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A Spatial Approach to the Search for Life

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Abstract

Scientists interested in the study of life in the context of the cosmos have limited resources to dedicate to missions. The use of these resources can be made more effective by applying spatial reasoning to projects. If you were to collect data on Earth with the hope of finding life, you probably would not search the Sahara Desert first. You could search the Pacific, but even given the bounty of life in our planet's waters there would be significant difficulties asosciated with landing in the middle of the ocean. Accordingly, astrobiologists use the discipline of geography to inform their search, a dicipline with a rich history of visualizing data about the universe. This essay will discuss that history, address the spatial reasoning involved in more current projects at NASA, and inquire into breaking applications for astrobiologists extending farther than our own solar system.

I. Introduction

Maps compose the visual vocabulary of scientific exploration. They are a fundamental tool to summarize observations about the places and spaces we occupy. As long as humans have inquired into the nature of their environements, they have referred to maps to articulate themselves. This is not limited to terrestrial exploration. Celestial cartography is a millenia-old subfield to the explorative practices of geography, the interdsicplinary study of mapping astronomical objects. One can trace celestial cartography across ancient civilizations, from the maps of preliterate peoples such as the Australian aboriginals, to star maps decorating the interiors of Pharoh's tombs, to in more recent memory the historical star tables of Ptolemy in 150 AD.

The oldest maps known to Man are the rock engravings in northern Italy known as the Bedolina map, estimated to have origins anywhere from 2000-1500BC (Thrower 3). It is a detailed plan for the area's land, progressing from pictorial to symbolic (Thrower 4). However, the oldest star chart known to man goes back by several more thousand years. An ivory mammoth tusk discovered in Germany has been dated to be 32,500 years old and features a carving resembling the constellation Orion (Lucentini 3), upsetting the Bedolina map's claim as the oldest chart (although not map). In addition, the Lacaux caves in France have depictions of the Pleiades open cluster of stars – estimated anywhere from 33,000 to 10,000 years ago (Whitehouse 2). Forward a few more thousand years and accurately dated star charts were appearing in Egypt, 1532 BC, followed by Mesopatamian star catalgoues from 1531-1155 BC (North 30).

As put by Dr. Thrower, a specialist in the history of geographic discoveries, "that such [preliterate] groups engage in mapping attests to the basic importance of cartography to humankind" (Thrower 3). Although Ptolemy, who made observations from 127-141 AD, is typically recognized as the Father of celestial cartography, it would be foolish to ignore these astounding records millenia before him. Between 1500-1800 AD we can trace over 160 astronomical cartographers, a so-called "heydey of pictorial representations of the stary sphere." (Warner 1)

Observing celestrial cartography as practiced across ancient, sometimes isolated civilizations is not simply anecdotal, but also useful to the contemporary explorer. In recognition of the discipline's continued relevance, the new Planetary Cartographer is inspired to press on with greater responsibilities than before. While once an intellectual exercise, celestial cartography is now informaed by real-time data. Dr. John Pickles of

Oxford notes that “from ‘comparative planetary geomorpholist’ to ‘nanotopographers’ – map-making has seized the cutlures of science in ways that are redrawing the maps of the world.” (Pickles 79)

Figure 1: Whole Earth

Proceeeding into the future of celestial cartography, each success confirms the field of geography’s responsibilities when representing data. The Cartesian commitment to vision as the privileged source of geographic information prioritizes mathematical forms of abstraction as a practice of depicting nature. In more clear terms, everything happening in the world can be described according to coordinates within a distinct spatial framework. This Cartesian gaze envisions nature from the perspective of the Whole Earth, imposing spatial order through locating, identifying, and bounding phenomena (Pickles 81)

Thanks to advancing technology, celestial cartography’s days of pedantic ideography have been transformed into a spatial science. Researchers armed with geographic information systems technology naturally fit into teams of astrobiologists searching to answer:

1. **Is there life elsewhere in the universe?**
2. ***Where?***

II. Over the Moon for All This Data

The new era of planetary cartography was hastened in by a surge of data provided by the 1994 Clementine space mission. Specifically sent to collect geographic information pertinent to the moon’s surface, the data collected would go on to represent the most detailed maps of a celestial body ever made. This project was a game-changer because it illuminated a smashing success of GIS when applied to space missions while highlighting future challenges scientists would need to respond to as they standardized a new discipline.

Perceptions of the moon had previously been marked by cutltural associations between the light and dark patterns covering it's surface. Intriguingly, the Chinese looked at the moon and compared it to an upright rabbit, pounding rice (Whitaker 4). Meanwhile, Shakespeare was referring to the patterns as "the dog, the bush, and the man." (Whitaker 6). It was Galileo who first published sketches of the lunar surface made from a telescope. He recognized the darker and lighter spots for valleys and mountains, straddling the idea of surface features on Earth occuring on the moon, making it feel less exotic than previous inquiry (Whitaker 19).

Figure 2: Chinese Rabbit

Fast-forward to 1992, and NASA was preparing Clementine, a mission that would map the moon and determine's it's mineral content. The spacecraft's adaptor was designerd to keep it in orbit around the moon as it carried out it's task when finally launched in 1994. The spacecraft was equipped with four cameras: an ultraviolet-visible (UVVIS) camera, a long-wave infrared camera, the laser-ranger high-resolution camera, and a near-infrared (NIR) camera (Nozette 1). The mission was a success in many ways- within 71 days, 38 million square kilometers of the moon were mapped (Nozette 1). The mission took high-resolution thermal images, created a complete map of the moon's topography, and provided insight into the moon's surface gravity field, meeting and exceeding expectations. The mission gave scientists the opportunity to study new geographic information in detail, creating “the first global digital data set for the moon.” (Nozette 4). NASA’s team estimated a better than 0.5 km absolute positional accuracy everywhere on the moon (McEwan 53). Clementine revealed a new picture of the lunar structure and the moon’s thermal history (Zuber 1839). This mission matters a great deal because it opened a door for scientists to approach their missions with GIS, knowing just how useful it had proven to be. This new process of collecting information on the cosmos we inhabit is useful to anyone interested in the environments’ extraterrestrial life could arise in.

III. Developing and Standardizing a New Field: Planetary Cartography

As international interest in planetary exploration mounts, planetary missions have been lauchecd to collect information from beyond the moon to Mars, Mercury, Venus, and even objects on the fringes of the solar system. By equipping these misisons with cameras that capture different angles and wavelengths, scientsists intepret the deverloment of planetary surfaces using maps. All spatial information about the universe is visalized with these topographic and thematic maps (Nass 1255).

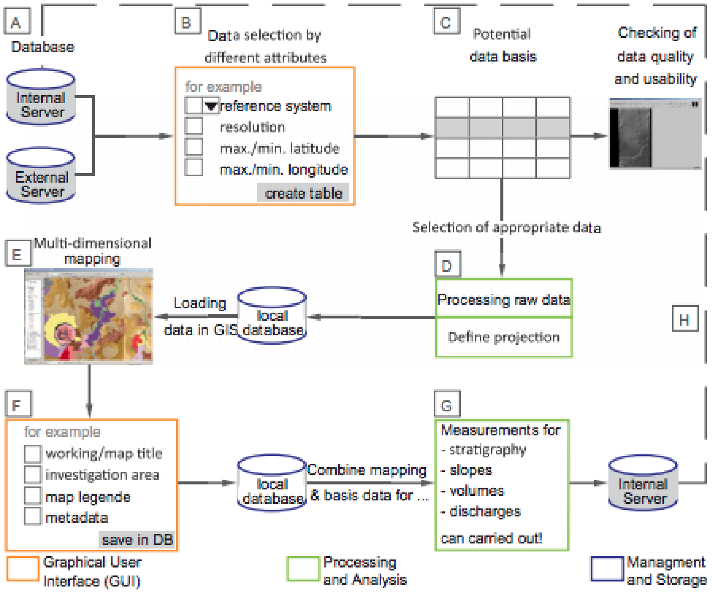

Figure 3: Planetary Mapping Workflow, (Nass 1257)

Since the first planetary missions to gather surface data began in the 1960s, geologic mapping has grown to be the premier anlaysis tool of mission exploration. The amount of data to work with continually grows, and technology is keeping up the pace. Primary advocates of geologic mapping missions since the 1990s include the United States Geological Survey and the National Aeronautics and Space Administration. Their first attempts to map the cosmos have been reworked over time by sophisticated geographic information systems, with the Enviromental Systems Research Institute (ESRI) at the helm building ArcGIS software. The basis of these mapping techniques is the identification of surface rock (Gasselt 203). While there are hundreds of GIS packages available to researchers, ESRI is endorsed by USGS as the discipline's standard.

USGS maintains GIS teams who work together to model planetary information. These teams are comprised of a Project Manager, GIS Manager, Geodatabase Administrator, GIS Analysts, and GIS Technicians. While the Project Manager defines the team's goals, the GIS Manager more disticntly defines the technical processes and is obligated to understand their software's limitations. The Geodatabse Administrator maintains the hardware and software, while the GIS Analysts implement predetermined procedures, write programs, and analyse their results (Hare 4). The GIS Technicians differ from Analysts in that their primary function is collecting and entering data, unlike the creative work of an Analyst. According to the USGS Planetary Training Guidebook, each of these employees are necessary to a successful GIS project and other industry leader's such as NASA share this team-oriented perspective. NASA's Planetary Geologic Mapping Handbook outlines the additional roles of Production Cartographer and Discipline Scientist (Tanaka 7).

A substantial degree of planetary observations can be represented by thematic geologic maps. Cartography allows researchers to shift from passively observing towards actively discerning. These maps typically reconstruct subsurface features as well as relate these reconstructions to a geologic timescale. To take full advantage of GIS technology these maps are being pushed to establish a spatio-temporal understanding of planetary geology (Gasselt 272). Like Earth's geology, the rocks present on the moon or Mars were formed in a process operating much slower than humanity's timescale. By identifying geographic patterns on the surface of a rocky planet, one can use the principals of stratigraphy to learn more about the history of the planet. This active process is observable and should be emphasized as continually progressing. Surface material can be observed not just for mineral content, but also spatial and temporal insights, the three dimensions of all planetary data thus far collected (Gasselt 273).

Cartographers note this three dimensionality of rock observations by using ESRI's ArcGIS to represent *Geological Unit Feature Classes* with lateral geometry, enabling the user to query "top-of or below-of queries" (Gasselt 275). For instance, the lunar Mare Oritentale Basin was constructed with ArcGIS to trace three generations of impact craters. The resultant stratigraphic model then gave historic values of probable era for each of these craters' dates, tying notions of place, time, and mineral identification together. Developing this model was challenged by dual needs to be both geneeral – applying established principles of geology to be used with any planetary object– and extremly detailed in qaulity of analysis in order yield valuable results.

Aided by rock samples collected by Apollo and Luna missions, a geologic chronology was established across the moons on a global scale. These theoretical models can connect the dots between craters and different parts of our solar system. The geologic chronology of the moon sheds light on the geologic chronology of different planets too (Kneissl 1243) . Measuring the impact-crater diameters at a precise degree is done using ArcGIS's CraterStats and CraterTools ArcMap toolbar to simplify the measurement process. This methodology is recommended internationally (endorsed by NASA and the ESA) as a new standard for determining crater size-frequency distributions (CSFDs). Unlike the moon and earth, we cannot yet determine the age of any rocks on the surfaces of other planets without the concreteness of radiometrically anlaysed rock samples. Despite this lack of quantitative data, remote sensing can still be engaged for qualitative age classifcations by surface imagery and stratographic relationships (Kneissl 1244).

Challenges presented by map projections are not just for Earthlings. Initially to counter distortion in the first planetary geological maps of the moon, multiple projections were first used to map the surface: between 30 degrees South and 30 degrees North used the Mercator Projection, between 30-65 degrees North and South used the Lambert Projection, and between 60 and 90 degrees North and South used Sterographic Projections (Kneissl 1245). Such a proccedure generated unacceptable distortions when measuring crater sizes. ArcGIS significantly improved this process by reprojecting crater areas for accuracy using individual Sinusoidal Projections (Kneissl 1253).

Althought the ArcGIS framework discussed above is closed source, a surprising variety of the geogrpahic tools being developed rely on an opensource framework. Collaborative mapping has opened the opprotunity to enthusiastic civilians to provide mapping insights as Citizen Scientists. Making valuable data about the moon accessible shaped new imaginative geographies in the public eye. How could this process of geographic information collection be applied to other planetary objects?

IV. GIS and the Mars Science Laboratry

Now that planetary mapping has come into it's own as a standardized discipline led by USGS and NASA, powered by ESRI, it is intriguing to explore the way it is applied to specific cases. For missions to Mars, GIS plays an important role in the perfecting of methodology still on Earth, the collection of data while arming spacecraft, and the analysis conducted with gathered imagery. Each of these roles contribute to it's critical place in the toolbelt of an astrobiologist keen to know where to look for life.

The Mars Science Laboratory mission was built to assess whether the Mars "was ever capable of supporting microbial life" (Vasavada 794). It's landing site was the equatorial Gale Crater, in 2011. The decison to land at this site was "deliberately delayed until late in the rover's development, to allow for more time for the scientific study of candidate sites from oribtal data sets" (Vasavada 795). Gale Crater possesses a complex physical geography. It is at the meeting of the southern highlands and northern lowlands, the kind of landscape unfamilar to most aside from the average Scottish farmer in Stirling, United Kingdom. Except, of coure, that it would be dry and totally barren. Because of it's topography's regional varations, researchers expected up-slope winds (Vasavada 809). GIS imagery was used to derive potential risk of dust storms in the region, of particular risk in the Martian summer, but local dust storms were found to be uncommon near this crater. By the time finalist sites were selected for the MSL, the thermal engineering team was able to adjust requirements accordingly – location information within so specific a region allowd scientists to tailor the craft to the geography it was created to explore (Vasavada 829).

To better assess the effectiveness of mapping techniqeus for Mars, researchers commonly use terrestrial analogs. These places are selected by using assumed past or present conditions of Mars to find locations on Earth deemed similar enough to act as enviromental models. One such analog is the SP Mountain area of the San Francisco Volcanic Field, Arizona. Mapping techniques used for Mars are tested here to better understand reasonable errors. For example, photogeologic mapping techniques were tested in Arizona because it shares morphologic and stratigraphic features observed in many regions of Mars: lava flows, vents, erosion valleys to name a few (Tanaka 512). These trials provided encouraging results for use on Mars.

The Mars Exploration Rover is equipped with the Science Activity Planner (SAP), a planning tool that among many uses applies geographical information systems to strategize data collection. Images collected by the rover can be viewed as a collection warped by SAP to appear as a panorama. When viewed in 3D, a scientist can position themself as if they have a camera surveying the action almost as though from above (Norris 1). Imagery collected by SAP are spatially indexed so that images can sought based on where they were found (Norris 4). This adds to the wealth of spatially tied information astrobiologists may be interested in, a kind of key to consult when tracing patterns for life.

Public interest throughout continued Mars discovery has resulted in access to research tools used by spatial thinkers working for NASA. Perhaps most notable is JMARS: Java Mission-Planning and Analysis for Remote Sensing, a geographical information application designed to work with raster, vector, and hyper-spectral data (Christensen, 5). Raster data is a matrix of cells representing information in grid form, the way in which satellite imagery is commonly organized. In contrast, vector data represents the world using points, lines and polygons. In context, while a crater's boundaries might be represented by vecotr data, the interesting observations such as temperature, topography, or geology per unit area are displayed using raster data. Hyper-spectral data adds insight in identifying objects and processes within this scene.

The creation of JMARS was in response to the needs of Odyssey THEMIS, which encouraged researchers to tie day and night imagery collected at 100 meter resoltuion and organize it into a grid, then georeference it to the Mars surface, creating global maps for the Martian planet. In the process of creating the software, a methodology was established to map any object in the solar system (Christensen 2). Key to our broader discussion, this geodatabse was used to select the landing site for the Mars Rover.

The JMARS software was orignally developed by Mars Space Flight Facility in collaboration with Arizona State University for orbiters and researchers as a mission planning and data analysis tool, but it also open to the general public – it's free and within a matter of moments the reader herself could be looking at up-to-date Mars data (Christensen 5). More recently it is being used to work with Earth and Moon data as well. Its strengths as an analytical tool include creating contour maps, the ability to compare layers from elevation to thermal inertia, and a scriptable environment. It also makes data accessible from the following missions: THEMIS, MOC, CTX, HiRISE, Viking, HRSC, CRISM, and Omega. This powerful GIS tool is the visual vocabulary of Mars geographic information, and helps researchers to visualize information to find insight into projects on the surface. At a very simple level, JMARS enabled sicentists to inform site selection with spatial data, but in more complex ways the combining of layers within the application allows them to evaluate the risks associated with different terrain and break the surface into regions of priority for inquiry. Nonetheless, researchers are commonly warned to avoid over-interpreting geologic history using remote photo mapping (Tanaka 531).

V. Looking Farther: Exocartography and Extrasolar Cartography

One day we may use new cartographic techniques to inform our search for life outside the boundaries of our own solar system. Exocartography, also known as extrasolar cartography, is the science of mapping planets that are outside of Earth's solar system. In this emerging field, physicists (innovators that actually are not geographers!?) are attempting to map planets using traditional imaging devices. Instead, they are writing equations to chart the brightness of stars distant planets are orbiting around (Cowan 914). When the planets eclipse, they are able to measure the changes in brightness of the stars to make inferences about several key pieces of information: how fast the planet is moving, the speed of the planetary year, and even the planet's size. This information enables them to begin mapping things like temperature, cloud cover, weather patterns, and even the existence of continents and water forms (Cowan 915). These advances in mapping techniques have the potential to prememptively identify habitable environments for life outside of our solar system. The primary focus of these investigations is detemining a way to distinguish water-covered planaets like our own. MIT scientists have already concluded that “it is possible to infer the existence of water oceans on explanets” (Cowan 915).

VI. Concluding Thoughts

Since the rise of technical planetary maps, some scholars have decided to replace the term cartography in favor of *planetary mapping*, insinuating the new effective manuel methodology takes precedent over the more general art of map making. However, planetary mapping’s storied history stretching back to pre-literate civilization suggests to me that our newfound astrobiological toolkit is meant to include so rigorous, imaginative a craft as *planetary cartography*. As long as astrobiologists use spatial reasoning to inform their decisions, planetary cartography will remain an indispensable art.

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