INTEROPERABILITY IN PLANETARY RESEARCH FOR GEOSPATIAL DATA ANALYSIS

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ABSTRACT: For more than a decade there has been a push in the planetary science community to support interoperable methods of accessing and working with geospatial data. Common geospatial data products for planetary research include image mosaics, digital elevation or terrain models, geologic maps, geographic location databases (i.e., craters, volcanoes) or any data that can be tied to the surface of a planetary body (including moons, comets or asteroids). Several U.S. and international cartographic research institutions have converged on mapping standards that embrace standardized image formats that retain geographic information (e.g., GeoTiff, GeoJpeg2000), digital geologic mapping conventions, planetary extensions for symbols that comply with U.S. Federal Geographic Data Committee cartographic and geospatial metadata standards, and notably on-line mapping services as defined by the Open Geospatial Consortium (OGC). The latter includes defined standards such as the OGC Web Mapping Services (simple image maps), Web Feature Services (feature streaming), Web Coverage Services (rich scientific data streaming), and Catalog Services for the Web (data searching and discoverability). While these standards were developed for application to Earth-based data, they have been modified to support the planetary domain.

KEYWORDS: interoperable, planetary, mapping, standards, OGC, metadata, data portal

Introduction

The motivation to support common, interoperable data format and delivery standards is not only to improve access for higher-level products but also to address the progressively distributed nature of ever increasing data volumes. The strength of using an OGC compliant approach is that it provides consistent access to data that are distributed across many facilities. While data-steaming standards are well-supported by both the more sophisticated tools used in Geographic Information Systems (GIS) and remote sensing industries, they are also supported by many light-weight browsers which facilitates large and small focused science applications and public use. Herein, we provide an update of geospatial interoperability initiatives, and examples of their successful application.

Background

Planetary mapping

Besides simple sketches created using the naked eye, mapping of the moon began in earnest in the early 1600s with the invention of the telescope (Schimerman, 1973). Earth-based telescopes were used until the advent of launched spacecrafts in the mid-1900s. In 1964, the United States Ranger VII spacecraft transmitted 4,316 high-resolution telescopic vidicon television camera photos during the last minutes of flight before impacting the Moon (Heacock 1965, Hall et al., 1997). These images represent the first large catalog of planetary remotely-sensed images as taken by a robotic satellite (Figure 1). The term for this, “remote sensing,” is commonly defined as collecting data or images at a distance (Greeley 1990).

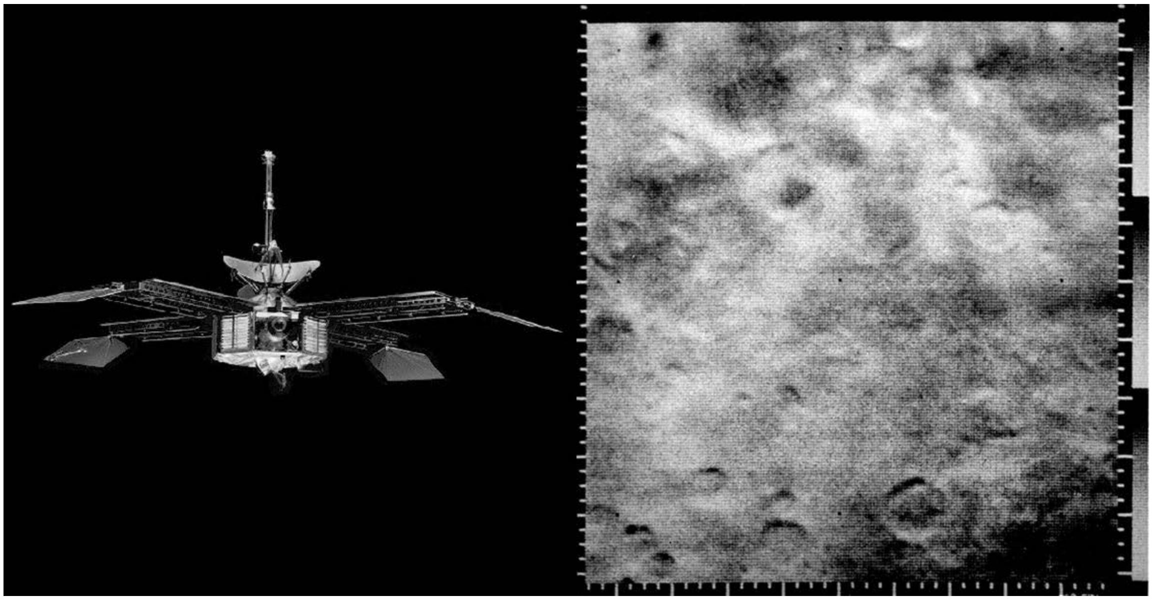

Figure 1: The image on the left shows the Mariner 4 satellite. Mariner 4 was the first spacecraft to successfully transmit digital images of an extraterrestrial planet. The image on the right shows the seventh picture (frame 07B) of Mars taken by the Mariner 4 spacecraft on July 15, 1965. This frame is considered to be the first image to clearly show impact craters. The image is centered at 14 S, 186 E and is approximately 262 km across. Courtesy: NASA.

Since the Mariner missions, numerous other missions from the United States and other countries have mapped the Earth’s Moon, Mars and most other planets, moons and several minor bodies. Even though the gas giants, Jupiter, Saturn, Uranus, and Neptune, have no solid surfaces that can be mapped using a GIS, they each have a number of solid (rock or rock-ice) moons (Madden, 2009). The geologic features of these bodies are enormously diverse and the mapping and study of their surfaces continues to be a very active field of planetary research. Of particular recent interest, Titan, has an atmosphere denser than Earth's and an active liquid (not water) transport cycle. Results from the radar instrument on the Cassini satellite show erosional “shorelines” and associated drainage channels, dunes, impact craters, and probable volcanoes. Lastly, several missions including currently ongoing missions like NASA’s Dawn mission have returned data from asteroids and comets.

The most obvious difference in using extraterrestrial data sets, as opposed to Earth data sets, is simply the shape or size of the planetary body including orbiting moons or an interplanetary body like a comet or asteroid. Fortunately, nearly all larger bodies in our solar system have defined geodetic parameters, documented by the International Astronomical Union (IAU), allowing capable mapping programs to study these bodies. Recognizing the need for standardized geodetic control on planetary bodies, the IAU established a Working Group on the Cartographic Coordinates and Rotational Elements of Planets and Satellites in 1976. This body reports every 3 to 5 years on the preferred rotation rate, spin axis, prime meridian, and reference surface for planets and satellites (Archinal et al., 2011), which helps ensure that digital mapping endeavors are effectively comparable. This planetary standards body provides the critical foundation for all other interoperable initiatives describe below.

Digital Image Processing

Despite the introduction of digitally transmitted data in the 1960s, it was not until the late 1980s that digital cartographic processing was technically practical. Today, the time-consuming and multi-step manual processes used in previous decades have been replaced almost entirely by digital techniques. Although much of the process is automated, the generation of an image mosaic often requires human interaction (Figure 2) due to complexities in image data such as surface homogeneity, poor or disparate illumination conditions, divergent viewing geometries, or a combination of these factors. The process of adjusting images as a group –a block bundle adjustment – helps geospatially locate individual images relative to each, establishing a control network. The bundle adjustment process itself can also result in new control networks with improved accuracies (Edmundson et al., 2012). This need to continually improve the positional accuracies not only supports the ability to more safely land robotic spacecrafts and in the future, humans, on a planetary surface but also allows cross instrument data fusion.

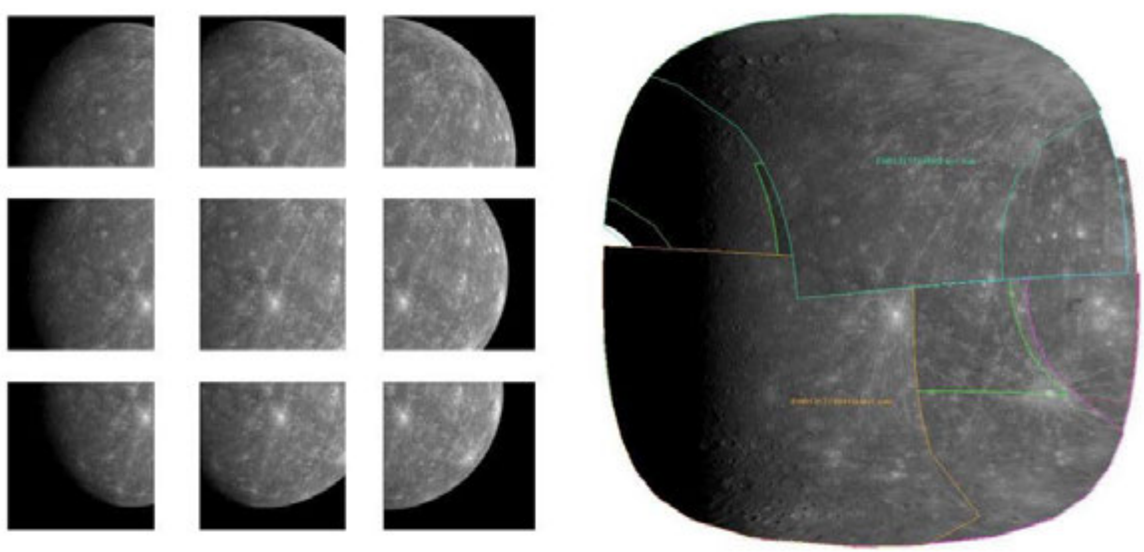

Figure 2: Images taken by NASA's Mercury Dual Imaging System (MDIS) on the MESSENGER spacecraft (left) and an example mosaic once the images have been controlled and then merged (right). Image credit: NASA/USGS (K. Becker)

Along with geometric correction, planetary software must also excel at correcting camera distortions, updating radiometry parameters and performing photometric corrections. Radiometric calibration recalculates the values in an image based on exposure time, flat-field observations, dark current observations and other factors that describe the unique electronics design and characteristics of the imaging system. Photometric corrections help to adjust images acquired under different illumination and viewing geometries such that the resulting images appear as if obtained under uniform conditions by adjusting the brightness and contrast prior to merging (Figure 3).

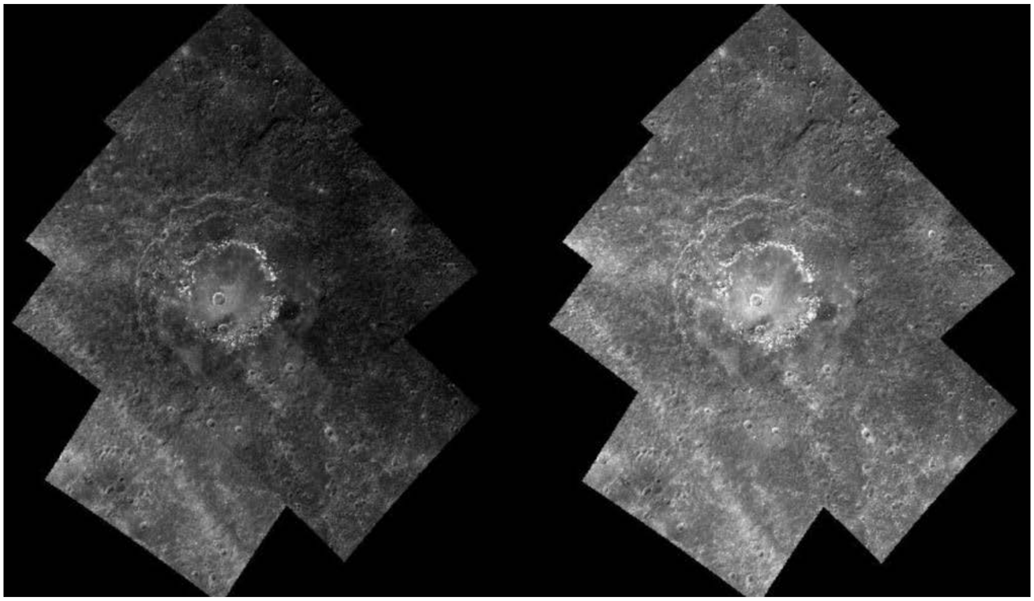

Figure 3: Example image mosaic of Raditladi crater (258 km diameter across) from NASA's Mercury Dual Imaging System (MDIS) on the MESSENGER spacecraft showing no photometric correction (left) and then the same image mosaic after applying the photometric corrections to the images prior to the mosaic creation (right). Image credit: NASA/USGS (K. Becker).

Interoperable Initiatives

Coordinate reference systems

Hare et al. (2006) originally proposed methods to support planetary coordinate reference systems (CRS) within existing OGC web mapping standards and geospatial applications Within a web mapping service, for each data set provided, the server must define a minimum set of information such that the client application understands not only the data layer but the current CRS and/or map projection. Generally, web mapping servers default to using the numeric European Petroleum Survey Group (EPSG) codes to define the CRS or Spatial Reference System (SRS). For example, code "4326" is the EPSG identifier for Earth's "WGS 84" geographic CRS. The server and client relay this code by passing an in-line SRS request using the string "SRS=nameSpace:code" (e.g. "SRS=EPSG:4326"). Additional EPSG codes were generated to attempt to catalog the most widely used cartographic map series from all countries (e.g. "32612" = WGS 84 / UTM zone 12N; "21413" = Beijing 1954 / Gauss-Kruger zone 13). One will quickly realize the options for these codes would be infinite. And if the CRS is not part of the EPSG database, and no planetary definitions are, there is the option to explicitly define custom settings.

To help solve this incompatibility among planetary servers, we have proposed our own set of codes outside of the EPSG namespace. The planetary coded system uses a combination of a published International Astronomical Union (IAU) document (Archinal et al., 2011) and previously coded values as defined by the Navigation and Information Facility (NAIF, http://naif.jpl.nasa.gov/). The IAU publication is updated every 3 to 5 years and the publication date defines the necessary namespace (e.g. IAU1979, IAU2000, IAU2009, etc.). The year specification allows the parameters of the body to be updated, which is common as better data is gathered or if new bodies are defined (e.g. newly discovered or imaged moons or asteroids).

These planetary codes will be modeled after the NAIF coding system. In short, the NAIF system defines the barycenter (center of mass) of the solar system as 0 and defines the Sun as 10. This leaves 1 through 9 to classify the planets starting with Mercury out to Pluto. The NAIF planet ID is then defined as the planet barycenter ID * 100 + 99. Thus Mars, in the NAIF system, is defined as “499”. To build upon that value, our new geospatial planetary code for the would now be derived as:

- Planetary GIS-IAU code = 499 * 100 = 49900
- WMS call: SRS=”IAU2000:49900”

The moons for each body, as defined by NAIF, start at planet barycenter ID * 100 + 1. For example, Phobos is defined as “401” and Deimos as “402”. The new planetary code would be defined as: Deimos GIS-IAU code = 402* 100 = 40200.

To continue with the Mars example, the first 10 numbers, 49900 to 49909, are reserved for geoid definitions (Table 1). Starting from 49910 to 49959, the codes are reserved for predefined projection definitions. Codes from 49960 to 49999 are for “AUTO” projections. AUTO projections allow the user to also submit the projection parameters (e.g. SRS=”IAU2000:49964,9001,100,45”. Where 49964 is Transverse Mercator, 9001 is the EPSG code for meters, center longitude=100º and center latitude=45º).

Table 1: Example planetary codes to support planetary WMS servers for Mars using the “IAU2000” namespace. Other bodies will follow similar definitions as derived from the NAIF planetary codes. Not all codes per body are shown here. Python scripts to generate codes are available on Github (Hare, 2006).

IAU Name	**Mars GIS-**	**GEOIDS**
IAU2000	49900	Mars2000, areocentric latitudes, positive East longitudes
IAU2000	49901	Mars2000, areographic latitudes, positive West longitudes
IAU2000	49902 - 49909	Available
		PROJECTIONS - Even codes=areocentric, **Odd codes**=aerographic
IAU2000	49910	Equirectangular (Simple Cyl), clon=0°, spherical equation, areocentric
IAU2000	49911	Equirectangular (Simple Cyl), clon=0°, spherical equation, aerographic
IAU2000	49912	Equirectangular (Simple Cyl), clon=180°, spherical equation, areocentric
IAU2000	49914	Sinusoidal, clon = 0°, spherical equation, areocentric
IAU2000	49916	Sinusoidal, clon = 180°, spherical equation, areocentric
IAU2000	49918	Polar Stereographic, clat=90°, clon = 0°, spherical equation, polar radius
IAU2000	49920	Polar Stereographic, clat=-90°, clon = 0°, spherical equation, polar radius
IAU2000	49922 ~ 49959	Available (1:2M Mars series handled by AUTO below)
		AUTO PROJECTIONS (parameter order)
IAU2000 or	49960	Auto Sinusoidal, spherical equation, areocentric, (clon)
IAU2000 or	49961	Auto Sinusoidal, spherical equation, aerographic, (clon)

IAU2000 or	49962	Auto (Polar) Stereographic, spherical equation, (clon, clat, scale)
IAU2000 or	49964	Auto Transverse Mercator, areocentric, (clon, clat, scale)
IAU2000 or	49966	Auto Orthographic, spherical equation, areocentric, (clon, clat)
IAU2000 or	49968	Auto Equirectangular (Simple Cylindrical) , areocentric, (clon, clat)
IAU2000 or	49970	Auto Lambert Conformal Conic, (clon, clat, std_p1, std_p2, scale)

As mentioned above, the EPSG coded system has a narrow set of predefined CRS systems. To help address this, the OGC has begun an effort to support and extend EPSG codes with a parametric URL-based CRS scheme called SECORE (Semantic Coordinate Reference System Resolver). Such a system catalogues and accepts URLs parametrizing CRSs as input and returns CRS definitions formatted using a verbose Geography Markup Language (GML) definition. We plan to extend and implement IAU code-set within SECORE (Rossi et al., 2016). Once available, these definitions can be dynamically converted to other formats, such as Proj4 or the "well known text" (WKT) map projection OGC standard.

Interoperable Tools

The U.S. Geological Survey's Astrogeology Science Center (ASC) is a major contributor of software for cartographic data processing for NASA missions and research programs, including the NASA's Planetary Program, Code S flight projects, research and data analysis projects, and the Planetary Data System (PDS). We support the Integrated Software for Imagers and Spectrometers (ISIS), a specialized image processing package for working with planetary image data (Keszthely et al., 2014). While it can ingest and export several different formats, it is only able to process in its own specialized format (ISIS3 .cub). In 2007, Geospatial Data Abstraction Library (GDAL) added reader support for the ISIS3 format to improve interoperability with other applications. This reader is geared toward using products finalized by ISIS, not as a method to manipulate files within an ISIS workflow. However, near-tem plans include an ISIS3 writer for GDAL.

GDAL: GDAL, released by the Open Source Geospatial Foundation (OSGeo), offers powerful capabilities for converting and processing planetary data. GDAL is a format translation library for geospatial raster and vector data (GDAL, 2016). In addition to the aforementioned ISIS3 reader, GDAL also supports other planetary formats including ISIS2, PDS, and Video Image Communication and Retrieval (VICAR). Some popular applications with GDAL support include, QGIS, GRASS, MapServer, Esri's ArcMap and ArcGIS Pro, Generic Mapping Tools, and Opticks. By supporting GDAL, the need to standardize on a single format is greatly reduced, which in turn has allowed us to more easily collaborate across different groups that may prefer to work with specific formats, either due to their preference or software requirements. For applications that do not use GDAL, the bundled routines released with GDAL can be used to convert these formats into more universal geospatial formats (e.g. GeoTiff).

Scripting Languages and GDAL: While GDAL is written in C/C++, it has bindings for use with many languages, including JAVA, PERL, Python, and .NET. As an interoperability example, we highlight Python which has a robust standard library and mature scientific computing stack (e.g. Numerical Python (NumPy), Scientific Python (SciPy), Pandas, Matplotlib). GDAL provides the interface to support data reads into a common, in-memory format, the NumPy array. This opens a world of extremely powerful image processing methods. At ASC, we utilize Python for both rapid prototyping and production development. For example, to support the NASA's InSight Mars lander and Mars 2020 rover missions, specialized topographic slope software was being supported in an outdated code base. Using GDAL, Python and existing array filtering functions in SciPy, we were able to quickly port the original source code, and integrate it with our digital terrain model workflow. During the port, we easily incorporated histogram binning (NumPy), to combine histogram and cumulative slope graphs (Matplotlib), and create colorized slope figures to assist in the ability to land the spacecraft safely on the surface (Figure 4).

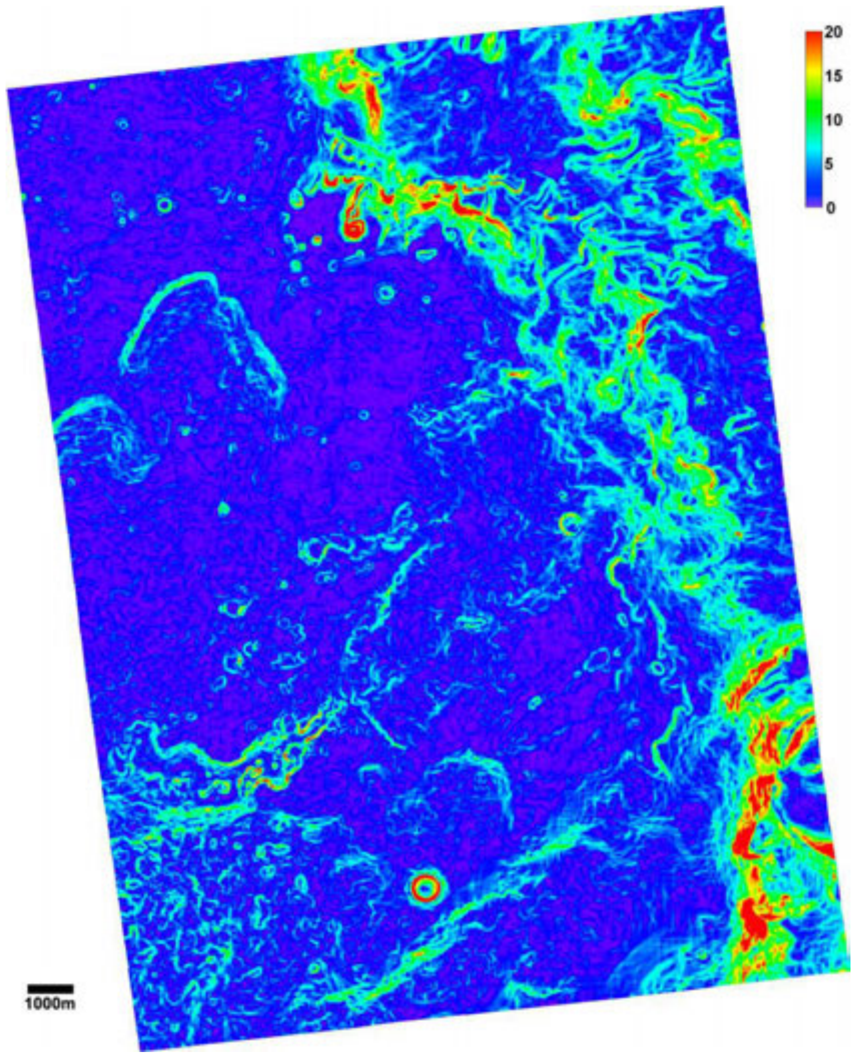

Figure 4: Example derived slope map at 20 meters/pixel within McLaughlin crater (center at 21.9° north 337.63° east) generated for the Mars 2020 rover mission. The slope map will be used to help assess the ability to land the rover safely on surface. Image credit: NASA/USGS.

Interoperable Formats

Most planetary data acquired by both NASA and non-US spacecraft are archived in a Planetary Data System (PDS) format (McMahon, 1994). The PDS is managed by NASA Headquarters' Planetary Sciences Division but consists of a collection of external facilities to support the archival and distribution of planetary data. The bulk of the PDS data holdings are cataloged in their original raw instrument form, however, to use these data sets in scientific applications, they should first be spatially referenced (map projected) to the planetary body. Unfortunately, the PDS format is not widely recognized. Two formats which have been targeted for their planetary support and are now commonly used in the community include GeoTiff and GeoJpeg2000.

GeoTiff: Probably the most popular geospatial format is GeoTiff. The GeoTiff format, fully within the public domain, was created by Dr. Niles Ritter in the 1990's while working at Jet Propulsion Laboratory (Ritter and Ruth, 2000). GeoTiff makes use of a geospatial (cartographic) tags embedded within the TIFF file format. It is one of the only image formats which allows the flexibility to support tag structures without causing issues for applications that do not support those tags. The image format can support 8-bit grayscale images, and up to 16, 32 and 64-bit floating point elevation models. TIFF also supports a variety of compression and tiling options to increase the efficiency of image reading and online distribution. The BigTIFF extension now allows single images to be greater than 4 gigabytes in size.

GeoJpeg2000: In recent years, the PDS has approved the use of the JPEG2000 format. This format supports the exact same tags as the GeoTiff format but stored within a Universally Unique Identifier (UUID) container. When utilized, this format is informally called GeoJPEG2000 (also GeoJP2™). In 2008, University of Arizona's Mars HiRISE instrument team was the first mission to release their map-projected PDS archives using a hybrid method combining the use of the GeoJPEG2000 standard and a detached PDS label (McEwen et. al., 2002). The simple text PDS label is necessary to hold required PDS metadata like author, instrument particulars, or mission dates which are not suitable for the geospatial container.

While this hybrid approach sounds like the best of both worlds, the JPEG2000 format does not yet support 32-bit floating point values, although it is part of the specification. There are PDS products that may simply not work well in this format. It is unfortunate that the open Jpeg2000 libraries (e.g. OpenJPEG or Jasper) are still far behind in capabilities and speed to proprietary solutions like the Kakadu library (http://kakadusoftware.com/).

Interoperable Web Services

The OGC is a consortium of more than 500 international companies, universities and government agencies which define standards such as the Web Mapping Services (simple image maps), Web Feature Services (feature streaming), Web Coverage Services (rich scientific data streaming), and Catalog Services for the Web (data searching and discoverability). Astrogeology supports both WMS and WFS allowing capable mapping clients to view full-resolution global and polar base maps and geospatial databases. In short, a WMS service accepts queries for map-projected layers and returns requested data in an image format (e.g., JPEG, PNG). A WFS service returns geographical features representing data such as a name, type, and the spatial geometries (point, line, or polygon). Our services currently support more than 100 image layers and over 30 different planetary bodies. Currently our largest single support image mosaic weighs in at half a terabyte in size. For ArcMap GIS users, these layers are also listed on the Esri's ArcGIS Online data portal under the Planetary GIS group (http://bit.ly/PlantaryGIS).

Several other facilities maintain custom planetary WMS servers which include support for the proposed IAU codes as described above (e.g. Lunaserv by Arizona State University, http://lunaserv.lroc.asu.edu/). However, it is still recommended for compatibility across software and online viewers that these planetary services also have a default for the decimal degree (latitude/longitude) Earth-based code "EPSG:4326". This allows nearly all viewers to visualize other extraterrestrial bodies correctly in degrees. But care must be taken when using these layers for measurements.

Mapping Interoperability

As describe above, the IAU defines the recommended rotation rate, spin axis, prime meridian, and reference surface for planets and satellites; however, their oversight does not cover other standards essential for digital mapping including common feature attributions, feature symbols, recommended mapping scales and finally the documentation of the data. When possible, it is recommended that digital maps use these standards so that consistent map products can be developed.

Feature attributes and their assigned symbols for planetary digital maps are commonly defined in the Digital Cartographic Standard for Geologic Map Symbolization (Skinner et al., 2011) prepared by the USGS for the Federal Geographic Data Committee (FGDC). For example, recommended attributes for geologic contacts or geologic unit boundaries include attributes for contact certainty. The nominal level categories are then given explicit symbolic representations such as solid black line for certain contacts or dashed black lines for approximate boundaries. Symbology is primarily drawn from the same set of attributes and symbols as used for Earth. This heritage facilitates the understanding of geologic or thematic planetary maps because readers are familiar with the feature attribution names and symbol types (Nass et al., 2010).

Standardized Metadata: In short, metadata is the ancillary documentation that helps describe the rationale, authorship, attribute descriptions, spatial reference, and other pertinent information for data. For planetary data, PDS archives are the recommended method to document data products. Unfortunately, PDS metadata is not readily supported in more widely used geospatial data portals. Most geospatial portals require metadata as defined by the FGDC or International Organization for Standardization (ISO). Methods for conversion from PDS to FGDC/ISO metadata standards should be possible given that the FGDC metadata standards only require a few minor additions to properly support planetary data (Hare, 2011). We are currently constraining this work to data sets that can be registered to a solid body (exempting, for the time being, products that focus on atmospheres, plasma, and rings).

Interoperable Data Portals:

One of the latest trends in the geospatial community, including the planetary community, is to provide data portals (e.g. http://www.data.gov/). These portals assemble data collections for on-line browsing and download. Many Earth-based data portals are built around the use of FGDC/ISO metadata to import, describe, and catalogue data for external users. For planetary data, most portals provide access to a data collection for browsing and retrieval but they often include minimal metadata and thus have limited search capabilities. And even if each product is properly catalogued on the host site, the full listing of products is not easily accessible to outside users (e.g., for searches). Methods defined by the OGC Catalogue Services for the Web (CSW) standard will facilitate such outside access, so that users need not build new search tools or application layer interfaces (API) (Figure 5).

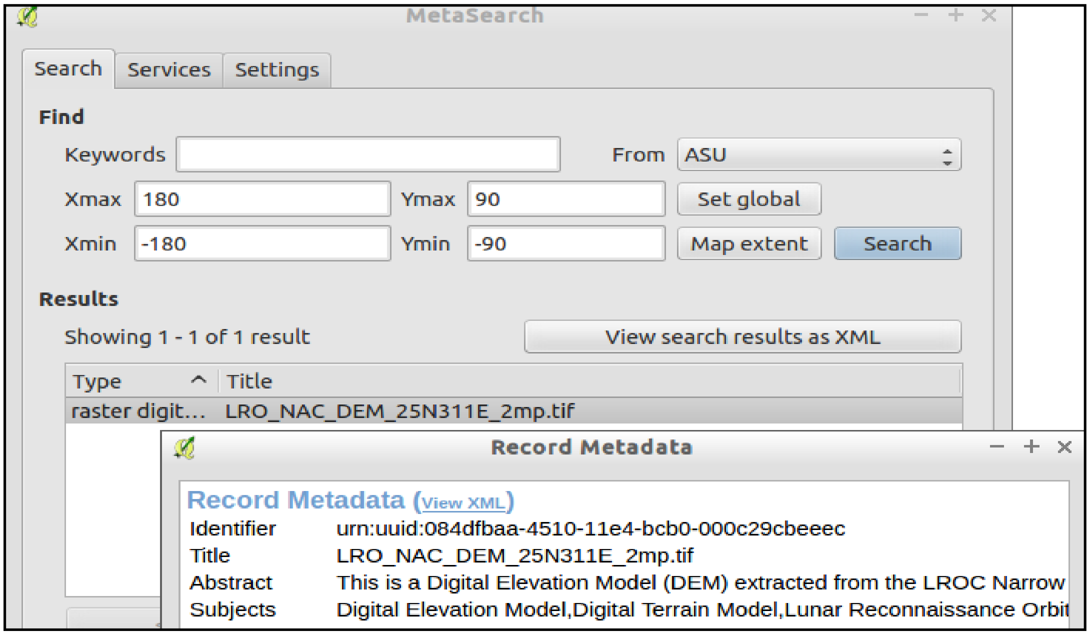

Figure 5: An example CSW search using the Desktop GIS application QGIS with a CSW plug-in. In this case, the CSW server returned a digital elevation model as derived from Lunar Reconnaissance Orbiter Camera images.

One major benefit of using the OGC CSW standard is that portals can support searches across data catalogues because the standard allows one data portal to index data in other portals. Products served by such mutually indexed portals have standardized metadata, and appropriate credit for and references to the data creators and the original host data portal are assured. In summary, the benefits for implementing a data portal using the OGC CSW standards include:

- Enabling easy search and discovery of existing geospatial data and services;
- Reduction of redundancy across portals; and
- Authoritative versions are better established.

To date, only initial testing for a standardized planetary CSW portal has been completed, although our current portal infrastructure can support this. We hope a proper planetary CSW portal will be an example for standardized data discovery for the community.

Conclusions

As data volumes grow, interoperable methods of accessing and working with geospatial data will continue to be more essential. Standardized methods for direct access to on-line planetary data will also continue to rapidly mature. We will continue to encourage more facilities to use OGC interoperable standards for distribution and hosting data sets. OGC-based technologies have proven they can handle diverse data sets like terabyte-sized mosaics, hyper-spectral imagery, and high-resolution non-continuous images while keeping access to the data layers easy but ready for mapping and research applications.

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