra, Universit´a degli Studi di Perugia, Perugia, Italy.

Introduction: The ISIS-GRASS project started as a set of tools and configuration scripts developed to combine the capabilities of the Integrated Software for Imagers and Spectrometers (ISIS, [1,2]) and the Geographic Resources Analysis Support System (GRASS, [3]) within a common working environment [4]. The complementary functionalities of ISIS and GRASS allow the planetary scientist to process a wide range of planetary data and to use the large number of spatial analysis tools available within a geographic information system (GIS) environment. Maps produced within this environment can be exported using Open GIS Consortium (OGC) interoperable digital formats and transferred over the network as files or served as Web services.

ISIS and GRASS characteristics: The development of software that converged into the current ISIS project started in 1970s at the U.S. Geological Survey (USGS) in Flagstaff, Arizona. The modular architecture allowed ISIS to survive through more than 40 years of developments. Since the 1990s the major milestones of the development of ISIS are represented by the porting to GNU/Linux systems, the refactoring in C++ (with ISIS version 3), and the introduction of a Qt-based graphical user interface (GUI).

The GRASS GIS project has experienced an evolution similar to the one of ISIS. Initially developed by the U.S. Army Construction Engineering Research Laboratory (USA-CERL), since 1991 it is maintained by an international team of developers and researchers and is distributed under the term of the General Public License, the same license of the GNU/Linux operative system [5]. GRASS shares the same modular architecture of ISIS with specialized software modules (more than 300 in the official distribution) that require a small memory footprint. The developments of the last 10 years introduced a GUI and the possibility to use the popular Free Open Source desktop GIS QuantumGIS as an integrated GUI within a GRASS session [3].

GRASS has been ported to most existing hardware platform and operative systems, from clusters to palmtop computers, and ISIS runs on most common UNIX-like operative systems. Both ISIS and GRASS come with software licenses that allow to access and improve the source code, encouraging users and developers to introduce new features or identify possible bugs and suggest solutions. ISIS is specialized in processing planetary instruments' data from the archived format (or level 0) to the map projected level (level 2) and offers a wide range of software modules to perform reprojection, mosaicking, radiometric and photometric correction, image registration, and pattern matching. GRASS GIS offers modules for these tasks that are not specialized for planetary data, but it provides advanced support for morphologic analysis, statistical analysis, and classification that are beyond the scope of ISIS. Being a full featured GIS, GRASS supports the vector data import/export, editing, and spatial analysis.

To provide a complete working environment where the user can process archive data and produce derived maps, we have worked on some solutions to allow a seamless integration of ISIS and GRASS.

The ISIS-GRASS working environment: The portability of ISIS and GRASS allows for the development of a integrated version of the architectures and operating systems that these two projects have in common: GNU/Linux, Solaris, OS X.

Our work was focused on three major points: (1) to control the two software systems from the same shell, (2) to share the same cartographic reference system, and (3) to avoid as much as possible the replication of data generated by export and import processes without compromising efficiency.

Having ISIS libraries and modules available on a customized GRASS session, named ISIS-GRASS, the user has access to modules from both projects within the same command line interface (CLI). This allows the user to run scripts and to access the GUI of both ISIS and GRASS when needed.

ISIS provides tools to project data on planetary surfaces. To make this data correctly available to GRASS, it has been necessary to develop a GRASS module that produces an ISIS-compatible projection definition. This allows to project ISIS data in the same cartographic reference system (CRS) used in the GRASS session. The new module, named g.isis3mt, also features options for defining the resolution and the extents of the projected data.

With the increase of resolution and coverage of the instruments, data volumes can be very large, and within ISIS-GRASS we tried to minimize data duplication. The major source of data replication between two different software is commonly represented by the import/export process. Thanks to the capabilities of the Geographic Data Abstraction Library (GDAL, [6]) which is used by various GRASS modules, ISIS data cubes can be registered within the GRASS session without being converted. This way, data processed by ISIS modules are accessible to GRASS GIS processing modules, without a significant performance reduction.

Figure 1 offers a screenshot of a typical ISIS-GRASS session using high-resolution imagery and topography for interpretative thematic mapping.

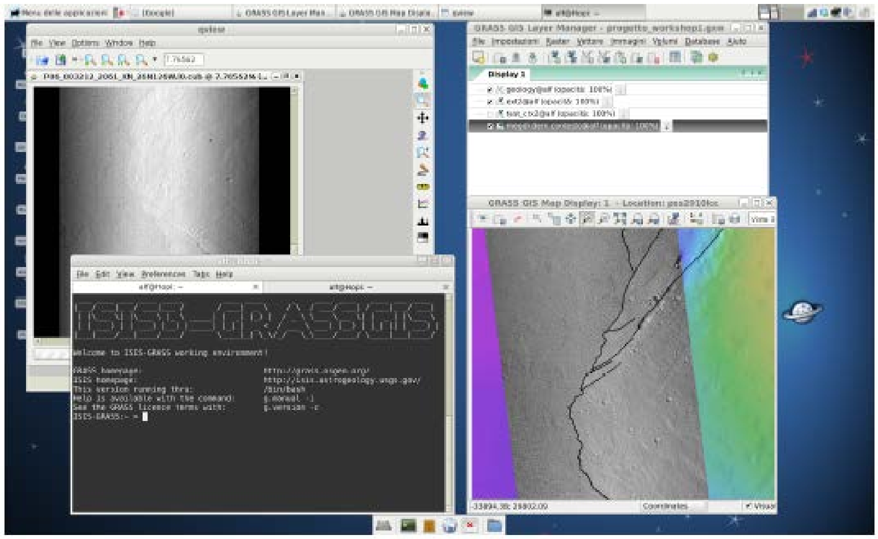

Figure 1: A screenshot of a desktop running a ISIS-GRASS session for the Halex Fossae region of Mars. On lower left, the Command Line Interface allows to enter commands by typing and to run scripts. On top left, ISIS' *qview* shows unprocessed (level 0) data from CTX. The same CTX image processed to level 2 using parameters generated by *g.isis3mt* is displayed in the *GRASS* Map Display (lower right) over a topographic map and used for mapping the geologic features of the area (unit's boundaries and tectonic features shown as black vector lines).

Status of the project and updates: Until the first half of 2012, the tools developed for integrating GRASS and ISIS have been distributed as a digital compressed archive downloadable from the first author's Web site, with the same license of GRASS [4].

The GRASS configuration file with the definition of ellipsoidal parameters for bodies of the Solar System included in the published archive has been submitted to the main GRASS code repository by Hamish Bowman of the GRASS developers team, as revision 48928 in the GRASS trac system (http://trac.osgeo.org/grass/). This, together with other planetary science-related tickets issued to the GRASS trac, will lead to a better support for working with planetary data in the future official GRASS releases.

Since the publishing of the code, some minor patches and modification have been necessary, and several workstations and desktop PCs run the ISIS-GRASS environment on GNU/Linux and OS X. To allow a more flexible development of the ISIS-GRASS scripts and tools we have moved the source code to a distributed version control system (DVCS) which includes issue tracking and wiki. The code, the documentation and configuration files are now available at https://bitbucket.org/afrigeri/isisgrass. This way, users can issue a ticket about a problem, propose and submit new modules and scripts, documentation can be developed collaboratively and developments can be easily tracked.

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The Astropedia Annex for the PDS Imaging Node—A Repository for Planetary Research Products. L.R. Gaddis[1], T.M. Hare[1], M. Bailen[1], S.K. LaVoie[2]; [1]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ; [2]Jet Propulsion Laboratory, Pasadena, CA. (lgaddis@usgs.gov)

Introduction: The Imaging Node (IMG) of the NASA Planetary Data System (PDS) archives and delivers digital image collections from planetary missions [for example, 1]. Included among these collections are nearly 500 terabytes (TB) of digital image archives, ancillary data (such as calibration files and software, geometric data), software, tutorials and tools, and technical expertise to support users of this collection. The Astropedia Annex is a new facility under development by IMG to support scientists who use PDS data to create derived geospatial products that can be registered to a solid planetary body. Examples of geospatial derived products are cartographic and thematic maps of moons and planets, local and regional geologic feature maps, topographic and perspective views of planetary landing sites, tabular data containing unit information derived from planetary data, and others. Many of these products will have been developed as a result of data analysis programs, often many years after active missions (and their accumulating archives) have ended.

Astropedia: The U.S. Geological Survey (USGS) Astrogeology Science Center hosts the Astropedia, a new online data portal that provides (http://astrogeology.usgs.gov/astropedia; [2]) a search interface to the decades of image and derived products created by Astrogeology. Many of these products have been derived from PDS data collections and are in the form of cartographic maps, digital image mosaics [for example, 3, 4], and geographic information system (GIS) projects and individual layers [for example, 5]. The goals of Astropedia are to provide quick and easy access to derived data products, a robust search interface supported by thorough metadata labeling of each products, cross-references to ancillary data and other related products, downloads in a variety of image formats, and interaction through a Web map services (WMS) interface that is easily maintained. The Astropedia data portal can be searched using multiple methods including target information, geospatial coordinates, mission or instrument keywords, and author and organization, as well as descriptive information available from the metadata.

The metadata standard used for Astropedia was created by the Federal Geographic Data Committee (FGDC) with small modifications to better support planetary data [6, 7]. These same standards, along with existing PDS3 standards [8], are being used to help develop updated image and file labels for PDS 4 products, the next generation archive now in development by PDS [9, 10]. Planetary data products such as published USGS maps and Lunar Mapping and Modeling Project (LMMP) results are already required to have associated FGDC records [11].

FGDC geospatial metadata, sometimes called “data about data,” is documentation that describes the rationale, authorship, attribute descriptions, spatial reference, errors, and other relevant information about a given set of data. Every data product served by Astropedia is required to have extensive associated metadata that follows the FGDC metadata standard. Use of these metadata standards will improve search and retrieval of data and allows us to greatly expand both the holdings and accessibility of planetary derived data products.

Approach: Astropedia is built entirely on an open-source infrastructure that includes the PostgreSQL database with the PostGIS add-ons [12] to support geographic objects, Alfresco Document Management System (DMS) as a data repository [13], Openlayers for Web-based interactive mapping [14], and Mapserver as a WMS to serve planetary geospatial data. A Web-based search form enables quick access to the Astropedia catalog. The interface provides a typical keyword-based search form and an interactive mapping tool that allows selection of planetary targets on which the user can specify a geographic bounding box and seek location-based search results. The map bases support Simple Cylindrical, North, and South Polar Stereographic projections. Users can restrict searches based on instrument or data type (for example, image mosaic, topography, geology), mission dates, data types, and more.

Astropedia Annex Requirements: The Astropedia Annex of the PDS Imaging Node will accept submission of geospatial products with PDS planetary data heritage. Submitted products will be required to have extensive metadata that meets PDS standards and benefits from FGDC standards. Data submissions and metadata development will be conducted through a forms-based Web site that guides users through the process and specifies which data entries are required for product metadata. Examples of required metadata entries are originator name and contact information, geographic coordinates, target body, descriptive caption, publication date, lineage and source information, validation and review status, quality and completeness assessments, linkages to other products, literature citations, etc. The information entered will be converted to xml format for ingestion and retrieval through the Astropedia content catalog. These detailed metadata can readily be viewed for any product and will facilitate easy access through the existing Astropedia search interface.

Geospatial products submitted to Astropedia Annex are required to be validated and reviewed prior to publication. Products that have already been published in professional science journals will be considered reviewed. Other products will require documentation of peer review by at least three researchers; IMG staff will assist with these reviews as needed. All data will be validated by PDS staff before public release in the Astropedia Annex.

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PDS Map-a-Planet Cartographic Web Service. P.A. Garcia, C.E. Isbell, J.M. Barrett, and L.R. Gaddis; U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ. (pgarcia@usgs.gov)

Introduction: The NASA Planetary Data System (PDS) Map-a-Planet Web service is a Web-based data delivery system (http://www.mapaplanet.org) that serves a variety of digital cartographic map products for several hard-body planets and moons of the Solar System [1-3]. Map-a-Planet (MAP) originated in 1998 [1] as part of the PDS Planetary Image Atlas and initially served only the Viking Orbiter global mosaic (a mosaicked digital image model or MDIM, [4, 5]). As the popularity of MAP grew, it was redesigned for increased interoperability and expanded for release as an independent Web site [3]. MAP now serves scientifically accurate planetary global mosaics via a Web interface that allows the user to visually navigate planetary imagery and create customized image maps. Over time, members of the planetary science community, educators, and others requested increased expansion of the data available in the MAP system. In response to these requests, we have continued to increase the number and types of datasets available to users. Here we describe MAP capabilities, data, and recent updates.

Cartographic Products and Data Served: MAP provides access to multiple diverse and scientifically interesting datasets. The system uses ISIS (Integrated Software for Imagers and Spectrometers) image-processing software and tiled MDIM data to create cartographic image maps of desired targets and regions [5-12]. An MDIM is compiled (typically with funding from the NASA Planetary Cartography Program) from mosaics of spacecraft images that have been geometrically, radiometrically, and photometrically corrected to provide a cartographically accurate and uniform representation of a planetary surface, usually in a sinusoidal equal-area map projection. The planetary bodies currently supported by MAP are Mars, Venus, Mercury, the Earth's Moon, four Galilean satellites (Callisto, Europa, Ganymede, Io), and five moons of Saturn (Rhea, Dione, Tethys, Iapetus, Enceladus).

Map-a-Planet Browser Interface: The MAP web interface allows for visual browsing of each dataset (fig. 1). This includes panning, zooming, defining latitude and longitude extents and selection of various map projections, image size, and resolution, RGB band selection, graticule placement, and application of image density stretch options. The browser interface then provides direct access to a JPEG image of the user defined area. In addition, an "order system" allows users to request a wider variety of user defined custom output products for later download.

MAP Capabilities: *Cartographic Processing*: In 2005–2006, the MAP site was redesigned to provide users with a more contemporary interface for searching for, selecting, and downloading cartographic products [3]. Users can readily create and modify custom image maps of any area of a number of planetary bodies in a variety of resolutions, sizes, map projections, density stretches, and image formats. In 2008–2009, the underlying MapMaker engine software was completely overhauled and now leverages the extensive development efforts invested in the U.S. Geological Survey (USGS) Astrogeology's "freeware" ISIS2 cartographic processing software ([13-15], http://isis.astrogeology.usgs.gov/Isis2/isis-bin/isis.cgi). The direct use of ISIS 2 software has significantly increased both the speed and the number of processing capabilities available for use within MAP. In keeping with current evolutions of ISIS, use of the newer ISIS 3 software [16] is also being tested for use in MAP. Work on a new Web service called Map-a-Planet 2, leveraging off the extensive development work done for MAP, is slated to begin soon.

Order Formats: In addition to JPEG, TIFF, and GIF image formats, MAP offers users the ability to order maps in 8-bit, 16-bit or 32-bit for PDS, raw , and ISIS2 image formats. Products are delivered to an ftp address for easy access. Users can now choose between Nearest Neighbor and Bilinear Interpolation methods for resampling map products. The long-awaited implementation of polar stereographic map projection in MAP is complete and users can now order maps from all data sets in the polar stereographic projection.

Derived and User-Defined Products: MAP users can now apply six predefined functions as well as virtually unlimited custom arithmetic operations to the data served. Selected elemental abundance, including three FeO weight percent (wt%) [18-20] derivations and TiO_2 wt% [18] and two optical maturity (OMAT [20, 21]) functions, are available for selection when ordering Clementine ultraviolet–visible spectroscopy (UVVIS) multiband products. The user-defined arithmetic operation function, available through the "Order" page in MAP, allows users to enter mathematical expressions and operators to be applied to any ordered dataset. Examples of such applications include single-band manipulation (for example, additive and multiplicative corrections as in radiometric calibration) or multiband functions such as ratios, differences, and more sophisticated capabilities such as spectral curvature, band depths, and band tilt maps [for example, 22].

New Data: During the last few years we have increased the number of data sets accessible to via Map-a-Planet. Among the more recently added datasets are the Kaguya Laser Altimeter Topographic Map [29], Clementine Near Infra-Red 6-Band Mosaic [24], Lunar Orbiter USGS Mosaic [17], Lunar Prospector Elemental Abundance data [23], Mars Global Surveyor (MGS) Thermal Emission Spectrometer (TES) Albedo and Thermal Inertia maps [25], MGS Mars Orbiter Camera (MOC) Wide Angle Mosaic [26], MGS Mars Orbiter Laser Altimeter (MOLA) maps [27], and MDIS/Mariner 10 Global Image Mosaic of Mercury [28].

Summary: The Map-a-Planet cartographic Web services offer substantial and unique cartographic functionality. This includes user interface and order system access to user-defined custom images maps of a wide variety of datasets. The development team continues to periodically add high-interest data to the system.

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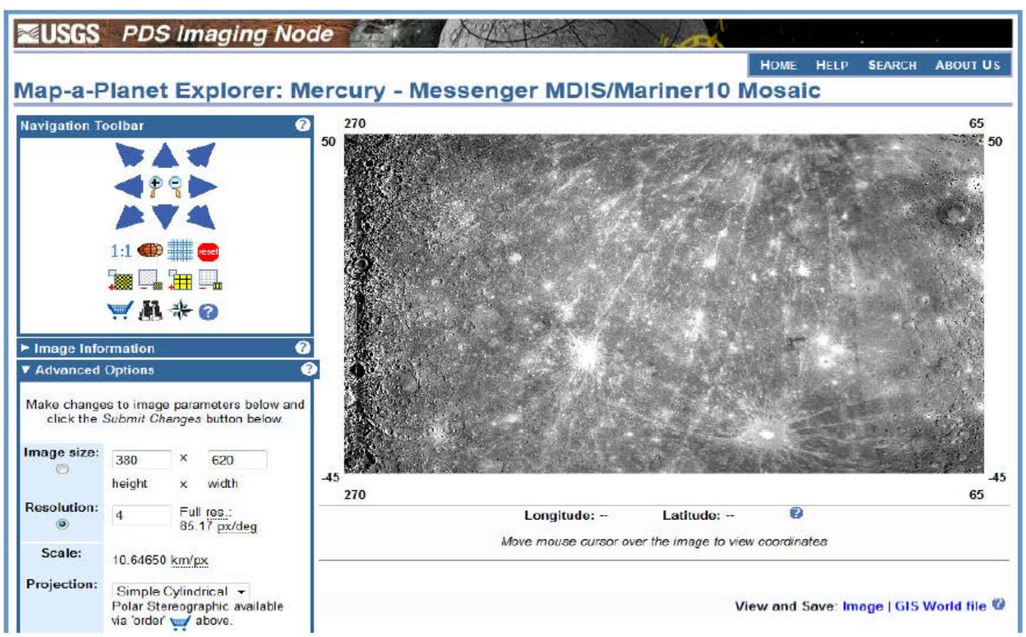

Figure 1. An example of the Map-a-Planet user interface featuring the MESSENGER MDIS/Mariner 10 Mosaic [28] of Mercury. The data product is created using MapMaker and ISIS 2 software.

OPUS: A Tool to Obtain Outer Planets Data from the Planetary Data System. M. K. Gordon, L. Ballard, M. R. Showalter, N. Heather, SETI Institute, 189 Bernardo Ave., Mountain View, CA 94043 mgordon@seti.org

Introduction: We will demonstrate the use and capabilities of OPUS (Outer Planets Unified Search) and briefly discuss additional capabilities under development.

Identifying the specific data you need within the Planetary Data System has become more challenging with the huge increases in the amount of data held. The Planetary Rings Node holdings are approaching 2 million individual data product. OPUS is a powerful, form based tool at the Rings Node which allows users to search our holdings using a wide range of relevant parameters. We will describe how to quickly find the specific data you need.

OPUS currently supports searches for data obtained by three Cassini instruments (CIRS, ISS, VIMS), Galileo SSI, New Horizons LORRI (Jupiter encounter), Voyager 1 and Voyager 2 ISS. Work is underway to expand the coverage to additional instruments including Cassini UVIS and HST observations that include the outer planets.

While the search parameters currently available are optimized for planetary rings, we are currently expanding the capabilities to support searches of planets and satellites as well. Search parameters will include latitude, longitude (in various systems if necessary), incidence, emission, and phase angles, spatial resolution, time, and wavelength. Unlike other search engines that sample just a few points on an image, the metadata underlying OPUS's capabilities is generated via sampling a fine grid of points within the field of view.

OPUS search results include preview images or footprint diagrams, and tables of information about each observation. These can be used to browse the search results and can be downloaded along with the selected data products. Recently added features include the capability to search for Cassini ISS movie sequences, to receive calibrated versions of Cassini ISS, and to receive calibrated and geometrically corrected Voyager images.

We will also discuss a prototype of OPUS2, currently under development. OPUS2 will introduce more powerful capabilities for cross-correlative searches among multiple data sets, using a streamlined user interface.

OPUS: http://pds-rings.seti.org/search/

Systematic Generation of Spectral Image Cubes from Cassini/CIRS Data. N. Gorius[1], J. Spencer[2], C. Howett[2] and M. Segura[3], [1]Catholic University of America (nicolas.gorius@nasa.gov), [2]Southwest Research Institute, [3]University of Maryland.

The Composite Infrared Spectrometer (CIRS) on board the Cassini orbiter is a dual interferometer acquiring data from 7 to 1000 microns (10 to 1400 cm-1) and has 3 focal planes referred to as FP1 (single circular field of view), and FP3 and FP4 (each a linear array of ten square pixels). The CIRS data volumes currently delivered to the PDS by the instrument team are time-ordered listings in multiple files, containing uncalibrated and calibrated spectra, and associated information on pointing, navigation and spacecraft orientation.

To simplify the problems of exploring the large and complex CIRS dataset and to assist with comparison with other instruments, we are generating CIRS spectral image cubes, following the PDS format, for the entire CIRS data set. This effort is part of the Cassini Higher Order Data Product program and is funded by the Cassini project. For each planned spacecraft observation, and for each target in the field of view during that observation, we generate a uniquely identified data product using two projection schemes. The first projection is in the plane of the sky, producing an image of the target comparable to the view seen from the spacecraft, thus preserving the viewing geometry of the observation and limb information (Fig. 1). The second projection is onto an equirectangular latitude/longitude grid to allow comparison with other mapping data (Fig. 2). In each case, each spatial pixel contains the average of all spectra falling on that pixel, in addition to backplanes giving geometrical information for the pixel. For each cube, we also generate an image in the spatial plane which can be used to browse the products and assess data coverage and quality. We plan to make the data products searchable via the Planetary Image Atlas at the PDS Imaging Node

Data products for Saturn, Titan, and the icy satellites are currently under review by PDS and should become part of the official CIRS delivery by the end of 2012. We are now developing similar products for Saturn's rings.

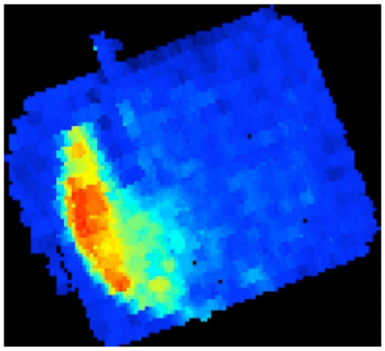

Figure 1 An example of one of the plane-of-sky image cubes generated by this program. This is a 600 – 1100 cm^{-1} image of Phoebe's thermal emission obtained with the CIRS FP3 detector on June 11th 2004 (observation 000PH_FP3REGION003). The cube contains spectral and geometric information at every spatial pixel shown here.

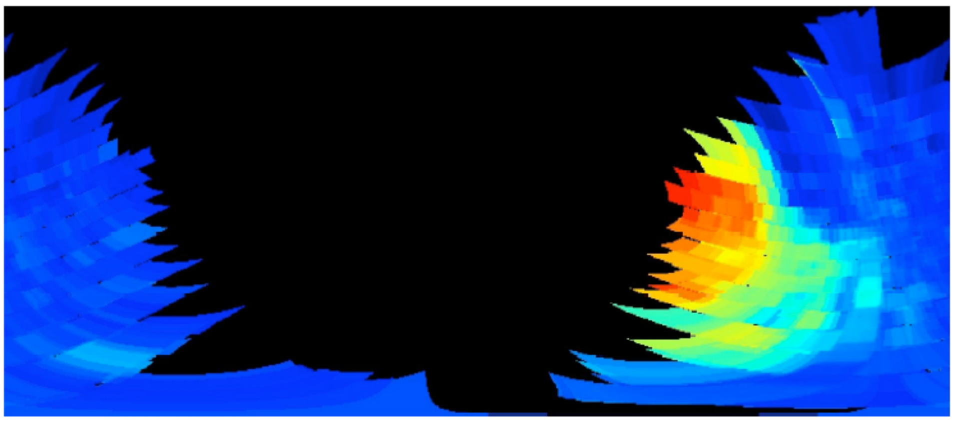

Figure 2 The corresponding latitude / longitude image cube of Phoebe, derived from the same observation as Figure 1.

The UCL RPIF: A Planetary Data Portal for the UK and Europe. P. M. Grindrod[1,2] and J. -P. Muller[2,3], [1]Earth Sciences, UCL, Gower Street, London, WC1E 6BT, UK, [2]Centre for Planetary Sciences at UCL/Birkbeck, Gower Street, London, WC1E 6BT, UK, [3]Space & Climate Physics, UCL, Gower Street, London, WC1E 6BT, UK. (p.grindrod@ucl.ac.uk, jpm@mssl.ucl.ac.uk)

Introduction: The Regional Planetary Image Facility (RPIF) at UCL is a NASA facility that provides two fundamental roles: (1) the RPIF houses rare and unique hard-copy and digital planetary data from missions spanning four decades of space exploration, which forms part of the Geology Collection, itself part of UCL Museums and Collections, and (2) the RPIF 3D facility provides hardware and software necessary for accessing, processing and analyzing planetary data for internal and external users. Both of these roles are unique in the UK. The current Director of the RPIF is Prof. Jan-Peter Muller (MSSL), and Dr. Peter Grindrod (Earth Sciences) is the Data Manager. Here we provide an overview of current facilities at the UK RPIF, including case studies, guest access and future plans.

RPIF Planetary Collection: The UCL RPIF houses approximately 30,000 objects, including photographs and negatives, slides, videos, maps, CDs, and publications. The extensive photographic collection includes rare images sets, such as a complete set of Magellan Venus C1-MIDR stereo images and F-Map large-scale images, and a large collection of prints and negatives of Mariner 9 and 10, Lunar Orbiter, Viking, Voyager, and Apollo Panoramic Camera images. Duplicates and negatives are stored in specialist storage off-site. Digital copies of images on CDs and DVDs and other data from Magellan, Voyager, Pathfinder and early Mars Global Surveyor are stored on site. Approximately one-third of the collection is currently in offsite storage, but is being returned to the UCL main campus. The hard-copy archives within the RPIF are part of the Geology Collection, which falls under the larger jurisdiction of UCL Museums and Collections. The UCL RPIF was the first RPIF outside of the US, remains the only RPIF in the UK, and is one of only five in Europe.

RPIF 3D: Since autumn 2009, the RPIF has provided hardware and software necessary for accessing, processing and analyzing planetary data, a service that is available to both internal and external users [1].

Planetary Data Facilities. At present the RPIF 3D houses 1 planetary data processing machine and 1 stereo workstation. For data processing we use a Mac quad G5 (running at 2.8 GHz) with 4 GB-RAM and 1000 GB-diskspace with dual 30-inch (2560 x 1600 pixel displays) and a 3D mouse. This machine runs ISIS 3.3, QPS Fledermaus 6.7, and ITTvis ENVI/IDL. The stereo workstation is a Dell dual-processor (running at 2.5 GHz) with 4 GB-RAM and 1000 GB-diskspace with stereo output to a CRT screen, a 27- inch (1920 x 1200 pixel) display. The installed software includes ESRI ArcGIS 10 and BAE Systems SOCETSET v5.4.1.

The RPIF also owns and manages a 16 inch MagicPlanet spherical projection display and a portable Geowall for display of stereo products created using the RPIF 3D at exhibitions.

Guest users and training. The RPIF 3D is a portal to allow geoscientists in the UK and the European mainland to process planetary data in general, but in particular produce stereo digital elevation models (DEMs) from HiRISE [2] and CTX data to combine with processed CRISM data. Users wishing to access the guest facilities are required to attend a training course, provided by the facility. The first of these training workshops was run in Summer 2009, with about half of the participants subsequently booking and using the facilities. A further two training workshops are planned over the next few years, and interested people should email the Data Manger Peter Grindrod (p.grindrod@ucl.ac.uk) for further information.

Case Studies: To date, the RPIF 3D facilities have been used to produce 28 HiRISE and 22 CTX stereo DEMs, resulting in seven individual projects either published or in review [e.g. 3,4]. These data products have been provided for 6 separate researchers in the UK and 3 from the rest of Europe. Here we outline some recent case studies to highlight the capabilities of the facility.

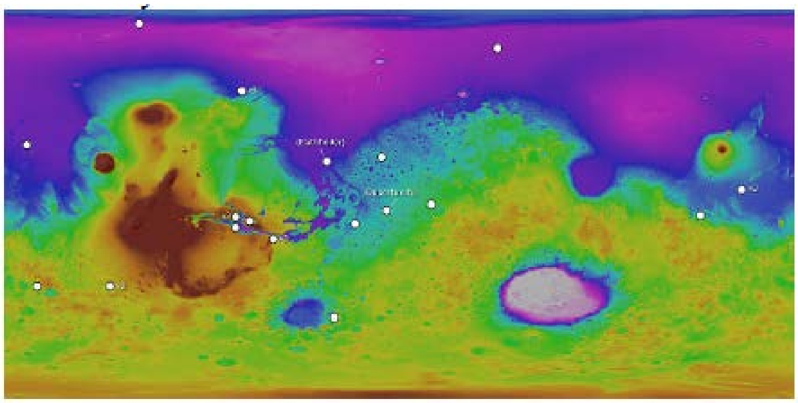

Figure 1. MOLA base map with the locations of HiRISE stereo DEMs produced at UCL RPIF.

Topography & geochemistry. Our recent studies have concentrated on combining HiRISE and CTX DEMs with complementary CRISM multispectral data (where available), in order to understand the complete geologic history of a region. This combination of data products provides a powerful tool when trying to understand the chemical and geomorphological stratigraphy of a region.

In one recent study [3] we identified a sequence of hydrous minerals that transitioned from phyllosilicate to sulfate /opaline silica in composition with increasing height in a probable sedimentary basin. Further studies of closed basins of this kind, which are likely Late Hesperian or younger in age can offer vital clues to understanding the paradigm of water on Mars.

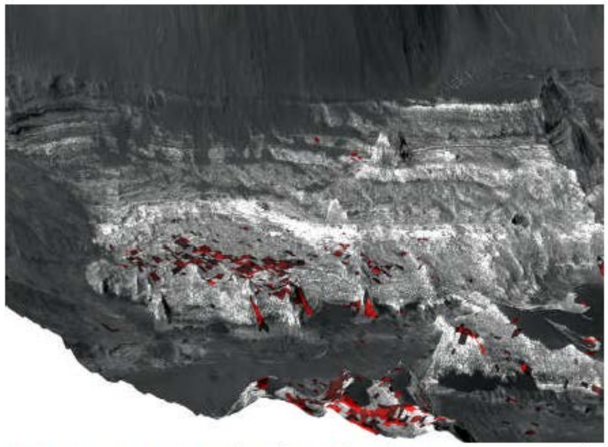

Figure 2. 3D perspective view of a HiRISE stereo DEM in Coprates Catena, with CRISM locations of Fe/Mg phyllosilicate-rich material towards the base of the trough.

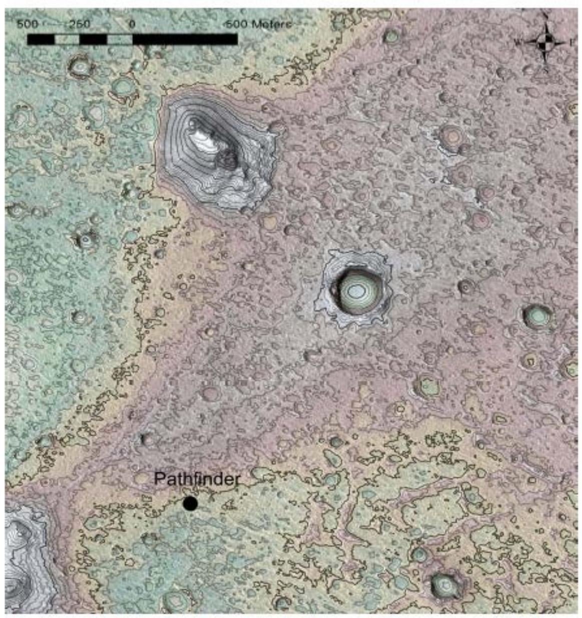

Figure 3. The Pathfinder landing site as revealed by a HiRISE stereo DEM produced at the UCL RPIF 3D.

Landing sites. We have produced stereo DEM products of landing sites on Mars in order to (1) compare the fidelity of orbital and in-situ data products, (2) test the capabilities of the facility in supporting landing site studies and operations, and (3) support outreach activities. Examples of these DEMs include the Pathfinder landing site in Ares Valles (Fig. 3) and the Opportunity landing site in Meridiani Planum (Fig. 4).

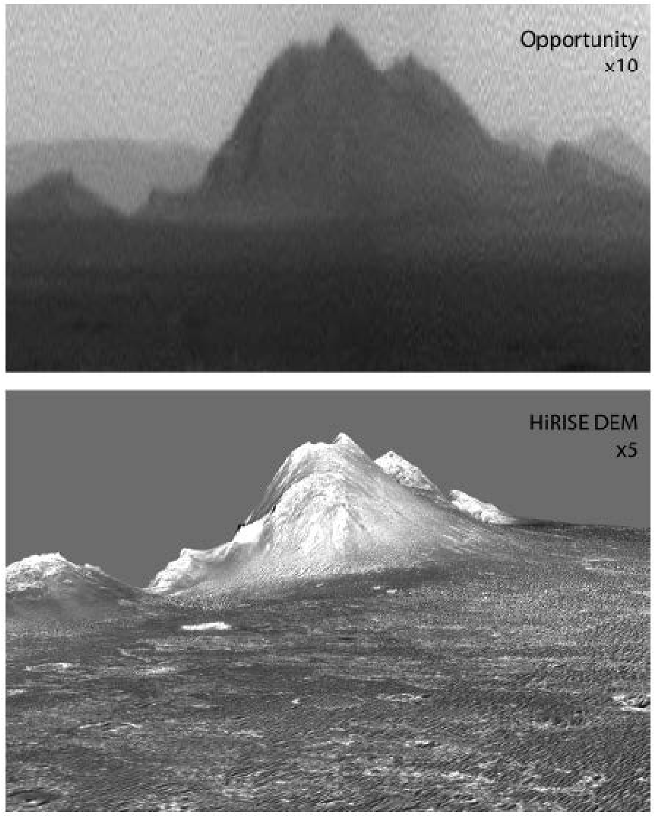

Figure 4. Comparison of Cape Tribulation as seen by Opportunity (top) and HiRISE DEM perspective view (bottom).

Future Plans: We will continue to develop the user facility, with funding already secured to upgrade the hardware and extend software licenses over the next five years. We welcome potential users and collaborators to contact us for more information.

References: [1] Muller J.-P. & Grindrod P.M. (2010) *EPSC2010,* #883. [2] Kirk R.L. et al. (2008) *JGR, 113*, E00A24. [3] Grindrod P.M. & Fawcett S.E. (2011) *GRL, 38,* L19201. [4] Grindrod P.M. et al. (2012) *Icarus, 218*, 178-195.

Acknowledgments: We thank all mission and instrument teams for providing a wealth of planetary data over the last 40 years, and in particular the USGS Astrogeology group for their support in sharing techniques.

The Regional Planetary Image Facility Network. J.J. Hagerty[1], and RPIF Network Node Directors and Managers; [1]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ (jhagerty@usgs.gov).

Introduction: NASA's Regional Planetary Image Facilities (RPIFs) are planetary data and information centers located throughout the United States, in Canada, and overseas. The U.S. locations are funded by both NASA (that is, the Planetary Geology and Geophysics Program) and their host institutions [1]. A network of these facilities was established in 1977 to "maintain photographic and digital data, as well as mission documentation. Each facility's general holdings contain images and maps of planets and their satellites taken by Solar System exploration spacecraft. These planetary data facilities, which are open to the public, are primarily reference centers for browsing, studying, and selecting planetary data including images, maps, supporting documentation, and outreach materials. Experienced staff at each of the facilities can assist scientists, educators, students, media, and the public in ordering materials for their own use" [2].

Since it was formally established, the network of RPIFs has expanded to nine U.S. facilities and eight facilities in other countries. The first RPIF to be established outside of the U.S. was in the United Kingdom in 1980 at University College London (UCL), and since then RPIFs have been set up in Canada, Finland, France, Germany, Israel, Italy, and Japan. Through its longevity and ability to adapt, the RPIF Network has leveraged its global reach to become a unique resource covering almost 60 years of international planetary science.

Historically the network nodes have had an inward focus, providing resources to local clients and communicating with other nodes only when the need arose. Using this methodology, the nodes of the RPIF Network have combined to serve an average of ~65,000 people per year since 2000. However, with the advent of simpler and more far-reaching forms of data transfer and sharing, it is clear that the nodes can operate together to provide the planetary science community and the public with greater access to: (1) archived mission products (for example, maps, photographs, films, and documents); (2) mission-enabling documentation (for example, data on previous mission design, development, implementation, and evaluation); (3) science and public research support, and (4) outreach experience and capabilities. Each node of the network has unique capabilities that meet one or more of the above criteria; however, by linking the nodes through a centralized Web site and database, it is now possible to provide a wider array of materials to a wider array of clients.

Resources: The RPIF Network, hereafter referred to as RPIFN, is staffed by experienced archivists who stand ready to assist in "Bringing planetary science data to you." Unique offerings of the RPIFN include, but are not limited to:

- All nodes of the Network have hardcopy and digital data, as well as supporting documentation from all U.S. and many foreign planetary missions flown since 1959.
- The online Earth Impact Database at the Canadian RPIF at the University of New Brunswick.
- More than 10,000 planetary images from Earth-based telescopes at the University of Arizona Lunar and Planetary Laboratory RPIF.

- A collection of near-IR reflectance spectra of small areas of the lunar surface at the University of Hawaii RPIF.
- An inventory of 60,000 U.S. Geological Survey (USGS) lunar and planetary maps, as well as field notebooks, drafts of seminal papers, and planning documents for lunar and planetary missions at the USGS Astrogeology Science Center RPIF.
- The Cornell University Meteorite Collection at the Cornell RPIF.
- An extensive collection of online maps, publications, and outreach tools maintained by the Lunar and Planetary Institute RPIF.
- The field analog terrains collection at the Arizona State University RPIF.
- The 3D Imaging Centre at UCL includes a stereo workstation for producing digital terrain models (DTMs) from High Resolution Imaging Science Experiment (HiRISE) and the Context Camera (CTX) and a twin Mac 30-inch display for viewing 5,000 pixels at full resolution [2].

Future Direction: The RPIFN is making strides to better serve its customers in the coming years. In an effort to learn more about the needs and concerns of the planetary science community, the RPIFN presented an abstract [3] and operated an informational booth at the Lunar and Planetary Science Conference in The Woodlands, Texas. The results of the booth indicated that the planetary science community is hungry for more information on (1) documentation for past missions and instruments; (2) basic knowledge about current planetary mission datasets; and (3) outreach materials to engage local communities. The bulleted points below describe methods by which the RPIFN can better address the needs of its clients.

- *Provide documentation for past missions and instruments*: Each node of the RPIFN will be charged with inventorying, scanning, and providing access to maps, photographs, films, reports, memoranda, and publications for past planetary missions. As current and future missions come to pass, their documentation (currently stored in mission-specific Web pages) will be ingested into the RPIFN. Nodes within the network will also begin collating key mission-related science publications.
- *Provide basic information about current mission datasets*: Beginning with the most recent annual RPIF review in October 2011, RPIF managers and directors will receive training on planetary datasets, such that they can serve as local resources for their clients. The training will provide overviews of datasets collected since the Clementine mission. The overviews will be geared toward providing basic knowledge of the mission goals, capabilities, data products, data processing tools, and science applications of the data. Several members of the RPIFN will participate in this Planetary Data Workshop.
- *Provide outreach materials*: By pooling their resources, the individual nodes of the RPIFN will have access to a wide array of space exploration materials. RPIF nodes that have unique data and (or) relations with current/future missions will share the information with the rest of the Network. Printing and distribution costs will be shared

by network nodes. These materials can then be used to engage the public during facility tours, public lectures, and/or school demonstrations.

In summary, the long term vision of the RPIFN is to be a resource that provides the complete story of space exploration by providing archived data products, historical documentation of previous missions, outreach materials for engaging the public, and up-to-date knowledge and expert advice on current and future planetary missions. The RPIFN will continually seek feedback and input from its clients via informational booths at international conferences, online surveys, and written or verbal comments.

For more information, or to request materials, please contact any of the RPIFs listed below. Additional, detailed information can also be found at http://www.lpi.usra.edu/library/RPIF.

Arizona State University
Space Photography Laboratory
RPIF@asu.edu

Ben-Gurion University of the Negev
Dept. of Geography and Environmental Development
blumberg@bgu.ac.il

Brown University
Northeast Regional Planetary Data Center
Peter_Neivert@brown.edu

Cornell University
Spacecraft Planetary Imaging Facility
kline@astro.cornell.edu

German Aerospace Center
Regional Planetary Image Facility
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JAXA
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Center for Earth and Planetary Studies
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University of Oulu
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petri.kostama@oulu.fi

U.S.G.S. Astrogeology Science Center
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RPIF-flag@usgs.gov

Acknowledgments: The U.S. nodes of the RPIF Network are supported by NASA's Planetary Geology and Geophysics program as well as by leveraging funds from host institutions.

References: [1] Shirley, J.H., and Fairbridge, R.W., eds., 1997, Regional Planetary Image facilities, *in* Encyclopedia of Planetary Sciences: London, Chapman and Hall, 686 p. [2] Muller, J.-P., and Grindrod, P., 2010, UK NASA 3D-RPIF—A european facility for extracting, analysing and visualising DTMs from HiRISE and CTX: European Planetary Science Congress 2010, p. 883-884. [3] Hagerty, J.J., and RPIF Network Node Managers, 2012, The Regional Planetary Image Network: 43rd Lunar and Planetary Science Conference, abstract 1548.

ESA’s Planetary Science Archive (PSA): Maximising the Long-Term Usability of Planetary Data. David J. Heather, S. Martinez, M. Barthelemy, N. Manaud, M. Szumlas, J. L. Vazquez, and the PSA Development Team, ESA-ESAC, PoBox 78, 28691 Villanueva de la Cañada, Madrid, Spain, Email: Santa.Martinez@sciops.esa.int

The European Space Agency's Planetary Science Archive (PSA) is responsible for the long- term preservation of all the scientific and engineering data returned by ESA’s planetary Missions, as well as for the provision of services to increase the accessibility and usability of the archived PSA data. This poster will outline the concept for a highly automated system that will streamline the current archiving process from end-to-end, providing support for data producers in the design, preparation and delivery phases, tracking data internally after delivery and through the standard validation, ingestion and release procedures, and delivering additional support tools for end users wishing to visualize, analyse and manipulate data from the PSA.

Provision of such a streamlined system requires a high degree of conformance to standard data definitions, and this is not easy to ensure, as for most of ESA’s planetary missions, instrument teams are responsible for processing, analyzing and preparing the data for the long-term archive. PSA staff currently have to invest a lot of effort to support the instrument teams through the design and definition of the data products and metadata structure / content to ensure that data conform to all of the standards and requirements. The proposed system will provide standard tools for the production of data and the definition of metadata, along with templates for all required supporting documentation. This will ease the load on the data producers and allow for a more standardized approach to the production of PSA data.

After delivery, a set of rigorous and well-defined archiving and validation procedures is followed. Validation of all data against NASA’s PDS Standards and the additional PSA requirements is completed, and an independent peer review in undertaken prior to data release. The new system will control and track each step of this procedure, managing and preserving the knowledge and data throughout the lifecycle of the mission.

Having these centralized procedures and software to support the overall workflow of the data has many advantages:

- It will help to ease the load of the PSA staff (primarily the Archive Scientists) and will allow them to concentrate on enhancing both data and services provided by PSA.
- It will allow PSA to provide better and more standard support and consultancy to the instrument teams and end-users.
- It will ensure the availability of mechanisms to preserve knowledge and information that would allow PSA to maintain data and software after the end of the mission.

This will increase the level and quality of the data and supporting information ingested into the PSA and will maximize the usability of the planetary data both now and in the long-term. By standardizing and automating the archiving process from end-to-end, a better guarantee of conformance to more restricted standards can be ensured, also allowing for the development of improved data visualization, analysis and manipulation tools for the end-users.

The HiRISE Pipeline Processing System. R. S. Heyd, R. Leis, and A. Fenemma, University of Arizona (rod@pirl.lpl.arizona.edu).

Introduction: A technical overview of the pipeline processing system at the HiRISE Operactions Center used to process HiRISE data acquired by the High Resolution Imaging Science Experiment. The processing environment consists of a Linux-based processing cluster utilizing the Conductor software to manage the processing and ultimately the production of HiRISE data products. Lessons learned and various problems and solutions found during the course of the evolution of the HiRISE processing system will be presented.

HiRISE Data Products Overview. R. S. Heyd[1] R. Leis[1], A. Fenemma [1], [1]University of Arizona (rod@pirl.lpl.arizona.edu).

Introduction: The High Resolution Imaging Science Experiment (HiRISE) on board the Mars Reconnaissance orbiter has been producing high resolution imagery of the surface of Mars for nearly 6 years. Over the years, the HiRISE Operations Team has produced and increasing number of products derived from these data, as well as applications and online tools to find and view the products created in the HiRISE processing pipelines.

Product Overview: A brief overview of the products currently being produced by the HiRISE team (EDRs, RDRs, DTMs, and Extras) and the various ways the product meta data can be searched and/or retrieved will be presented. In addition, an overview of some new products currently in development will be presented.

Software Tools: Software such as the HiView JPEG2000 viewer will be discussed as well as several different online resources that can be used to find and retrieve science products.

Polygon Model-Based Data Analysis and Archive System for Irregular Shaped Small Bodies. N. Hirata, K. Kitazato, H. Demura, J. Terazono, C. Honda, Y. Ogawa and N. Asada, CAIST/ARC-Space/Department of Computer Software, University of Aizu, 90 Kami-Iawase, Tsuruga, Ikki-machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan. (e-mail: naru@u-aizu.ac.jp).

Archives and analysis tools of exploration data are important for scientific research in planetary sciences. As location-oriented functions such as data search and georegistration are fundamental for these data systems, method for description of geolocations of data is important. Because most of these systems target spherical bodies, they adopt geographic coordinate systems to represent geolocations. However, spherical coordinate systems including geographic coordinates may be failed on highly irregular-shaped small bodies. Here we propose a novel concept to manage coordinates on the surface of irregular-shaped small bodies with polygon shape models.

As a unique number is assigned to each polygon (Polygon ID) of the polygon shape model, it can uniquely identify a particular location on the small body. The coverage information of image can be expressed by the list of polygon IDs included in the image FOV. Polygon ID specified on the shape model is a key to retrieve image of particular location. Three dimensional computer graphics representation of a polygon shape model is also useful for a user interface to specify a user-interest location on the small body and visualization of map data of the body. With this concept, we develop a data archive system providing a location-oriented search function, and a 3Dgeographical information system (3D-GIS) for irregular-shaped small bodies.

The data archive system is developed to store image data obtained Hayabusa and NEAR-Shoemaker missions [1]. Image coverage-polygon ID databases are constructed for two missions. Our 3D-GIS is based from a prototype developed in our laboratory [2]. While the prototype was a standalone application, the latest version works as a Java applet in a web browser. Most functions implemented in the previous version are ported to the Java applet. We have also just started to a new project to refresh this tool with more modern technologies including HTML5 and WebGL.

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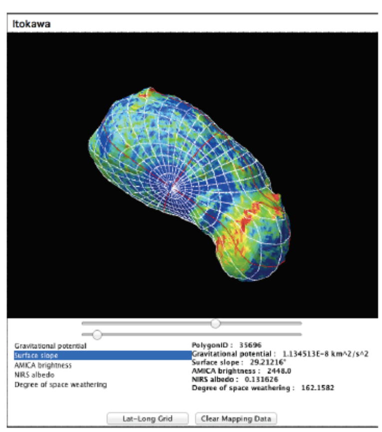

Fig. 1 A snapshot of 3D-GIS displaying Itokawa with a slope map

Study Dikes on Mars with JMARS. J. Huang[1,2] [1]Planetary Science Institute, China University of Geosciences, Wuhan, 430074, P. R. China (jhuang.cug@gmail.com), [2]Mars Space Flight Facility, Arizona State University, Tempe, AZ, 85287-6305, USA

Dikes are igneous intrusions into pre-existing layers or bodies of rock and they record fundamental processes in the geological evolution of terrestrial planets [1]. As a volcanically active planet, Mars has been extensively studied and several occurrences of dikes have been reported through associated surface morphologies [2], magnetic [3] an topographic anomalies [4], and higher spatial and spectral resolution remote sensing data [1, 5-7]. Using JMARS (Java Mission-planning and Analysis for Remote Sensing: jmars.asu.edu), a geospatial information system (GIS) developed by Mars Space Flight Facility in Arizona State University, I am able to query, analyze and visualize different data-sets and data products. JMARS is extremely helpful in the study of new discovery of dikes on Mars [8].

To assess the morphological characteristics of the dikes and the surrounding areas, we used a variety of data sets from imaging instruments orbiting Mars. The Thermal Emission Imaging System (THEMIS) Daytime IR global mosaic with a spatial resolution of 100 m/pixel, highlights the relative surface temperatures of different geological units. Context Imager (CTX) data with spatial resolution 6 m/pixel, and HiRISE images with spatial resolution of 25 cm/pixel are used to identify different morphological features in detail. The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) hyperspectral and THEMIS multispectral datasets were used for compositional analysis.

First of all, I searched all the available data sets and data products in JMARS, and labeled all the regions of interest (ROI). Then I measured and calculated the geomorphology parameters of ROIs. Cooperating with Davinci (davinci.mars.asu.edu) for image and spectral processing, I was able to import the processed data products into JMARS and visualize them with other data sets conveniently. In addition, I even shared my customized maps with my colleagues in China with JMARS, and they did not worry about the data acquiring, processing and visualizing. Finally, I output the results easily for manuscript figures.

In sum, JMARS deals with lots of technical details of remote-sensing data sets and helps my colleagues and me greatly. We are able to focus on the science aspects in our research projects without worrying about data processing.

Acknowledgments: JMARS (http://jmars.asu.edu/) and Davinci (http://davinci.asu.edu/) team in Mars Space Flight Facility in ASU is greatly appreciated for development and support of the software.

References: [1] Head, J.W., et al. Geology, 2006. 34(4): p. 285-288. [2] Mege, D. and P. Masson. PSS, 1996. 44(12): p. 1499-1546. [3] McKenzie, D. and F. Nimmo. Nature, 1999. 397(6716): p. 231-233. [4] Schultz, R.A., et al. Geology, 2004. 32(10): p. 889- 892.[5] Korteniemi, J., et al. EPSL, 2010. 294(3-4): p. 466-478. [6] Pedersen, G.B.M., J.W. Head, and L. Wilson. EPSL, 2010. 294(3-4): p. 424-439. [7] Flahaut, J., et al. GRL, 2011. 38. [8] Huang et al., GRL, in preparation.

The PDS4 Data Standard Core Components and How They Can Be Extended. Steve Hughes, Dan Crichton, Ron Joyner, Sean Hardman, and Paul Ramirez, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA *steve.hughes@jpl.nasa.gov*

Abstract: The core components of the PDS4 Data Standards have been developed to remove the ambiguity often associated with the PDS3 standards. However even though rigorously defined, the PDS4 standards can be extended to allow specific metadata at the discipline and mission levels. In the following an overview of the core components of the PDS4 data standards will be provided. In addition the mechanism for extending the standards at both the discipline and mission level will be explained.

Introduction: Early in 2008 the PDS data model working group reviewed the PDS3 data standards and compiled a large list of problems, the most significant being ambiguity. To address these problems the PDS4 Data Design Working Group (DDWG) was formed with the goals to rigorously define a single shared information model, [1,2] eliminate ambiguity, and improve system interoperability and data correlation. The DDWG selected an ontology modeling tool to manage the domain knowledge gleaned from domain experts. The resulting knowledge-base is used as the source for generating the majority of the PDS4 standards documents, including the XML Schema and data dictionary documents. The DDWG also leveraged several information system standards. A metadata registry standard [3] was adopted for the data dictionary, an open archive reference model [4] was adopted to ensure that the archive would conform to good archiving principles, and a general purpose registry model was adopted to ensure that data object management and tracking could be accomplished.

The Core Components: The PDS4 Information Model is product centric. For example observational data, documents, and ancillary files are all managed as products. Each is assigned a unique and immutable global unique identifier at ingestion. Each product also has a logical identifier (LID) and version identifier (VID) defined by the PDS. The two identifiers (LIDVID) concatenated also result in a unique identifier. Users typically query for a specific product using the LIDVID however the LID can be used alone in a query. A LID logically represents the set of all versions of a product.

All products have identification and reference areas. The identification area contains the logical and version identifiers, a title for display purposes, and the standards version identifier. Citation information, modification history, and aliases are also allowed but optional. The reference area allows this product to reference other products using either LIDVIDs or LIDs. For example, observational product could reference a specific version of a calibration report using a LIDVID or the latest version of a mission description using an LID.

Observational products are used for observational data. They have an observation area that includes both in-line descriptions and references to products for information about related targets, investigations, observing system (e.g. spacecraft and instruments), time coordinates, geometry, and cartography. An observational product also has a file area that provides file information. Nested within the file area are the descriptions of the data objects. For example, an imaging product might have one file that contains both an image header and the image.

The context product provides descriptive information about targets, investigations, and other things related to an observational product. Each context product describes one type of thing. The collection product is used to group related products, for example all observational products from a single instrument. It has an inventory or table of references to the member products. The bundle product is used to group collection products. Similar to the collection product, it has a table of references to the member collections. The bundle product is similar to the PDS3 data set and is used to create a bundle of related collections for the archive.

The data objects within observational products are described using one of four fundamental data structures. The array fundamental data structure defines a homogeneous N-dimensional array of scalars and is the parent of 2- and 3-dimensional images and spectra. The table base structure defines a heterogeneous repeating record of scalars and is the parent of binary and character tables. The parsable byte stream is used for data structures that conform to an external standard, that are parsable, and that are needed for the archive, for example SPICE kernels. The encoded byte stream data structures also conform to an external standard, but are encoded, for example PDFA.

Extensions to the Model: Discipline level extensions are currently being designed as object-oriented extensions, restrictions, or optional components of the information model. These include cartography, geometry, and other metadata required for describing array extensions such as hyperspectral cubes. These extensions are being merged into the information model with the responsible PDS discipline node assigned as steward. From a user's perspective these extensions are integral components of the information model. Extensions are added at this level whenever a need is identified across either a single or multiple displines. Most often these needs are discipline specific however cross-discipline needs are common.

Mission level extensions are defined as needed to meet specific needs for a single mission or team. Most often these are locally defined and then inserted into the mission area of the model. These extensions can be designed as object-oriented extensions, restrictions, or associated components. Examples include special geometry, time, or mission operations metadata.

Conclusion: The PDS4 information model is currently being released for operations as part of the PDS4 system. By adhering to the adopted registry reference model and a model driven approach, the data and systems development efforts have been able to proceed in parallel with minimal team interaction. The use of an ontology modeling tool resulted in a rigorously defined set of core components that adhere to object-oriented principles and that are compliant to archive and metadata registry standard models. The flexibility needed to address the archive requirements of the diverse planetary science community is addressed through the use of object-oriented extensions and restrictions and by allowing the ad-hoc insertion of discipline and mission level metadata. This model driven approach for the development of the PDS4 system will help meet the expectations of modern planetary scientists for science data preparation, archive, discovery, access and use.

Acknowledgments: The authors would like to acknowledge the member of the PDS4 Data Design Working Group (DDWG) and other participants. These domain experts were instrumental in the development of the knowledge base from which the information model is produced. The significant amount of time and effort that they provided and their willingness to take part in the process are very much appreciated. These individuals include E. Bell, R. Chen, D. Crichton, A. Culver, P. Garcia, M. Gordon, E. Guinness, S. Hardman, L. Huber, S. Hughes, C. Isbell, S. Joy, R. Joyner, D. Kazden, J. Kodis, J. Mafi, M. Martin, K. Melville, T. Morgan, L. Neakrase, P. Ramirez, A. Raugh, E. Rye, T. King, B. Semenov, S. Slavney, and D. Simpson.

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INTEGRATED MEDIUM FOR PLANETARY EXPLORATION (IMPEx): an infrastructure to bridge the gap between space missions data and computational models in planetary science. M.L Khodachenko[1], E.J. Kallio[2], V.N. Génot[3], T. Al-Ubaidi[1], F. Topf[1], W. Schmidt[2], I.I. Alexeev[4], R. Modolo[5], N. André[3], M. Gangloff[3], and E.S. Belenkaya[4], [1]Austrian Academy of Sciences, Space Research Institute, Graz, Austria, [2]Finnish Meteorological Institute, Helsinki, Finland, [3]IRAP, CNRS & UPS, Toulouse Cedex 4, France, [4]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russian Federation, [5]LATMOS, CNRS & UVSQ, Guyancourt, France.

The **FP7-SPACE project I**ntegrated **M**edium for **P**lanetary **Ex**ploration **(IMPEx)** has been officially started in June 2011. The aim of the project is the creation of **an integrated IT framework** where data sets from space missions are connected to numerical models, providing a possibility to:

- **simulate planetary phenomena** and interpret spacecraft data;
- **test and improve models** versus experimental data as well as alternative models;
- **fill gaps in measurements** by appropriate modeling runs;
- **solve technological tasks** of mission operation and preparation.

Data analysis and visualization within IMPEx will be based on advanced computational models of planetary environments. Specifically, the initial modeling sector of IMPEx is based on four well established numerical codes and their respective infrastructures:

- **3D hybrid modeling** platform HYB for the study of planetary plasma environments, hosted at **FMI**;
- an **alternative 3D hybrid modeling** platform, hosted at **LATMOS**;
- **MHD modeling** platform *GUMICS* for 3D terrestrial magnetosphere, hosted at **FMI**;
- the **global 3D Paraboloid Magnetospheric Model** for simulation of magnetospheres of dif- ferent Solar System objects, hosted at **SINP**.

Modeling results will be linked to the corresponding experimental data from space and planetary missions via several online tools. Initially the following tools will be integrated:

- ***AMDA*** (*Automated Multi-Dataset Analysis*) which provides cross-linked visualization and operation of experimental and numerical modeling data
- ***3DView*** which will offer 3D visualization of spacecraft trajectories in simulated and observed environments
- ***CLWeb*** which enables computation of various micro-scale physical products (spectra, distribution functions, etc.).

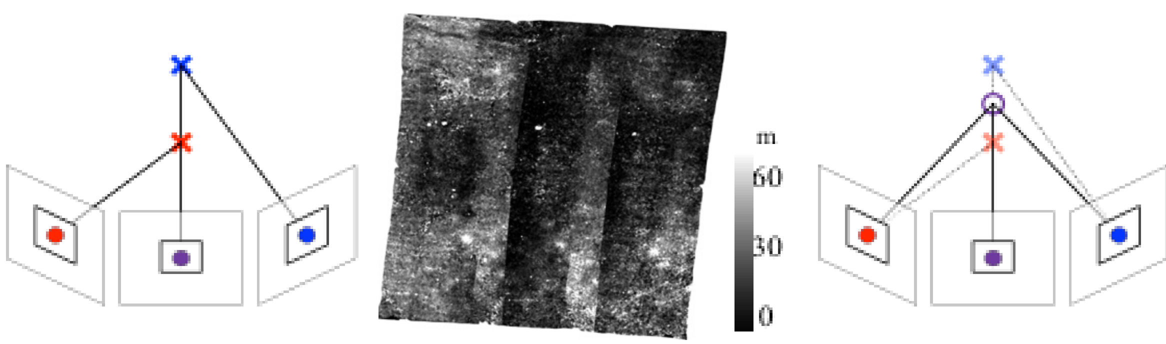
In practical terms, IMPEx is going to provide its user community with straight forward access to an **extended set of space and planetary missions' data** and **powerful, world leading computing models**, complemented by advanced visualization and data analysis tools. By building a comprehensive software infrastructure, IMPEx will merge spacecraft databases and scientific modeling tools, providing their joint operation for the better understanding of related space and planetary physics phenomena.

Another goal of the envisioned software architecture is to provide **straight forward procedures for future extensions** of the system by carefully designing **interfaces, protocols** as well as **data models** that are used by the various components to store information and to communicate with other data sources and tools. Here existing standards and recommendations as those defined by **IVOA** play a pivotal role. In theory the scope of scientific applications is not constrained to planetary magnetospheric and heliospheric physics. Future developments of the IMPEx infrastructure could **focus on generalizing the approaches taken** a step further and - building on the experiences gained - provide a versatile environment in which a wide range of measurements and modeling data sets can be superimposed, analyzed and processed in a variety of ways.

MULTIPLE VIEW CORRELATOR FOR ORBITAL IMAGES T. Kim[1] and K. Husmann[1], [1]NASA Ames Research Center, Moffett Field, CA 94035, USA (taemin.kim@nasa.gov).

Introduction: Since 2007, the NASA Lunar Mapping and Modeling Project (LMMP) has been actively developing maps and tools to improve lunar exploration and mission planning. One of the requirements for LMMP is to construct geo-registered digital elevation models (DEMs) from historic imagery [1]. A joint effort between Arizona State University and NASA Johnson Space Center finished scanning the original film negatives [2]. The Intelligent Robotics Group at NASA Ames Research Center has developed the Ames Stereo Pipeline (ASP), a collection of cartographic and stereogrammetric tools for automatically producing DEMs from orbital images acquired with the Apollo Metric Camera during Apollo 15-17 [3]. The ASP currently generate DEMs from consecutive image pairs. However, two DEMs generated from different image pairs have different values for the same point due to noise, shadows, etc. in the images (Figure 1a). Consequently, IRG's current topographical reconstruction of the Moon contains fairly substantial random errors (Figure 1b).

The multiple view correlator (MVC) will address this problem by finding multiple view correspondences between images that minimize the reprojection error of all associated image patches. The MVC will determine the unique 3D position by treating all image patches at once (Figure 1c). The accuracy and robustness of DEMs produced by IRG will thus be improved by making use of multiple wide baseline observations and by considering their goodness of fit.



(a) Stereo Correspondences (b) DEMs Errors (c) Multiple View Correspondences

Figure 1: Stereo and Multiple View Correspondences. (a) Two stereo correspondences have different elevation values (two crosses). (b) DEMs created by stereo can have substantially large errors. (c) The multiple view correspondence determine the unique elevation value (circle).

Multiple View Correlator: To improve the DEMs produced by IRG, we proposed to use multiple view geometry and photometry for lunar orbital images. A linear approximation of the lunar terrain and reflectance simplifies the multiple view correlation function. For geometry, we use a planar approximation of lunar terrain, which simplifies the tensor representation of multiple views into a homography representation. For photometry, we propose to use a linear approximation of the lunar reflectance. The statistical behavior of the photons is model by the Poisson distribution to derive the cost function that compares the multiple view windows. Once development of the MVC is completed, it will replace the pair-wise sub-pixel refinement and triangulation currently used in ASP.

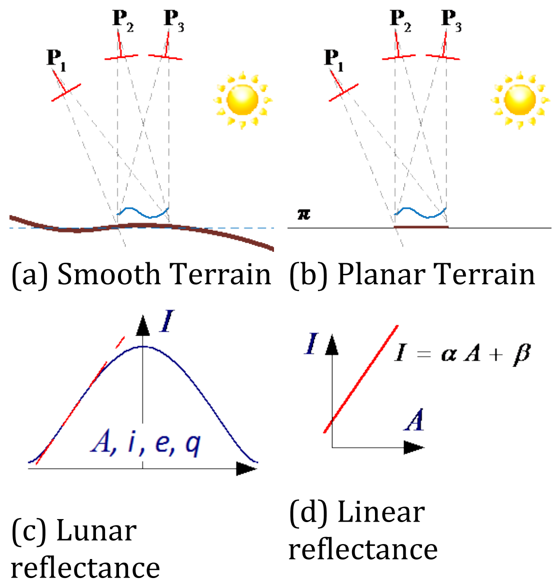
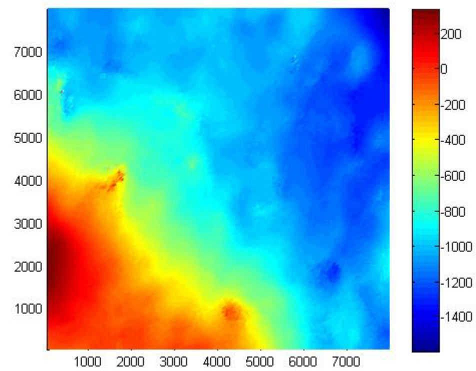


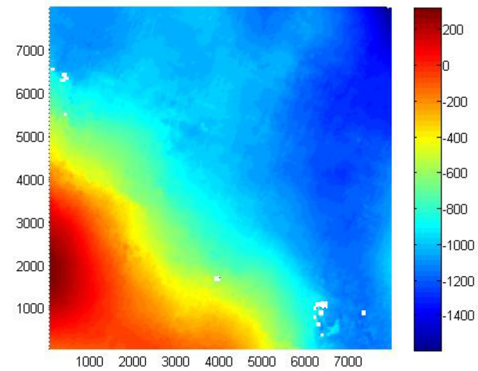
Figure 2: Linear Approximation of Lunar Terrain and Reflectance. (a) Smooth local terrain in a small field of view is approximated by (b) planar one. (c) The lunar reflectance model is approximated by a linear function. (d) The linear reflectance is a linear function of surface albedo (A).

Experimental Results: The algorithm was implemented in Matlab and a small DEM was created using four orbital images from the Apollo 15 mission: (Apollo metric frame AS15-M-1090 through AS15-M-1093). The camera parameters from the metadata in the orbital imagery were refined in a bundle adjustment process by the ASP. The resulting DEM and reconstruction errors are displayed in **Figure 3**(a) and (b). Using the stereogrammetry pipeline in the ASP, we created a DEM using the first two of the four orbital images in our set. The ASP uses a subpixel correlation scheme described in [1] to resolve the planetary terrain at a high level of detail with a bayesian outlier detection scheme. Its results along with a comparison to the multiple view algorithm can be found in figure **Figure 3**(b) and (d).

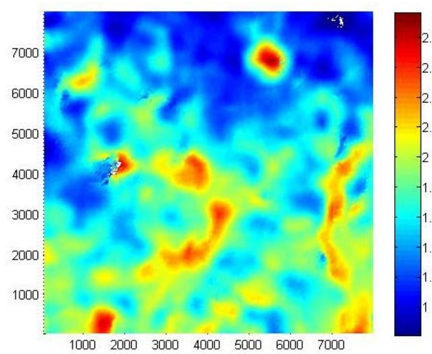
The multiple view approach seems to resolve features at a mid-scale that the ASP does not while their high level features are identical. In addition, the ASP results have a wavy noise characteristic not present in the multiple view approach.



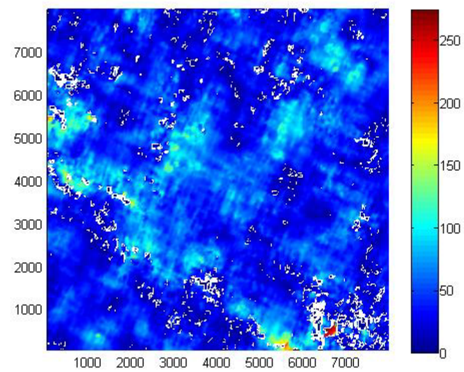
(a) DEM of MVC



(b) DEM of ASP



(c) Precision of MVC



(d) Precision of ASP

Figure 3: Comparison of MVC and ASP. Note that all units are in meter. (a) A DEM of MVC with four consecutive orbital images. (b) Corresponding DEM of the ASP by averaging the consecutive three DEMs. (c) The precision of MVC is obtained by taking the derivative of the error with respect to elevation. This is way smaller than that of the ASP. (d) The precision of ASP is obtained by standard deviation of three consecutive DEMs.

Conclusion: A scalable multiple-view correlation algorithm was developed for constructing dense DEMs from orbital imagery with known camera parameters. The algorithm modeled the image formation process by linearly approximating local geometry and photometry. DEMs generated using this method were comparable to DEMs generated with a standard stereophotogrammetric approach.

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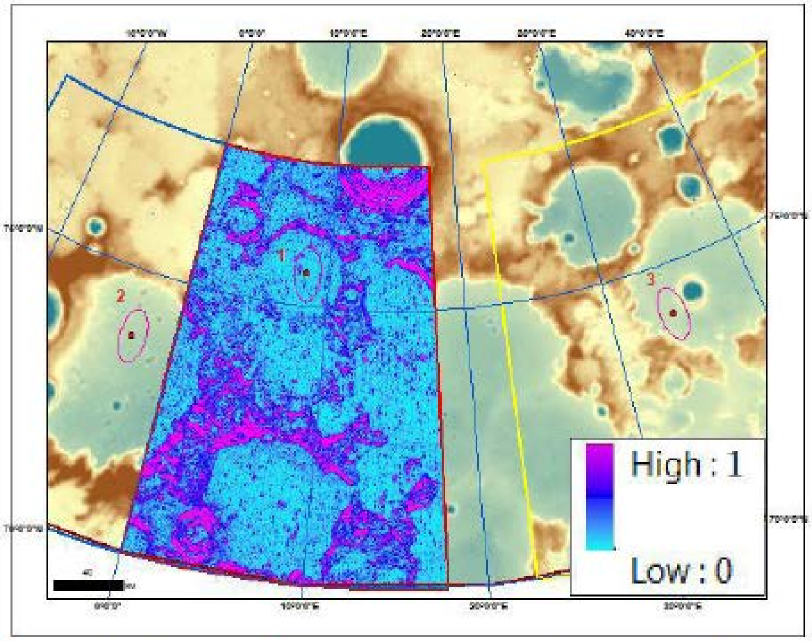

Figure 1. Regional map of roughness, here using the standard deviation of elevations (background – color relief from "GLD100")

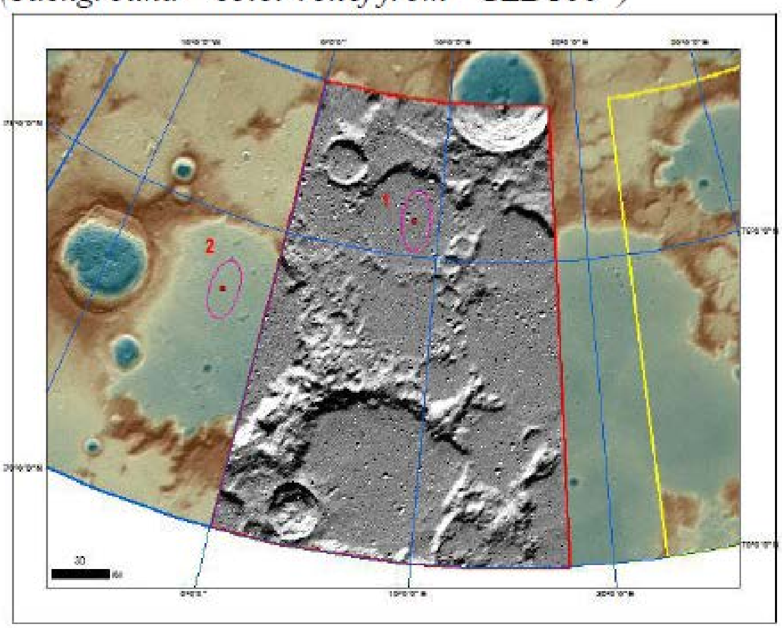

Figure 2. Hill-shaded relief map. Azimuth 315°, solar elevation angle 45° (background – color shaded relief from "GLD100")

Generating Digital Terrain Models from Overlapping LROC-NAC Images using the Ames Stereo Pipeline. J. Laura, The Pennsylvania State University, State College PA. (jzl5325@psu.edu)

Introduction: As a member of the Penn State Lunar Lion team competing in the Google Lunar XPrize, a competition to place a lander on the lunar surface, the generation of high resolution Digital Terrain Models (DTMs) to facilitate site selection, has been a high priority goal. Currently available high resolution DTMs, processed by government and educational institutions as part of the now defunct Constellation Mission, do not cover all potential areas of interest. Traditional DTM generation techniques, using SOCET SET ©BAE are not being utilized due to the low operating budget and limited number of trained personnel. To that end, a highly automated processing pipeline was needed to process large numbers of DTMs. The Ames Stereo Pipeline fulfills this teams technical requirements.

This work seeks to provide an overview of the processing steps, from data sourcing to DTM generation as implemented by this team. One should note that each pair of overlapping images is unique. The steps outlined below should act simply as a framework by which this team has been able to produce results within our own accuracy and precision metrics.

Required Data Sets: This team has utilized a series of freely available datasets in the selection of suitable overlapping stereopairs and the generation of relatively accurate DTMs. The following datasets are essential in our processing pipeline:

• LROC-NAC imagery, captured by a push-broom sensor with ~0.5m resolution and available via PDS or the Arizona State University (ASU) WMS browser provide the input imagery which ASP utilizes.
• LROC-NAC Footprints, available via PDS, provide a means to select overlapping images via a GIS.
• LROC-NAC Cumulative Index, available via PDS, stores tabular index files of image specifications.
• Lunar Orbiter Laser Altimeter (LOLA) Reduced Data Record (RDR) Tracks, available via PDS, provide ground control points to tie LROC-NAC images to the lunar body.
• 100m/pixel WAC DTM, available via ASU, provides a high resolution surface model for ASP during processing.

Required Software: The generation of hi-res DTMs requires a series of open source software packages. These package are available on Mac OS X and most varieties of Linux. This team processes DTMs using an Ubuntu 11.10 workstation. The selection of ground control points currently requires the use of ESRI's ArcGIS. Once QGIS, an open source GIS package, fully supports planetary projections it should be possible to use an entirely open source processing pipeline.

The Integrated Software for Imagers and Spectrometers (ISIS3) is required to convert data from the Planetary Data System (PDS) format into and ISIS3 data cube, embed the camera model, calibrate the input images, bundle adjust the data set, and finally map project the data. ISSI3 binaries are freely available via the USGS Astrogeology website. Finally, the Ames Stereo Pipeline (ASP), available as a binary from the ASP website is required to generate the DTM. ASP is built against a specific version of ISIS3 and it is therefore required that the user's version of ISIS3 match the version required by ASP.

Image Selection: The derivation of a DTM requires two or more overlapping images. [1] state that expected, theoretical DTM vertical precision can be calculated as a function of image convergence angle, where convergence angle is the total parallax angle between two images. This team strove to select images with convergence angles between 15° and 35°, providing a theoretical precision under 1m vertical. To facilitate image selection, LROC-NAC Footprints are loaded into a GIS. The LROC-NAC Cumulative Index, which stores the image incidence angle is then normalized in a spreadsheet program, removing quotations and all WAC records. Once normalized a join is performed to associate each footprint with the complete image specifications. This process is currently being automated and loaded into a webGIS. The final deliverable from this step is a data layer which allows the author to spatially select overlapping footprints and quickly calculate their convergence angle.

Preprocessing With ISIS3: Once sourced the necessary images are downloaded from PDS. It is essential that preprocessing occurs using ISIS3 to calibrate and bundle adjust the input images. Images are converted to ISIS3 format with *lronac2isis and* calibrated with *lroccal*. The spice kernel is then embedded using *spiceinit*. As per [2] we define a custom shape using the 100m/pixel WAC DTM when running *cam2map*. This team processes all cubes to level 2 in this manner, while still retaining the unprojected, level 1 cube for later use.

Bundle Adjustment: The ASP documentation describes bundle adjustment as "the process of simultaneously adjusting the properties of many cameras and the 3D locations of the objects they see in order to minimize the error between the estimated, back-projected pixel location of the 3D objects and their actual measured location in the captured images."[3] In essence, bundle adjustment reduces the intrinsic error in each image by examining the location of selected points in all images. Modifications are made simultaneously to each image and each camera to find the best least squares fit for all points. It cannot be stated strongly enough – bundle adjustment is an essential step in the DTM derivation process. Successful bundle adjustment is dependent upon selecting tie points between images and ground control points to tie the images to a vertical datum.

Tie point selection has been tested using two methods, *autoseed* and *qnet.* In this team's experience, *autoseed* rapidly generates a high number of tie points, many of which are quite good. Unfortunately, some tie points do not correlate well. For our specific usage case, we hand select tie points using *qnet.* While this process requires more human computer time, it offers the opportunity to ensure that only high quality tie points are selected. When utilizing *qnet*, sometimes it is not possible to sub-pixel register a tie point. In this case, the blink feature allows users to nudge images into proper alignment for visual subpixel alignment. Again, this process is time consuming, but in our opinion, less so that cleaning *autoseed* output.

Ground Control Points (GCPs) tie images to an underlying surface. The accepted lunar, vertical reference topographic surface is LOLA. For use in our processing pipeline, LOLA is available as either individual tracks (RDR) or gridded (GRD) formats. At a pixel resolution of 1024 pixels / degree, the highest resolution LOLA data available, it is difficult to resolve a sufficient number of ground control points in some areas. Additionally, the elevation data reported by this gridded data set is interpolated from binned LOLA returns.

Currently, we are testing the selection of ground control points from individual LOLA tracks. To do this, the WAC-DTM, LOLA EDR tracks, and individual LROC-NAC images are loaded into ArcMap. The 3D-Analyst point profile tool is utilized to generate an elevation profile of the LOLA track. Assuming that LOLA tracks have a horizontal accuracy of 300m, as stated in the USGS DEM, we visually identify crater bottoms which are visible in both the LROCNAC image and the LOLA tracks. The WAC-DTM serves to help in the visual alignment process. We believe that using this method, it should be possible to attain higher vertical accuracy than using the method below. Unfortunately, we are unsure of how to manually insert the identified ground control points into an ISIS3 control network.

[4] documents the use of *qtie* to select ground control points for HiRISE processing and suggests a workflow for use with LROC-NAC images. We tested this process using the 100m/pixel WAC DTM and were able to resolve a sufficient number of features. Utilizing this method we must add the LOLA offset to the WAC-DTM offset and any potential offset in our ASP processed DTM to calculate total potential error.

After tie and ground control points are selected, the images are bundle adjusted using *jigsaw*. Assuming more than two images were processed, pairs are selected and the level 1 image B cube is map projected using the level 2 image A cube. This speeds the correlation process because map projection roughly aligns the two input images.

Ames Stereo Pipeline Processing: The *stereo.default* parameter file controls the ASP stereo session. This team begins processing each image pair using a modified *stereo.default* file which resembles the one provided in the ASP documentation[CITEPAGE]. Two parameters are altered to improve processing speed and remove interpolated values. When using the 100m/pixel WAC DTM we comment out the H_CORR and V_CORR parameters, allowing *stereo* to calculate the ideal correlation windows. This improves processing speed and has resulted in high quality
DTMs. FILL_HOLES is set to false (0). We realize that it is possible to use the GoodPixelMap.tif file as a mask, but in our usage, we are most interested in non-interpolated values.

Conclusion: Using the above processing step, this team has been able to generate DTMs to facilitate lunar site selection. Bundle adjustment, specifically the selection of ground control points, remains the most challenging aspect of this work. This team continues to explore automated means for the generation of tie points, and hopes that the ISIS3 team or ASP team will continue to improve and document techniques for the selection of ground control points. These control points allow us to generate highly accurate DEMs with little offset from LOLA.

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Asynchronous Collaborative Web GIS: Proposed System Design to Support Lunar Site Selection. J. Laura, The Pennsylvania State University, State College PA. (jzl5325@psu.edu)

Introduction: Site selection analysis, in any context, is a complex, often contentious process requiring the domain specific knowledge of a diverse array of content area specialists. [1] assert that "those affected by a decision should participate directly in the decision making process." This abstract proposes design requirements and suggests suitable technologies to facilitate the creation of a browser based lunar landing site selection GIS which supports the asynchronous collaboration of spatially distributed science teams. This system strives to provide a tool for geospatially based argumentation (geoargumentation) and consensus building for the complex, multi-answer problem of lunar site selection. This research as a whole seeks to provide a design framework that facilitates the creation of asynchronous, collaborative webGISystems on a mission by mission basis.

Background Cooperative and Collaborative WebGIS: Pickles argues that the relative complexity of GIS creates a divide between expert practitioners and the general public "when used for planning and decision making applications"[2]. [3] expand upon this concept, suggesting that the "main challenges of GISbased spatial decision-making applications lie in bridging this gap by providing a tool for enhancing public participation and addressing the issues of access and equity". To that end, the world wide web currently offers the primary vehicle by which spatial decision-making can be equitably distilled for participation by all stakeholders. In combination with multi-criteria decision analysis (MCDA), the gap between GIS practitioners and data users can be bridged. [3]

[4] define collaborative GIS as "an eclectic integration of theories, tools, and technologies focusing on, but not limited to structuring human participation in group spatial decision processes." System design must facilitate the combined decision making of a diverse field of content area experts striving to communally solve complex, multi-solution problems. Therefore, a distinction between cooperative and collaborative GIS must be drawn. Cooperative GIS implies the high level combination of tasks from disparate sources, while collaboration suggests a lower level of task integration. In a collaborative GIS, the knowledge of the participants is applied to each task instead of applying individual knowledge to separate endeavors.

Current research suggests that there are a number of components which are key to differentiating a cooperative decision making system from a collaborative decision making system. [5] cites argumentation mapping, or adding a spatial context to argumentation, as a key component of collaboration. [6] define argumentation as occurring when "[c]onsensus is achieved through the process of collaboratively considering alternative understandings of the problem, competing interests, priorities and constraints." To that end, a collaborative GIS must offer a method by which discussion, debate, and consensus building can be expressed as an annotation to a spatial construct.

Location and Synchronicity: [7] most succinctly describe four primary spatial and temporal classifications of collaborative GIS. In short, these can be described as locally synchronous, remotely synchronous, locally asynchronous, and remotely asynchronous. To define collaboration as local indicates that the participants are geographically together, ie. in the same office. In contrast, remote collaboration indicates that participants are geographically separated by some distance. Separation does not necessarily indicate a large geographic distance, just that all participants are not clustered around the same workstation. Additionally, collaboration can be defined as either synchronous, indicating that users are interacting at the same time (as is the case with a chat room), or asynchronous indicating that users are not collaborating in real time (as would be the case with leaving a note on a colleague's desk or sending an email).

Given the geographic separation and diverse schedules of team members, as well as the complexity of site selection analysis, asynchronous collaborative GIS (aCGIS) offers the only opportunity to empower team members to either participate in or audit the landing site selection process.

aCGIS provides a number of benefits to the site selection process which would not be available to either on-site synchronous or remote synchronous systems. [1] argue that collaborative decision making, as opposed to cooperative decision making, levels the hierarchical social structure within a group and subsumes personal ownership for decisions. Given the complex, often contentious nature of space exploration and group decision making, an asynchronous system offers an opportunity to reach satisfactory resolution to questions without definitive answers. "[T]here are several aspects of decision outcomes that are important. Among them are the substantive nature of results discovered, the satisfaction with and consensus regarding those results, and the efficiency, effectiveness, and equity associated with the results "[1]. The multimillion dollar price tag, low margin for error, and potentially high spatial error in input data represent unique challenges to planetary GIS site selection. While previous, well publicized missions have successfully landed without the quantity or quality of data presently available, the opportunity for mishap is ever present in a system as complex as a lander. For that reason, the quantity and quality of collaborative input lessens the probability of avoidable errors. This system offers an additional layer of risk avoidance.

Annotations: [8] define annotations as "a datum created and added by a third party to the original document, which can be a written note, a symbol, a drawing or a multimedia clip". In the context of this research annotations are created by users to foster argumentation and decision-making. Annotations are spatially defined. Annotations store references to earlier annotations. [9] describe annotations as *nested*, in that an annotation maintains the dialogue by "linking to other annotations".

Needs Assessment: The iterative development of tasks and the products those tasks derive has been developed through scenarios and a user questionnaire. Briefly, scenarios are ""sketch[es] of use" which are "intended to vividly capture the essence of an interaction design" [10]. These scenarios are therefore the primary means by which the interaction between users and the system have been explored. Scenarios offer the opportunity to analyze the consequences of multiple, potentially contradictory, design decision. The proposed system must:

- Be browser based and network accessible
- Provide a tiered authentication architecture
- Provide the necessary map layers and data sets
- Allow traditional map navigation
- Provide tools for the creation of annotations
- Store context, that is the state of the map document at the time an annotations is recorded.
- Push notification to users of newly added annotations or comments. This can occur via email or on login.

• Allow navigation by annotation where a user's map is redrawn centered on a recent annotation at a reasonable extent.
• Archive annotations in a semantically enabled way.
• Provide rudimentary geoprocessing capabilities to foster individual knowledge synthesis through higher order spatial operations.
• Persist derived data to a backend for storage.

Proposed Architecture: Given the, roughly, identical functionality between ArcGIS Server and OSGeo's webGIS stack, system software selection becomes difficult. One key consideration in the selection of a platform must therefore be interoperability, reusability of code, documentation, support, and cost. To that end, OSGeo offer's an open source solution with an active community and robust code base. This research proposes to leverage earlier work by [9] in the create of an aCGIS.

The client side will be served by a combination of OpenLayers, jQuery, and HTML5. OpenLayers efficiently renders data served using OGC web standards. jQuery provides robust AJAX access to the backend and allows for much of the coding to be reusable. For example, layers are not explicitly defined, but are programmatically generated based on availability.

The backend system leverages Apache2, PostGreSQL with PostGIS, GeoServer and Python CGI scripts. Two databases, one to store annotation data and one to store spatial data are utilized. Flat file tile caches allow for basemaps to be rapidly rendered. FDGC metadata and serving of OGC web resources is handled by Geoserver.

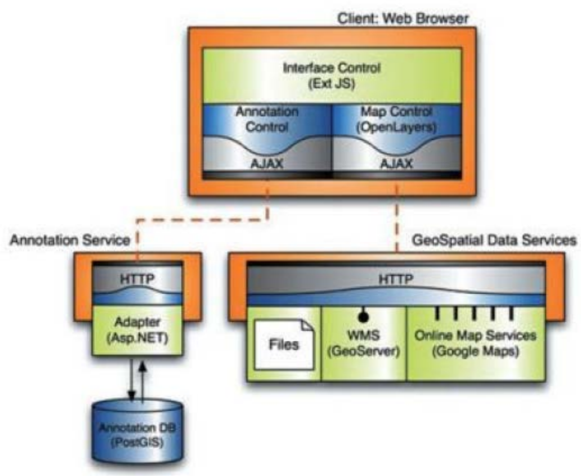

Figure 1: GeoDAT system architecture as described and illustrated by [9].

Conclusion: While the needs assessment and system design described above speak directly to a lunar site selection process, the system design and implementation provide an easily modifiable framework by which additional applications can be rapidly developed.

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ISIS3 in the Amazon Cloud. J. Laura, The Pennsylvania State University, State College PA. (jzl5325@psu.edu)

Introduction: Planetary data storage and processing is often constrained by available storage, and to a greater extent, processing power. Whether stored on a local server, local server farm, or personal desktop workstation, data storage and processing are constrained by limited computing resources. Additionally, the setup and installation process for many of the open-source planetary data processing tools is fraught with potential pitfalls, as evidenced by the frequent posting to the ISIS3 installation support forum. These can include operating system mismatches, missing dependent libraries, or insufficient computing power (RAM, disk space, or processing power).

Data users have likely already integrated cloud based services into their work flows, whether they are using a Google product (Gmail, Docs, Search) or Amazon Web Services (AWS). To support cloud based planetary data processing, an AWS Elastic Cloud Compute (EC2) Image running the Ubuntu Linux Operating System (OS), has been created with a fully functioning suite of planetary data processing tools including GDAL, ISIS3, and the Ames Stereo Pipeline.

Cloud Characteristics: The National Institute of Standards and Technology (NIST) defines the cloud as "a model for enabling ubiquitous, convenient, ondemand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction". [1] Unlike a local server farm, the cloud must fulfill five essential characteristics. It is these very characteristics which are leveraged to draw additional functionality from existing software solutions and to facilitate the development of next generation data processing tools.

The cloud must support ubiquitous network access from a variety of devices. The cloud must be on-demand and self serve. This requires that services be available to users without consultation with a network administrator. The cloud pools resources, serving many distinct clients on a shared pool of hardware. The cloud is elastic and scalable to meet the needs of the user. Finally, the cloud is metered, with users paying only for the resources which they need, when they need them. [2]

ISIS3 Cloud Services: ISIS3 can leverage the very characteristics which make the cloud unique to facilitate improved data storage, data processing, and data sharing. The 'always-on' network access which is required by the cloud ensures that a user can, if they desire, always share their data under any tiered privileges schema. Additionally, a cloud hosted workstation is accessible from any internet connection; at home, at work, or while traveling. The on-demand, self service nature of the cloud allows users to dynamically scale storage and processing power without procuring additional hardware or requesting additional server time from an administrator. The scalability of the cloud allows users to dynamically launch instances to meet their own specific needs while maintain consistent OS and software layers. Currently, available instance hardware ranges from a single core, 630MB of RAM ($0.02 per hour) instance to an 88 core, 60GB of RAM instance ($2.10 per hour). Storage is virtually unlimited and charged per GB per month ($0.10 / month). Finally, the cloud is metered, requiring that users pay only for the processing and storage that they use.

Cloud Service Models: NIST cites three service models by which users leverage the cloud. Infrastructure as a Service (IaaS), provides users access to the raw machine. Under this model, users are purchasing computing power and have the freedom to utilize it as they desire, loading any operating system and executing any run time services they desire. Platform as a Service (PaaS), provides the user access to a preloaded operating system and suite of pre-installed programs, allowing them to work or develop in a pre-configured environment. This is the level of access currently available to an existing ISIS3 cloud based solution. Finally, the Software as a Service (SaaS) model is often used to support web applications . These are browser based services which are accessible via any web enabled device (Netflix, Gmail, Facebook, Google Apps, etc.). The user does not manage any of the hardware, software, or data. They simply utilize the service.

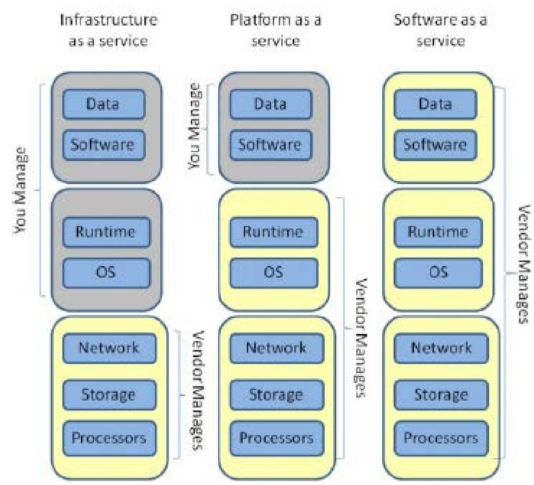

Figure 1: Three cloud service models. The ISIS3 image, available via AWS utilizes a PaaS approach [2].

Amazon Web Services (AWS): The current cloud based installation of ISIS3 is stored in the AWS Cloud. AWS is one of the largest cloud computing service providers, offering easy registration, instance access, and management to a suite of Cloud computing options. This AWS roll out of ISIS3 utilizes Elastic Block Storage (EBS) to store data local to each instance and Simple Storage Service (S3) to store periodic snapshots for additional data redundancy. Amazon Elastic Cloud Compute (EC2) provides the scalable, cloud based computing power required to process data. Both services are metered and billed either per gigabyte per month (EBS / S3) or per hour per month (EC2).

Instance, AMIs, and EBS: A developer wishing to share a snapshot of their development machine, in this case an installation of ISIS3, can create, modify, and disseminate an Amazon Machine Image (AMI). This image is a snapshot of their machine, which can be thoroughly tested and vetted prior to release to the community. When a user wishes to access a developer's AMI, they simply create an instance. An instance is a separate, isolated realization of the developer's machine. Changes to the developer's image will not propagate to the user's instance and changes to a user's instance will not be written to the developer's image. In this way a user can maintain a specific version of ISIS3 or recover from an error on their machine by reloading the developer's AMI. Each instance can have one or more EBS units attached. These are, in essence, external hard drives which can be used to store data or share datasets between a user's instances. For example, a user working with a micro instance that decides they need the computing power of a large instance could detach the EBS from one instance and attach it to another; seamlessly transferring the data.

Current State of ISIS3 – PaaS: Currently, the most full featured implementation of ISIS3 in the cloud is provided as PaaS. The author acts as the vendor, managing the minimum underlying hardware requirements, network accessibility, storage, operating system, and preloaded software. The software layer is shared publicly via an AMI [3]. Users can access this AMI via either a web URL or a keyword search within AWS. This AMI has been designed to support any instance size and has been tested using micro to large instances. The base ISIS3 data and the LRO mission data are preloaded on an attached EBS. Additional mission data footprints are being continually added. Users are able to access ISIS3 using a graphic user interface via remote desktop protocols, command line with GUI support with X11 forwarding, or strictly via the command line. A micro instance does not support the full GUI due to limited resources. Tutorials to support instance launching and login are available.

Current State of ISIS3 – SaaS: The author of this abstract is also soliciting for community input as to the value of an ISIS3 cloud roll out which leverages the SaaS model. Using this model, a user would supply a PDS URL pointing to a data product. A cloud based ISIS3 service would process that data product, and then make it available for download. Using this model a user would not have, or need access to the underlying hardware or software. This system would function much like any other web software service.

As a developer, this system functions simply by wrapping ISIS3 in python and calling a Common gateway Interface (CGI) script. Currently, support using this technique is limited as each ISIS3 command needs to be manually wrapped. It is hoped that in the future the Simplified Wrapper and Interface Generator (SWIG)[4] will be used to wrap most, if not all, of the ISIS3 functions for scripting languages.

Conclusion: AWS provides an ideal platform to support extensible planetary data storage and processing at a reduced cost. For the developer, time spent providing installation technical support can be focused on the generation of usage examples or tutorials. Higher level troubleshooting tickets can be rapidly processed in a known environment, where the developer explicitly knows what packages and libraries are installed on an instance. In short, the cloud offers an improved user experience, reduced developer support time, and an ideal platform for elastic data processing.

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Image Processing for Visualization using Python. J. Laura, The Pennsylvania State University, State College PA. (jzl5325@psu.edu)

Introduction: Images, whether hyperspectral data cubes, monochromatic images, or calibrated radar returns are, n-dimensional arrays which store *z,* some pixel value, at their most basic. Once map projected each element, or pixel is definable by its *x, y,* & *z* value. often characterized by their large file sizes; often in excess of 1 GB once calibrated. Planetary image data is unique in that many data products, especially once calibrated and/or mosaiced, exceed available RAM within a traditional workstation. This limitation makes post processing of images for visualization challenging. Additionally, planetary images often contain necessary cartographic information with a header (projection and transformation) which must be propagated in any derived products. ISIS3 offers limited support for pixel by pixel image manipulation and offers no support for running operations which segment the image into smaller processing windows. To that end, an image manipulation script was rapidly developed, using python, to allow any desktop computer to manipulate planetary imagery for visualization.

Python: Python was selected to generate this code because it offers rapid application development, holistic, readable code, language interoperability, extensive documentation, and a number of mature, open source libraries which facilitate processing planetary images. This project utilizes the Geospatial Data Abstraction Library (GDAL), Numerical Python (Numpy), and Scientific Python (SciPy).

GDAL: At its core, GDAL provides an array of drivers which access geospatial data. The GDAL API is accessible through C, C++, and Python. It may also be possible to access GDAL through additional languages, as it has been wrapped in SWIG. For this project GDAL reads and writes both map projected and unprojected raster images, converts arrays, in memory into a format which Numpy is able to process, and propagates projection and transformation information to the output images. GDAL's currently implemented drivers include support for ISIS2 and ISIS3 .cub, PDS, GeoTiff, and with the proper drivers, numerous implementations of JPEG 2000. [1]

Numeric Python: Numpy, originally developed to facilitate scientific computing through python, provides two fundamental objects: "an N-dimensional array object and a universal function object". [2] In the context of this project, Numpy is used to simplify array manipulation. Utilizing algorithms coded in python and Numpy's built in functions which perform element wise math on an N-dimensional array, it is possible to rapidly manipulate the pixel value of an input image. *Scientific Python:* SciPy, another mature python library with a large user base, is utilized to generate normal distributions and histograms, calculate the cumulative distribution function of images, and process image filters.

Image Segmentation: The large size of planetary images and limited RAM available on many desktop systems requires that segments of images be read into memory for processing. In memory processing is substantially faster than writing segments of the image to disk for processing. To that end, vertical, horizontal, and box masks have been implemented. Masks iterate over the entire image, processing each segment using the user specified stretch. Mask size and shape is user definable based upon available resources and image tiling schema.

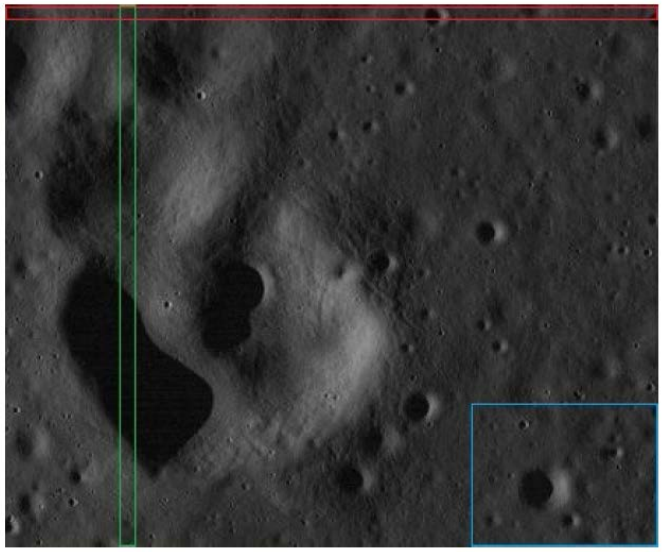

Figure 1: Implemented image segmentation masks. Horizontal in red, vertical in green, and box in blue.

Linear Contrast Stretches: The following contrast stretches are currently supported by the image processing script:

- Linear with user definable clip
- Percentage or Standard Deviation with user definable σ
- Binary with user definable threshold
- Inverse

Non-linear Contrast Stretches: The following non-linear contrast stretches are currently supported:

- Gamma stretch with user definable gamma
- Logarithmic Stretch
- Histogram Equalization
- Gaussian

Filters: Finally, this script supports a number of different filters with a user definable kernel size. The supported filters include:

- Laplacian Filter
- Lowpass Filter
- Conservative Filter
- Gaussian Filter
- Mean Filter

Usage Example: This script was initial developed to perform a running standard deviation stretch using a vertical filter on CTX images. Figure 2, below, clearly shows the contrast curvature which is present in many early CTX images. This curvature reduces image usability in many applications from interpretation to mosaic creation. Figure 2, below, illustrates the output of the running standard deviation stretch after having run *cam2map.* The banding present in the image is intentional, to illustrate the vertical mask which is used to process the image. Cross track curvature is completely removed in the output image and map projection is propagated.

Figure 2: Image P05_003064_1480_XI_32S038W after running *pds2isis* and *ctxcal.* Notice the distinct darkening at the image edges.

Caveats: The development speed and off the shelf component use does require that a few limitations be implicitly stated prior to the use of the scripts.

- The images processed using these tools are stored in 8-bit (0-255) format. 32 or 16-bit inputs are processed, and down sampled during image normalization.
- Processing time can be long if the image is read against the input image block size.
- The software is in alpha and results should be verified before publication.

Future Improvements: Numerous future improvements are planned to improve the speed and functionality of this script.

- Multithreading support will be added to speed processing. This will require some code refactoring.
- Additional image manipulation algorithms, including Fourier transforms and histogram matching will be included.
- Kernel weightings.
- Creation of CGI interface to allow script functionality to be available via the web

Conclusion: Python offers a rapid development language by which off the shelf libraries can be leveraged to facilitate rapid image processing. Development times are kept low by the availability of extensive documentation and strong, active, user base. Using the built-in python module *subprocess*, integration of this script into existing workflows is trivial. In short, python offers the ideal, rapid development environment for the creation of tools for processing planetary data.

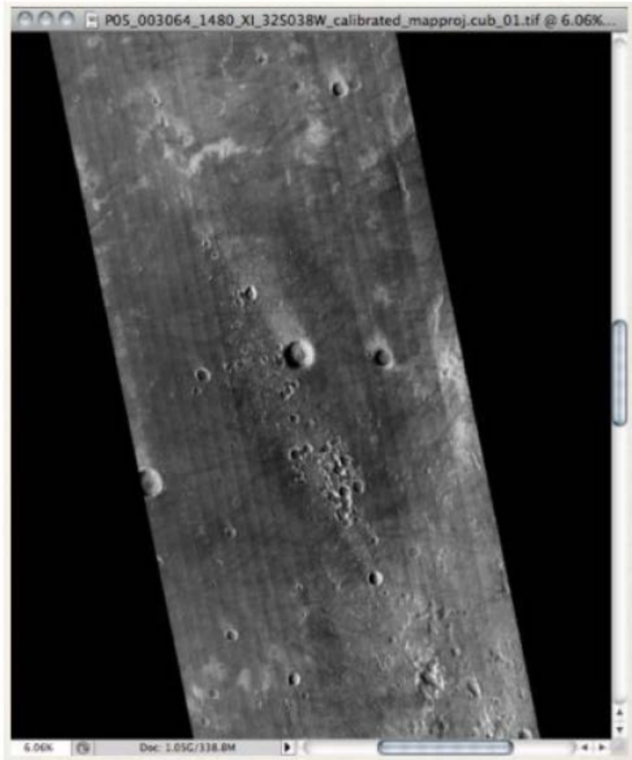

Figure 3: The same cube, after being processed using the python image processing script. Notice that the dark image edges are removed, highlighting numerous additional features.

References: [1] Warmerdam, F. (2012) http://www.gdal.org [2] Oliphant, T. (2006) Guide to *NumPy,* 18-13.

Combination of High-Resolution Images and Multiple Topographic Datasets to Investigate Inverted Fluvial Features on Mars. A. Lefort[1], D. M. Burr[1], R. A. Beyer [2, 3], [1] University of Tennessee Knoxville, Knoxville, TN (alefort@utk.edu), [2] Sagan Center at the SETI Institute, Mountain View, CA, United States, [3] Space Science and Astrobiology Division, NASA Ames Research Center, Mountain View, CA, United States

Introduction: The roughly biennial cadence of spacecraft missions to Mars has led to consistent increases in resolution of both imaging and topographic datasets. Continued use of the older, lower resolution datasets improves coverage. Thus, combining these high-resolution datasets with lower-resolution data from previous missions is the most efficient way to obtain both global geomorphic and topographic coverage, and localized high-resolution geomorphic and topographic information. Moreover, observation of similar features in several topographic datasets rules out any instrument artifact as the origin of the features.

We have adopted this approach of using multiple topographic and imaging datasets in our investigations of martian paleochannels. These features are on the order of a few tenth of meters to a few kilometers wide and thus require precise image co-registration and topographic analysis. Here we describe our approach for deriving 3D data on the scale of martian paleochannels.

Background: Because water seeks the lowest equipotential level, longitudinal profiles of fluvial features are a useful tool for detecting post-flow deformations, caused, for example, by tectonic uplift or sediment compaction during or after fluvial flow [e.g. 1, 2]. The scale of the post-flow deformations may vary from a few hundreds of meters to several kilometers. Paleo-river channels in inverted relief – formed through preferential induration of the channel beds and regional erosion of the surrounding landscape – are no longer susceptible to modification by infilling processes and therefore are likely to provide information on regional post-flow deformation. However, although the inverted channels are not susceptible to infill, they may be affected by erosion on a scale similar to the post-flow deformations. On Mars, a large population of sinuous ridges (SRs, [3]), interpreted as inverted fluvial features [3, 4] has been observed in the western Medusae Fossae Formation (MFF [5,6,7]) an extensive light-toned deposit located along the dichotomy boundary [e.g. 8] and dated to the Hesperian/Amazonian epochs [e.g. 5, 6]).

Data: We use the THEMIS Day IR 512 ppd mosaic [9] (100 m/pixel) as basemap, as well as HiRISE images [10] (~10% coverage of our study area) and CTX images [11] (~95% area coverage) for high-resolution geomorphic information. MOLA individual data points (~150-m-footprint and ~300-m-along-track spacing [12, 13]), as well as three CTX digital elevation model (DTMs) and one HiRISE DTM, created from stereo pair images, provided topographic information. Because of their large footprint and between-track spacing (up to kilometers at this equatorial location), the MOLA data have a relatively low resolution compared to the CTX and HiRISE DTMs, but they cover most of the study area, whereas CTX and HiRISE DTMs provide high-resolution topographic information but are available over only certain SR networks. All the data were acquired from the Planetary Data System (PDS, http://pds.nasa.gov/)

Site selection criteria: Available data have enabled us to look at ~two dozen well-preserved SRs within that area. We chose these SRs on which to focus based on:

- the good state of preservation of the SRs.
- the availability of stereo pair images from CTX and HiRISE, from which to derive DTMs.
- the desirability of a broad geographic distribution of SRs.

Processing of non-topographic data: The CTX and HiRISE images were radiometrically corrected and projected using the Integrated Software for Imagers and Spectrometers (ISIS; [14, 15, 16]). They were then imported into ArcGIS where all the data were co-registered using the georeferencing tool. A shaded relief of the MOLA DTM was used as the first base layer. Over the MOLA shaded relief, we overlaid the THEMIS mosaic, which was accurately co-registered to the MOLA and did not require any adjustment. The CTX images were then co-registered to the THEMIS mosaic and the HiRISE images to the CTX images.

Processing of topographic data: *Individual MOLA data points*: MOLA data tracks where imported into ArcGIS and projected over the CTX images. As the CTX images were previously co-registered to the MOLA DTM, we consider that the possible mis-registration errors between the individual MOLA data points and the CTX and HiRISE images are minimal. MOLA data points located on top of the SRs as seen in the CTX and HiRISE images were manually selected and exported into new ArcGIS layers (one layer for each SR). The large footprint of the MOLA data points is a possible source of error. For narrow SRs, the MOLA footprint may overlap the SR top, sides and the surrounding terrain, therefore providing an inaccurate topographic elevation value for the top surface of the SR. To minimize these errors, we selected MOLA data points that are located as centrally on top of the SR (i.e. as far from the sides of the SR) as possible. Those data points for each SR were then plotted on a graph in ArcGIS to create the SR profiles.

CTX and HiRISE DTMs: CTX and HiRISE stereo pair images were radiometrically corrected and projected using ISIS. Then, the CTX DTMs were produced using the Ames Stereo Pipeline (ASP, [17]) and the HiRISE DTMs were produced using SOCET Set [18]. The DTMs were then imported into ArcGIS. For each of the DTMs produced with the ASP, we resampled the 16 ppd MOLA areoid (acquired from the PDS, http://pds.nasa.gov/) to the resolution of the DTM, then subtracted the resampled MOLA areoid from the DTM. We did not perform bundle adjustment or incorporate MOLA ground control points when using the ASP, and as a result the derived models were offset from (lower than) the MOLA data by about 300 m vertically. This offset was simple to correct a posteriori by creating a difference map between the MOLA and CTX DTMs, then adding the median of the difference histogram to the CTX DTM values. The result is general alignment between the CTX and HiRISE DTMs and the MOLA DTM. These DTMs have a vertical accuracy of 10-20 m (CTX) and 20cm (HiRISE, [18]), and a horizontal accuracy of about 18 m (CTX) and 1 m (HiRISE), respectively. Small mis-registrations with the CTX and HiRISE images were also corrected in ArcGIS using the georeferencing tool.

Data analysis: For each of the SR networks investigated in detail, topographic data from at least two of the three types of topographic data were used. Longitudinal profiles of ~ 2 dozen SRs were derived in ArcGIS by selecting MOLA data points located on top of the SRs. Longitudinal and cross-sectional profiles of the same SRs were also created from the HiRISE and CTX DTMs, using the 3D Analyst profiling tool in ArcGIS. The SR profiles were then analyzed comparatively with the morphology of the SRs as shown by the CTX and HiRISE images.

Results: The data from the multiple independent sources generally agreed well, in spite of the difference in spatial resolution. The derived fluvial SR profiles do not decrease monotonically in a single direction, as expected for ancient fluvial features, but exhibit long wavelength undulations (λ~2000 m) with amplitudes greater than 50 meters. These undulations are observed in all topographic datasets. Cross-sectional profiles show that the relief of the SRs is within the 10-30 m range.

Interpretation: The fact that the undulations are observed in all topographic datasets allows us to rule out the possibility that the observed undulations may be data artifacts. Combining morphological and topographical observation shows that in most cases, the SR morphology appears relatively constant over the length of the profile. In particular, the upper surface of the SR is distinct (preserved surficial SR morphology) at the lowest and highest points of the undulating profile. Moreover, the parallel analysis of SR longitudinal profiles and cross-sections shows that the amplitude of the undulations is greater (50 m or more) than the relief of the SRs (~10-30 m). Both of those observations suggest that the undulations cannot be attributed to differential erosion but, instead, that the drops in elevation along the longitudinal profiles are produced in the subsurface. We interpret these long-wavelength undulations as the result of post-formation deformation of the SRs, most likely due to long-wavelength subsurface processes, such as differential compaction or tectonic activity within the western MFF.

Conclusion: The combination of high-resolution images and multiple topographic datasets in ArcGIS has proved to be an efficient way to analyze post-flow deformation in inverted fluvial features.

Acknowledgments: We thank Becky Williams for helpful discussion and Edwin Kite for his offer of a HiRISE DTM. This work was funded by a Mars Data Analysis Program grant to DMB.

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Metadata-Preserving Image File Format Conversion. S. R. Levoe, R. G. Deen, Jet Propulsion Laboratory, Steve.Levoe@jpl.nasa.gov.

Introduction: This poster presents a method for converting image files from one format to another while preserving and translating the metadata attached to them.

Converting file formats for image data is easy. However, for planetary data, the metadata associated with the file is almost as important as the image itself. This metadata, however, is hard to preserve and translate.

The Java language includes an API known as ImageIO. This API and associated components are used to provide reading and writing of numerous image file formats. Once an image has been read using ImageIO, Java Advanced Imaging (JAI) operators may be applied to modify the image data. The resulting image can then be written to a file using an ImageIO writer, possibly in a different format. The image readers and writers are implemented as plugins which are automatically discovered if the jar containing the plugin is on the classpath. This allows applications to auto-detect installed plug-ins, and choose plug-ins based on format name, file suffix, file contents, or MIME type.

The ImageIO API also supports the ability to read and translate the metadata associated with an image from one format to another format. The metadata is stored as an XML object in memory. This type of plugin is known as a transcoder.

Poster Content: JPL has created a set of plugins utilizing the Java ImageIO API for the VICAR, ISIS, PDS, and FITS formats. JPL has also created a set of utility programs using ImageIO and JAI. These utilities allow us to convert images between all of the supported formats.

Metadata conversion is accomplished in three stages. First, the reader converts the metadata to an input-format-specific XML representation. Second, an XML Stylesheet Language (XSL) script transforms, or transcodes, that XML to the representation needed by the writer. Finally, the writer converts the outputformat- specific XML to that needed by the file format.

Although the transcoder is still specific to a given input and output format, the use of XSL significantly simplifies the conversion and makes it practical to have multiple format converters. Different XSL scripts can be used for different kinds of data, for example, MER vs. MSL or attached vs. detached PDS labels.

This transcoder capability has been particularly useful in creating and modifying pds labeled files, with both attached and detached labels. Every PDS image file created by the Multimission Image Processing Lab (MIPL) for MER, Phoenix, and MSL has gone through this transcoder.

Image formats currently supported:

Readers

- By Java: TIFF, WBMP, JPEG2000, GIF, PCX, RAW, JPEG, PNM, PNG
- By JPL/MIPL: VICAR, PDS, ISIS, FITS

Writers

- By Java: TIFF, WBMP, JPEG2000, GIF, PCX, RAW, JPEG, PNM, PNG
- By JPL/MIPL: VICAR, PDS, ISIS

Metadata Transcoders

- VICAR to PDS, PDS to VICAR

Development of MarsMapper and OrbiterMapper Software at OSU and Support for Planetary Exploration Missions Through Geospatial Data Processing, Analysis, and Distribution. R. Li, X. Meng, L. Lin, W. Wang, R. Wu, D. Li. Mapping and GIS Laboratory, CEGE, The Ohio State University, 470 Hitchcock Hall, 2070 Neil Avenue, Columbus, OH 43210-1275, li.282 at osu.edu.

Introduction: Supported by the Participating Scientist Programs of the NASA Mars Exploration Rover (MER) 2003 mission and Lunar Reconnaissance Orbiter (LRO) mission, the Mapping and GIS Laboratory at The Ohio State University (OSU) has developed MarsMapper for rover image-based mapping and rover localization and OrbiterMapper for high-precision topographic mapping from orbital images. Since 1998, the OSU team has been collaborating with the JPL Computer Vision Group on Mars data processing and rover localization and mapping to support the MER mission [2]. The resulting MarsMapper system has been used on a regular basis to support mission operations. The OrbiterMapper software was developed to model orbital sensors, particularly HiRISE (High Resolution Imaging Science Experiment) and LROC NAC (Lunar Reconnaissance Orbiter Camera-Narrow Angle Camera) data, for high-resolution stereo photogrammetric mapping [7]. These software applications have been used to support MER mission operations and to produce topographic products in response to scientific requests for both MER and LRO research. A Web-based GIS system (called OSU Mars WEBGIS) has been established to distribute and archive the mapping and localization products [4].

MarsMapper: OSU developed MarsMapper, a specialized software system built in the Visual C++ environment, to implement photogrammetric techniques to process and analyze ground-based imagery obtained by the MER rovers for rover localization and topographic mapping during the 2003 MER mission.

One critical component in MarsMapper is the bundle adjustment (BA) of an image network formed from stereo images acquired by the navigation (Navcam) and panoramic (Pancam) cameras onboard the MER rovers. With initial rover localization information from telemetry (including visual odometry) along with a sufficient number of well-distributed tie points, the BA process adjusts camera center positions, the three rotation angles of each image in the network, and the 3D positions of the tie points. From these adjusted camera and image orientation parameters, improved rover locations are estimated [2, 4].

In addition to rover localization and traverse mapping, MarsMapper is capable of mapping craters and other geology features by applying short (rover)-baseline or wide-baseline mapping techniques to ground images taken by the MER rovers. Short base-line mapping refers to local-area mapping using stereo images acquired by the rovers' stereo cameras that are separated by the physical baseline of the rigid camera bar. Due to the relatively short length of this bar, it is most effective for mapping nearby objects [2]. To generate high-accuracy topographic products of distant terrain or large features, an extended mapping capability has incorporated into MarsMapper based on wide-baseline mapping that uses images taken at two or more rover positions to form a wide baseline [2].

OrbiterMapper: OrbiterMapper was developed in the environment of Visual Studio.NET to photogrammetrically process sub-meter-resolution orbital images integrated with laser altimetry data for high-resolution planetary topographic mapping. OrbiterMapper is capable of processing HiRISE stereo images from the Mars Reconnaissance Orbiter [7] and LROC NAC stereo images from the LRO mission [5, 7].

The overall process of DTM generation incorporated into OrbiterMapper consists of two major components: (1) image processing, which primarily involves image preprocessing and a hierarchical coarse-to-fine hierarchical stereo matching algorithm for the extraction of dense matching points; and (2) geometric processing, which primarily consists of a BA to remove geometric inconsistencies in the exterior orientation (EO) parameters. With dense matching points and bundle-adjusted EO parameters, highly accurate 3D terrain models can be constructed and then registered to Martian or lunar laser altimetry data for vertical control. Technical details about OrbiterMapper data processing can be found in [5, 6, 7].

Planetary Mapping: To date, MarsMapper and OrbiterMapper have been applied successfully to generate accurate topographic products in support of MER mission operations and LRO scientific exploration.

MarsMapper, used to process ground-based rover images, has produced 564 orthophotos and DTMs, eight 3-D crater models, timely-updated rover traverse maps, and other products for scientific research and mission operation such as crater ingress and egress support maps, Columbia Hills DTM, and north-facing slope maps. Topographic products and crater maps of Santa Maria are shown in Figure 1. Figure 2 illustrates MER Opportunity rover traverse maps (up to Sol 2816) based on rover localization as well as north-facing slope maps of Cape York generated to support the selection of the over-wintering site.

OrbiterMapper has contributed to both the MER and LRO missions. In the MER mission, several HiRISE stereo pairs have been processed to generate 3D terrain models to support topographic characterization of the two landing sites and science targets and to support long-term operational planning for crater ingress/egress and hill climbing. The basemaps shown in Figures 2a and 2b are HiRISE orthophotos generated by OrbiterMapper using BA and Mars Orbiter Laser Altimeter (MOLA) data. Figure 2c shows a HiRISE-derived north-facing slope map at Cape York. In the LRO mission, topographic products derived using LROC NAC data have been used by LRO science team members to study the formation of lunar features such as craters (Figure 3a) and lunar lobate scarps (Figure 3b).

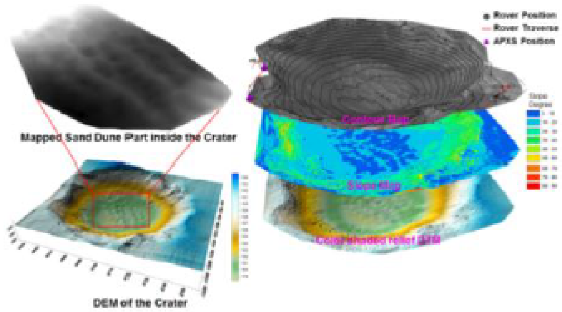
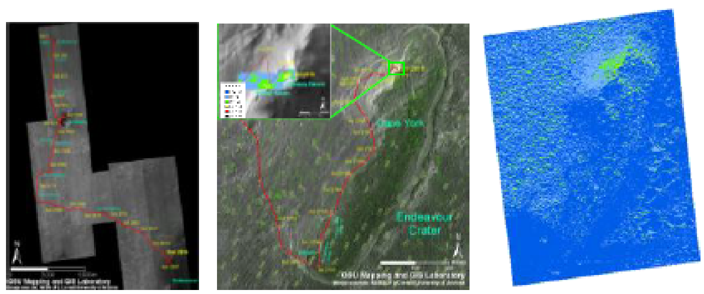
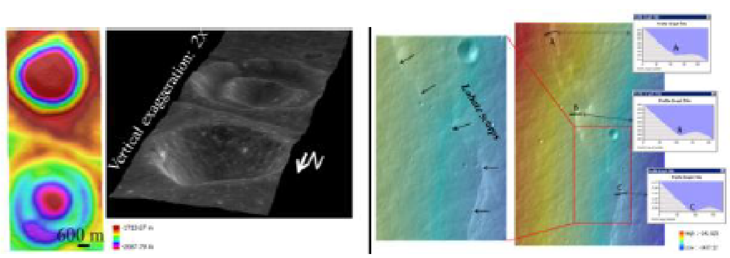


Figure 1. Detailed mapping products of Santa Maria Crater generated using wide-baseline mapping.



(a) (b) (c)

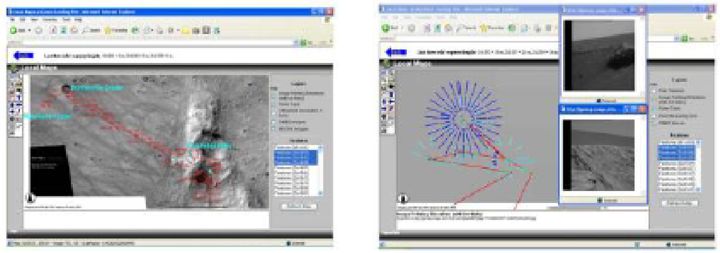
Figure 2. (a) HiRISE orthoimage of the Meridiani Planum landing site and MER Opportunity rover traverse, (b) rover traverse at Cape York with inset of ground-imagery-based north-facing slope map, and (c) HiRISE image-derived north-facing slope map at Cape York.



(a) (b)

Figure 3. OrbiterMapper lunar topographic products: (a) DEM and 3D view of a concentric crater, and (b) DEM and elevation profiles of lobate scarp near Mandel'shtam Crater.

OSU Mars WEBGIS: A planetary web-based GIS (OSU Mars WEBGIS) system has been developed to process, analyze, and distribute geospatial information about the Martian surface [4]. This WebGIS system provides MER landing-site topographic mapping products along with useful tools and information sources (Figure 4) to planetary scientists and engineers for sup-porting planning, mission operations, and scientific analysis.



(a) (b)

Figure 4. OSU Mars WEBGIS interface: (a) local information interface (Gusev Crater), and (b) local information interface (image-pointing hyperlink to linked rover imagery).

WebGIS technologies (including HTML, Javascript and ESRI's ArcIMS Server) have been employed to develop the Mars WEBGIS designed for the dissemination of MER rover localization information and topographic mapping products derived from both the MarsMappers and OrbiterMapper applications. Frequently used functions in this WebGIS, including hyperlinks and tools for visualization (zoom in, zoom out, pan) and measurement (distance, direction), are developed to assist MER mission team members to explore spatial information and perform complex scientific analysis of the spatial data results distributed by the system [4]. Throughout the eight years of the MER mission, the Mars WEBGIS has shown itself to be an effective tool for the integration, distribution, and presentation of multi-source spatial data to support planetary mission operations and exploration.

Conclusions: This abstract summarizes the development of MarsMapper and OrbiterMapper software systems at OSU and their applications to planetary data processing as well as the distribution of topographic mapping products through the OSU Mars WEBGIS system. Continuous maintenance and improvement are being made to support current and future planetary missions and data processing efforts.

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Automatic Fusion of Image Data System for Planetary Mapping (AFIDS). Dr. Thomas Logan and Dr. Nevin Bryant, Jet Propulsion Laboratory 4800 Oak Grove Dr. Pasadena, CA 91109, Contact: Thomas.L.Logan@jpl.nasa.gov

Introduction: Image co-registration is the process of transforming different sets of data into one coordinate system. Data may be multiple images, data from different sensors, from different times, or from different viewpoints. The process is widely used in compiling and analyzing images and data from satellites. Registration is necessary for the comparison and integration of the data obtained from these different measurements.

Presently, co-registration is a rigorous and time intensive operation and is very difficult to do across missions. This means that only a limited number of cases can be prepared for any study, mission, or across missions. The proposed capability is designed to automate the process of registering new mission image data to existing image-map bases, and/or creating new map-projected mission databases.

AFIDS[1] (Automatic Fusion of Image Data System) is a system built on VICAR[2] that supports the automatic co-registration of multiple images from the same sensor and fusion of imagery from different sensors. Imagery co-registration/fusion achieves sub-pixel accuracy by incorporating satellite ephemerides, projection, and auto-registration points with a local elevation model in an ultra-fine tiepoint grid to produce a master ortho-rectified base mosaic with minimal pixel resampling. AFIDS has been used to create regional and global-scale orthorectified mosaics involving thousands of images. For example, 8500 scenes were used to create a 30m global (8 band) Landsat mosaic of the Earth; 266 Aster scenes were processed to create a 15m mosaic of California; and 250000 airborne images of Africa were orthorectified for a DOD client. Versions of AFIDS are currently operational registering and map-projecting commercial and US intelligence imagery for the DOD.

Internally, AFIDS will add the mapping parameters associated with MGSS[3] Planetary bodies such as geocentric/geodetic reference coordinate systems, vertical datum, map projections, data format reference and target, reference topography and control, and potentially specific sensor geometries such as Rational Polynomial Coefficients (RPC) or SPICE Kernels. Externally, AFIDS will interface with existing MGSS systems using either direct software integration, or a Web Processing Service (WPS), specifically the Open Geospatial Consortium Open-GIS WPS, which provides language-, hardware-, and operating system- neutral interfaces between software systems to minimize integration costs. Web browser clients (such as Internet Explorer, Firefox, etc.) are used for query data exchange and Google Earth roam/zoom and time-slider applications. In addition, the AFIDS baseline will be expanded to create regional and global-scale orthorectified mosaics of hundreds/thousands of images. These mosaics can be ingested to the SSV Fusion Server, which prepares Google Earth (and Planetary) databases accessible to any Web browser, for operations team, science team, or public access.

As of now this capability has only been utilized in Earth-only applications but the authors believe that it is also well suited to the Planetary missions. Funding, which has not been acquired yet, is needed to make this happen.

References: [1] AFIDS/Earth was initiated ten years ago under a NASA/ESTO initiative by Nevin Bryant and Albert Zobrist of NASA JPL Section 388, and has been under continuous upgrades since, with many years of support by Thomas Logan and other JPL personnel. [2] VICAR, which stands for Video Image Communication And Retrieval, is a general purpose image processing software system that has been developed since 1966 to digitally process multi-dimensional imaging data. VICAR was developed primarily to process images from the Jet Propulsion Laboratory's unmanned planetary spacecraft. It is now used for a variety of other applications including biomedical image processing, cartography, earth resources, astronomy, and geological exploration. It is not only used by JPL but by many universities, NASA sites and other science/research institutions in the United States and Europe. Currently maintained by the IOS element of MGSS. [3] MGSS – Multimission Ground System and Services is the organization responsible for the management, implementation, maintenance and operation of the Advanced Multi-Mission Operations System (AMMOS) which provides multimission tools and services that enable mission customers to operate at a lower total cost to NASA.

Computing Volumes of Lunar Craters Using ISIS, ArcMAP, ENVI and MATLAB. P. Mahanti, S. D. Koeber, M.S. Robinson, Lunar Reconnaissance Orbiter Camera, School of Earth and Space Exploration, Arizona State University, Tempe,AZ,USA; pmahanti@asu.edu

Introduction: Computing impact crater volumes from remote sensing data is important and desirable for planetary geomorphological studies. During and beyond the Apollo era, volume computations were (and still are) typically achieved using shadow and shading based methods [1, 2, 3]. However, more recently stereo cameras and laser altimeters on planetary spacecraft provide dense elevation information typically distributed as Digital Elevation Models (DEMs). Volume computations from continuous high resolution DEMs= provide much more accurate results than the historic methods.

Numerous software solutions for analyzing DEMs exist. In this study we explore and contrast methods for crater volume computation using four well known software packages for processing planetary data . All four software packages handle geo-referenced elevation information and are often used for planetary data analysis but none of these packages have dedicated interfaces or tools for crater volume computation.

This study compares our experiences using these four packages for crater volume computation; specifically the degree to which these packages allow user interaction, their flexibility to different problems and file types and their accuracy. Some relevant simple image analysis methods and algorithms within the selected software packages are also discussed. DEMs obtained from the Lunar Reconnaissance Orbiter Narrow Angle Camera (LRO-NAC) [4] images were used for our study.

Characteristics of the NAC-DEMs: Although not designed as a stereo system, the LRO-NAC obtains stereo pairs through images acquired from two orbits (with at least one off-nadir slew) with similar lighting conditions. The high pixel scale of NAC images (0.5 meters) subsequently leads a large range of crater sizes (down to 50 m diameter) for DEM based computation, for both small and large craters. The elevation data is computed from the lunar surface and is in meters.

Crater volume computation methods: Successful estimation of the crater volume from a DEM begins with accurate identification of the crater rim leading to the segmentation of the DEM with the crater as the region-of-interest (ROI). While surface texture based metric (e.g. slope) or elevation variations can be used for thresholding a DEM to segment craters, often a visual interaction is the most accurate choice. Once the portion of the DEM that defines the crater is selected, the elevation information from the DEM is used to compute the volume.

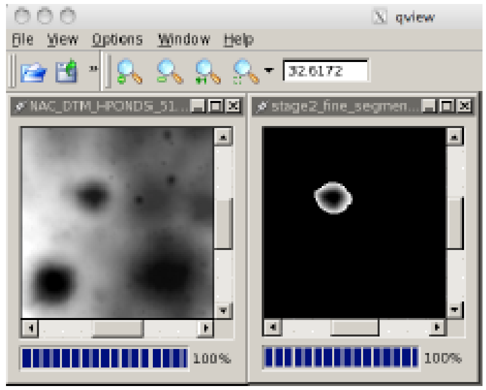

Figure 1: Crater boundary segmentation in ISIS-3

ISIS: The United States Geologic Survey (USGS) Integrated Software for Imagers and Spectrometers (ISIS) is a widely used planetary image processing software package. In the current version of the software (version 3) there are tools to read DEM data and display using QView. However neither QView nor any other program that is part of the ISIS 3 package allows for interactive selection of ROIs. Hence the user is required to use other modules in ISIS-3 to generate a non-interactive, but effective form of image segmentation based on image statistics. The DEM elevation values of the segmented region can then be used for volume computation. We show (Figure 1) how such a shell script can be written that employs ISIS-3 to select ROIs and compute volumes.

ArcGIS: The latest release of ArcGis (from Esri) has four tools to calculate volume and surface area from a polygon. The surface volume tool computes the volume from a polygon (area) above or below a horizontal plane at a stated elevation, and cut/fill computes the volume change between two surfaces. The surface difference tool computes the volumetric difference between two triangulated irregular networks (TIN), or terrain datasets, and finally the polygon volume tool computes the volume of a surface above or below a polygon (the horizontal plane) at a stated elevation. As an example, we show the computation of volume of individual craters using the polygon volume tool. This is a multistep process beginning with the import of the DEM in to Arc Map to covert the DEM to a TIN image. Next, polygons of each individual crater rim were digitized and a specified elevation for each polygon was selected.

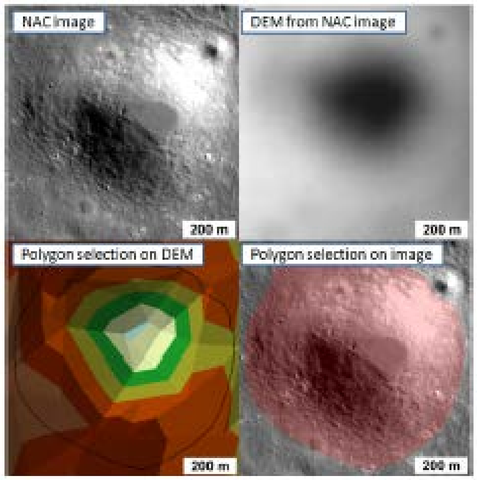

Figure 2: Using ArcGIS for volume computation : Polygon ROI selection on the DEM

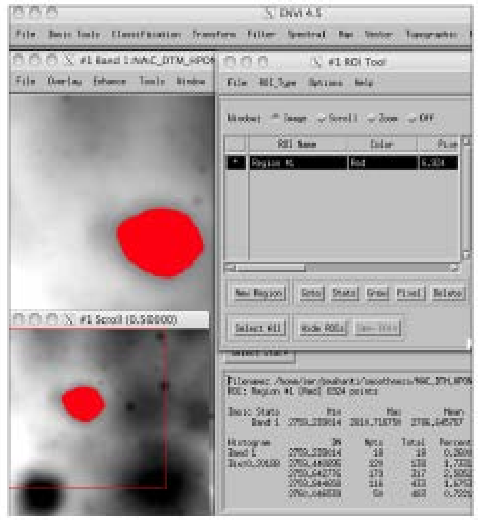

Figure 3: Selection of Crater region-of-interest in ENVI

The specified elevation was entered in to the table of attributes for each polygon and is used as the horizontal plane to compute volume of surface below the polygon which then gives the volume of the crater. The elevations along the rim were used to avoid over calculating the volume of the crater.

ENVI: Environment for Visualizing Images (ENVI) (from Exelis) allows several image processing options on DEMs that can be read in as an image file. Once the DEM is imported and loaded as a band, ENVI has a selection of ROI tools allowing the user to interactively select a crater on the DEM by various means. Along with the available ROI selection tool, ENVI also has the option of using region-growing and that can be used effectively for crater boundary segmentation. After the crater is selected, the volume of the DEM can be computed by obtaining the statistics for the ROI.

MATLAB: Unlike the previous three tools, MATLAB (from MathWorks) is a coding and scripting based platform. However, it has dedicated toolboxes including those for handling geological data and image processing. Functions from these toolboxes can be used to analyse DEMs. We show here the flexibility in using MATLAB for creating dedicated and interactive crater selection tool and also discuss the problems associated in using MATLAB.

Conclusion: Each of the four different software packages that we discuss here have their own flexibilities and problems. A comparison is done with respect to the ease of importing and handling data, the degree to which crater boundaries can be selected interactively and the accuracy of computation, highlighting the merits and demerits for each software package.

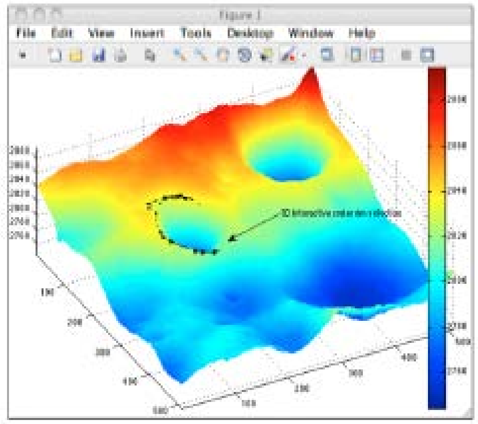

Figure 4: 3D interactive crater boundary selection and surface fitting in MATLAB

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Geospatial Analysis and Mapping of OMEGA Data Sets: A User and Developer View. N. Manaud[1], J.-P. Bibring[2], D. Heather, [1]European Space Astronomy Center (ESAC), Madrid, Spain, nmanaud@sciops.esa.int, [2]Institutd'Astrophysique Spatial (IAS), Orsay, France

The OMEGA experiment, on board the ESA's Mars Express spacecraft, is mapping the surface composition of Mars at a 0.3- to 5-kilometer resolution by means of visible–near-infrared hyperspectral reflectance imagery operating from 0.35 to 5.1μm. Since its orbit insertion in January 2004, it has been acquiring hundreds of millions of spectra, which have allowed the identification of key minerals of importance to trace the evolution of Mars.

The OMEGA data sets, archived in the ESA's Planetary Science Archive (PSA) [1], currently contain uncalibrated observation data records along with calibration routines, and geometry data associated to each observation. Geometry data provide key information for the mapping and photometric analysis of the observational data, and for cross-instrument data analysis.

However, important issues must be tackled to improve the usability of the OMEGA data sets for geospatial analysis and mapping applications, mostly: unsystematic georeferencing errors (~2.5 pixels) in the geometry data, no common and systematic procedures for the production of 'GISready' map products, and lack of interoperability of the OMEGA data search interfaces with GIS environments.

A collaboration between ESA and the OMEGA team has been initiated to study existing methods and tools, and required development, to produce and distribute controlled global mosaics of Mars' mineral abundance and physical parameters, such as grain size.
In this presentation, we report on the progress that have been made (1) to improve the geometrical calibration of the detectors [2], (2) to fuse hyperspectral data products into regional mosaics, (3) to provide an OGC-compliant interface to derived map products [3].

References:

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[3] N. Manaud et al. *Study of an Open Web Mapping Service for ESA's Planetary Surface Data Sets*. EPSC-DPS Joint Meeting 2011 vol. 6 pp.109.

CRISM Analysis Toolkit (CAT). F. Morgan, F. P. Seelos, S. L. Murchie, and the CRISM Team, The Johns Hopkins University, Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel, MD 20723 (frank.morgan@jhuapl.edu)

Introduction: The CRISM Analysis Toolkit (CAT) is an ENVI-based software system for analyzing and displaying data from the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM). We will describe CAT's capabilities, walk through a typical analysis flow, and discuss some recent updates to CAT's atmospheric correction and summary product generation functions.

CRISM: CRISM [1] is an imaging spectrometer onboard the Mars Reconnaissance Orbiter. It covers the visible-near IR spectral range 0.4-3.9 μm at ~10 nm spectral resolution. The spectrograph consists of two channels, the VNIR channel covering 0.4-1 μm, and IR covering 1-3.9 μm. Both spectrographs are fed by a common telescope. For most surface observations, data are acquired in a pushbroom-like configuration. The entire instrument is gimbaled on the along-track axis in order to reduce the scan rate for targeted observations, reaching spatial resolution of ~20 m from MRO's ~370 km altitude. Mapping survey data is acquired by staring at nadir and binning 10 spatial pixels, with resolution ~200 m.

CAT Functions: CAT's primary functions include opening CRISM data files and deriving ENVI headers from PDS labels, applying photometric and atmospheric corrections, calculating summary products, and map projecting spectral data. Data filtering algorithms are provided as well. CAT runs as an ENVI add-on, so ENVI's built-in image display and spectral analysis tools are available once CRISM data is loaded and processed.

CAT opens all CRISM data products, including Targeted Reduced Data Records (TRDR), Map- projected Reduced Data Records (MRDR or "map tiles"), and Map-projected Targeted Reduced Data Records (MTRDR) [2,3].

Much of CAT's functionality is replicated by the processing now incorporated into the newly developed MTRDR products [3]. However, CAT remains of interest to CRISM data analysts. For example, CAT tools allow the analyst to go back to the original calibrated data and confirm that interesting spectral features are not introduced by the I/F noise filtering or MTRDR corrections.

Recent Updates: Two CAT functions have recently undergone major updates. Summary parameter calculations have been revised, and atmospheric correction has been improved.

Summary parameters [4] are simple band-math calculations designed to indicate where interesting mineralogies may be located in CRISM images. CRISM summary parameters are currently being updated to reduce interference between mineral groups and improve detection sensitivity.

CAT employs a "volcano scan" technique [5] for atmospheric correction. Certain spectral features of mineralogical interest are obscured by absorption in Mars' CO2 atmosphere. The absorption features are removed to first order by dividing out an empirical atmospheric transmission spectrum. The transmission spectrum is derived from observations over Olympus Mons. Since the Tharsis area is dusty and dominated by spectrally bland material, dividing spectra from the base (~0 km elevation) by the summit (~20 km elevation) removes the surface spectrum yields the absorption spectrum of two passes through the intervening 20 km atmospheric path. However, there are two artifacts that result from using this to correct CRISM data. First, a bowl-shaped dip near 2 μm results from the pressure and temperature dependent variations in the shape of the Olympus base and summit spectra [6]. An artifact correction has been developed to reduce the effect of this spectroscopic artifact. Second, a small (~0.1 pixel) instrumental wavelength shift causes spikes near the steep edges of the 2 μm CO_2 absorption if the wave- length offsets of the volcano scan data and the observation being corrected do not match. Two improvements reduce the wavelength shift artifact. New volcano scan data have been processed, providing transmission spectra at additional wavelength offsets. Also, a new volcano scan selection procedure optimizes the choice of volcano scan for a given observation to minimize the resulting shift artifact.

Obtaining CAT: CAT can be downloaded at:
pds-geosciences.wustl.edu/missions/mro/crism.htm

References: [1] S. Murchie et al. (2007) JGR 112, 10.1029/2006JE002682. [2] S. Murchie, E. Guinness and S. Slavney (2012) Mars Reconnaissance Orbiter CRISM Data ProductSoftwareInterfaceSpecification,pdsgeosciences.wustl.edu/missions/mro/crism.htm. [3] F. P. Seelos et al. (2012) Planetary Data: A Work- shop for Users and Software Developers. [4] S. M. Pelkey et al. (2007) JGR 112, 10.1029/2006JE002831. [5] Langevin Y. et al. (2005) Science, 307, 1584. [6] S. M. Wiseman (2012) LPS XLIII Abstract #2146.

SciBox, An End-to-End Science Planning and Commanding System. Hari Nair, Teck H. Choo, Michael Lucks, James A. McGovern, Lillian Nguyen, Frank P. Seelos, Joseph P. Skura, and Robert J. Steele. Johns Hopkins University Applied Physics Laboratory, Laurel, MD 20723 (Contact: Hari.Nair@jhuapl.edu)

Introduction

Science planning often involves a labor-intensive process to derive an operational schedule, with iterative refinement and coordination of science instrument activities, guidance and control analyses, engineering review, and command sequencing. This iterative process ensures that science observations not only meet the science objectives but also comply with operational and scheduling constraints. However such a process can take weeks to months to obtain a conflict-free, compliant set of commands. The delay in responding to changes in constraints results in underutilization of resources, including downlink bandwidth and observing opportunities.

SciBox is an end-to-end automated science planning and commanding system written in Java [1]. Increasingly sophisticated versions have been used over the past decade for missions such as TIMED (Thermosphere Ionosphere Mesosphere Energetics and Dynamics), Cassini/MIMI (Magnetospheric IMaging Instrument), MRO/CRISM (Compact Reconnaissance Imaging Spectrometer for Mars), and MESSENGER (Mercury Surface, Space Environment, Geochemistry, and Ranging).

Planning using SciBox starts with science objectives expressed as algorithms, and ends with commands validated against resource constraints and health and safety rules, ready for uploading to a spacecraft. The process is largely automated, with user capabilities to edit the end sequence if needed. The immediate benefits of an automated system are improved operations efficiency and flexibility and reduction in operations cost through a reduction in manpower effort.

JMRO

CRISM has been taking scientific data in Mars orbit aboard MRO since September 2006. The CRISM SOC (Science Operations Center) uses the JMRO (Java Mars Reconnaissance Orbiter) planning tool to create a weekly schedule of observations [2]. Targets are read from an existing database (which is frequently updated by the science team) along with constraints such as desired illumination or season. Opportunities for observing targets are calculated, ranked, checked for operational constraint violations, and scheduled in order to minimize idle time for the instrument. As targets are acquired, they are retired from the database. A wide variety of observation types can be scheduled using JMRO, such as targeted surface images of varying spatial and spectral resolution, map- ping strips, atmospheric monitoring, limb observations, and routine calibrations. At the end of the planning process, a command sequence suitable to be uploaded to the instrument is produced.

CRISMview is a Java Web Start application, also built on SciBox, that shows the operation of the instrument in real time. It is freely available to the public at http://crism.jhuapl.edu/science/CRISMview/.

MESSENGER SciBox

SciBox is used to plan orbital observations for the MESSENGER mission [3], generating uploadable commands for the spacecraft sub-systems (nine sensors, the guidance and control (GNC) system, the solid-state recorder (SSR), the solar panels, and radio frequency communications). All instruments are mounted behind a sunshade. The GNC system ensures that the spacecraft attitude keeps the instruments out of direct sunlight, as well as away from the hot planet itself if necessary.

The entire mission is simulated each week, with the first week's command sequence uploaded to the spacecraft. This allows coverage gaps to be identified early and minimized by changing the observing strategy. Because sequence generation is automated, trades in observation configuration and timing due to changes in constraints such as orbit prediction are evaluated in a matter of hours. These capabilities also enable mission design trade studies including orbit inclination, period, and altitude, and evaluation of the science impacts of different orbit-correction maneuver strategies. These trade studies can be run in parallel.

The first year of science operations included acquisition of approximately 80,000 images, over 4 million spectra, magnetic field and charged particle measurements, and more than 200,000 commands. MESSEN- GER is now in its extended mission, through March of
2013.

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Gaining Experience with PDS4: Lessons from LADEE. Lynn D. V. Neakrase[1], Lyle Huber[1], Shannon Rees[1], Matias Roybal[1], Dylan White[1], Reta Beebe[1], Daniel J. Crichton[2], John S. Hughes[2] [1]Planetary Data System Atmospheres Node, Department of Astronomy, New Mexico State University, Las Cruces, NM 88003 [2]Planetary Data System Engineering Node, Jet Propulsion Laboratory, Pasadena, CA, 91109

Introduction: The NASA Planetary Data System (PDS) is the distributed system of discipline nodes responsible for archiving all planetary data acquired by robotic missions, manned missions, and NASA sponsored ground-based observational campaigns. Beginning late in 2012, the PDS will be publicly moving from version 3 to version 4 of its archival system. The first mission to archive under PDS4 standards will be the Lunar Atmosphere & Dust Environment Explorer (LADEE) spacecraft. LADEE is scheduled for launch in May 2013 and is currently beginning pipeline development and will serve as an initial test case for the new PDS system. The instrument teams are working closely with their discipline nodes to adapt to the new changes and to help develop best practices for future data providers. The PDS discipline nodes involved in this effort include Atmospheres (ATM), Small Bodies (SBN), the Navigation and Ancillary Information Facility (NAIF), and Engineering (EN).

LADEE and PDS4: The *Lunar Atmosphere & Dust Environment Explorer* (LADEE) [1,2] is a short mission that aims to study the exosphere and dust environment surrounding the Moon, investigating sources, sinks, and surface interactions as well as controls on the distribution and variability of the lunar atmosphere. The mission presents an excellent opportunity to test out the end-to-end process of archiving data from an active mission into the new architecture of the PDS. The instrument package includes three main instruments providing data to the archive: Neutral Mass Spectrometer (NMS), UltraViolet Spectrometer (UVS), and the Lunar Dust Experiment (LDEX). Each of these instruments share heritage from past flown experiments and should provide "well-behaved" ASCII-Table data to exercise the new structure of the archive system. Thus, the limited number of instruments, producing data in few data structures that were included in the initial release of PDS4, makes it an ideal test case.

Data Organization with PDS4: PDS4 will be implemented using eXtensible Markup Language (XML), which allows better interfacing between users, the data, and the Internet. XML uses schema documents (analogous to blueprints) to determine the structure of the corresponding XML labels. In the case of PDS4, these schemas allow management of the labels and their content by forcing validation dictated by the underlying Information Model. The use of a central, underlying Information Model will be a vast improvement over PDS3 because of the uniformity it provides across all the discipline nodes.

Under PDS3, the organization structure revolved around the "Volume" for datasets [3,4]. A Volume was a logical grouping of data and accompanying documentation specifically designed to be delivered via physical media, so volumes became synonymous with the Tape, CD, or DVD it was written on. In PDS4, the motivation is to make data truly accessible across the Internet, with very little reliance on physical media [4]. The structure and organization of the data products allows for more user services as opposed to distributing data as "volumes". As a result, PDS4 will implement a product-centric approach for archiving data and supplemental documentation. Products can be organized into *Collections*, which are logical groupings of files. The Collections can be then organized into *Bundles*, in which all collections are logically related. An example of this structure would include an Instrument Bundle for a mission. Within that Bundle end users should expect to see various collections of documents and data products, organized into directory structures for the respective instrument and data types including all references for documenting the use and provenance of the data [4].

Another change under PDS4 will be how the archive is organized across discipline nodes. Replacing the PDS3 central catalog will be the *Central Registry*, in which all products (including bundles and collections and tutorial pages, etc.) will be registered and therefore accessible to search engines [3,4]. Because PDS4 is product-centric, and documents, data, cross-references, and other ancillary data are all products, everything will be registered within the system. Together with the XML implementation, the Central Registry will allow the search routines to be more complex and inclusive than they have been in the past. Better searching will help in providing uniformity across the PDS and better data coverage should lead to better user confidence in the system.

Progress in Pipeline Development: Currently, LADEE instrument teams are in the process of developing their pipelines for PDS4 data archiving. This process is fundamentally unchanged from PDS3, with a few notable exceptions. The XML process differs from the past ODL approach, although the philosophy behind label development is nearly identical. The discipline nodes are working closely with the teams to provide PDS4/XML expertise. PDS has provided label templates to the LADEE instrument teams. The teams are progressing well in development of their own labels by editing provided templates. Instrument team members have had limited experience with XML until now, and that fact has not hindered their ability to work with the discipline nodes and produce valid PDS4 product labels.

Using this interaction between PDS and the instrument teams, PDS further aims to document and construct future pipeline development protocols that ensure PDS4 compliance and ease of use for both data providers and end users for subsequent missions. Currently, the process is tied to the PDS nodes producing generic XML label templates from the Master PDS4 Schema document, which is linked directly to the Information Model. Specific needs of the instrument teams can be added to the template via use of Mission/Node dictionaries that add components as needed. Added components can be validated against the Master Schema/Information Model, Mission/Node dictionaries, and external 'schematron' documents. Each of the pieces allows PDS and the instrument teams to constrain the rules governing the added components and to ensure compliance with the overriding rules setup within the Information Model. Implementation using expanded capabilities available in XML should allow streamlining of the schema-to-label process, and most of the discipline nodes are developing techniques to allow data providers not well-versed in XML to edit and design their labels with help from the nodes. This first mission should be a good shakedown test of the new PDS4 system from start to finish providing a vital resource to the final development steps bringing PDS4 to the public later this year (2012).

When fully implemented, PDS4 should make the archive a more usable tool for data providers and end-users alike. Most importantly as the archive moves to PDS4, the integrity and usability of all the data in its holdings will be assured, continuing the long tradition of making planetary data accessible to the public.

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Lunar Albedo Reconstruction From Apollo Metric Camera Imagery. Ara V. Nefian[1], Oleg Alexandrov[2], Zack Moratto[2], Taemin Kim[3], Ross Beyer[4] and Terry Fong[3], [1]Carnegie Mellon University, [2]Stinger Ghaffarian Technologies, [3]NASA Ames Research Center, MS 245-3, Moffett Field, CA, USA (ara.nefian@nasa.gov), [4]Carl Sagan Center at the SETI Institute

Orbital images contain rich information, including the exposure time, and the Sun and camera position at the time of the image capture. The goal of this research is to model the image formation process and extract the albedo information using digital elevation and surface reflectance models. This paper presents the Lunar albedo reconstruction at 40m/pixel resolution obtained from images captured by the Apollo Metric camera. The method generalizes to both archival scanned and more recent digital images.

Introduction

Figure 1 shows an example of a scanned stereo image pair captured by the Apollo metric camera (AMC). These images are scanned at an approximate resolution of 20,000× 20000 pixels and have an average overlap of 75% between consecutive images [1]. The stereo pairs are used to generate high resolution digital terrain models (DTM) using the Ames Stereo Pipeline [2]. A robust bundle adjustment technique [3] refines the original estimates for the orientation and position of the AMC and co-registers the stereo image pairs into an accurate orbital image and a DTM Mosaic.

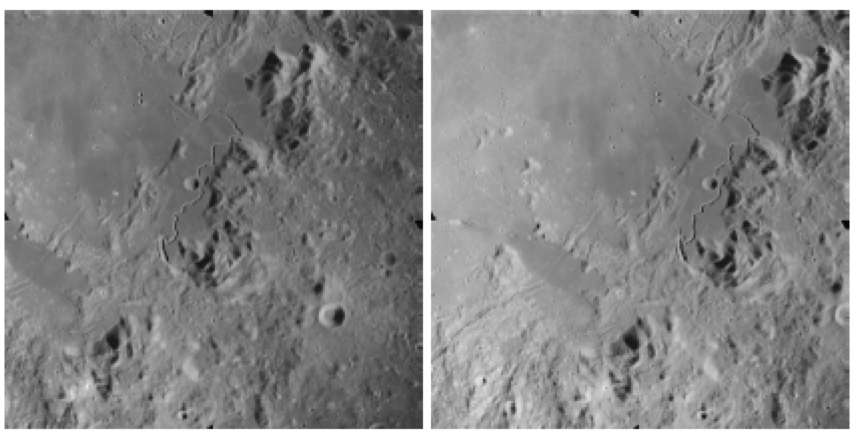

Figure 1: Apollo metric camera stereo pair.

The next section will describe our approach for extracting the estimate of the surface albedo from multiple overlapping images using the DTM and the Sun and camera positions.

Image Formation Modeling and Reconstruction

Let $I_{ij}^k, A_{ij}, X_{ij}, R_{ij}^k, T^k$ be the observed image value, albedo, DTM, reflectance, and exposure time at pixel (i , j)and k-th image. The goal of is paper is to determine the set $\tilde{A}_{ij}, \tilde{T}^k = \arg\min_{A_{ij},T^k} \mathbf{Q}$

where

$$Q = \sum_k \sum_{ij} [(I_{ij}^k - A_{ij} T^k R_{ij}^k)^2 S_{ij}^k w_{ij}^k] \qquad (1)$$

Here, S_{ij}^k is a shadow binary variable, $S_{ij}^k = 0$ when the pixel $(i\,,j)$ is in the shadow and 1 otherwise. The weights w_{ij}^k are chosen such that they have linearly decreasing values from the center of the image ($w_{ij}^k = 1$) to the image boundaries ($w_{ij}^k = 0$). The choice of these weighs insures that the reconstructed albedo mosaic is seamless.

In the above equation the reflectance is computed using the Lunar-Lambertian model and is given by

$$R_{ij}^k = (1 - L(\alpha))\cos(\mathbf{i}_{ij}^k) + L(\alpha)\frac{\cos(\mathbf{i}_{ij}^k)}{\cos(\mathbf{i}_{ij}^k) + \cos(\mathbf{e}_{ij}^k)} \qquad (2)$$

where $L(\alpha) = 1 + A\alpha + B\alpha^2 + C\alpha^3$ is a weighting factor between the Lunar and Lambertian reflectance models that depends on the phase angle (α), i_{ij}^k and e_{ij}^k are the incident and emission angles at image k and pixel $(i\,,j)$.

Determining the best albedo reconstruction from a set of images and the corresponding DTM is formulated as a cost function minimization problem for all pixels (i, j) and images k (Equation 1). An iterative solution to the above least square problem is given by the Gauss-Newton updates described below.

- **Step 1: Initialization:** Compute the average DTM from the overlapping set of images, initialize the exposure times and initialize the albedo by averaging over the overlapping pixels. Initialize the exposure time to compensate for the average image reflectance.

- **Step 2:** Re-estimate the albedo using Equation 3.

$$\tilde{A}_{ij} = A_{ij} + \frac{\sum_k (I_{ij}^k - T^k A_{ij} R_{ij}^k) T^k R_{ij}^k S_{ij}^k w_{ij}^k}{\sum_k (T^k R_{ij}^k)^2 S_{ij}^k w_{ij}^k} \qquad (3)$$

- **Step 3:** Re-estimate the exposure time using Equation 4.

$$\tilde{T}^k = T^k + \frac{\sum_{ij} (I_{ij}^k - T^k A_{ij} R_{ij}^k) A_{ij} R_{ij}^k S_{ij}^k w_{ij}^k}{\sum_{ij} (A_{ij} R_{ij}^k)^2 S_{ij}^k w_{ij}^k} \qquad (4)$$

- **Step 4:** Compute the error cost function Q for the re-estimated values of the albedo and exposure time

- **Convergence:** If the convergence error between the consecutive iterations falls below a fixed threshold then stop. Otherwise return to step 2.

- **Step 5:** Estimate the accuracy of the albedo reconstruction at each pixel using the formula

$$E_{ij} = \frac{\sum_k (I_{ij}^k/(T^k R_{ij}^k) - A_{ij})^2 S_{ij}^k w_{ij}^k}{\sum_k w_{ij}^k} \qquad (5)$$

Figure 2: Albedo estimation from the Apollo metric camera.

The albedo reconstruction results are shown in Figure 2. It can be seen that the albedo appears rather uniform and seamless, and that most of the artifacts from overlapping images and global variations in brightness are reduced.

Conclusions and Future Work

This paper introduced an albedo reconstruction and exposure time compensation for orbital images. The system has been successfully tested on the Apollo metric camera images of the Apollo 15, 16 and 17 missions at a resolution of 40m/pixel. Future work will focus on masking out pixels in shadow from the albedo and exposure time calculations, and the use of robust cost function to replace the current least square approach. Furthermore, we will investigate the use of “shape from shading” approaches to correct the DTM values.

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Derivation of Map-Projected Products from LROC Data: A Progress Report. D. M. Nelson[1], S. D. Koeber[1], T. R. Watters[2], M. E. Banks[2], M. S. Robinson[1], E. Bowman-Cisneros[1]. [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85281 (nelson99@ser.asu.edu), [2]Center for Earth and Planetary Studies, Smithsonian Institution, Washington, DC, 20560.

Introduction: The Lunar Reconnaissance Orbiter Camera (LROC) Science Operations Center (SOC) is compiling LROC Science Team identifications of key lunar features into a uniform database. These products consist of digitized vector maps of structural features (lobate scarps, wrinkle ridges, graben), impact melt deposits and mare boundaries from across the whole Moon. Features are identified from LROC Narrow Angle Camera (NAC) and Wide Angle Camera (WAC) images and mosaics [1].

Background: Since the Lunar Reconnaissance Orbiter entered lunar orbit in June 2009, LROC has acquired over 500,000 high quality observations of the Moon's surface (as of Apr. 30, 2012). From this accumulated wealth of data, the LROC team has identified thousands of significant morphologic features from both NAC and WAC observations. To track all these discoveries and put them into a sensical geographic framework, their locations are entered into a GIS database.

Digital mapping is performed at the LROC SOC primarily using ArcGIS, while some researchers use QGIS or ENVI. Features are first visually identified through the analysis of high resolution (0.5 m/pixel) NAC images. WAC basemaps are referenced for spatial context. Structural features, such as rilles and scarps, are digitized as lines, whereas geologic units, such as mare, are recorded as polygons. From the completed maps, feature lengths and areas can be calculated, and volumes can be estimated from Digital Terrain Models (DTM), e.g., the WAC Global Lunar DTM 100 m ("GLD100") or from higher resolution (2 to 5 meter) NAC DTMs.

Mapped Lunar Features: The generation of five specific map products are part of LROC team efforts to digitize significant features across the Moon. The map products are outlined below.

Lobate scarps. Small linear to arcuate structural features (generally <20 km in length) that are interpreted as tectonic in origin. They have steep scarp faces, typically <100m in height, caused by thrust faulting [2]. An initial listing of features as data points was collected LROC team members and citations from the scientific literature. This list of points and associated NAC images were used to locate and digitize the scarps as segmented line features. From the initial list, hundreds of these scarps have been digitized, either individually or in clusters, and are globally distributed, mainly in the highlands.

Wrinkle ridges. These structures, also known as dorsa, are much larger in scale than lobate scarps, some extending over 100 km, and can reach up to 350m in height. Unlike lobate scarps, wrinkle ridges are located in nearside and farside mare. They are formed by the compression of surface materials, sometimes as a manifestation of subsiding mare materials superposed over an impact crater [3]. In general the locations of wrinkle ridges are known, but digitizing them into a uniform cartographic framework will enable quantitative studies of their spatial distribution and thus formation mechanisms.

Impact craters. Craters are the most pervasive features on the surface of the Moon. While there are nearly 1600 uniquely named craters, it is estimated that there are more than 300,000 craters >1km in diameter [4]. Researchers at Brown University released a vector file containing 5185 craters > 20km [5, 6, 7] digitized from the Lunar Orbiter Laser Altimeter global DTM. We are adding craters to this initial work, extending the coverage down to 10 km diameter, or smaller. Included in the annotation table of the crater database will be the name (where applicable), center coordinate, diameter, and area of each crater.

Impact melt, crater exteriors. Analysis of several Copernican age craters of <40 km diameter reveal significant impact melt deposits on their flanks. At this point of the study, 50 craters have been identified using three bands of the WAC (1 (320 nm), 3 (415nm), and 7 (690 nm)) [8]. In each case, bright rays, which were prominent in these bands, facilitated the location of the melt deposits. NAC images were used to confirm the existence of melt deposits. The extent of the melt deposits were mapped in order to calculate area. In future work, WAC DTMs and NAC stereo pairs will be utilized to estimate the volume and slope of the external melt deposits. These measurements will allow us to compare the volume of exterior melt to interior melt, calculate the viscosity of each flow, and map the volume distributions of the deposits [9].

Mare deposits. From Apollo era photography, workers estimated that seventeen percent of the lunar surface area is comprised of maria [10]. For this work, the majority of the mare deposits were digitized as polygons on WAC grayscale (band 4) and band ratio (1, 3, and 7) basemaps. Once completed, the polygons will be used to calculate area and, in conjunction with the global DTM, estimate volumes. Following this mapping, the individual flow units in each mare will then be digitized and compared by volume and composition.

Feature Digitizing: We are following the guidelines as suggested by the USGS [11], including: 1) establishing a specific map scale that is appropriate for each mapped feature type, and 2) digitizing while zoomed-in at a factor only 3-4 times that of the set scale (e.g., digitizing at 1:250k for a 1:1M map). For example, an appropriate map scale might be 1:500k for mare deposits, whereas 1:50k is necessary to delineate the much smaller lobate scarp features. Once the initial vector maps have been completed, they will be peer-reviewed first by researchers at the LROC SOC, and additionally by researchers from outside institutions depending on the original source of the data.

Archive Of Final Products: Each of the completed maps will be released to PDS in the form of shapefiles (developed by ESRI [12]), this format is compatible with common GIS systems (ArcGIS, QGIS, and ENVI).

References: [1] Robinson M. S. et al. (2010) *Space Sci. Rev., 150,* 81–124. [2] Watters T. R. et al. (2010) *Science, 329,* 936-940. [3] Wilhelms D. E. (1987) *USGS Prof. Pap., 1348,* 302. [4] http://www.lpi.usra.edu/science/kring/epo_web/impact _cratering/lunar_cataclysm/ [5] http://www.planetary. brown.edu/html_pages/LOLAcraters.html [6] Head J. W. et al. (2010) *Science, 329,* 1504-1507. [7] Kadish S. J. et al. (2011) *LPSC XLII*, Abstract #1006. [8] Koeber S. D. et al. (2012) *European Lunar Symposium,* Abstract #59. [9] Denevi B. W. et al. (2012) *(in press)*. [10] Head J. W. (1976) Rev. Geophys., 14, 265-300. [11] http://astrogeology/ usgs.gov/PlanetaryMapping/guidelines/PGM_ Handbook_2010.pdf [12] http://www.esri.com/library/ whitepapers/ pdfs/shapefile.pdf

PLANETSERVER: Towards Online Analysis of Planetary Data. J. H. P. Oosthoek[1], A. P. Rossi[1], P. Baumann[2], D. Misev[2], P. Campalani[2,3] , [1]Earth and Space Sciences, Jacobs University, Germany, Email: j.oosthoek@jacobs-university.de, [2]Electrical Engineering and Computer Science, Jacobs University, Germany, [3]ENDIF, Via Saragat 1, 44122 Ferrara, Italy.

Introduction: The Jacobs University Bremen Planetary EarthServer (PlanetServer) is part of the European Union funded EarthServer project [1]. EarthServer is a 3 year project (September 2011 - August 2014) with the goal to allow online access and analysis of massive (10^3 TB) Earth Science data. In order to achieve this, data are ingested into the Rasdaman [2,3] Array Database System. Open Geospatial Consortium (OGC) web standards allow clients to access the data via simple HTTP requests.

PlanetServer is one of 6 Lighthouse Applications, each targeted to host 100+ TB (Figure 1). Each application will demonstrate the feasibility of this online access approach using Rasdaman. The project helps further standardization to advance OGC specifications. Rasdaman itself is also under development to enhance and expand the ingestion of very diverse datasets.

Planetary (Mars) data ingestion: For EarthServer we are planning to ingest 100+ TB into the Rasdaman database. Before starting the ingestion we first determined the current (18 April 2012) size of a first subset of various Mars datasets available on Planetary Data System archives:

- MRO HiRISE RDR is 21TB
- MEX HRSC Level 4 is 509GB.
- MEX HRSC Level 3 is 4,265TB
- MRO CTX is 4,675 TB
- MRO CRISM Full Resolution Target is 11TB
- MRO SHARAD RDR is 3,387 TB
- MEX OMEGA is 569 GB

Access to hyperspectral and DTM data via WCPS/WCS: A PlanetServer web (GIS) client is under development [4] enabling analysis of hyperspectral and DTM data via the OGC Web Coverage Processing Service (WCPS) and Web Coverage Service (WCS) protocols. The current demo consists of javascript (jQuery) and PHP code and for now only shows a single CRISM data example. All data ingested into Rasdaman will be immediately made available for analysis through this client. In time more and more features will be added to the client such as a DTM profile tool.

We are also planning to develop a Toolbox for ESRI ArcGIS written in python. This toolbox will have the same options as the PlanetServer client.

Access to visual imagery data: The PlanetServer client will allow for the visualization of visual Mars imagery. Visual imagery ingested into Rasdaman (e.g. HRSC, HiRISE, CTX) will be placed on a global Mars background map (MOLA and THEMIS IR) using the OGC Web Map Service (WMS) protocol. Through the client the data will be made made accessible in various ways:

1. Complete data download as GeoTIFF
2. Subset download as GeoTIFF. The user can select the subset in the client.

Through WMS the data will also be accessible to external clients. The planned Toolbox for ESRI ArcGIS 10 Desktop will also have WMS support.
Also a 3D preview of HRSC Level 4 data is planned. Here the HRSC visual imagery will be draped over the HRSC DTM. This will make use of the Web3D X3D standard [5] developed by EarthServer partner Fraunhofer IGD.

Planetary Coordinate Reference System (CRS) support: The Petascope component of Rasdaman provides service interfaces for among others WCS, WCPS and WMS.

Within the EarthServer project Petascope is currently being enhanced to allow the use of non EPSG coordinate reference systems. A custom made resolver is being developed for EarthServer providing various Mars CRS GML codes. Petascope is also developed towards an augmentation of CRS to include temporal dimension, pressure, etc.

The client will be made to work with these codes. Support for external viewers (e.g. ESRI ArcGIS) will be investigated.

Reprojection of one CRS onto another is being considered. This process would rely on the functionalities of Rasdaman Enterprise [6]

PlanetServer is currently accessible at: http://www.planetserver.eu

References: [1] http://earthserver.eu EarthServer web site. [2] Baumann, P., et al. (2009) Efficient Map Portrayal Using a General-Purpose Query Language (A Case Study). DEXA 2009 [3] http://rasdaman.org Rasdaman Open Source web site. [4] http://www.planetserver.eu PlanetServer web (GIS) client (under development) [5] http://www.web3d.org Web3D X3D web site [6] http://www.rasdaman.com/ Rasdaman Enterprise web site.

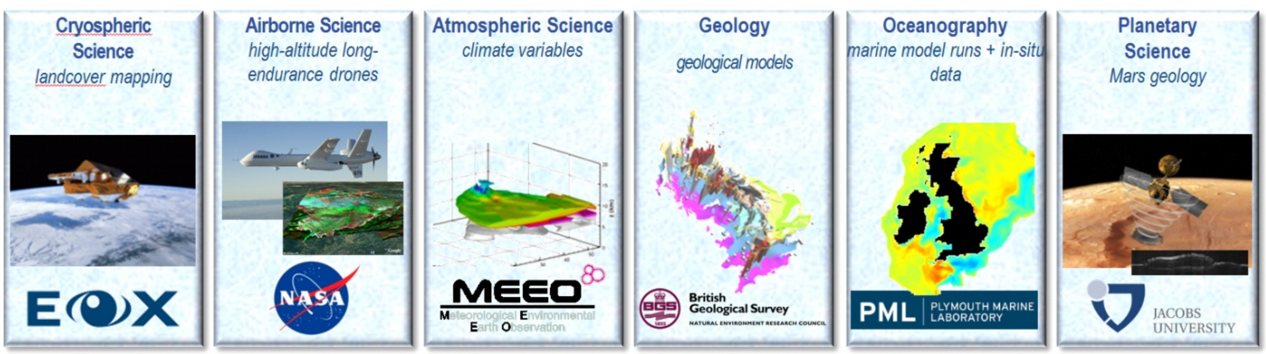

Figure 1. The Lighthouse applications of EarthServer

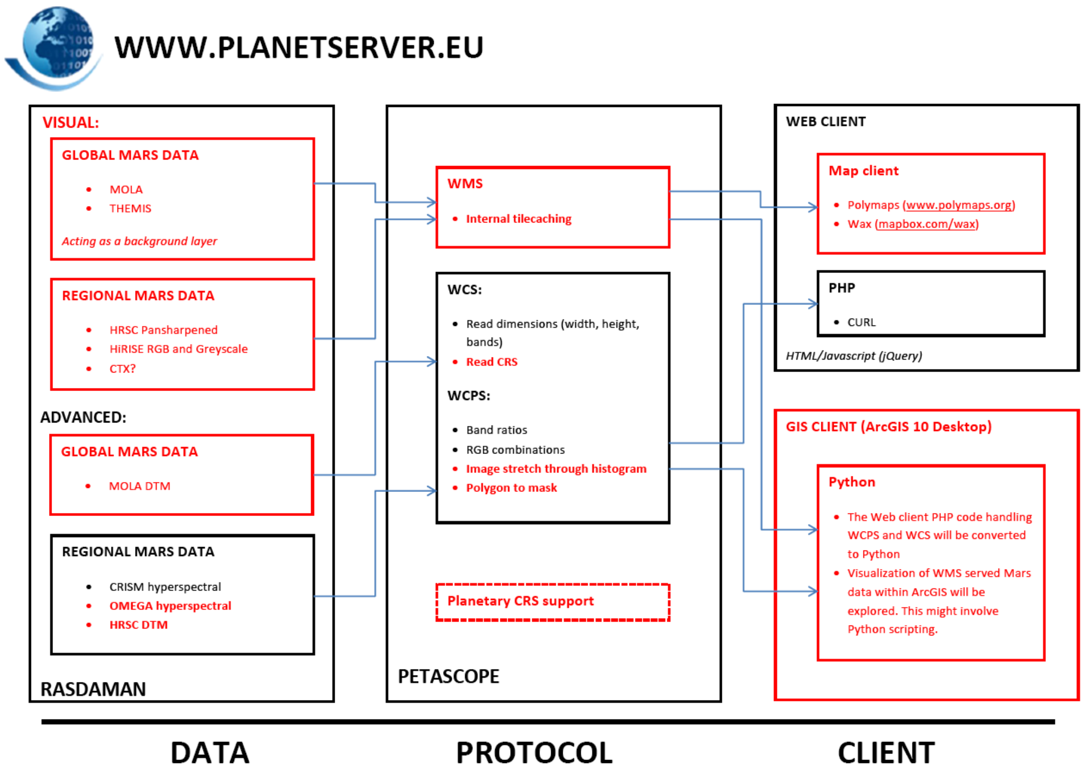

Figure 2. Diagram of planned PlanetServer. In black describes the current demo. Red is planned.

The Apollo Digital Image Archive. K. N. Paris[1], M. S. Robinson[1], S. J. Lawrence[1], E. Bowman-Cisneros[1], A. Licht[1], W. Close[2], R. Ingram[2], [1]School of Earth and Space Exploration, Arizona State Univ., Tempe, AZ, [2]Johnson Space Center, Houston, TX.

Introduction: Photographs acquired by the Apollo astronauts comprise not only a detailed record of the surface of the Moon, but also serve as historical documentation of humans' first venture off the Earth. The analog Apollo flight films are carefully stored and archived at Johnson Space Center (JSC). Due to the delicate nature of the film negatives and their historical significance, only duplicate (second or third generation) film products were available for study. To facilitate a permanent archive with full accessibility, the original flight films are being scanned and archived in a web accessible format [1]. The original flight film is scanned at JSC and digital copies are sent to the Arizona State University (ASU) School of Earth and Space Exploration (SESE) for processing and web archiving. The scanned images are available online along with details of the scanning process [http://apollo.sese.asu.edu].

Scanning Status: The analog film is scanned at JSC and the digital files are saved as a 16-bit TIFF file format, the files are put onto external hard drives, which are then sent to ASU. When these drives are received, they are copied to the high capacity storage array, cataloged, and vetted for file integrity. Scanning is ongoing with estimated completion in the summer of 2017 [2]. In conjunction with the Apollo Digital Image Archive project, the Mercury and Gemini flight films were also scanned, processed, and have been made available to the public [http://tothemoon.ser.asu.edu].

Metric frames. All of the Metric frames have been scanned and received at ASU. 94% of the Apollo 15 frames, 56% of the Apollo 16 frames, and 55% of the Apollo 17 frames are available to the public via the web interface. The majority of the frames that are not yet available are dark images and trans-Earth images. Work continues to process these frames and make them available.

Panoramic frames. The Apollo 15 Panoramic frames have all been scanned by JSC, received by ASU, and released to the public web interface. Scanning is ongoing with the Apollo 16 frames and those that have been received at ASU are available on the website. New frames will be published as they are received with minimal lag time.

35mm frames. Many (but not all) of these frames have been scanned and received. The collection is undergoing review before processing. Currently, this includes frames from the Apollo Lunar Surface Closeup Cameras from the Apollo 11, 12, and 14 missions; frames from the Apollo Low Brightness, Astronomical Photography experiment from the Apollo 16 and 17 missions; (this spanned the Apollo 14, 15, 16 and 17 missions); and the Nikon camera for Apollo 17.

70mm frames. Most of the 70mm Hasselblad images have been scanned and received; however, most of the black and white magazines have not been scanned. The frames that have been received are undergoing review before they are then processed and then released on the website.

Stellar frames. The Stellar camera was part of the Mapping Camera System on Apollo 15, 16, and 17 [3]. All of the stellar frames have been scanned and received and will be available via the Apollo website.

Processing: The Metric frames undergo multi-step processing to generate a usable product: the original scan is imported into the Integrated Software for Images and

Spectrometers (ISIS) format, the image is rotated and calibrated, reseaus are removed, the image is converted back to a 16-bit TIFF and lower resolution browse products are generated.

Because the Panoramic frames are 44 inches on film, a frame is digitally scanned as 8 separate tiles. These tiles are stitched into a single mosaic in JPEG2000 format. The tiles and the JPEG2000 are received by ASU and the JPEG2000 is used for generating browse products.

Products: Currently, the frames available on the public interface have some sort of "browse" products available in the form of an 8-bit Portable Network Graphic (PNG) files in addition to the 16-bit TIFF raw scans and in the case of the Pans, the 16-bit mosaicked JPEG2000:

Metric Products:

- 16-bit TIFF raw scan
- 16-bit TIFF stretched image
- Three 8-bit PNG files at varying resolutions

Panoramic Products:

- 16-bit TIFF raw scan tiles
- 16-bit JPEG2000 mosaic
- 8-bit PNG of the center 50% of the stretched JPEG2000 (down-sampled from full resolution by 50%)
- Three 8-bit PNG files at varying resolutions

Future work: Complete processing and release all of the Apollo Metric frames with an estimated completion in the spring of 2012. The Panoramic frames are still being scanned and are being released as they are received and processed by ASU. Enhance the website with additional search functionality, request re-scanning of corrupt Metric files, WMS display of Pan footprints, making the SPICE data available [3].

References: [1] Robinson M. S. et al. (2008) 39th *LPSC*, Abstract #1515. [2] Paris K.N. et al. (2012) 43rd *LPSC*, Abstract #2273. [3] Masursky H., Colton G. W., El-Baz, F. (1978) *Apollo Over the Moon: A View From Orbit*, NASA SP-362. [4] Paris K.N. et al. (2012), this conference. *Apollo Ephemeris.*

Apollo Ephemeris Data. K. N. Paris[1], A. Licht[1], M. S. Robinson[1], E. Bowman-Cisneros[1], D. Williams[2] [1]School of Earth and Space Exploration, Arizona State Univ., Tempe, AZ, [2]National Space Science Data Center, Greenbelt, Goddard Space Flight Center, Greenbelt, MD.

Introduction: Critical support ephemeris (state vectors) associated with Apollo Metric and Panoramic observations were originally computed and recorded to paper, and later recorded to microfilm. Having these data available is important because it enables the Apollo frames to be map projected. In conjunction with the Apollo Digital Image Archive project [1], the National Space Science Data Center scanned the microfilm records to Tagged Image File Format (TIFF) formatted files. The state vector collection consists of 6 "sets" of state vectors: Metric and Panoramic state vectors for each of the Apollo 15, Apollo 16, and Apollo 17 missions.

The state vectors contain data pertaining to the position and orientation of the spacecraft relative to the Moon, and the orientation of the camera relative to the spacecraft in the case of the Panoramic camera [2]. For the most part, the Metric and Panoramic state vectors contain similar fields of data; however, there are extra footprint fields in the Panoramic state vectors to accommodate the large area covered by the Panoramic frame. There are also right ascension and declination fields in the Apollo 16 and 17 Metric state vectors.

Converting to Text: Due to the poor state of preservation of the state vectors on the original paper, some of the records were never converted to microfilm and are missing from this reconstruction of kernels. The digital scans of the microfilm were received at Arizona State University (ASU) and a custom Optical Character Recognition (OCR) algorithm converted the raster image of the microfilm frames to text format. The success rate of the OCR algorithm varied with the series of state vectors being scanned.

Almost all of the Metric state vectors were able to be automatically converted to text. Because the format of the state vectors (i.e. number of pages, position on the page) and quality varied between missions, the OCR program had to be modified between missions and camera. Manual methods were used to vet the resulting state vector data for inaccuracies and interpolate values that were unrecoverable.

For the Panoramic camera, only about half of the Apollo 15 state vectors were able to be converted to text. The remaining half and all of the Apollo 16 and Apollo 17 mission state vectors have not been able to be successfully run through the OCR program and are currently being manually entered into spreadsheets.

Since the OCR algorithm is not 100% accurate because of the state of some of the scans (as a result for the microfiche), the data need to be vetted. The state vector data is put into a spreadsheet, with one row representing one frame and each column represents a field from the state vector scan. The data for each column are individually plotted and any outliers are manually edited to the correct value.

SPICE: Spacecraft positioning (SPK) and orientation (CK) SPICE kernels have been produced from the recovered state vectors and used to map project some of the Metric frames. The kernels are currently undergoing review internally and with the Navigation and Ancillary Information Facility (NAIF) group [1]. Once the review process is complete, the kernels will be released to the public.

References: [1] Paris, K.N. et al. (2012) *43rd LPSC*, Abstract #2273. [2] Cunningham H. H. (1972) *Apollo 15 Photograph Evaluation (APE) Data Book*, MSC-06886. [3] http://naif.jpl.nasa.gov.

Data Input and Output Constraints for VIMS Hyperspectral Data Mining. V. D. Pasek, D. M. Lytle, R. E. Watson, P. D. Moynihan, and R. H. Brown, The University of Arizona, Lunar and Planetary Lab, Tucson, AZ.

The Visual and Infrared Mapping Spectrometer dataset has grown to more than 200,000 records during the seven years since the Cassini spacecraft began orbiting the Saturnian system. The extended time frame and large volume of this dataset lends itself well to temporal and spatial data mining activities, where the objective is to develop partially automated searching techniques to elucidate patterns within the data. Developing software to data mine the VIMS hyperspectral dataset has several key challenges, including input and output format, the generation and retention of derived geometrical parameters and platform portability.

The VIMS operations center receives data from JPL in EDR (Experimental Data Record), or raw, format, which consists of a PDS label, the science data, and possibly cube suffix data. The science information of a typical VIMS data cube might contain 352 two- dimensional images of 64 x 64 0.5mrad pixels, each taken at a separate, contiguous waveband. The embed- ded PDS label contains some operational status meta- data that is useful for data mining, but does not contain any geometry information about the science payload. This geometry data is key in the identification of data taken at similar locations and distances, but at different times.

VIMS Operations calculates the geometry data for each pixel of a cube, whereas the PDS uses an algorithm that generates one set of data per cube file. This subtle but important distinction greatly affects a user's ability to quickly narrow their search to the items of interest, but also produces a much larger secondary dataset. VIMS Operations has chosen to store the calibrated cube data and the derived geometric data in what we call a "pixel database". This database contains a hyperspectral spectrum and the associated geometrical values for each pixel of VIMS data, which amounts roughly to 64 x 64 x 200,000 pixels available for mining.

The data calibration process has 17 adjustable parameters, making it difficult to define a standard data calibration. For this reason, VIMS Operations has never created or maintained calibrated data. In addition to the multitude of calibration choices, kernel updates may require data to be recalibrated to have the most accurate geometry data. The data mining software offers users the ability to download pre-calibrated data using published calibration parameters, or to transfer their search results (list of cubes that contain their data) back to the calibration pipeline where the calibration parameters are tailored to the specific science goals. It is possible that the program could also save data in a variety of common hyperspectral data formats, such as HDF5, which could then be used in other software packages.

The VIMS data mining software uses Java Remote Method Invocation (RMI), which allows methods of a remote java object to be called by a Java Virtual Ma- chine that may be located on a different host. This approach abolishes the difficulties associated with distribution and increases the security by keeping the ITAR- protected data in a central location that is not accessible from outside the VIMS Operations facility.

In summation, we build upon common tools such as MySql and Java to create unique solutions to data mining requirements for VIMS hyperspectral data. Our software program facilitates the location of user- defined datasets without removing the users from the variety of choices could affect the quality of their science. The data mining software must have calibrated data and geometrical products as its inputs, but the user may choose a variety of output options once the pertinent records have been located. The user could down- load the pre-calibrated data, they could use their search results to recalibrate the raw data using their own custom calibration, or they could even output the dataset in a variety of standard hyperspectral data formats.

Towards PDS 4 – A Multimission Instrument Data Transformation Service. C. Radulescu[1] and E. M. Sayfi[2], [1]JPL (Costin.Radulescu@jpl.nasa.gov), [2]JPL (Elias.M.Sayfi@jpl.nasa.gov).

Introduction: This talk will present an ongoing effort to provide a multimission instrument data transformation service which interfaces mission data-providers' data processing system with the new Planetary Data System 4 (PDS 4) archive to ensure compliance to standards in a schedule-/cost-efficient manner (i.e. streamline the delivery of data between the mission and the new PDS 4).

PDS is in the process of migrating to PDS 4, a new model-driven architecture which provides improved data definition, validation, and discovery capabilities. The Multimission Data Transformation Service supports both data ingestion and distribution into/from PDS 4, providing a data format independent bridge from instrument data providers to end-users (including, but not limited to imaging products).

This service is built from a collaboration between Advanced Multi-Mission Operations System (AMMOS), namely the Instrument Operations Subsystem (IOS) and PDS. The goal is to utilize and extend current AMMOS/PDS 4 tools and services to improve the efficiency of project pipeline processes. Moreover, the service shares tools to support the transformation of data to/from PDS 4 supported standards, which in turn improves data access and usability.

Presentation: The talk will present an overview of the service and its capabilities. Next, it will describe its components at a high-level, and present a mapping to goals and capabilities. Various data formats and transformations to/from PDS 4 will also be presented along with example applications and possible usage scenarios. Finally, examples of current and future capabilities will be presented to show how it facilitates rapid adaptation and configuration of domain-specific implementations into PDS 4.

Expanding the Planetary Data System Developer Community Through an Open Strategy for Tools and Services. Paul Ramirez[1], Sean Hardman[1], Dan Crichton[1], and Steve Hughes[1] [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, paul.m.ramirez@jpl.nasa.gov

Abstract: The Planetary Data System (PDS) is comprised of a set of distributed nodes that form the PDS Archive. PDS4, the 4th generation of the PDS system, is a major upgrade of both the PDS data standards and the software system aimed at improving the efficiency, management and usability of both the software and the data. One of the goals of PDS4 is to provide more support to both the user and tool development communities. The focus here will be on a subset of changes in the PDS4 effort that affect the developer community and work towards an open strategy.

In PDS4, a conscious effort has been made to adopt widely accepted standards, use and develop open source software, and provide a common set of services and tools. Moreover, we are changing our culture to think of the planetary science development community as a whole with an emphasis in not turning them into users of our system but making them partners. This new approach is illustrated through our strategy on services and tools and will be elaborated on below through a set of high level PDS4 development goals which directly support the aforementioned needs.

Goals: One of the cornerstones of the PDS4 effort is aimed at providing online services for accessing, discovering, and operating on PDS Archive holdings for both internal PDS developers and the external community of developers. To that end, we are building an inventory system based on a distributed *Registry Service*, whose interface is RESTful and will be published to the Apache Software Foundation [1]. On top of the Registry Service, we will deploy a *Search Service,* based on Apache Solr [2], which will provide query support for the International Planetary Data Alliance (IPDA) Planetary Data Access Protocol (PDAP) [3], a PDS search protocol based on Solr's syntax as well as response formats encoded as JSON, XML, the International Virtual Observatory Alliance's (IVOA) VOTable [4], and other formats provided by Solr. The Search Service will be deployed across PDS to improve search integration and interoperability amongst the PDS websites through a set of REST parameters as laid forth in PDAP. Finally, all data products within the PDS Archive will be exposed by a persistent URL allowing one to directly access or reference any data item.

Accessibility of metadata and data within the archive will be addressed through a series of efforts aimed at serving our developer community. The first is adoption of the XML standard [5] for the capture of PDS metadata. By adopting the XML standard, PDS is able to take advantage of the multitude of tools available for manipulating, validating, and transforming XML documents. Second, we are defining a set of core data formats for structuring all observational data. In both cases, the plan is to provide a common software library in a variety of programming languages, which can be used for reading, writing, validating, and transforming PDS data products, both metadata and data. Following an open strategy, the library will be made available to the planetary science community as a building block for developing advanced tools to work with PDS data.

While this has only touched on a few of our development goals for PDS4, what should be apparent is an effort towards an open, integrated system with an eye towards providing software to support the planetary science development community. Significant progress has been made with early deliveries of a PDS4 system. As we continue to make deliveries over the next year, software libraries will be made available to the broader community for testing, feedback and suggestions. We believe that the PDS4 software architecture and development strategy will allow international systems, tools and services to be developed that will enhance the use and analysis of the planetary science results returned from exploring the solar system.

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Additionally, the authors of this document acknowledge the members of the PDS System Design Working Group (SDWG): Todd King, Mike Martin, Jordan Padams, Alice Stanboli and Thomas Stein.

References: [1] Apache Software Foundation, http://apache.org, Accessed: 2012. [2] Apache Solr, http://lucene.apache.org/solr/, Accessed: 2012. [3] J. Salgado, et. al. (Nov. 2011) IPDA Planetary Access Protocol. [4] F. Ochsenbein, et. al. (2009) VOTable Format Definition Version 1.2. [5] Extensible Markup Language, http://www.w3.org/XML, Accessed: 2012.

Processing and Utilizing the Lunar Prospector Magnetometer Data. N. C. Richmond[1,2] and L. L. Hood[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, United States (nic@lpl.arizona.edu, lon@lpl.arizona.edu). [2]Planetary Science Institute, Tucson, AZ, United States.

Introduction: Lunar Prospector was launched in January 1998 into a high altitude (~100 km) polar lunar orbit chosen for optimum compositional mapping. During the extended phase of the mission (January through July 1999), the spacecraft altitude was lowered to approximately 15-45 km to provide improved coverage for mapping the magnetic and gravity fields. It is the low altitude data from 1999 that we consider here. Early processing and mapping of the magnetometer (LP MAG) data used very strict data selection and editing criteria [1, 2]. While advantageous in some respects, this restricted the available coverage and resulted in only ~40% coverage. A follow-up study revisited the LP MAG data and used a different data selection and mapping approach to identify as comprehensive coverage as possible [3]. The results of that study yielded the first global map of the lunar magnetic field and provided data that have been used to investigate topics ranging from the correlation of magnetic fields with surface geology and albedo, to magnetization associated with large lunar impact basins.

Here, we summarize the data analysis methods that were used to develop the global field map, and finish by summarizing some of the research that has been carried out utilizing the LP MAG data.

Data Analysis: There are two methods that have been applied to generate lunar crustal magnetic field maps: direct methods [1, 2] and a spherical harmonic approach [4]. While the spherical harmonic approach has the advantage that the correction for altitude differences is made automatically in the process of solving for the model coefficients, the direct approach can yield more accurate and highly resolved regional maps. For that reason, we used a direct approach.

The starting point was the Level 1 LP MAG measurements available from the Planetary Data System (PDS), and associated ephemeris data. The primary steps in the processing followed from the approach that was used to prepare the Level 2, 3 and 4 data that are archived with the PDS. Those data, prepared and submitted by Richmond and Hood, provide the along pass orbit data in lunar centered coordinates, with external fields minimized or removed (Level 2), gridded data files at spacecraft altitude (Level 3), and gridded data files approximately continued to constant altitude (Level 4).

The steps that were followed in the preparation of the data for the global map are described in the following sections. Full details are given in [3].

Data Selection: Initially, all low altitude data were considered, regardless of the location of the Moon relative to the Earth's magnetosphere or the location of the spacecraft relative to the Moon. This is different from previous analyses, which selected passes when the spacecraft was in the geomagnetic tail. The tail region is typically a very quiet magnetic environment. In contrast, the magnetosheath, terminator and dayside regions are often dominated by short- and long-period magnetic fields of high amplitude (relative to lunar crustal sources). However, to improve data coverage, all low altitude passes were analyzed and examined to identify as full low-noise coverage as possible.

Data Processing: The data were converted to a lunar centered radial, east and north coordinate system. At this stage all passes are catalogued according to whether a) the spacecraft was on the nightside, dayside or terminator of the Moon and b) whether the Moon was in the magnetotail, magnetosheath or exposed to the solar wind. In order to remove long wavelength external fields, a low order polynomial was then fitted and removed from each component of each orbit. The final stage of processing was the removal of remaining short period external fields. This was done by visually examining all passes and identifying measurements that do not repeat on adjacent passes.

Selecting Passes for the Global Map: Using the method described in the previous section, 2,360 complete or partial low altitude passes were identified as being sufficiently low in external field contamination to be usable for investigating the nature and origin of lunar crustal magnetization.

The passes remaining after the analysis were examined to identify the cleanest data for each region of the Moon. The best coverage, with the lowest contamination by external fields, was found using 329 passes from March, April, May and July. The passes from March, April and May were primarily nightside data obtained when the Moon was in the solar wind or geomagnetic tail. These are high quality data from quiet external conditions, which can be used for quantitative study of the lunar anomalies. The July passes are primarily terminator passes when the spacecraft was in the solar wind or geomagnetic tail. While measurements in the terminator region are susceptible to external noise contamination, comparisons of coverage from different months indicated that the signals in the passes represent genuine crustal sources, not external fields. Consequently, these data were included in the global data set.

Two small gaps in coverage remain, at ~70°E and ~220°E. While coverage of those areas exists in the clean dataset, the altitudes of those passes were significantly different from those of adjacent passes. In selecting the data for the global map, pass selection was a trade-off between the remaining external fields in the data and the altitude of the passes. External fields present an obvious problem, and magnetic field measurements are strongly impacted by spacecraft altitude. To minimize the variation in altitude, gaps remain at those two locations.

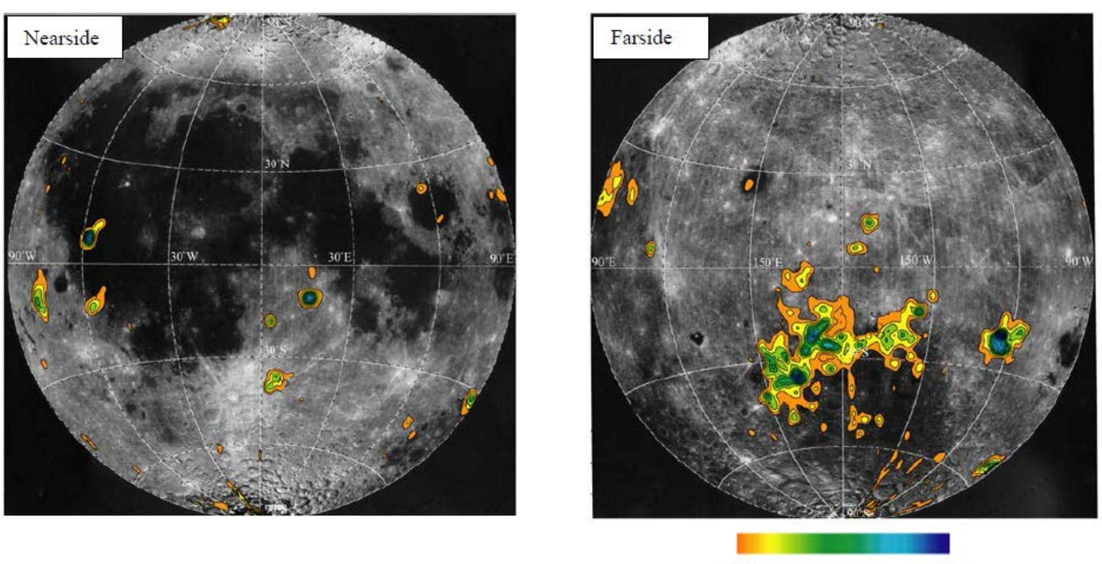


Figure 1: Total magnetic field at 30km constant altitude

Global Map at 30km Constant Altitude: The data were approximated to a constant altitude using an inverse power upward continuation approach [1, 3]. Following approximate continuation, the data were filtered two-dimensionally using a moving boxcar algorithm to produce a gridded dataset suitable for contour plotting the lunar magnetization. The 30km total magnetic field is presented in Figure 1.

Consistent with previous studies the mapping indicated that the largest distributions of crustal anomalies are located antipodal to the Crisium, Serenitatis, Imbrium and Orientale basins. There is a tendency for the strongest anomalies antipodal to Imbrium to lie along the edge of the pre-Nectarian South Pole-Aitken (SPA) basin [5, 6]. SPA is clear on the Clementine maps (Figure 1) as a dark circular feature in the southern farside. In addition to the anomaly clusters, we also map the previously studied isolated anomalies at Reiner Gamma, Rima Sirsalis, Descartes and Airy [1, 7 and others]. The Descartes anomaly is the strongest isolated anomaly on the Moon. Previous LP MAG studies of Descartes [8] were limited due to partial coverage of the anomaly. The processing summarized here provided multiple sets of complete coverage of the anomaly at Descartes, a significant improvement over previously available LP MAG data.

Utilizing the Global Coverage: Most recently, the data described here have been used to investigate the possible existence of a lunar core dynamo field early in lunar history. Anomalies have been identified within several pre-Nectarian and Nectarian aged basins [9, 10]. These findings are being used to provide further constraints on the time period within which a core dynamo field existed, and to investigate the origin of the lunar magnetization. We will overview the findings of those studies during the workshop.

References: [1] Hood L. L. et al. (2001) JGR, 106, 27825-27839. [2] Richmond N. C. et al. (2005) JGR, 110, doi:10.1029/2005JE002405. [3] Richmond N. C. and Hood L. L. (2008) JGR, 113, doi:10.1029/ 2007JE002933. [4] Purucker M. E. and Nicholas J. B. (2010) 115, doi:10.1029/2010JE003650. [5] Purucker M. E. et al. (2006) Lunar Planet. Science Conf. 36, Abstract #1933. [6] Hood L. L. and Artemieva N. A. (2007) Icarus 193, 485-502. [7] Halekas J. (2001) JGR 106, 27841-27852. [8] Richmond N. C. et al. (2003) GRL 30, 1395-1398. [9] Hood L. L. (2011) Icarus, 211, 1109-1128. [10] Richmond N. C and Hood L. L. (2012) Lunar Planet. Science Conf. 43, Abstract #1898.

Tools and workflow for synthesis of spectral information and visible imagery: Application to understanding ancient crustal materials on Mars. A. D. Rogers, Dept. of Geosciences, Stony Brook University, Stony Brook, NY 11794-2100, adrogers@notes.cc.sunysb.edu

Overview: The ancient highlands of Mars contain numerous isolated exposures (**Figure 1**) of high thermal inertia materials that exhibit higher abundances of olivine and/or pyroxene than surrounding, lower thermal inertia regolith [1-3] (**Figure 2**). These units have been interpreted as volcanic in origin, with emplacement conditions analogous to flood basalts on Earth [2, 4]. In Mare Serpentis, a low-albedo region located northwest of Hellas Basin, the units contain spatial variability in thermal infrared spectral properties at 102 m spatial scales [1] (**Figure 3**), which is near the spatial resolution capabilities of THEMIS. Targeted full resolution (FRT) CRISM images over Mare Serpentis rocky units show that variations in pyroxene composition and olivine abundance (**Figure 4**) contribute to the variations observed in THEMIS data. The available data show that the rocky exposures in this region are vertically stratified, with at least two igneous lithologies present.

Understanding the origin and history of these materials calls for constraints on: a) the mineralogical composition of each unit, b) the geographic extent of each unit, and c) the stratigraphy and thickness of units. This requires synthesis of information from THEMIS, CRISM/OMEGA, TES, visible imagery, and digital terrain models at the maximum possible spatial resolution of each data set over a wide study region. I will show how available data from these sensors are located and analyzed to meet the research objectives above. The primary tools used are JMARS [5], Davinci, and ENVI, including the ENVI CRISM Analysis Tools [6].

JMARS: JMARS is a Mars-based GIS that contains a variety of numeric and graphical layers derived from Mars mission data [5].

Locating and selecting images. In this work, JMARS is used to 1) Display base maps such as THEMIS daytime or nighttime radiance, 2) Find and display available image stamps ("stamp"=projected outline of the geographical extent of each image) over the areas of interest, 3) Browse the content of each image by rendering decorrelation stretched (DCS) THEMIS images or CRISM spectral index maps, and 4) Locate, select and download available TES spectra over small areas of interest.

TES layer. The JMARS TES layer supplies a GUI interface for the "vanilla" TES database. One can use a pre-loaded standard TES query or create and save their own query constraints. Projected TES footprints are retrieved from the query as well as the requested TES-derived fields (such as emissivity, dust opacity, albedo, etc.). Spectral indices can be calculated on-the-fly within the TES layer and displayed/overlaid at full TES resolution (**Figure 2**).

Mapping. JMARS contains functionality for creating ESRI-format shapefiles by clicking points, lines and polygons. This, combined with the ability to render high-level derived data products such as THEMIS DCS images or CRISM summary parameters within JMARS, allows for easy mapping of features/compositional units of interest. The shape files can be used to query numeric maps such as MOLA elevation or TES thermal inertia, and to calculate fields such as polygon area or perimeter length.

Davinci: *THEMIS analysis.* Selected THEMIS images are preprocessed for instrument-related artifacts and atmospheric emission using the web-based THEMIS processing tool (http://thmproc. mars.asu.edu). Detailed THEMIS image analysis and spectral extraction is carried out in Davinci (ASU-based image and spectral analysis software) and/or ENVI. Davinci includes custom tools for analysis of THEMIS data as well as many standard data reduction methods (e.g. PCA), thus it is the tool of choice for most aspects of THEMIS image analysis. THEMIS images are loaded into Davinci and atmospherically corrected using the methods of *Bandfield et al.* [7]. Rectangular or square areas of interest can be selected for spectral averaging and plotting. When non-rectangular ROIs are necessary, such as with small areas of interest, ENVI is used for spectral averaging. Derived products such as spectral end-member images or DCS images can be quickly displayed in JMARS using the Davinci stamp layer.

TES. TES data are atmospherically corrected and modeled using Davinci functions. Thermal emission spectral libraries for modeling can be created using Davinci or the online spectral library tool at http://tes.asu.edu

ENVI: *CRISM*. Detailed CRISM image analysis and spectral extraction is carried out using the CRISM Analysis Toolkit (CAT) for ENVI [6]. CRISM .img files and related products are first downloaded from the Mars Orbital Data Explorer (http://ode.rsl.wustl.edu/mars/). The CAT functions are used to atmospherically correct and project CRISM images. ENVI standard functions are used for spectral averaging and plotting, and comparison to CRISM library spectra.

References: [1] Rogers A. D. et al. 2009, *Icarus 200*, 446-462 [2] Rogers A. D. and R. L. Fergason 2011, JGR doi:10.1029/2010JE003772 [3] Loizeau D. et al. 2012, *Icarus 219*, 476-497 [4] Fergason R. L. and A. D. Rogers, 2011 *Fall AGU*, P33H-03 [5] Gorelick N. et al., 2003 *LPSC XXXIV*,#2057[6]http://geo.pds.nasa.gov/missions/ mro/crism.
htm#Tools [7] Bandfield J. L. et al. 2004, *JGR 109*, E10008.

Figure 1. Two regions where high thermal inertia, mafic exposures have been studied in detail by [1-2, 4]. The pink region is Mare Serpentis.

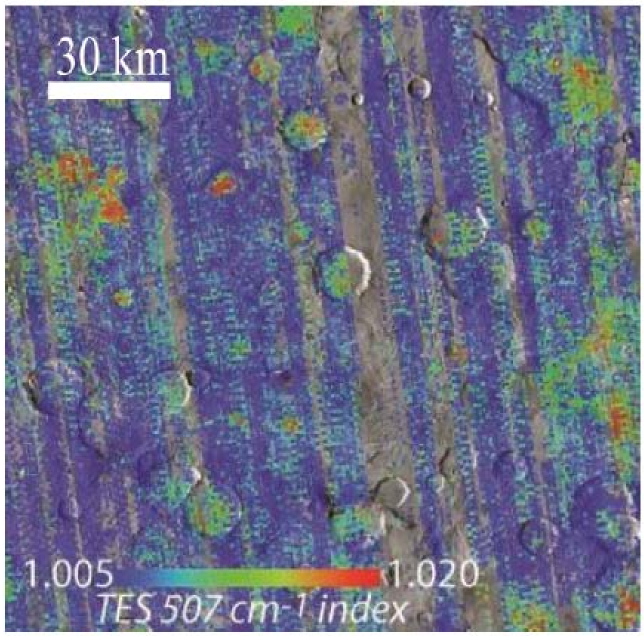
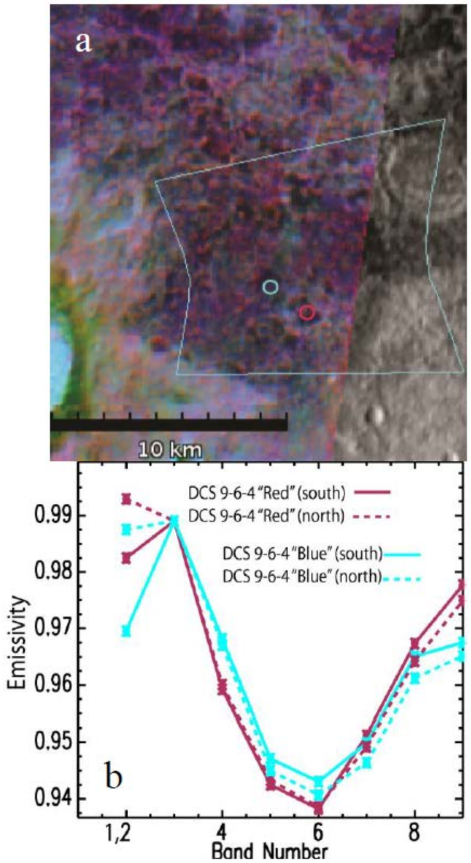


Figure 2. Typical out-crop spatial pattern of mafic rocky exposures. The exposures are identified using a TES spectral index that maps the emissivity slope between ~425-507 cm-1 which is sensitive to olv and/or pyx abundance [2]. This map was created using the JMARS TES layer. Individual TES orbits and detectors can be seen.



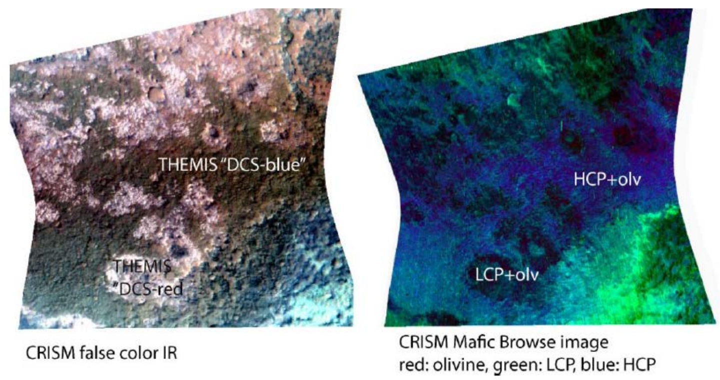


Figure 3 (Left). a. THEMIS DCS 09-6-4 image with outline of CRISM image in Figure 4. Circles show locations of "south" spectra in b. b. THEMIS surface emissivity spectra of two units within mafic bedrock exposures.

Figure 4 (Right). CRISM browse images of location shown in Figure 3A. Variations in tone and pyroxene composition are associated with THEMIS units.

andIsis: an Isis on Windows solution. E. I. Schaefer[1] and A. S. McEwen[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 (schaefer@lpl.arizona.edu).

Introduction: The U.S. Geological Survey's Integrated Software for Imagers and Spectrometers (Isis) [1] is not currently available for the Windows platform, yet some software that is often used in conjunction with Isis, including Esri's ArcGIS® and BAE Systems' SOCET SET®, are only available for Windows. To address this situation, we are developing andIsis [**Fig. 1**], which brings Isis 3 to Windows via seamless virtualization of a Linux environment, including permitting a single script to call both Windows and Linux software.

More specifically, andIsis is a fork of andLinux, a (nearly) out-of-the-box, Ubuntu-based distribution of coLinux [2]. coLinux is “a port of the Linux kernel that allows it to run as an unprivileged lightweight virtual machine in kernel mode, on top of another OS kernel” [3]. Put simply, coLinux turns the two operating system kernels into two encompassing coroutines that each individually manage their resources, though the host OS (Windows in this case) maintains exclusive control of the physical hardware [3].

Development of andIsis involves three main areas: modification of the andLinux setup executable; enhancement of the existing andCmd executable, which allows commands for the Linux environment to be passed from the Windows environment; and construction of a user interface to facilitate management of andIsis, including downloading and updating Isis mission modules.

andIsis setup executable: The andLinux setup executable was modified for andIsis to address two problems encountered immediately after installation. First, the user was unable to manually start or stop andLinux unless the relevant batch scripts were explicitly executed with administrator privileges, and this failure would occur silently if the batch scripts were executed via Windows Explorer. Second, unnecessary compatibility flags prevented Xming from loading at startup, and thus prevented Linux windows from displaying.

Additionally, to ensure that andIsis works out of the box, a few andLinux options were removed, such as the option to mount the Windows file system via Samba instead of CoFS.

andCmd2: andLinux includes andCmd.exe, an executable whose arguments are passed to the Linux environment as a shell command via a socket. Unfortunately, andCmd only provides one-way communication, so we developed andCmd2, a wrapper for andCmd that adds the following functionality:

- returns stdout, stderr, and the return code of the Linux command to the corresponding streams in Windows
- translates absolute Windows paths to equivalent Linux paths before passing the command to Linux, and reverses this conversion for paths in stdout and stderr

- better handles situations in which the andIsis service and/or the andCmd socket are down

Module Manager: Although Isis installs on POSIX systems without a frontend, the situation is significantly more complicated for andIsis because Isis and its modules cannot be installed directly on the Windows file system. Instead, they must use a virtual ext3 file system that permanently claims hard drive space from Windows (until uninstallation). Optimizing this allocation requires knowing beforehand the size of the modules to be downloaded, the available free space within the current virtual ext3 file system, the user-specified desired free space available on the ext3 file system after installation, the ability to incrementally allocate more space to the ext3 file system as required by the user or expanded modules, and allowance for ext3 file system overhead, since the virtual file system must be resized based on its reported size within the Windows file system rather than its apparent size to Linux applications.

To address these complications, we developed the Module Manager, which allows the user to select Isis 3 modules for update and download and specify the desired size of the swap volume, main Linux volume, Isis volume, and available free space on the Linux and Isis volumes after installation. Module Manager then automates all volume querying and resizing as well as all module downloading and updating.

Current limitations and future work: andIsis is currently in early beta testing and is expected to be released for external beta testing this summer. At that time, all andIsis code will be released as open source.

Current andIsis limitations are primarily those inherited from coLinux. Probably most importantly, coLinux is incompatible with 64-bit Windows operating systems. Although both ArcGIS and SOCET SET, as examples, are natively 32-bit, they nonetheless each benefit from the higher amount of RAM that 64-bit Windows operating systems can support (e.g., up to 192 GB in Windows 7) vs. their 32-bit equivalents (generally 4 GB), although 32-bit Windows Server operating systems can support up to 64 GB with Physical Address Extension [4].

In addition, coLinux can only access one processor, and the dependence of Module Manager on the Windows utility fsutil (for volume resizes) limits compatibility to Windows XP and later. (coLinux itself is separately incompatible with systems prior to Windows 2000.) Finally, the virtual ext3 file systems necessitate large (>2 GB) file support. Such support is afforded by the New Technology File System that has been standard since Windows XP.

References: [1] Anderson J. A. et al. (2004) *LPSC XXXV,* Abstract #2039. [2] andlinux.org [3] Aloni D. (2004) *Proceedings of the Linux Symposium*, 23-31. [4] http://msdn.microsoft.com/en-us/library/windows/ desktop/ aa366778(v=vs.85).aspx#physical_memory_ limits_windows_7

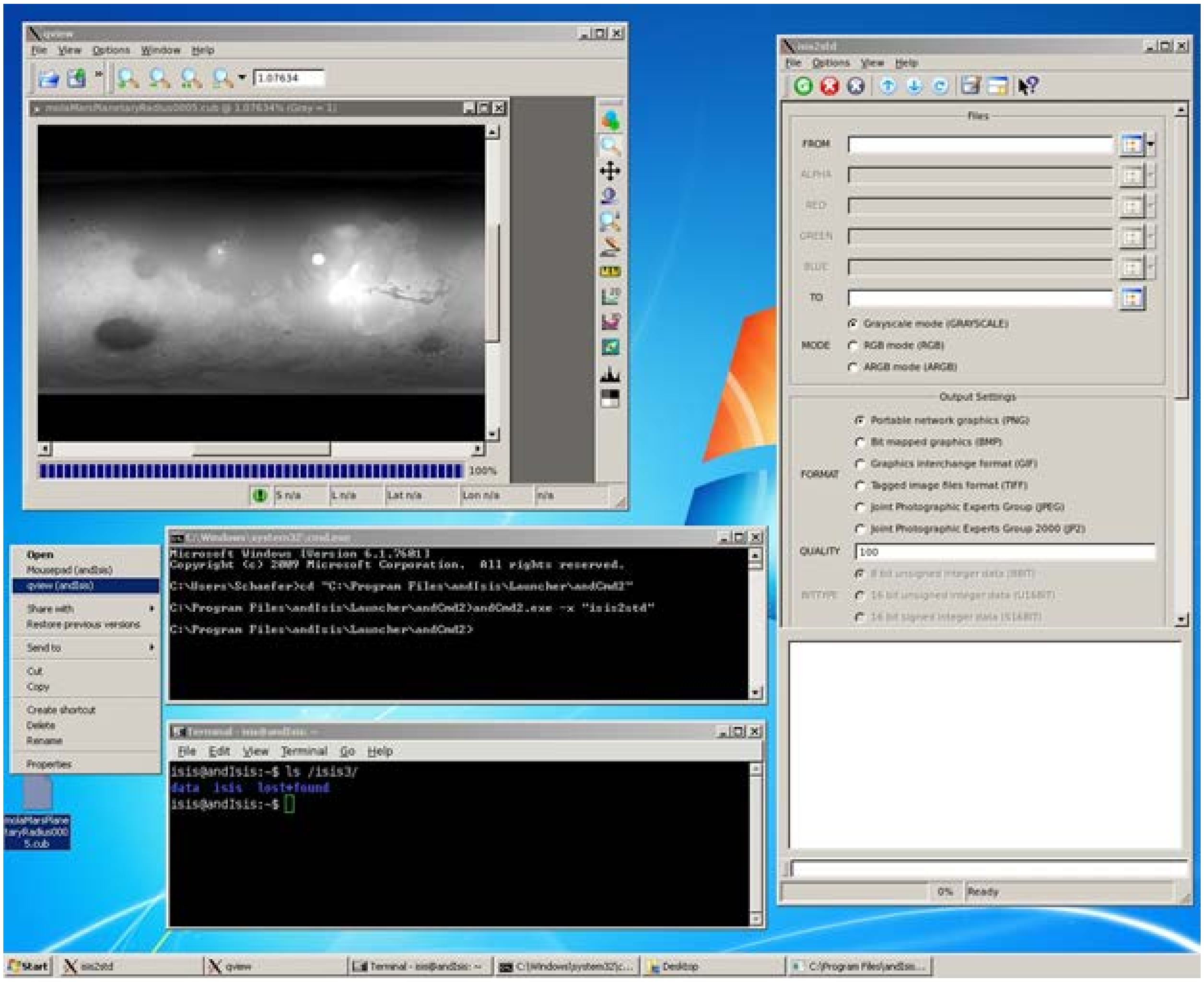


Fig. 1
andIsis on Windows 7. The MOLA cube was raised in Isis's qview (upper left) from the icon in the lower left via the context (right-click) menu. The Windows terminal (center) and andIsis Linux shell (lower center) are both shown, and an andCmd2.exe command in the Windows terminal was used to raise the isis2std window (right).

CRISM Map Projected Targeted Reduced Data Records (MTRDRs) – High Level Analysis and Visualization Data Products. F. P. Seelos, M. F. Morgan, H. W. Taylor, S. L. Murchie, D. C. Humm, K. D. Seelos, O. S. Barnouin, C. E. Viviano, and The CRISM Team, Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD, 20723 (frank.seelos@jhuapl.edu).

Introduction: The Mars Reconnaissance Orbiter (MRO) Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) team is finalizing software, specifications, and definitions for a new high level analysis and visualization data product suite – the Map Projected Targeted Reduced Data Record (MTRDR) product family. The MTRDRs are derived from CRISM hyperspectral targeted observations - Full Resolution Targeted (FRT), Half Resolution Long (HRL), Half Resolution Short (HRS), and Along Track Oversampled (ATO) – with the image cubes processed through a series of standard and empirical spectral corrections, spatial transforms, parameter calculations, and renderings. The MTRDR product suite represents a major advance in the accessibility of CRISM-derived spectral information and is expected to become the preferred entry point into the CRISM targeted observation data set for a large portion of the Mars science community.

MTRDR Motivation: CRISM PDS-delivered targeted observation TRR3 (Targeted Reduced Data Record version 3) data products accurately report the observed spectral radiance (or apparent I/F) but include a number of characteristics traceable to the instrument configuration or operational scenario (separate VNIR and IR detectors, gimbal motion), minor radiometric calibration residuals (spectral smile), and observational circumstances (illumination geometry, atmospheric state) that complicate the visualization, intra-scene evaluation, and inter-observation comparison of surface spectral variability.

Standard Corrections. The MTRDR pipeline (Figure 4) includes two standard corrections - a basic photometric (Lambertian) correction (PHT), and an updated 'volcano scan' atmospheric correction based on the application of empirically derived atmospheric transmission spectra (ATM) [1]. The revised volcano scan correction includes a large selection of reference atmospheric spectra that track subtle shifts in the instrument wavelength calibration, and procedural improvements that minimize spectral and spatial correction residuals. The latter includes the post-correction application of the Ratio Shift Correction (RSC) to mitigate the reintroduction of along-track column striping.

Empirical Corrections. CRISM targeted observations are acquired with a continuously varying emission and phase angle geometry due to the requisite gimbal image motion compensation. This typically results in an asymmetric, wavelength-dependent, along-track gradient primarily related to variation in atmospheric path length and aerosol scattering. These effects are addressed by the Empirical Geometric Normalization (EGN) procedure that characterizes the geometric dependencies across all segments of a targeted observation (central scan bounded by reduced spatial resolution higher emission angle images), and normalizes the central scan to a reference geometry.

Spectral smile is an optical artifact whereby the wavelength calibration shifts as a function of spatial position. The CRISM radiometric calibration has a small residual related to spectral smile that appears as a wavelengthdependent cross-track gradient. This is addressed by the Empirical Smile Correction (ESC) which characterizes intra-channel wavelength sampling dependencies and normalizes the data to a reference wavelength vector.

The aggregate effect of the standard and empirical corrections [2] on a representative CRISM targeted observation is shown in Figure 1 and Figure 2.

Geometric Reconciliation. The CRISM VNIR and IR optical designs were individually optimized – as a result a given source (ground location) is sampled differently and mapped to different coordinates on the two detectors. The MTRDR VNIR/IR sensor space transform uses the known ground location of every VNIR and IR pixel to construct a spatial transformation that maps the VNIR data into the IR reference frame. This transformation allows for the integration of VNIR and IR spectral information and the generation of full spectral range sensor space and map projected data products (e.g. Figure 3).

Summary Parameters and Browse Products. Spectral summary parameters are band math calculations that quantify diagnostic or indicative spectral structure. CRISM browse products are RGB composites of thematically related summary parameters. The spectral summary parameter code library implemented in the MTRDR pipeline has been updated to consistently and appropriately make use of the targeted observation hyperspectral sampling. The resulting suppression of spectral noise in the parameter calculations, in combination with the addition and revision of selected parameter formulations, has resulted in a suite of standard data visualization products with expanded scope and improved fidelity.

MTRDR Product Status. The motivation, generation, application, nomenclature, and data availability plan for the MTRDR family of high level data products will be presented. The pipeline generation and subsequent PDS-delivery of MTRDRs for all CRISM hyperspectral targeted observation that meet a set of data quality and completeness criteria is slated to begin in late 2012. Selected prototype MTRDR data products were made available in association with the 2012 CRISM Data Users' Workshop and are hosted at the PDS Geosciences Node [3].

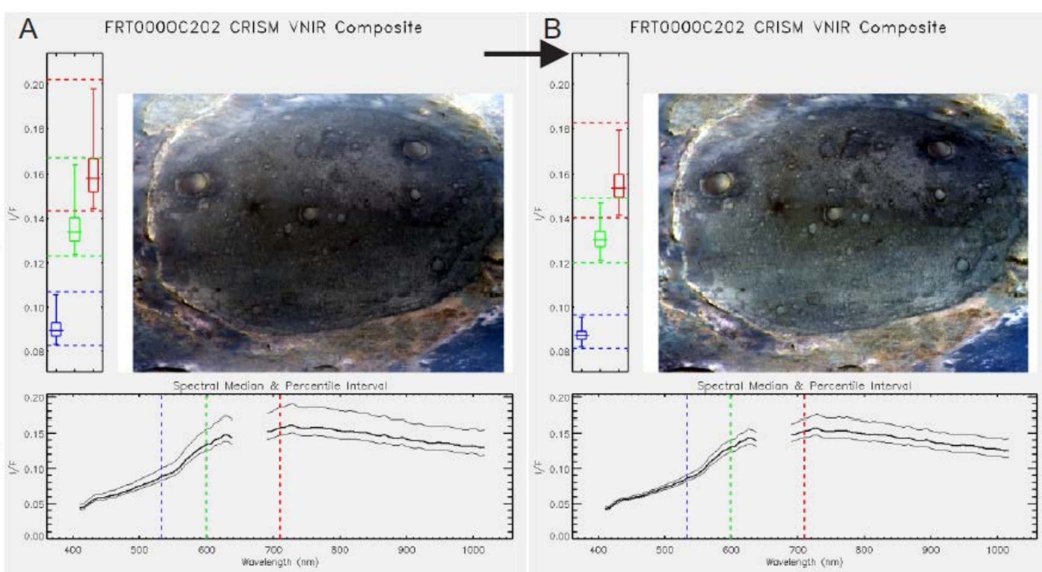


Figure 1. FRT0000C202 MTRDR VNIR spectral processing - three panel composites. (A) TRR3 VNIR image cube after photometric correction (PHT). (B) TRR3 VNIR image cube

after all subsequent MTRDR systematic spectral processing (EGN, ESC). The spectral and boxplot scales in (A) and (B) are identical, allowing for a direct evaluation of the MTRDR data processing. The most obvious change between (A) and (B) – the mitigation of the wavelength dependent along-track gradient - is the result of the EGN procedure.

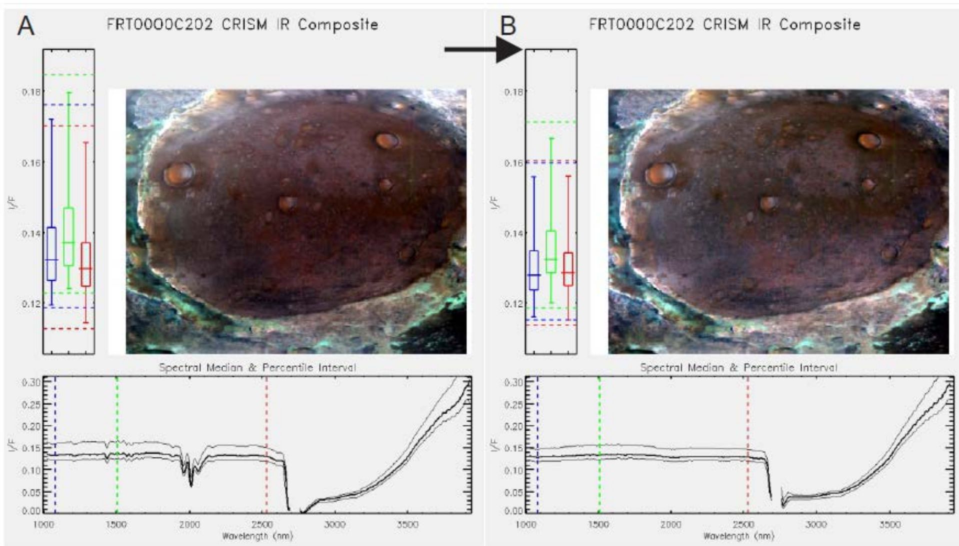
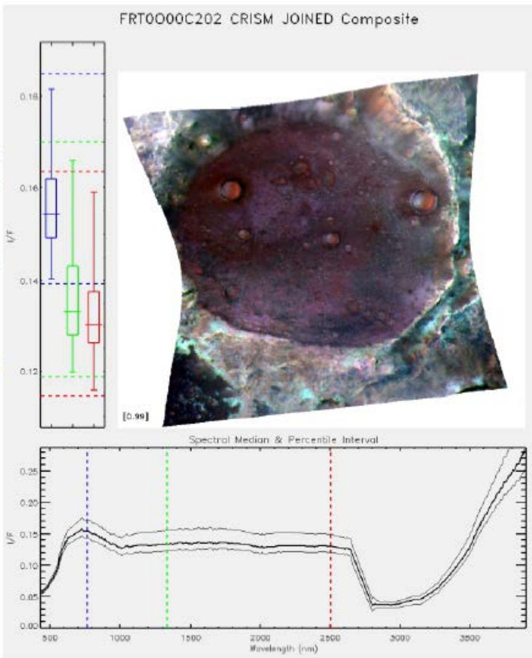


Figure 2. FRT0000C202 MTRDR IR spectral processing - three panel composites. (A) TRR3 IR image cube after photometric correction (PHT). (B) TRR3 IR image cube after all subsequent MTRDR systematic spectral processing (ATM/RSC, EGN, ESC). The spectral and boxplot scales in (A) and (B) are identical, allowing for a direct evaluation of the MTRDR data processing. The most obvious change between (A) and (B) – the correction of the ~2000 nm CO2 absorption and other minor atmospheric features - is the result of the ATM correction.



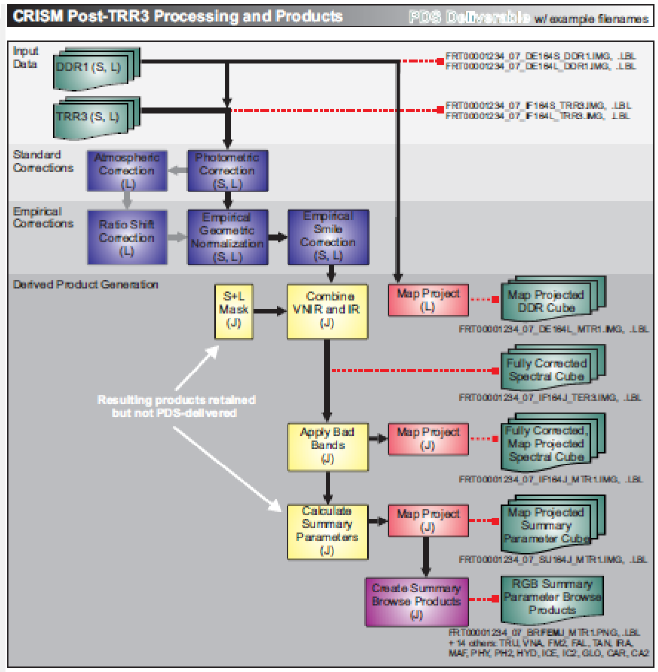


Figure 3 (Left). FRT0000C202 MTRDR three-panel composite. The spectral MTRDR data product incorporates all of the VNIR and IR detector-specific data processing (Figure 1, Figure 2) and the VNIR/IR sensor space transform to spatially align the constituent image cubes. The map projection is consistent with the 'rolling equirectangular' MRO standard. Note that the MTRDR RGB composite combines bands that source from both the VNIR (B: ~770 nm) and IR (G: ~1330 nm; R:~2510 nm) detectors.

Figure 4 (Right). CRISM MTRDR data processing pipeline. PDS-deliverable data products are shown in green. Figure 3 is a visualization of the 'Fully Corrected Map Projected Spectral Cube'.

References: [1] Morgan M. F. et al. (2011) LPSC XLII, Abstract #2453. [2] Seelos, F. P. et al. (2011) LPSC XLII, Abstract #1438. [3] MRO/CRISM 2012 Data Users' Workshop (2012) [PDS Geosciences Node] [APL].

PHOTOMOD – A Standalone Software System for Planetary Image Analysis. Semenov M., Zubarev A., Nadezhdina I, Patraty V., Shishkina L., MExLab (MIIGAiK Extraterrestrial Laboratory) 105064 Gorokhovskii pereulok 4, Moscow, Russia, fair-max@yandex.ru, info@mexlab.ru

Introduction

«PHOTOMOD» [1] is digital photogrammetrical software for the Earth images processing and DTM, orthophotoimages and mosaics development.

In 2011 the «PHOTOMOD» software has been upgraded for the possibilities of the planetary images to be processed and 3-D models developing.

The upgraded software «PHOTOMOD» are testing at MIIGAIK Extraterrestrial Laboratory and can be used for tiepoint measurements, bundle block adjustment, mosaic and orthophotoimages preparing, control point measurements and images analysis for planetary bodies of the Solar System.

We have plans to integrate the output of the «PHOTOMOD» software with PDS database.

Acknowledgments: The authors have been supported by a grant from the Ministry for Education and Science of the Russian Federation (Agreement # 11.G34.31.0021 dd 30/11/2010)

References:

[1] http://www.racurs.ru/?lng=en&page=634.

Of Backplanes and Metadata: Python Tools in Development at the PDS Rings Node.
M. R. Showalter and B. S. Wells, SETI Institute (189 Bernard Avenue, Mountain View, CA 94043, mshowalter@seti.org, bwells@seti.org).

Introduction. We present an overview of the capabilities of Object-Oriented Python and SPICE ("OOPS"), a software package in development at the PDS Rings Node to support our on-line facilities. OOPS is a set of Python modules that overlay the SPICE toolkit, enabling a broad range of fast, highlevel planetary geometry calculations.

Overview. The Python programming language provides a unique set of features for scientific programmers. It is a scripting language with a highly expressive and efficient syntax, enabling users to prototype and test software rapidly. Its object-oriented design facilitates the development of modules that can encapsulate extremely powerful algorithms within easily used packages. The array-based nature of its operations makes it nearly as fast as optimized C or FORTRAN for many applications. Finally, unlike other widely-used scientific scripting languages, it is free.

OOPS is a framework for a variety of sophisticated planetary geometry calculations. It has the following features.

- We have developed Python interfaces to most of the CSPICE subroutines via SWIG.
- A SQLite3 database tracks SPICE kernels and their release dates. The most recent kernels are loaded automatically at run-time, obviating the need for direct SPICE kernel management by the user.
- All calculations can be performed simultaneously on arrays of arbitrary shape and size.
- Abstract object classes such as "Surface", "Path" and "Frame" can be easily extended to provide new features, many of which are not intrinsically part of the SPICE toolkit.
- General methods are available to define photon departure and arrival "events" and to determine their separations in space and time. For example, a few function calls are all it takes to (a) define the photon arrival events for an image, (b) determine the associated photon departure events from Saturn, (c) determine the photon departure events from the Sun associated with the arrivals at Saturn, thereby defining the lighting geometry at Saturn's surface, and (d) determining which of these photon paths form the Sun intercepted the rings first, thereby defining the rings' shadow on the planet.
- A hierarchy of instrument "reader" classes open data files or indices and return the associated observation event(s), making it possible for a single program to work across multiple instruments and missions.

Backplanes. OOPS obtains its most basic information via embedded calls to the SPICE toolkit, but replaces all higher-level calculations with vectorized, Python-native algorithms. We have found that this vectorization is the key to making planetary geometry calculations fast enough for eventual deployment as web services. For example, as we will demonstrate (see Figure 1), we can generate full-resolution (1024×1024 pixel) geometric backplanes of Cassini images in a matter of seconds. A few lines of Python are all it takes to generate image quantities such as the following.

- Ring intercept radius and longitude.
- Surface latitude and longitude.
- Planetary limb geometry.

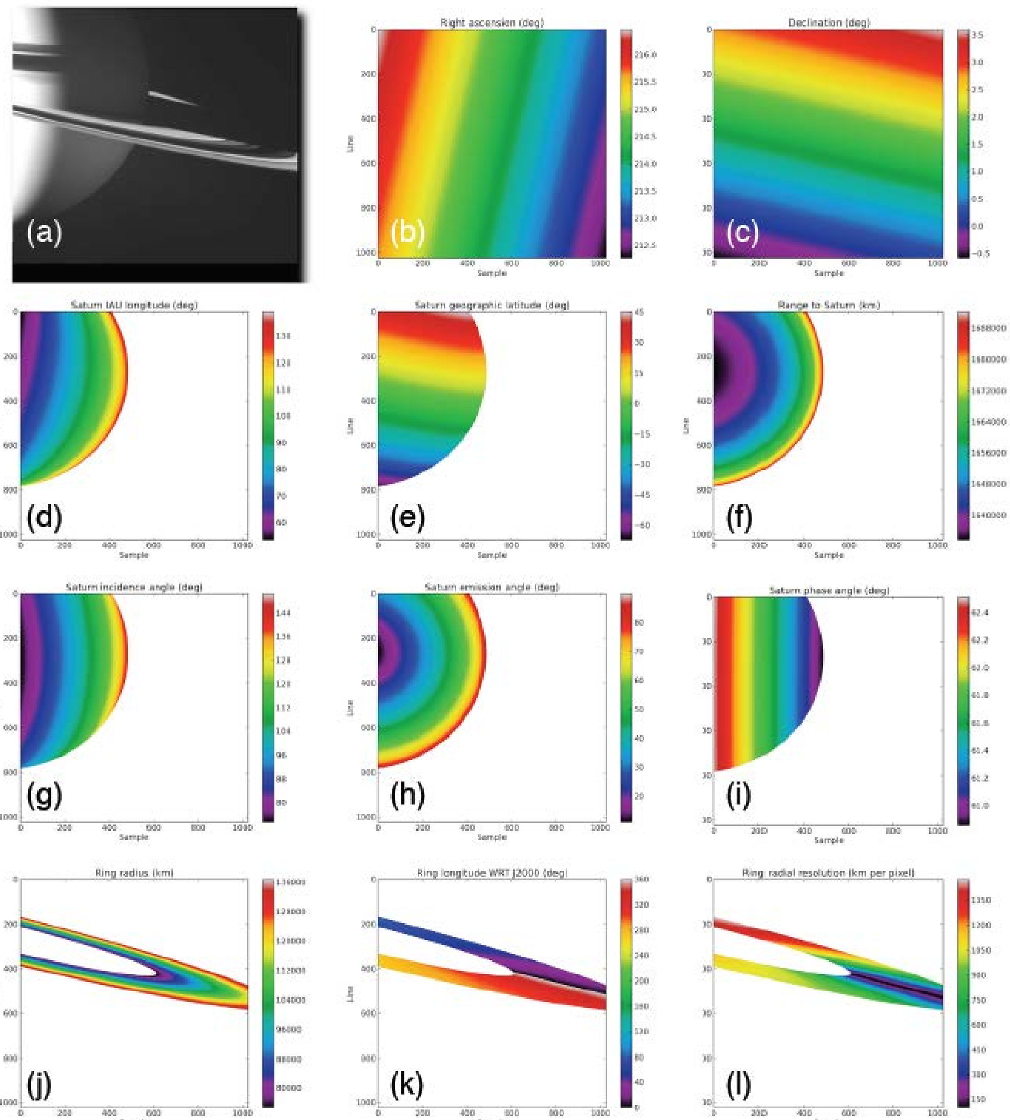
- Distance to an (almost) arbitrary surface.
- Incidence, emission and phase angle on an arbitrary surface.
- Spatial resolution on an arbitrary surface.

The code can also generate “mask” images providing such information as:

- The frontmost body at each pixel in an image.
- Locations within an image where one object obscures or shadows another. Readers for other kinds of instruments such as rasterscanning and “push-broom” cameras are in development.

Metadata and Search. Using a combination of backplanes and masking, the Rings Node is in the process of generating a complete set of geometric metadata for all of the Cassini Saturn data products from the optical remote sensing instruments: ISS, VIMS, UVIS and CIRS. This metadata will be integrated into “OPUS” shortly, providing new and more powerful search capabilities. Eventually, we hope to extend this work to additional data sets from the outer planets. We will also discuss future on-line tools that are being prototyped at this time.

Acknowledgments: This development has been supported by the Planetary Data System, by JPL through a special grant from the Cassini Project, and by research grants from STScI and NASA.



(a)
Right ascension (deg)
(b)
Declination (deg)
(c)
Saturn IAU longitude (deg)
(d)
Saturn geographic latitude (deg)
(e)
Range to Saturn (km)
(f)
Saturn incidence angle (deg)
(g)
Saturn emission angle (deg)
(h)
Saturn phase angle (deg)
(i)
Ring radius (km)
(j)
Ring longitude WRT J2000 (deg)
(k)
Ring radial resolution (km per pixel)
(l)

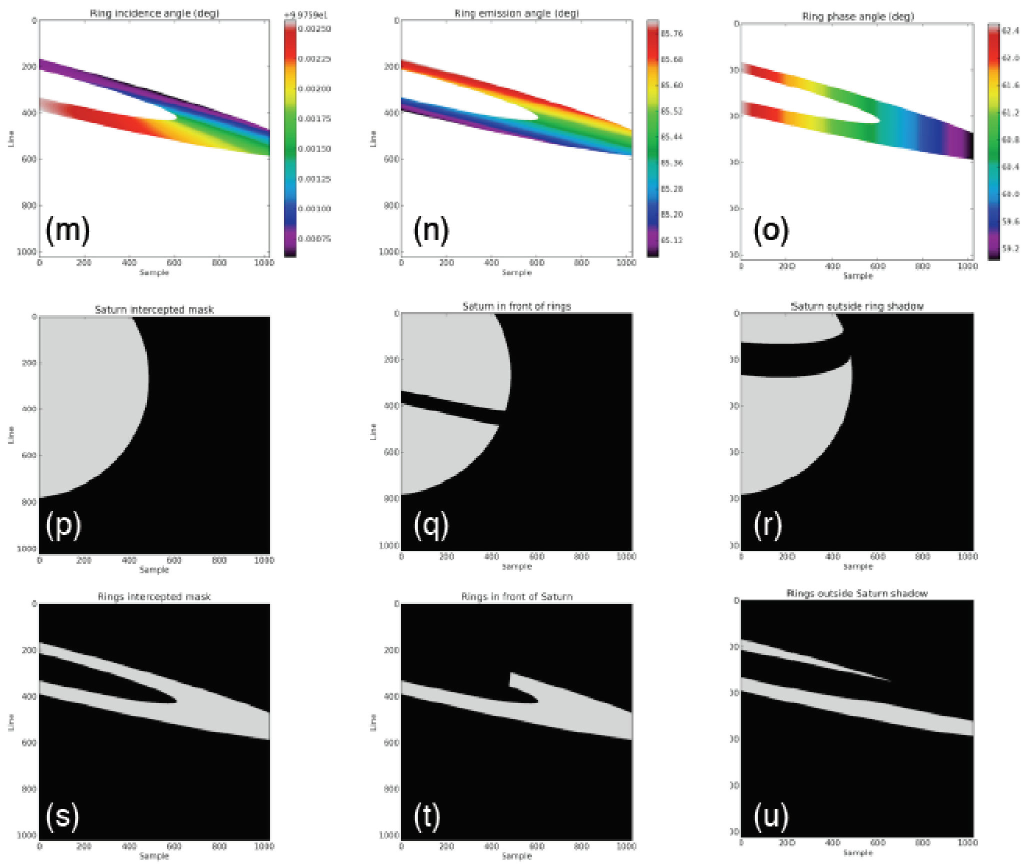


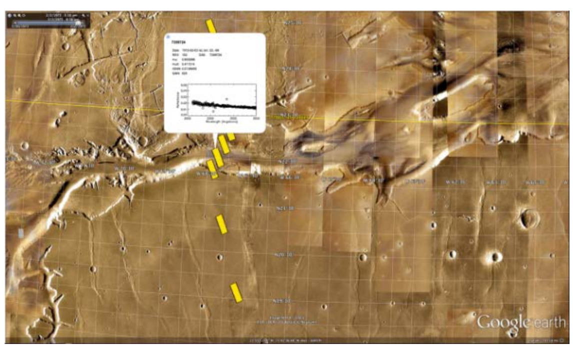
Figure 1. A sample Cassini image with a gallery of backplanes and masks. Backplanes are color-coded from a minimum value in violet to a maximum value in red. Masks are white where "true" and black where "false". All of these full-resolution images were generated in less than 80 seconds on a Macintosh laptop.

(a) The original Cassini image, W1573721822_1.IMG.
(b) Right ascension backplane (°).
(c) Declination (°).
(d) Saturn IAU longitude (°).
(e) Saturn geographic latitude (°).
(f) Cassini-surface distance (km).
(g) Saturn incidence angle (°).
(h) Saturn emission angle (°).
(i) Saturn phase angle (°).
(j) Ring radius (km).
(k) Ring inertial longitude (°).
(l) Projected radial resolution in the ring plane (km/pixel).
(m) Ring incidence angle (°).
(n) Ring emission angle (°).
(o) Ring phase angle (°).
(p) Mask of points intercepting Saturn.
(q) Mask of Saturn points not obscured by the rings.
(r) Mask of Saturn points not shadowed by the rings.
(s) Mask of points intercepting the rings.
(t) Mask of ring points not obscured by Saturn.
(u) Mask of ring points not shadowed by Saturn.

MARINER 9 GoogleMars. K. E. Simmons[1], K. D. Mankoff[2], C. A. Barth[1]. [1]LASP, University of Colorado Boulder, 3665 Discovery Drive, Boulder, CO, 80303, karen.simmons@lasp.colorado.edu, [2]Earth and Planetary Sciences Department, University of California, Santa Cruz, 1156 High Street, Santa Cruz, CA 95060, kdmankof@UCSC.edu.

Abstract: The Mariner 9 spacecraft entered Mars orbit on November 14, 1971. The Mariner 9 Ultraviolet Spectrometer (UVS)[1], built at the University of Colorado's Laboratory for Atmospheric and Space Physics (LASP), measured the upper atmospheric airglow during the limb scans [2] and mapped the topography [3] of a substantial area of the surface after the subsidence of the planet wide dust storm. Recent reanalysis of these data, using newer solar irradiance data obtained two solar cycles later from the 1994 SORCE mission [4], has produced a new Mariner 9 UV Reflectance data set. We have now incorporated this Reflectance data into a Google Earth Mars data layer using a set of KML files generated for this new analysis using the kdm-idl code library [5] thus creating an extremely useful visualization tool that enables one to directly compare the Mars image map with the UV profiles. This new tool is called GoogleMars.

The UVS topographic mapping continued from January 19 to February 29, 1972. The twelve-hour orbit was designed to map the entire planet, however, even numbered realtime orbits resulted in higher quality downlinked data so these were used in this analysis. The 2107 to 3497A portion of the F-channel Reflectance obtained from each spectrum is presented as a color-coded rectangular field-of-view footprint displayed on GoogleMars representing the UV intensity at 3049A. At this wavelength the pressure of the atmosphere, the presence of dust and ice crystals and the ground albedo influences the intensity. Individual footprints can be selected in this GoogleMars version to display a balloon containing the Reflectance plotted between 2100 and 3500A plus the viewing geometry, date and spacecraft clock (DAS) time, along with the orbit number and the 3049A Reflectance value. For a further description and to explore this new Mariner 9 Reflectance data on GoogleMars, see http://lasp.colorado.edu/home/mariner9/GoogleMars .



References: [1] Hord C. W., Barth C. A., Pearce J.B., (1970) *Icarus, 12,* 63–77. [2] C. A. Barth, C. W. Hord, A. I. Stewart, A. L. Lane, (1972) *Science, 175*, 309-312, [3] C. W. Hord, K. E. Simmons, L. K. McLaughlin, (1974) *Icarus, 21,* 292-302. [4] http://lasp.colorado.edu/sorce/data [5] https://code.google.com/p/kdm-idl/ .

Understanding NASA surface missions using the PDS Analyst's Notebook. T. Stein, Washington University in St. Louis, Missouri, USA, tstein@wustl.edu.http://an.rsl.wustl.edu

Abstract

Planetary data archives of surface missions contain data from numerous hosted instruments. Because of the nondeterministic nature of surface missions, it is not possible to assess the data without understanding the context in which they were collected. The PDS Analyst's Notebook (http://an.rsl.wustl.edu) provides access to Mars Exploration Rover (MER) [1] and Mars Phoenix Lander [2] data archives by integrating sequence information, engineering and science data, observation planning and targeting, and documentation into web-accessible pages to facilitate "mission replay." In addition, Lunar Apollo surface mission data archives and LCROSS mission data are available in the Analyst's Notebook concept, and a Notebook is planned for Mars Science Laboratory (MSL) mission.

1. Populating the Notebook

Each Notebook contains data, documentation, and support files for a given mission. For MER and Phoenix, inputs are incorporated on a daily basis into a science team version of the Notebook. The public version of the Analyst's Notebook is comprised of peer-reviewed, released data and is updated coincident with PDS data releases as defined in mission archive plans.

Data. The MER and Phoenix Notebooks contain publicly released, peer-reviewed PDS archives from all science instruments. The data are provided by the instrument teams and are supported by documentation describing data format, content, and calibration.

Both Operations Products Generation Subsystem (OPGS) and Science data products are included in the MER and Phoenix Notebooks. The OPGS versions were generated to support mission planning and operations on a daily basis. They are geared toward researchers working on machine vision and engineering operations. Science versions of observations from some instruments are provided for those interested in radiometric and photo-metric analyses.

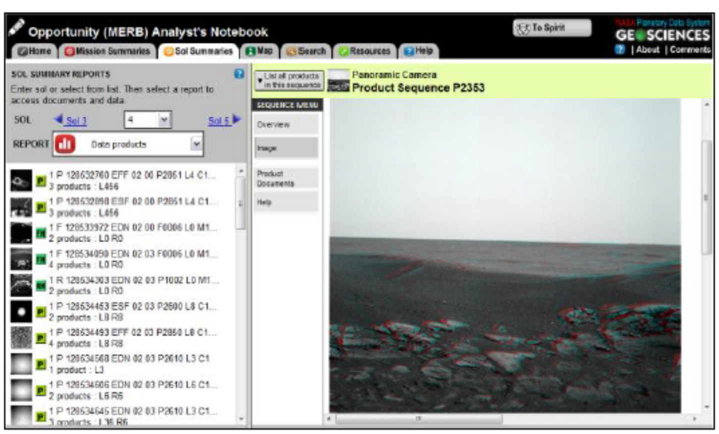


Fig. 1. MER Notebook summary page showing data products for Opportunity sol 4. The anaglyph image on the right was generated on demand.

Apollo data are organized by mission, instrument, and station. Data are added to the Notebook as they are restored from original tapes, reports, and microfilm. Where data have not been restored the user is redirected to external data providers such as the National Space Science Data Center (NSSDC).

Documents. Several types of documents are included in the Note-book. Mars Notebooks contain data set documentation and sol (i.e., Mars day) documents. The sol documents are the mission manager and documentarian reports that provide a view into science operations—insight into why and how particular observations were made. The reports have not been edited except for grammar and spelling, and to remove spacecraft and instrument sensitive materials.

Data set documents contain detailed information regarding the mission, spacecraft, instruments, and data formats.

The Apollo Notebook contains references to preliminary science reports, overviews, and catalogs for experiments and collected samples.

Science Plans. For the MER and Phoenix Notebooks, observation planning and targeting information is extracted from each sol's tactical science plan. This information includes instrument set-tings such as filters used and sensors selected, as well as observation parameters such as distance to target.

2. Navigating the Notebook

A number of methods allow user access to the Notebook contents. The feature set of each Notebook varies, depending on the types of input available.

Mission Summaries. Timelines and summaries of mission data are presented in the mission summaries. For Phoenix, a mission over-view and dig summary are included. Coordinated Observations—concurrent data collection by the Phoenix, Mars Reconnaissance Orbiter, and Mars Express missions—are listed along with links to the data.

Mission data from LCROSS are grouped by instrument and mission phase. Instrument pointing information is overlaid on time-lapse videos of acquired data for context.

Sol Summaries. The Sol Summaries are the primary interface to integrated data and documents contained within the MER and Phoenix Notebooks (fig. 1). Data, documents, planned observations, and features are grouped for easy scanning. Detailed information is displayed as items are selected by the user.

Data products are displayed in order of acquisition, and are grouped into logical sequences, such as a series of image data. Sequences and the individual products that comprise them may be viewed in detail, manipulated, and downloaded. Color composites and anaglyph stereo images may be created on demand. Graphs of some non-image data, such as spectra, may be viewed. Data may be downloaded as zip or gzip files, or as multiband ENVI image files.

Mission-specific features are also available in the sol summaries. In the MER Notebook, activity plan listings are interspersed with the resulting products. In the Phoenix Notebook, graphical timelines contain planned observations and links to data products. Locations are identified through use of context images as well as position offset within the lander frame.

Maps. The MER and Apollo Notebooks offer a map interface for locating data. The Apollo Notebook map denotes each station, including sample locations and links to the data. The MER Note-book contains two maps for each rover, one showing the drive traverse, and the other an interactive map showing the location of imaging and Mossbauer products for each site.

An additional traverse map is available for MER using the Mosaic Viewer tool that allows users to begin with a base map of each rover's traverse on Mars (fig. 2). As users zoom into the map, higher resolution map tiles in the area of interest are read from a data base, streamed in real time to the client, and seamlessly dis-played. Pop up windows display available mosaics at a given location on the user's request. In turn, the user can select an individual mosaic for further inspection.

When displaying a mosaic, a listing of the source frames is available that shows a thumbnail image and the archive product ID of each source frame along with a link to further details available in the Analyst's Notebook. Users also can display "footprints" of the source frames on the mosaic. These footprints show the location of individual frames within the mosaic. Finally, users can download mosaic and source frame data and documentation from a simple order form.

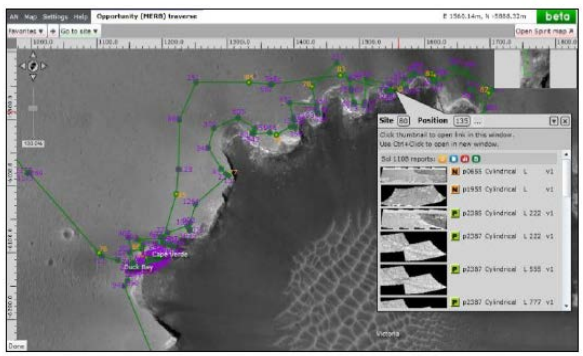


Fig. 2. Mosaic Viewer tool showing traverse map for Opportunity rover. The popup dialog lists mosaics available for viewing.

Searching. Three types of searching through data and documents are available within the MER and Phoenix Notebooks. Free text searching of data set and sol documents are supported. Data are searchable by instrument, acquisition time, data type, and product ID. Results may be downloaded in a single collection or selected individually for detailed viewing.

Resources. Data set documents and references to published mission papers are contained in the Resources. In addition, links to related web resources are listed.

Online Help. Guidance is provided through a series of searchable help pages. Topics include release notes, mission phases, landing site, coordinate frame, instruments, data processing, and data product file naming and structure.

3. Future Development

Work continues to improve functionality, including a Notebook planned for the Mars Science Laboratory mission. A number of Notebook functions are based on previous user suggestions, and feedback continues to be sought. (User feedback should be sub-mitted to an@wunder.wustl.edu or to the online user forum.)

Acknowledgments
The Analyst's Notebook is developed through funding provided by the Planetary Data System Geosciences Node, the Mars Exploration Rovers Mission, and the Phoenix Mission. Cooperation of the MER and Phoenix science and operations teams is greatly appreciated.

The Analyst's Notebook is available at http://an.rsl.wustl.edu.

References
[1] J.A. Crisp, M. Adler, J.R. Matijevic, S.W. Squyres, R.E. Arvidson, and D.M. Kass: Mars Exploration Rover mission, JGR, 108(E12), 8061, doi:10.1029/2002JE002038, 2003.
[2] Smith, P.H. et al.: Introduction to the Phoenix Mission, JGR, 113, doi:10.1029/2008JE003083, 2008.

Implementation of an ISIS Compatible Image Matching Tool for 3D Stereo Reconstruction. E. Tasdelen[1], K. Willner[1] and J. Oberst[1,2], [1]Technische Universität Berlin, Institute for Geodesy and Geoinformation Science, Planetary Geodesy, Berlin, Germany, [2]German Aerospace Center (DLR), Berlin-Adlershof, Germany.

Introduction: The department for Planetary Geodesy at TU Berlin is developing routines for photogrammetric processing of planetary image data to derive 3D representations of planetary surfaces. The ISIS software, developed by USGS, Flagstaff, is readily available, open source, and very well documentation. Hence, ISIS was chosen as a prime processing platform and tool kit. However, ISIS does not provide a full photogrammetric stereo processing chain. Several components like image matching, bundle block adjustment (until recently) or digital terrain model (DTM) interpolation from 3D object points are missing.

Hence, our group aims to complete this photogrammetric stereo processing chain by implementing the missing components, taking advantage of already existing ISIS classes and functionality. With this abstract we would like to report on the development of a new matching software that is optimized for both orbital and close-ranged planetary images and compatible with ISIS formats and routines.

Software Details: The matching software supports multithreading in order to increase the performance and to handle large images, such as Lunar Reconnaissance Orbiter Camera (LROC) data, efficiently. Currently supported image formats are Vicar, TIFF and ISIS CUBE. The Matcher integrates different area based matching algorithms like normalised cross-correlation (NCC) and least-squares matching (LSM). NCC delivers an approximate value of disparity. LSM is applied in order to refine the result to subpixel accuracy. Within the software, different types of matching strategies are possible: Matching without Preprocessing, Coarse-to-fine Hierarchical Matching and Grid Based Matching. The definition of the search space, which is the maximum expected image coordinate difference (disparity) in overlapping stereo images, is the main difference between the approaches.

Matching without pre-processing, as the name implies, tries to determine conjugate image points in stereo images without applying any pre-processing. The search space is defined by the users.

Coarse-to-fine hierarchical matching creates image pyramids from input images and performs matching on these images. The results from pyramid images are used to define the search space for the main matching runs.

Grid based matching uses projective transformation in order to decrease the search space. Tie points and transformation parameters are calculated automatically. It follows the computation of the transformation for the whole image or smaller sized grids which can be obtained after portioning the image. The latter, leads to unique transformation parameters and search space parameters for each defined section of the image.

Postprocessing: To further improve the results and especially identify remaining mismatches postmatching filters were developed. The results improved significantly.

Overlapping Area Check: Projective transformation is used in order to remove outliers that are accumulated on the non-overlapping areas. The first step is the determination of the tie points and the transformation parameters. With the help of these parameters, any matching results from non-overlapping areas can be discarded.

Epipolar Check: With the help of epipolar geometrical relation [1], all the matched points are controlled and the distances of the points to the corresponding epipolar lines are calculated. Points exceeding a set threshold distance to the epipolar line are discarded. A processing chain to create 3D reconstruction of the matcher results has been created. Further filtering, applied to the 3D point cloud, resulted from this process.

3D Point Filtering with Octree Structure: This filter uses octree data structure created from 3D point cloud data. This enables spatial partitioning, down sampling and search operations on the point data set [2]. The removal of noise is done by checking the density of each child node (voxels). Nodes with low density, containing only few points, are considered as noise.

Results: The matcher was tested with two different stereo image pairs. Figure 1 shows close-range images that were acquired during a field trial. The second data set contains LRO orbital images (Fig.3). The results of the matcher presented here were carefully compared to the results of another image matching software, e.g. software used at DLR (Deutsches Zentrums für Luftund Raumfahrt), with respect to number of matches found, completeness and quality of the visual 3D representation.

The first tests were made on close-range images. The main difficulty for these kind of images is the large disparity-variety and resulting large search areas that cause high probability of mismatches. The results showed that in terms of coverage and completeness, TU matcher shows high quality. However, it suffers from large number of outliers. Thus, a post-processing step was applied and mis-identified corresponding points were subsequently removed by applying different filter techniques. Figure 2 shows the resulting 3D reconstruction.

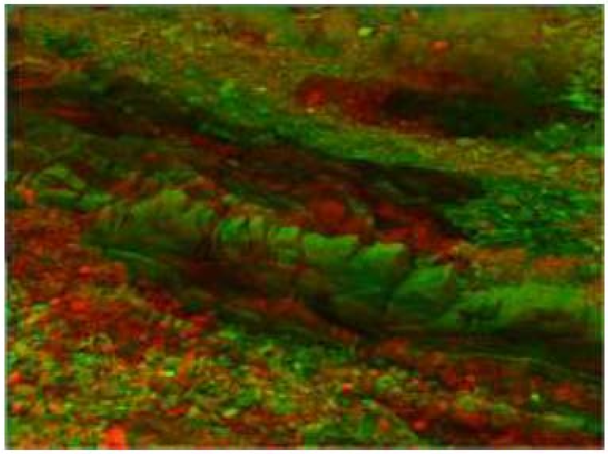


Figure1: Clarach Bay Stereo Images

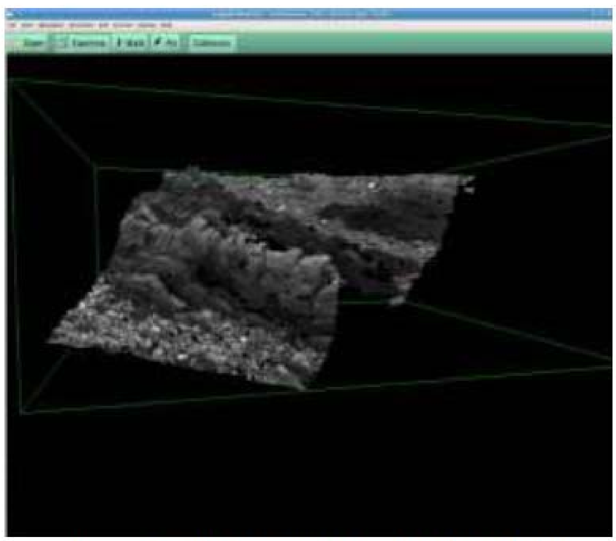


Figure2: 3D construction of Clarach Bay

The second test was conducted on LRO orbital images (Fig.3). The resulting disparity map (Fig.4) and visual control of the final DTM (Fig.5) show very good agreement with the 3D reconstructions from different software solutions [3]. However, we anticipate that further improvement of the our matching algorithm will lead to even better matching result and consequently better 3D reconstruction representation.

More tests and comparisons based on different data sets will be performed in order to judge the capabilities of the matcher, especially, in terms of accuracy and completeness. Results will be reported during the workshop.

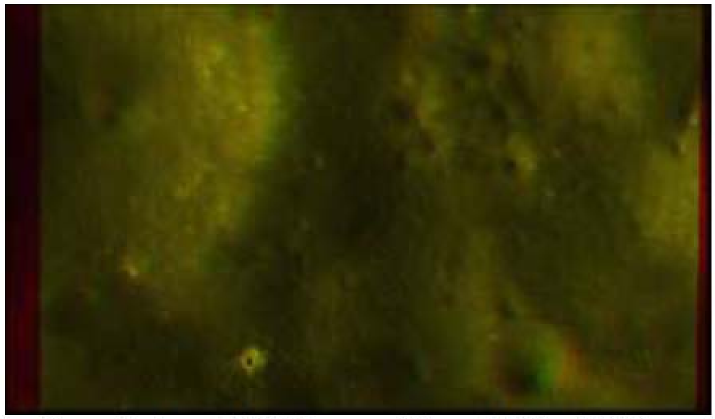


Figure3: Input LRO Images (Size: 5800 x 3000)

Figure4: Resulting Disparity Map From LRO Images

Figure5: Perpective View of DTM

References:

[1] Richard Hartley and Andrew Zisserman. “Multiple View Geometry in computer vision”. Cambridge University Press. ISBN 0-521-54051-8, 2003. [2] R. B. Rusu and S. Cousins, "3D is here: Point Cloud Library (PCL)," in Proceedings of the IEEE International Conference on Robotics and Automation (ICRA), Shanghai, China, 2011. [3] I. Haase et al., “Mapping the Apollo 17 landing site area based on Lunar Reconnaissance Orbiter Camera images and Apollo surface photography”, J. Geophys. Res., doi:10.1029/2011JE003908, in press, 2012.

WISE-CAPS: Data Archiving, Browsing, Sharing and Analyzing Environment for Lunar and Planetary Data. J. Terazono[1], R. Nakamura[2], S. Kodama[2], N. Yamamoto[2], H. Demura[1], N. Hirata[1], Y. Ogawa[1], [1]The University of Aizu (Tsuruga, Ikki-Machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan; terazono@u-aizu.ac.jp), [2]National Institute for Advanced Industrial Science and Technology (AIST).

Introduction: Our recent lunar and planetary exploration data amount is rapidly increasing, from gigabytes order to terabytes order, and foreseeing petabyte order in a coming few years.

Also, the style of analysis is changing. Currently, many groups for analyzing data are established across the country and affiliations. They are forming "virtual" community by using the Internet for communication.

However, the way of distribution and sharing of data are remaining in old manner, despite using the Internet as a medium or using physical media. Such manner is outdated and have a risk of data leak and loss. Moreover, it takes much time for data transfer (downloading and uploading) and is contradicting to current policy in data analysis which should be agile and group-based.

We are now developing integrated environment, called WISE-CAPS (Web-based Integrated Secure Environment for Collaborative Analysis of Planetary Science) [1][2][3][4] to solve these problems. WISE-CAPS is server-oriented environment which includes all function for data archiving, browsing, sharing and analyzing (to be implemented).

System Description: The WISE-CAPS system has the following characteristics:

- Fully web-based: All activities including data browsing, sharing and analyzing are executed with-in web browsers. This means the users do not care their environment if their device has web browsers.
- Fully Open-Source Based: The WISE-CAPS system are developed with open-source software from its base (Linux) to application software (OpenLayers [5]). The merit of usage of open-source soft-ware is that we can freely add and modify the function we need.
- Open Standard Compliant: The WISE-CAPS com-plies with open standards such as WMS (Web Mapping Service) [6] and WFS (Web Feature service) [7]. This ensures interoperability with other systems that supports the same protocols.

A sample snapshot of the system is shown in Figure 1.

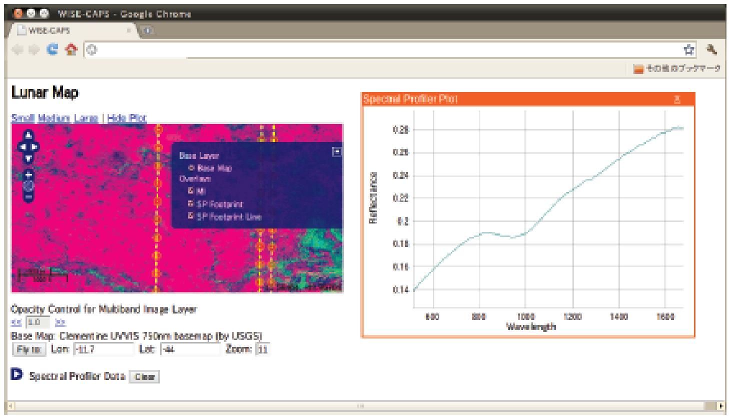


Figure 1. One of WISE-CAPS system example, Kaguya LISM data integreated display system [4][9].

Current Implementation: The base of the WISE-CAPS is Linux (CentOS 5 and 6), and essential software such as a web server (Apache httpd server) and database servers (PostgreSQL and MySQL) are build and installed upon this platform.

The middleware application such as MapServer [8] is build from the source including required libraries. Finally, OpenLayers [5], JavaScript-based layer handling utility is used for dynamic layer loading and controls.

We are now focusing on improvement of several peripheral utility software including automated data registration system and layer control utility.

Future Prospects: We will start development of full-fledged subsystem for data analysis. This project includes both development of in-browser data analysis system and web APIs. These two functions will dramatically contribute in usability betterment of WISE-CAPS.

We will also conduct improvement of system software. Particularly, replacement of web server for new version (2.0 to 2.2 line, or 2.4 if possible) is the pressing task. We kept using 2.0 based Apache httpd for security control module (GridSite [10]), however, we are now designing totally new security scheme, and it helps to keep introducing up-to-date software in the WISE-CAPS.

References: [1] Terazono J. *et al.* (2010) *LPS XLI,* Abstract #1516. [2] Terazono J. *et al.* (2010) *DIEW 2010, LNCS 6193,* 58-68. [3] Terazono J. *et al.* (2012) *LPS XXXIII,* Abstract #1158. [4] Terazono J. *et al.* (2012) *LPS XXXIII,* Abstract #1158. [5] http://www.openlayers.org [6] http://www.opengeospatial.org/ standards/wms [7] http://www.opengeospatial.org/ standards/wfs [8] http://www.mapserver.org [9] Sugawara T. (2012) Master Thesis, Univ. Aizu. [10] http://www.gridsite.org

Automatic Detection and Removal of Image Registration Errors in the Bundle Adjustment. Orrin Thomas; U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ. (othomas@usgs.gov)

During the Lunar Mapping and Modeling Project it became apparent that the process of finding and eliminating false matches in control networks was the most labor intensive step in the production of cartographic products. Thus, the ability to automatically identify and remove bad data has great potential to reduce the cost and possibly improve the quality of these products. To accomplish this, three separate but related capabilities have been added to Integrated Software for Imagers and Spectrometers (ISIS). First, to produce more robust solutions, and hence more accurate residuals, maximum likelihood estimation capabilities have been added to the ISIS bundle adjustment (jigsaw). Second, the cnethist application now allows residual histograms from an essentially unlimited number of jigsaw solutions to be plotted together comparative evaluation. This allows objective selection from jigsaw parameterizations (including maximum likelihood estimation options). Finally, the cnetwinnow application selectively removes measures with large residuals beginning at the worst offenders. The automated removal process in cnetwinnow is subject to user defined limitations in how much the area of convex hull of image measures and the number of measures in individual images can be reduced. It is also not permitted to split a network into islands. Any measures with high residuals that cannot be automatically winnowed are reported for manual consideration.

HiiHAT: an IDL/ENVI Toolkit for Rapid Hyperspectral Inquiry, with Applications to Onboard Processing – JPL/MIPL. D. R. Thompson, B. Bornstein, R. Castaño, S. A. Chien, M. Gilmore, and D. Tran. Jet Propulsion Laboratory, David.R.Thompson@jpl.nasa.gov

Introduction: Large data volume is a principal challenge facing any user of planetary imaging spectrometers. For the scientist, Terabyte archives preclude exhaustive manual analysis. For the mission planner, the complex subtleties of spectral image cubes are difficult to summarize in tactically-meaningful timescales. Finally, low communications bandwidth means imagers operate at a fraction of their potential duty cycle. All would benefit from a robust, automatic method to summarize spectral data.

We discuss the HiiHAT (Hyperspectral Image Interactive Holistic Analysis Tools) system developed for the IDL/ENVI environment. This drafts mineralogical maps and generates summaries of novel detections, drawing attention to areas of interest for further investigation. HiiHAT incorporates several novel techniques, including the concept of superpixel decomposition for noise removal and image feature enhancement. It attends to special needs of planetary geologists such as low signal-to-noise ratios and a lack of representative reference spectra from the surface.

We describe previous science investigations using the tool, and a flight demonstration onboard EO-1 demonstrating transition between the offline analysis algorithms and real time use by spacecraft.

Acknowledgments: This research was performed at the Jet Propulsion Laboratory, California Institute of Technology, with support from the Advanced MultiMission Operations System (AMMOS). HiiHAT is available for use through JPL Licensing, contact the authors for more info.

Building and Customizing MATLAB Software Modules for Planetary *Research*. B. J. Thomson, Boston University Center for Remote Sensing, Boston MA 02215 (bjt @ bu.edu).

Introduction: Many research tasks in planetary science require specialized software tools to complete. Although a degree of reusability is desirable, some project needs may require a unique capability that exceeds what is available in commercial or open-source software packages (i.e., a one-off).

MATLAB® (matrix laboratory) is a high-level technical computing language developed by MathWorks that is available to many academic researchers at low or reduced cost (excluding the cost for additional specialized modules termed "toolboxes"). Since MATLAB runs on many different operating systems (e.g., Mac, PC, Linux), it provides an ideal platform for development and dissemination of small software packages.

ISOPAQ, a MATLAB example: One example of a MATLAB module (i.e., a set of programs and functions) developed to accomplish a specific set of tasks was published by Monnet et al. in 2003 [1]. Their software package, ISOPAQ, is an interactive desktop tool for spatial analysis, interpolation, and display of stratigraphic data. It was designed to allow users to reconstruct the 3D geometry of subsurface layers to create interpolated thickness maps, or isopach maps (an isopach is a contour that connects points of equal thickness; an isopach map therefore illustrates thickness variations within a stratigraphic unit). Four different interpolation methods are included: nearest neighbor, linear and cubic triangulation, inverse distance, and splines (**Figure 1**). Each method has its own set of advantages and disadvantages, and it is difficult to say *a priori* which method is best for a given application.

Versioning issues: A critical issue in using the ISOPAQ software today is the version of MATLAB in which it was published. It was built and tested on MATLAB version 6.0 (release name R12) on Windows 98, MATLAB version 5 (R8-R11.1) on Windows NT, Mac, and Unix, and MATLAB 6.5 (R13) in Windows XP. Versioning and backwards compatibility is an issue with any software, be it commercial or open-source. Current MATLAB license holders may request prior software versions to run outdated programs, but many prior versions are hardware-limited (e.g., to pre-Intel Macs, or PCs running Windows XP). Work is currently underway to (a) install a prior version of MATLAB to run ISOPAQ, and (b) rebuild the source code in the current version of MATLAB. The latter exercise is obviously more time-consuming than the former but is necessary for further customization and expansion.

Future work: The author envisions numerous potential uses for this software one it is updated, adapted, and expanded (to include additional interpolation schemes, for example). Despite issues with versioning, a similar methodology to that demonstrated in [1] – building and publishing a small software package in MATLAB – holds promise for future planetary research endeavors.

References: [1] Monnet C. et al. (2003) *Comp. GeoSci., 29,* 1101–1110.

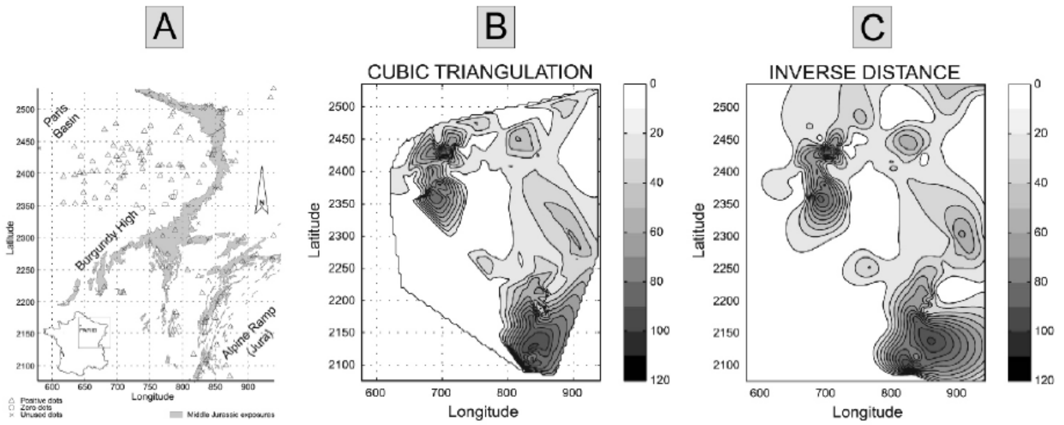


Figure 7. Example of ISOPAQ software (from [1]). **(A)** Location map of input data points from the Bajocian carbonate platforms of eastern France. **(B)** Interpolation results from cubic triangulation. **(C)** Interpolation results using inverse distance method.

Development of an ISIS-based DTM Interpolation Tool. H. Unbekannt[1], K. Willner[1] and J. Oberst[1,2], [1]Technische Universität Berlin, Institute for Geodesy and Geoinformation Science, Department of Planetary Geodesy, Berlin, Germany, [2]German Aerospace Center (DLR), Berlin-Adlershof, Germany

Introduction: An interpolation tool is developed to create digital terrain models (DTM) from large 3- D point clouds by using the development library of the software package ISIS (**I**ntegrated **S**oftware for **I**magers and **S**pectrometers). The goal of this software element is to complement a full photogrammetric processing chain for production of stereo DTMs (see companion abstract by Tasdelen et al., this conference). We wish to create a flexible tool with an adaptive user- and data-interface. The development uses classes and functions of the current ISIS implementation. Besides a flexible and modular design, the main emphasis will be given to the height interpolation strategy.

Design: Large clouds of 3D object point coordinates are used as base data for the DTM interpolation. As a first step, these coordinates are map-projected into a pre-defined cube file, which serves as a target container. The input data can be provided in non-sequential order and there are no specific requirements in terms of spatial distribution or homogeneity of the distribution of the points. The point clouds may suffer from gaps. On the other hand, it is possible that several object points define only one pixel of the target projection. In our first preliminary implementation of the tool, this is accounted for by applying distance-defined weighting to determine exactly one value for the resulting pixel.

The implementation of further interpolation methods is in progress. Envisaged methods are nearest neighbor, bilinear and bi-cubic interpolation. This will enable the user to define different interpolation radii and to define for instance how many points are needed to define one final pixel.

The conversion from 3D-space to map space is handled by the map projection class of ISIS. Therefore, the user can enter the desired map parameters by using a graphical ISIS-interface or a terminal based command sequence.

Aimed Functionality: The tool should provide a intuitive user-interface to specify various processing options. Besides the definition of all parameters by the users, default values will be of provided, e.g. for setting the reference body parameters or the map projection parameters. Furthermore, the developed interpolation tool will obtain parameters, like e.g. the valid spatial extend of the map-coordinates automatically.

Another feature is the user-defined input and output. The user will be able to define the format of the object-file (text file or a binary file of different coordinate format). Various output formats will be provided, such as ISIS-Cube, Vicar-Image, Erdas-Raw, and the well known BMP and TIFF formats, etc.

Testing and Benchmarking: This tool was tested with 3D points derived from stereo image matching of Lunar Reconnaissance Orbiter's Narrow Angle Camera (NAC) images and Mars Express' High Resolution Stereo Camera of the Martian Moon Phobos. A preliminary result is shown in Figure 1.

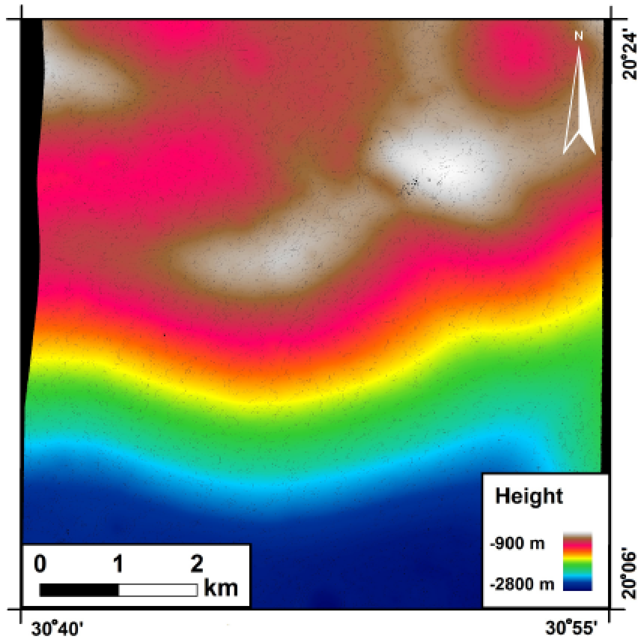


Figure 1: Subset of a preliminary DTM (1.5 meter/pixel) derived by our interpolation tool. Gaps within the terrain model, 1-2 pixels in size, are visible and were caused by slight inhomogeneities of the points spatial distribution. (Area: North Massif adjacent to the Apollo 17 landing site.)

Further assessments of this tool will be carried when using all implemented interpolation methods by comparisons with equivalent datasets from different software packages.

A GDAL Driver Module for the VICAR file format. S. Walter (sebastian.walter@fu-berlin.de), Freie Universitaet Berlin, Institute for Geological Sciences, Berlin, Germany

Introduction

A Geospatial Data Abstraction Library (GDAL, [1]) driver for the Video Image Communication And Retrieval (VICAR, [2]) file format has been developed at Freie Universitaet Berlin. The driver provides full functionality of the GDAL library to access VICAR image data. This includes the usage of the command-line tools like gdalinfo, gdal_transform and gdalwarp, as well as library support for higher-level software packages such as QGIS, GRASS and ArcGIS.

What is GDAL?

GDAL is a cross-platform translator library for raster geospatial data formats released under an Open Source license by the Open Source Geospatial Foundation (OSGeo). It provides an abstract data model to calling applications for the supported formats. Data formats are implemented as format specific drivers. GDAL provides the primary data access engine for many applications and it is the most widely used geospatial data access library[1].

What is VICAR?

The VICAR software system is developed by the JPL Multi-mission Instrument Processing Laboratory (MIPL). VICAR has its own file format which contains raster image data in integer or floating-point values together with meta-information [3]. This file format is used as the native format for imaging instruments onboard many planetary missions, such as the High Resolution Stereo Camera (HRSC) on Mars Express. It has an ASCII label part which contains a sequence of keyword=value pairs with information about the structure and type of the data, as well as a history of the processing that has been applied to the image. Parsing the label is necessary to access the binary part of the file, containing the raster image data in band-interleaved or band-sequential organization. For a complete description of the VICAR file format, see [4].

Implementation of the Driver

The GDAL data model, loosely based on the OpenGIS Grid Coverages specification, is published at [5]. The dataset is an assembly of related raster bands and commonly shared information such as the raster size and the spatial reference system (SRS). For regular binary scanline oriented formats such as VICAR data, GDAL provides the RawDataset and RawRasterBand classes that can be utilized to implement raw raster image data access in C++. With the support for the Planetary Data System (PDS) format since GDAL version 1.5, the handling of planetary SRS's has been implemented. The main part of the VICAR driver development consists of new routines for the label parsing of the VICAR file format.
Current functionality is read access of multiband VICAR data, including digital terrain model data, with support for planetary projections and metadata such as nodata values or

band statistics. The driver will be submitted to the GDAL project repository for possible inclusion into the official code base.

VICAR GDAL Module in ArcGIS

For custom built versions of GDAL like the one used in ArcGIS, the driver can be built as a Dynamic- Link-Library (DLL) plugin. The VICAR file can then be identified and opened directly in ArcGIS using the according projection information and metadata. A compiled DLL version of the plugin will be distributed by the author. The plugin must be dropped in the ArcGIS\bin\gdalplugins program directory, and the format with according file suffixes has to be registered in ArcGIS's RasterFormats.dat. A readme.txt file is distributed for detailed installation information.

References

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Enabling Planetary Data for Modern Web. Z. Xing, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109 (xing@jpl.nasa.gov)

Introduction: Planetary data are huge and complex. Making them accessible in easy use form has been a quest of the undaunted. We will report our current work, which enables direct and uniform web exposure of planetary data, as part of a larger system modernization effort sponsored by the Multimission Ground System and Service (MGSS) Office.

The World Wide Web has evolved from a successful publishing media to a powerful application platform. In this work, we are employing Webification (w10n), a nascent enabling technology, to make planetary imagery data easily manipulatable on the web platform. The w10n specification defines a common way to map an arbitrary data store into a hierarchical tree and have its inner entities available through meaningful URLs. As a simple web service API, w10n is fashioned in ReSTful style and includes both READ and WRITE calls, corresponding to the GET and PUT methods of the Hypertext Transfer Protocol (HTTP).

Many benefits can result from webifying planetary data. Among them the obvious ones are ubiquitous data access and data format independence. Most importantly, with webified data, powerful web applications can be created through mashup that will lead to a fundamental change in how planetary science data and information is viewed, accessed and exchanged.

Presentation: We will present an overview of our on-going w10n effort with a live demonstration of new in-browser tools on planetary imagery data.

Kaguya HDTV Data Archive and Publication System. Y. Yamamoto[1] , R. Honda[2] , J. Yamazaki[3], S. Mitsuhashi[4], and J. Tachino[3], [1]Japan Aerospace and Exploration Agency, [2]Kochi University, [2]NHK Engineering Service, and [4]NHK.

Introduction: From 2007 to 2009, Kaguya High Definition Television System (HDTV) had taken more than five hundred movies over the Moon [1]. The main purpose of this instrument was to promote public outreach, and most of technologies HDTV adopted were based on those of private sector. Therefore, it was believed the instrument would be broken down in a few month after launch. However, the instrument had been alive for 21 months beyond our expectation, and had sent many movies and images until the Kaguya main orbiter impacted the Moon on June 10, 2009.

The obtained data are already partially open through YouTube [2] and JAXA Digital Archives [3], and people can enjoy their movies from the Internet. Not only for the outreach, but also for scientific use are expected. To promote scientific use, the attempt of the calibration for the HDTV instrument was performed [4]. In this paper, we explain accessible dataset and publication system.

HDTV Data Set: The HDTV took both movie and still image during the Kaguya operations. A movie is also composed of many still images, therefore, we provide all data as a still image. The raw data without credit are in the form of FITS files with attached FITS headers and detached PDS labels. They are only permitted to use for the scientific purpose, and users who want to use these data are required to submit proposal. All data are converted to JPEG images with JAXA/NHK credit. These JPEG images are accessible for everyone. In addition, the footprint product is prepared to track the footprint HDTV traveled. Table 1 shows the summary of the data set we provide.

Table 1: Kaguya HDTV Data Set

Data Set Id	credit	format
SLN-L/E-HDTV-5-JPEG-LOGO-V1.0	yes	jpeg
SLN-L-HDTV-5-FOOTPRINT-V1.0	yes	jpeg
SLN-L/E-HDTV-2-FITS-V1.0	no	fits

Footprint Definition: For a still image, we define 'Frame Footprint' which has the coordinates of the upper-left, upper-right, lower-left, and lower-right corners respectively (Figure 1). For a movie, we define another footprint, 'Movie Footprint'. The 'Movie Footprint' is created by the integration of the first line in each frame in the movie.

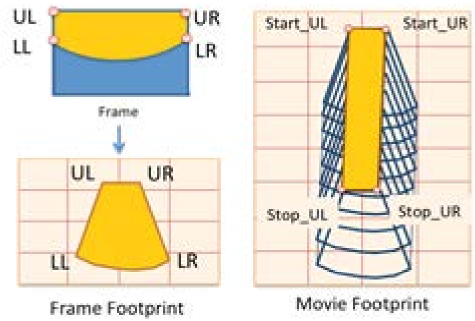

Figure 1. Footprint Definitions The 'Frame Footprint' shows the footprint of a still image on the moon surface. The 'Movie Footprint' shows the footprint of the integrated image of the first horizontal line of each image in the movie.

System Overview: The system is composed of three sub-systems: Data Server, Search Server, and Web application (Figure 2). User can access all sub-systems independently.

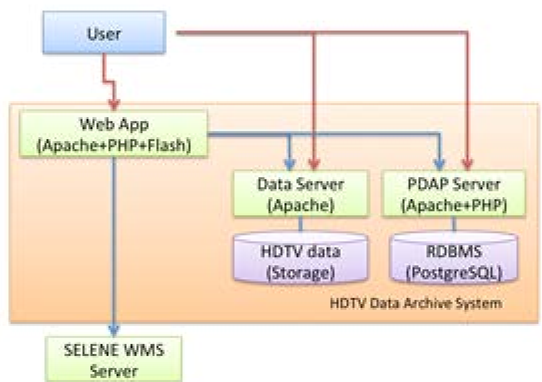

Figure 2. The HDTV publication system is composed of three subsystem and one external system. Each subsystem is independently accessible.

Data Server opens a simple directory-index by HTTP to keep data publication safely over more than several decades without complex maintenance.

Search Server is designed on Planetary Data Access Protocol, PDAP, which will be standard protcol to share planetary data [5]. PDAP is a kind of Web Service API, and specifying search parameters with GET/POST methods, the PDAP server returns each result in a specific XML format, VOTable [6]. To respond more complex search request beyond PDAP specification, the original extension is implemented such as locale or movie title.

The web application is designed to provide a rich interface for users (Figure 3). The application has the functions of both clients of the Data Server and the PDAP Server. The application also refers the Web Map Service, WMS, to display lunar maps.

Conclusion: The HDTV data archive was performed considering long-term preservation, interoperability, and user-availability. PDS like directory structure was adopted for the long-term preservation. PDAP is used as a search protocol to enable the interoperability in future, and graphical user interface is implemented for user-availability.

References: [1] J. Yamazaki *et al.* (2010) *Space Sci. Rev.* **154**, 21-56. [2] youtube JAXA channel; http://www.youtube.com/user/jaxachannel. [3] JAXA Digital Archives; http://jda.jaxa.jp/. [4] R. Honda *et al.* (2011), *5th KAGUYA (SELENE) Science Working Team (SWT-5) Meeting.* [5] J. Salgado *et al.* (2009), *PV2009.* [6] International Virtual Observatory Alliance; http://www.ivoa.net/Documents/VOTable.

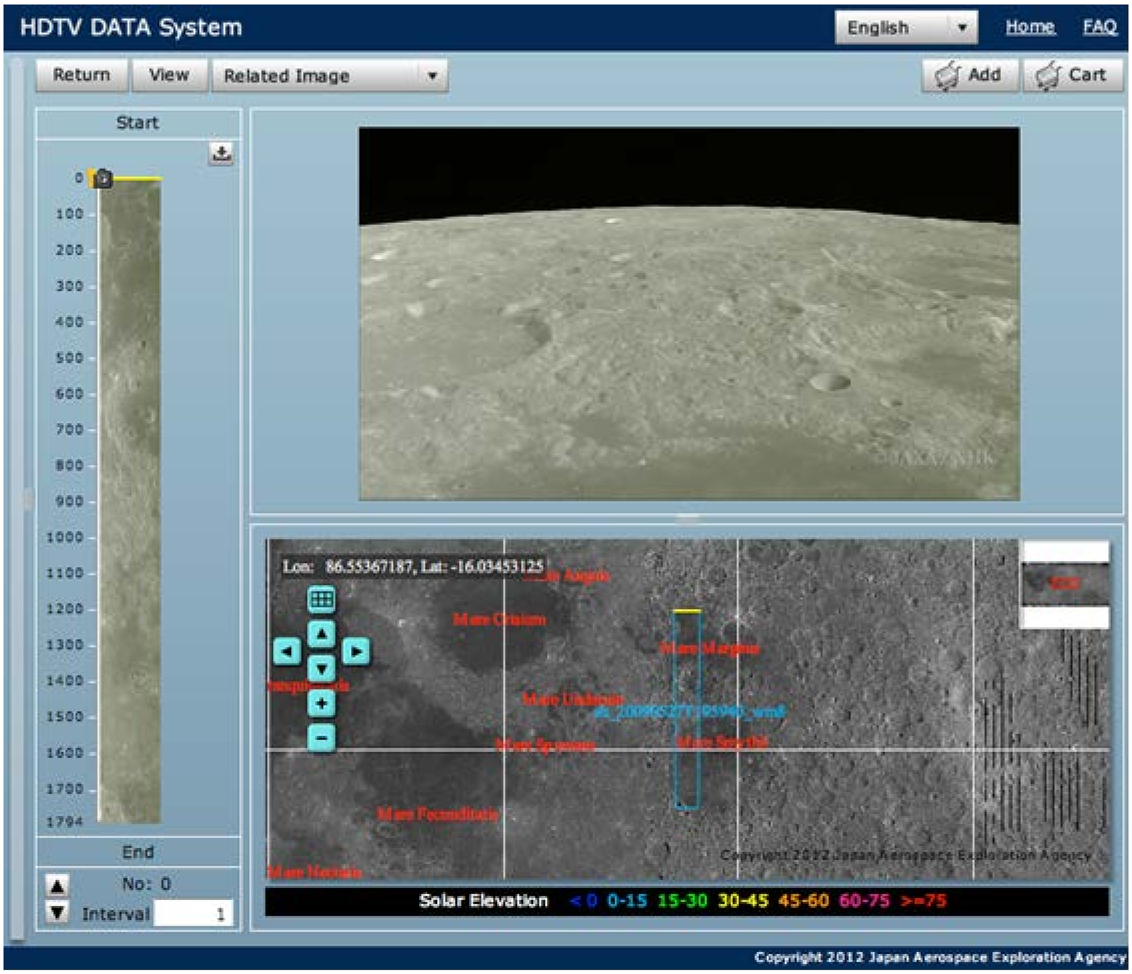

Figure 3. Web Application provides a rich interface for users. The application is both clients of Data Server and PDAP server. In addition, WMS server is used to display lunar maps.

A Tool for NEO Data Discovery and Query, Yulie Zografou, Harvard-Smithsonian Center for Astrophysics

We have developed a software system that allows users to access Near Earth Object (NEO) data distributed across multiple data archives, combine them with a simple query and save computer readable results for their own analysis. A query might be for an individual NEO, a list of NEOs or, more generally, a search on a particular subset of NEO properties, returning all NEOs that satisfy the search criteria. While our project is focused on NEOs, the system has no knowledge of NEO specific data and can be used just as well for accessing any other astronomical data in archives that conform to a standard interface.

The software system follows a client-server architecture and implements the Table Access Protocol (TAP), a general interface for tabular data access recommended by the International Virtual Observatory Alliance (IVOA). TAP is a web-service protocol and requires that a data server behind a service stores, in addition to the data, a standard set of metadata that describe the organization and characteristics of the data. Metadata include table names and relationships, and column names, descriptions, datatypes and units. Client applications can browse the metadata and query the data using ADQL, a language like SQL with extensions for astronomy.

Our product development includes a server component and a client application. The server component is a Java Enterprise Edition (JEE) application that provides a TAP interface to an archive with data stored in a Relational Database Server (RDBMS). The client application, called seleste, is a Java Web Start (JWS) application that accesses TAP services. Through a graphical interface provided by seleste, a user can discover TAP enabled data archives and automatically display their metadata. For a selected archive, a user can graphically build a query based on the available columns in the data by adding them into results and selection criteria lists. Queries can be readily modified, refined, saved, recalled, and repeated, until the user is satisfied. Queries can also be displayed and edited in ADQL. One or more queries to an archive or multiple archives can be submitted to run asynchronously and their status can be monitored and displayed in seleste. Upon completion of a query, the results, including data and their metadata, are available to display, save, or transmit for further processing to other applications enabled with the IVOA Simple Access Message Protocol (SAMP).

With the software in place, and in order to match the scope and timescale of the project, we focused on NEO data from three complementary sources: orbits from the Minor Planet Center at the Smithsonian Astrophysical Observatory (SAO), lightcurves from the Asteroid Lightcurve Database at the Palmer Divide Observatory and spectra from the MIT-UH-IRTF Joint Campaign. By using the unique NEO number and designation identifiers common in the three data sets, we expected to be able to cross-identify objects and search them by combining their properties. In an ideal scenario, a TAP service would be deployed at the site of each archive and make the local data available. Such an effort is currently in progress at one of the sites. Due to the time constraints of our project, we deployed a prototype TAP service at SAO where we imported the three data sets and constructed the appropriate metadata. In order to meet requirements specific to our NEO research project, a number of derived quantities, such as delta V and time of next apparition were calculated for each NEO and were stored in additional tables. With the software and data in place, we are able to query the data, walk through a science use case and demonstrate how the same query capabilities can be available when accessing the same data stored in more than one archives.

The presentation will outline the software system and data architecture and will demonstrate a use case example.

Print-Only Abstracts (No Presentations)

Planetary Nomenclature—A Review. J. Blue[1], L. Gaddis[1], R. Schulz[2], K. Aksnes[3], G. Burba[4], G. Consolmagno[5], R. Lopes[6], P. Masson[7], M. McGrath[8], K. Meech[9], B.A. Smith[10], G. Williams[11], C. Wood[12]; [1]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ; [2]European Space Agency Research and Scientific Support Department, Noordwijk, The Netherlands; [3]Institute for Theoretical Astrophysics, Oslo, Norway; [4]Vernadsky Institute, Moscow, Russia; [5]Specola Vaticana, Vatican City State; [6]Jet Propulsion Laboratory Caltech, Pasadena, California; [7]Universite de Paris-Sud, Orsay, France; [8]NASA Marshall Space Flight Center, Huntsville, Alabama; [9]Institute for Astronomy, Honolulu, Hawaii; [10]Santa Fe, New Mexico; [11]Minor Planet Center, Cambridge, Massachusetts; [12]Wheeling Jesuit University, Wheeling, West Virginia. (jblue@usgs.gov)

Introduction: The task of naming planetary surface features, rings, and natural satellites is managed by the International Astronomical Union's (IAU) Working Group for Planetary System Nomenclature (WGPSN). WGPSN members include Rita Schulz (chair) and 11 other members who hail from countries across the globe. Given the recent increase in planetary exploration and research, and the fact that many planetary surface features of likely scientific interest have yet to be named, it is timely to summarize the status of planetary nomenclature, the purpose and rules, the process for submitting name requests, and the IAU approval process.

Status: There are currently 14,713 surface feature names in use (not including names that have been dropped but retained in the database for reference). Table 1 shows the breakdown of the number of adopted surface feature names for each body. A table showing the named rings and ring gaps can be seen on the Web page http://planetarynames.wr.usgs.gov/Page/Rings; planet and satellite names are listed on the Web page http://planetarynames.wr.usgs.gov/Page/Planets.

Table 1. Named Surface Features on the Planetary Bodies.

System/Body	Number of named surface features currently in use
Mercury	356
Venus	1,972
Earth	
Moon	8,990 (7,057 of which are lettered craters)
Mars	1,681
Deimos	2
Phobos	20
Asteroids	
Eros	41
Gaspra	34
Ida	25

System/Body	Number of named surface features currently in use
Dactyl	2
Itokawa	17
Lutetia	37
Mathilde	23
Vesta	50
Jupiter	
Amalthea	4
Thebe	1
Io	224
Europa	111
Ganymede	184
Callisto	153
Saturn	
Epimetheus	2
Janus	4
Mimas	42
Enceladus	84
Tethys	53
Dione	93
Rhea	143
Titan	116
Hyperion	5
Iapetus	69
Phoebe	25
Uranus	
Puck	3
Miranda	18
Ariel	26
Umbriel	13
Titania	18
Oberon	10
Neptune	
Proteus	1
Triton	61

Purpose and Rules: Planetary nomenclature is a tool used to uniquely identify a feature on the surface of a planet or satellite so it can be readily located, described, and discussed. Approved names are listed in the Transactions of the IAU [1] and the Gazetteer of Planetary Nomenclature Web site [2].

Planetary names must adhere to rules and conventions established by the IAU WGPSN (see http://planetarynames.wr.usgs.gov/Page/Rules for the complete list).

- Planetary names should be simple, clear, and unambiguous.
- The number of names chosen for each body should be kept to a minimum.
- Features should be named only when they have special scientific interest and when the naming is useful to the scientific and cartographic communities at large.
- Duplication of the same name on two or more bodies, and of the same name for satellites and minor planets, is discouraged.
- Solar system nomenclature should be international in its choice of names.
- Names having political, military, or religious significance are not allowed.

Commemoration of persons is not a goal in itself, but may be employed in special circumstances and is reserved for persons of high and enduring international standing. Persons being so honored must have been deceased for at least 3 years.

Submitting a Name Request: The gazetteer includes an online Name Request Form (http://planetarynames.wr.usgs.gov/FeatureNameRequest) that can be used by members of the professional science community who have a specific scientific need to name a planetary surface feature. The form requests all of the necessary information (requester's contact information, feature type and location, scientific justification for the request, and images showing the feature) and becomes a record for the WGPSN. A specific name may be suggested for the feature, but the name is subject to IAU review and there is no guarantee that it will be approved. A published reference (Web sites are not allowed, but scanned online books suffice) is required for each name. Suggested names must also fit the approved theme for each feature type on each body (see http://planetarynames.wr.usgs.gov/Page/Categories).

Before submitting a name request, the online database and maps showing named features (http://planetarynames.wr.usgs.gov/Page/Images) should be reviewed to assure that the feature is not already named. If a specific name is included in the request, the database should also be checked to ensure the name has not already been approved for a different feature.

Name Approval Process: Name requests are first reviewed by one of six task groups (one for each of the following: Mercury, Venus, Moon, Mars, Outer Solar System, and Small Bodies). After a task group has successfully reviewed a proposal, it is submitted to the WGPSN. Allow six to eight weeks for the review and approval process, but more time may be necessary if the proposal is complicated or if questions are raised during the review process. Name requests should be submitted well in advance of publication deadlines. Upon WGPSN approval, names are considered formally approved and it is then appropriate to use them in publications. Approved names are immediately entered into the database and reflected on the Web site.

Summary: The members of the WGPSN and its task groups have worked since the early 1970s to provide a clear system of planetary nomenclature that represents cultures and countries from all regions of Earth. This activity supports ongoing planetary research, and the participation of knowledgeable scientists and experts in this process is vital to its success. Questions about the nomenclature database and the naming process should be sent to Jennifer Blue, U.S. Geological Survey Astrogeology Science Center, 2255 N. Gemini Dr., Flagstaff, AZ 86001, or by email to jblue@usgs.gov.

References:

[1] International Astronomical Union, 2012, Publications; Transactions—Reports on astronomy (vol. A): International Astronomical Union Web site, accessed March 13, 2012, at http://www.iau.org/science/publications/iau/transactions_a/.

[2] International Astronomical Union, 2012, Gazetteer of Planetary Nomenclature: International Astronomical Union Working Group for Planetary System Nomenclature Web site, accessed March 7, 2012, at http://planetarynames.wr.usgs.gov/.

Overview of Data Services Provided by the Imaging Node of the NASA Planetary Data System (PDS). L. Gaddis[1], S. LaVoie[2], S. Akins[1], R. Alanis[2], M. Bailen[1], K. Boggs[2], A. Culver[2], P. Garcia[1], T. Hare[1], C. Isbell[1], J. Padams[2], E. Rye[2], A. Stanboli[2], B. Sucharski[1]; [1]U.S. Geological Survey Astrogeology Science Center, Flagstaff, AZ; [2]Jet Propulsion Laboratory, Pasadena, CA. (lgaddis@usgs.gov)

Introduction: The Imaging Node (IMG) of the NASA Planetary Data System (PDS) archives and delivers digital image collections from planetary missions [for example, 1]. IMG provides expertise and a variety of data access tools and services to support users of the digital image archives in the full collection. Each of these services is linked individually and through the Imaging Node site (http://pds-imaging.jpl.nasa.gov/). Included are the Photojournal, Planetary Image Atlas (Atlas), Map-a-Planet (MAP) and the new Map-a-Planet2 (MAP2), the Unified Planetary Coordinates (UPC) database, the Planetary Image Locator Tool (PILOT), and the Astropedia Annex (Annex).

Imaging Node: IMG is one of six PDS Science Discipline Nodes [including Atmospheres (*R. Beebe*, New Mexico State University); Geosciences (*R. Arvidson*; Washington University), Small Bodies (*M. A'Hearn*, University of Maryland); Planetary Plasma Interactions (*R. Walker*, University of California Los Angeles), and Rings (*M. Showalter*, SETI)] that operate, along with two support nodes (Engineering Node, EN, Jet Propulsion Laboratory (JPL), *D. Crichton*; Navigation and Ancillary Information Facility(NAIF), JPL, *C. Acton*) and the Radar function (*D. Simpson,* SETI), as a distributed data archive managed cooperatively as a federation within PDS. IMG is operated through a partnership between the U.S. Geological Survey (USGS) Astrogeology Science Center of the (*L. Gaddis*, USGS, Flagstaff, Ariz.) and the Instrument Software and Science Data Systems Section of the Jet Propulsion Laboratory (*S. LaVoie*, JPL, Pasadena, Calif.) of the California Institute of Technology. The emphasis on mission operations support, ground data systems, planetary data cataloguing and distribution services, and integration of the Multi-Mission Image Processing Laboratory (MIPL)-based data processing pipelines used by many NASA missions at JPL, are highly complementary to the expertise in planetary science, cartography, geodesy, photogrammetry, and science software development at USGS.

IMG supports three active PDS Data Nodes (DNs) that provide archiving services for NASA missions: (1) the Mars Odyssey Thermal Emission Imaging System (THEMIS) DN [*P. Christensen*, Arizona State University (ASU)]; (2) the Mars Reconnaissance Orbiter High Resolution Imaging and Science Experiment (HiRISE) DN [*A. McEwen*, University of Arizona (UA)]; and (3) the Lunar Reconnaissance Orbiter Camera (LROC) DN [*M. Robinson*, ASU]. Together, IMG infrastructure and these DNs support PDS in the areas of mission interface, data archiving, and distribution for more than 21 historic and ongoing NASA missions and a current (and growing!) data volume of nearly 500 TB.

IMG Web Site: The primary interface to IMG data and services is the Imaging Web site (http://pds-imaging.jpl.nasa.gov/). In addition to links to each of the major data access tools described here, users can view a Data Portal serving data from 20 missions (http://pds-imaging.jpl.nasa.gov/portal/), a Data Release Calendar, a Subscription Manager, the Space Images application for iPhone and iPad and Android mobile devices, and updates for mission data deliveries. Users can also view and link to all data volumes and holdings at IMG, documentation relevant to mission archives, tools and tutorials supporting data holdings, a summary of IMG personnel, and a help page. Each dataset is further supported by a separate Mission page providing users with a one-stop interface for mission and instrument information and related data, ancillary files, and tutorials. An All Data Holdings link provides status reports on all data supported by IMG and lets users know whether any given data are archived, accumulating, in lien, safed (not fully PDS-compliant, available on request), superseded, or in pre-peer review status. Finally, the IMG page provides links to all other PDS nodes and services, as well as to the main PDS site where cross-mission and -discipline searches can be conducted (see http://pds.nasa.gov/tools/data-search/).

Photojournal: The Photojournal provides access to the "best of" planetary image collection from recent and current missions and offers image highlights, press release images, derived products such as mosaics and perspective views, and other image products. (http://photojournal.jpl.nasa.gov/index.html). JPL media relations jointly funds this service, and it delivers more than 6.6 terabytes (TB) per month and has more than 100 images added per month.

Atlas: The Atlas (http://pds-imaging.jpl.nasa.gov/search/) provides access to the entire collection of IMG data through links to online holdings and DN catalogs. It allows a geographic search for many targets, use of instrument and observational data constraints, searching by feature name, bulk data downloads, and other items. The Atlas also supports the data delivery services of other nodes (for example, the Orbital Data Explorer of Geosciences Node [2]). Nearly 14 TB/month of data are delivered to users across the globe by the Atlas.

MAP/MAP2: The Map-a-Planet (MAP) Web site (http://www.mapaplanet.org/) serves custom planetary maps created from PDS digital image data, typically as global mosaics and derived products [for example, 3]. Planetary bodies currently supported by MAP are Mars, Venus, Mercury, the Earth's moon, four Galilean satellites (Callisto, Europa, Ganymede, Io), and five moons of Saturn (Rhea, Dione, Tethys, Iapetus, Enceladus). In 2013, a revised version, MAP2, will be released. MAP2 will offer improved performance, streamlined addition of new products, and an architecture wherein new features and capabilities can easily be added. The new site will make use of and extend the Astropedia Annex product database and use of a processing cluster for rapid product delivery. These updates will allow users to (1) search for products on Astropedia based on a planetary body, geospatial area, feature name, and other searchable criteria; (2) sort through the results with full access to preview images, metadata, and supporting information; (3) select the product(s) of interest and processing options; and (4) download the product(s) individually or in bulk in several common image file formats.

UPC/PILOT: The Unified Planetary Coordinates (UPC) database [4] addresses the problem of the multiple and disparate coordinate systems in which PDS image data can be delivered by standardizing all coordinates to 0° to 360°, and positive east longitudes for select image data. The UPC database is available through the Planetary Image Locator Tool (PILOT, http://pilot.wr.usgs.gov/). PILOT provides an interface to select planetary targets on which users can specify a geographic bounding box and execute searches resulting in rendered footprints, thumbnails, and browse images. Users can restrict searches based on instrument and observational and (or) positional constraints (for example, incidence angle, solar longitude, pixel resolution, and phase angle). Complete or partial sets of resulting images can be retrieved using an automated download script.

Astropedia Annex: The Astropedia Annex is a new facility [5] under development by IMG to support scientists who use PDS data to create derived geospatial products that can be registered to a solid planetary body.

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[3] Garcia, P., Isbell, C., Barrett, J., and Gaddis, L., PDS Map-a-Planet cartographic Web service [abs.]: this meeting.
[4] Bailen, M., Akins, S.W., Sucharski, B., Gaddis, L., Hare, T., and Raub, R., 2011, Improvements to the PDS Planetary Image Locator Tool (PILOT): 42nd Lunar and Planetary Science Conference, abstract 2214.
[5] Gaddis, L., Hare, T., Bailen, M., LaVoie, S., The Astropedia Annex for the PDS Imaging Node—A repository for Planetary Research Products [abs.]: this meeting.