FRAMEWORK FOR THE DEVELOPMENT OF A EUROPA PLANETARY SPATIAL DATA INFRASTRUCTURE.
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Introduction: Spatial data infrastructure (SDI) is the framework composed of spatial data users, data interoperability agreements, policies and standards, data access mechanisms, and the spatial data themselves [1,2]. Spatially enabled planetary science data are any data with a spatial component such as remotely sensed orbital data or geotagged sample data (e.g., Apollo samples). As described previously [3,], the goal of SDIs is to make spatial data discoverable, accessible, interoperable, and usable by non-spatial data experts. We note that the term is used to describe both the framework of ideas that support spatial data usage and as an umbrella term for the implemented systems. Herein, we describe the use of the SDI-framework, coupled with an implementation strategy to developer a Europa centric SDI-implementation.

SDI-frameworks are an area of active research within the terrestrially focused geography and Earth science communities given the large volumes and rapid data collection velocities of spatial data. Likewise, academic, government, and non-government organizations research and implement SDIs to fulfill the spatial data utilization goals previously enumerated. It is from these bodies of work that the planetary science community can develop a Europa or Jovian focused SDI implementation.

Considerable sections of this work have been drawn from the recently published article *Framework for the Development of Planetary Spatial Data Infrastructures: A Europa Case Study* [2]. We are intentionally omitting the theoretical foundations from which the proposed Europa SDI is derived and suggest the aforementioned article to the interested reader.

Product Based SDI: SDIs are complex adaptive systems [4, 2]. Therefore, describing an SDI from a single perspective can result in a gross oversimplification of the entire system. We have already taken a product based view [1] of SDIs in describing them as being composed of spatial data users, policies, standards, access mechanisms, and the spatial data themselves. Throughout we use the product based view as the reference model for an SDI. In order to develop an implementation plan for a Europa-SDI it is first necessary to perform a knowledge inventory. A knowledge inventory is a systematic review of the available knowledge assets, the state of those assets, and the people who own, maintain, or manage said assets.

Policies and Standards: Two broad classes of policy documents currently exist to support the development of a Europa SDI. The first of these are developed and published by flight missions where processes that coordinate and govern what data are to be collected and how instrument teams within a flight mission will (inter)operate. The second of these policies are established by NASA (and the PDS) and describe the methods by which the data need to be delivered for archiving and long-term preservation. While these policies are critical to the functioning of the mission and the long-term availability of the data, they do not adequately support the goals of an SDI. Therefore, we suggest that an explicit Europa SDI governance model be developed akin to the Dutch SDI model (a federated collection of organizations with voluntary participation) where a coordinating, government entity with strong connection to the funding institution(s) drives the creation and long-term development of said SDI. This coordinating entity should be a member of a Europa SDI management board that is tasked with developing the necessary memorandum of understanding and implementation arrangements between participants. An example implementation arrangement might define that some data provider will make some data set available under some set of standards for a given duration at some level of custodial support.

It is premature to identify specific standards to support a Europa SDI as standards should come from the user community based on needs. We identify four places from which standards should be drawn: (1) MAPSIT as a coordinating, community wide entity for spatial data leading practices, (2) terrestrial SDIs as those user communities have identified leading practices through extensive trial and error, (3) the OGC that lead spatial interoperability efforts and standards development and maintenance, and (4) the International Astronomical Union (IAU).

Users: Users are classified as enablers, suppliers, developers, marketers, and end users. *Enablers* set policy, provide funding, and/or develop and maintain standards recommendations. *Suppliers* are data stewards, who are responsible for data collection and maintenance, standards development, quality control and metadata maintenance [5,6]. Data stewards are both mission teams and organizations with spatial expertise who value add to the raw or low-level data. *Suppliers* also include custodians who focus on data discrepancy tracking, quality assessment, and maintenance for accessibility [5]. S*uppliers* can also be data integrators that act as the bridge between the aforementioned suppliers and end users. *Developers* have the expertise to create and maintain the technical solutions that make SDIs function. *Marketers* promote the SDI to end users and potential funders. We see, in the case of the astronomy focused virtual observatory that the primary marketers are those researchers that are afforded a competitive advantage due to data discoverability and interoperability. Finally, *end users* are those stakeholders that use the spatial data.

User Class	Organization / User Group
Enablers	NASA PSD; OPAG; MAPSIT
Suppliers	PDS; ASU RPIF; USGS Astrogeology; Europa Clipper Team; JUICE Team; data creators (e.g., [7,8,9,10,11]
Developers	Broadly spread across the community
Marketers	Funding groups; Advisory Groups; Users
End Users	The community

Table 1: User classes and potential user groups within a Europa SDI.

Data: We direct the reader to [2] for a full description of the currently available data and data products. Currently, data is primarily available from the Voyager 1 / 2 and Galileo missions. Data from Pioneer 10 / 11, New Horizons, Cassini, and Juno are (to the best of our knowledge) not well suited for use cases requiring moderate to high spatial efficacy. From the Voyager 1 / 2 and Galileo data, the following foundational data products [2] are available: (1) Voyager and Galileo controlled and orthorectified digital mosaic with 1 km (stated) horizontal accuracy, 500m per pixel spatial resolution, global coverage, and availability in GeoTIFF, PDS3, ISIS3, and WMS formats; (2) Galileo Satellite pseudo-controlled and orthorectified regional image mosaics available in TIFF and PNG format; (3) Globale Shape model [12] with 1km vertical accuracy; and (4) RAND control networks. We also note that a number of other foundational data products are either in preparation or not publicly available.

From the context of an Europa SDI valuable data are available in formats and via interoperable standards likely to be adopted by the community. Therefore, these foundational data allow the development of an SDI before future missions begin collecting new data. In fact, the existence of an Europa SDI would provide a foundation into which newly collected data could be well-integrated.

Data Access: Data are currently available from three primary sources. First, the PDS stores Voyager 1, Voyager 2, Galileo, Cassini, and New Horizons missions. These data are discoverable via label elements, spatial coordinates, time, and viewing geometry queries. All spatial and temporal queries utilize a priori SPICE information and are only as accurate as the SPICE provided ephemeris data. Second, the ASU RPIF archives and serves affine warped Voyager 1 and Voyager 2 regional mosaics that are discoverable by orbit number. Finally, the USGS Astrogeology Science Center makes Voyager and Calileo controlled and orthorectified image mosaics that are discoverable via text-based search (no spatial or spatio-temporal search capabilities exist). Even with these existing data access mechanisms, three primary issues still exist: (1) the community generally lacks spatially enabled data products to work with and those products that are available are summary in nature (the available image mosaics are a subset of the total available data), (2) a high number of foundational data products are not publicly available [2] and many foundational data products would benefit from rigorous accuracy and efficacy assessments, (3) metadata to support data discovery are largely label or spatially derived and lack depot to support inherited knowledge (knowledge that is passed from data user to data user).

Given the current data and data access landscape, we suggest that (1) all available data be spatialized to an existing orthomosaic and made available in OGC compliant formats, (2) organizations or teams with expertise to spatialize said data should be engaged as data custodians (implying that a Europa SDI governance model has been adopted), (3) a Europa spatial data clearinghouse should be created.

Conclusion: A Europa SDI offers both short- and long-term benefits to the discoverability and usability of Europa data that supports current science studies and future flight missions. Herein, we have sought to summarize [2] in presenting a rough sketch of what form a Europa SDI might take.

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