CSCI 586 Project Report

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"Analysis of SWEET (Semantic Web for Earth and Environmental Technologies) Ontology"

[2a]

University of Southern California

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Submitted by:

Shashank Jivan Vernekar

Varun Mittal

Tanvi Juneja

Hema Narayana Reddy

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ABSTRACT

In current times, Web searches for Earth science data and information are generally clogged by syntax mismatches between information user and information provider. If the user does not enter the "correct" search terms, either not enough or too many hits are returned. The underlying cause is a lack of "common sense knowledge" inherent in the search tool. Each community has its own standards and infrastructure, which makes integrating data from those different sources a difficult task and sometimes impossible. Thus, the emerging solution is using the "Semantic Web" which encodes common sense knowledge directly into web pages themselves, using broadly agreed upon namespaces and ontologies to define terms and their mutual relationships.

Also these days, there is a lot of research and development going on for improving semantic understanding of web resources by software tools, with specific application to discovery and use of Earth science data. Therefore, several ontologies have been developed to address interoperability issue across those disciplines. NASA's Semantic Web for Earth and Environmental Terminology (SWEET) is a collection of ontologies covering a wide range of concepts and relations among them in the domain of Earth and environment. SWEET is a collection of ontologies in the DAML + OIL ontology including concepts like (space, time, phenomena etc.). Also Success and Evaluation of SWEET along with its accomplishments and problems encountered is analyzed in the report.

Keywords: *Earth Science, Semantic Web, SWEET, Ontology*

INTRODUCTION

Scientists in the Earth and Environment Sciences (ESS) domain increasingly use ontologies to analyze and integrate their data. Ontologies define the terms in a domain, provide constraints on values and provide semantics that will enable automated reasoning.

The SWEET ontology was developed to allow discovery and use of Earth science data, through software understanding of the semantics of web resources [1]. SWEET contains a collection of ontologies in the Ontology Web Language (OWL) and available as open source technology [3]. SWEET 2.3 is modular with 6000 concepts in 200 ontologies. The entire concept space can be viewed using the sweetAll.owl file by using OWL tools such as Protégé, and Karma. The current version of SWEET has nine top-level ontologies and concepts [4].

The SWEET ontology is based on NASA Global Change Master Directory (GCMD), which includes both controlled and uncontrolled keywords. The controlled keywords approximately contain 1000 Earth science terms. Some examples for controlled keywords are instruments, data centers, missions etc. The uncontrolled keywords consist of 20000 terms submitted by data providers for example climatology, remote sensing, marine, geology etc.

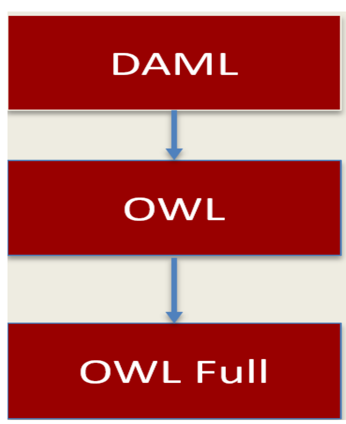

Fig 1: Language Evolution of SWEET

The evolution of SWEET is based on the identification of general SWEET classes, which serve as the superclass of the domain concepts. This requires an inter-relationship between domain concepts as well as identifying the dependent concepts such as physical properties, units including their relationship to external concepts. Thus, domain concepts are represented as standalone new classes or subclasses of current SWEET ontologies [4]. Then existing relationships are changed, and also we can introduce new relationships based on domain theories.

In taxonomy, properties are not passed on from parent to child so it's not suitable for current knowledge representation system. So GCMD keywords [10] were used as a guide in developing the ontologies.

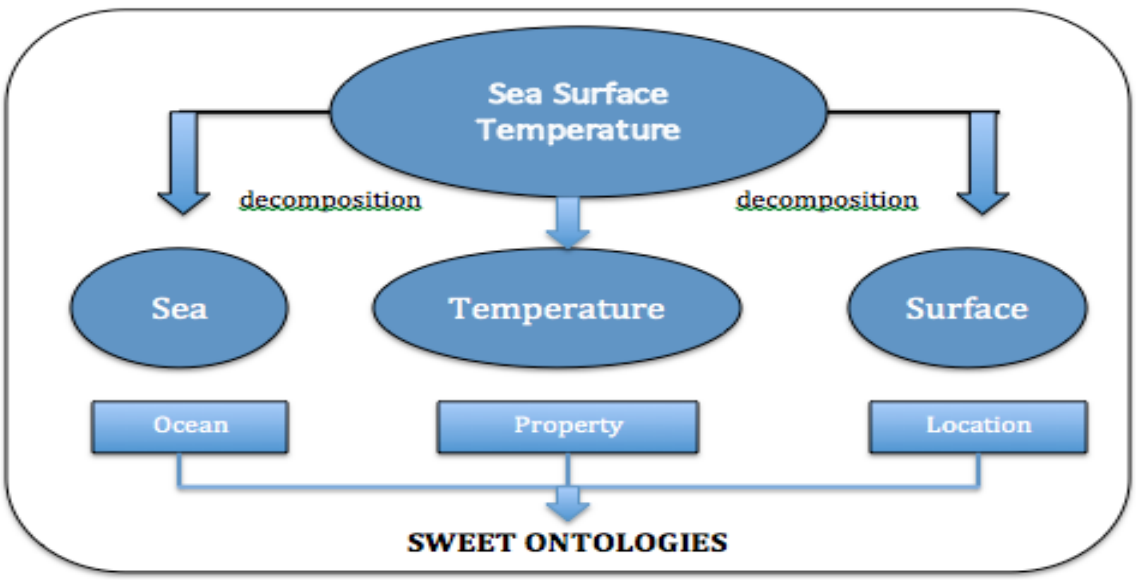

Fig 2: SWEET Ontologies

Decomposing science concepts in the above mentioned manner would help to achieve a scalable solution to science knowledge representation environment.

DEVELOPMENT OF SWEET

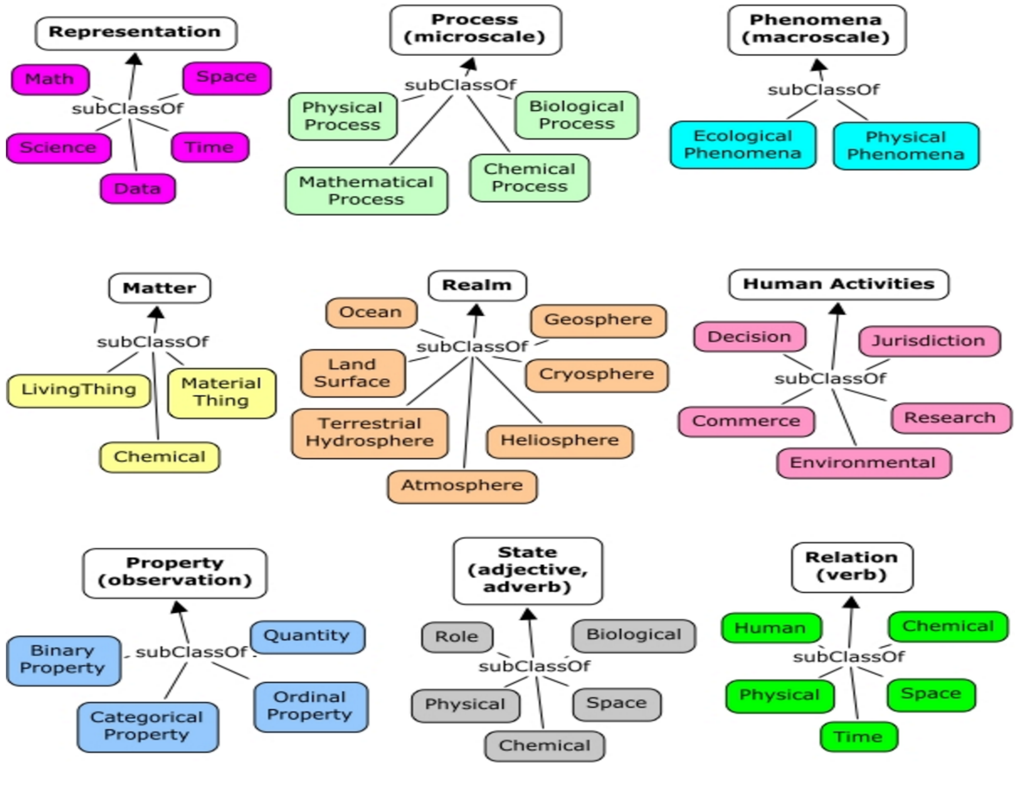

Fig 3. SWEET Overview

The Sweet ontologies [4] are developed using the collection of following ontologies:

- **Earth Realm**: It constitutes of the “spheres” of the Earth, which will be based upon the physical properties of the planet. Elements of this ontology include “atmosphere”, “ocean”, “solid earth” and associated sub realms such as ocean floor. Also the sub realms are distinguished from their parents based on property of altitude.
- **Living Element**: It basically includes plant and animal species. It was imported from biosphere taxonomy of GCMD.
- **Non-Living Element**: This includes mainly the non-living components of nature like particles, electromagnetic radiation and chemical components [4].
- **Physical Property**: It’s altogether independent ontology comprising of “temperature”, “pressure”, “Height” etc. used for interaction with other ontologies.

- **<u>Units</u>**: Units are defined using Unidata's UDUnits. There will be conversion factors occurring in the final ontology. Prefixed units such as km will be defined as a special of m with the corresponding conversion factor [4]
- **<u>Numerical Entity</u>**: Numerical extends include: interval, points, 0 and numerical relations include lessThan, max etc.
- **<u>Temporal Entity</u>**: TTime is a numerical scale with terminology specific to temporal domain. Extents include duration, season, century and duration includes after, before.
- **<u>Spatial Entity</u>**: space is a 3-D numerical scale with terminology specific to the spatial domain. Space ontology is developed in which the spatial extents and relations are special cases of numeric extents and relations. Extents include country, equator etc and relations include above, northOf etc.
- **<u>Phenomena</u>**: It's mainly used to define complex processes. It crosses bounds of other ontology elements. Example includes: earthquake, hurricane, volcano, space etc.
- **<u>Human Activities</u>**: It's included for representing impacts of environmental phenomena. It includes commerce, fisheries etc.

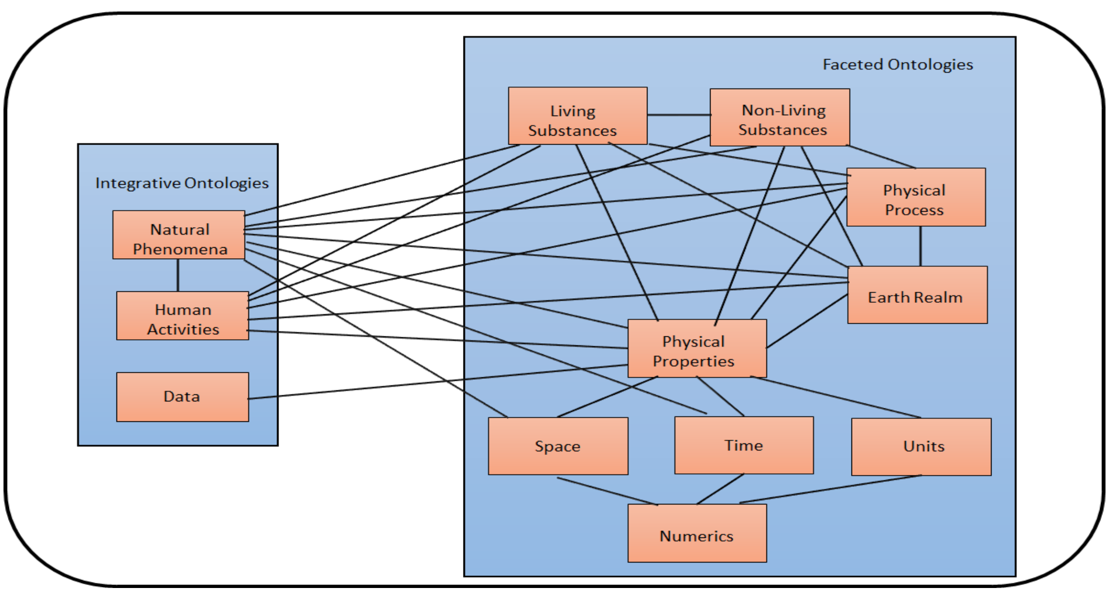

Fig 4: SWEET Ontology Levels

APPLICATIONS OF SWEET

SWEET was on improving search for NASA Earth science data resources but after being developed it was used to solve various problems in the field of Earth Science. SWEET has applications in various fields like:

1. **Data Mining**

   The target of a data-mining algorithm generally is a discovering phenomenon of interest. The definition of the phenomena often is hidden or incomplete, as there is no standard language for its expression. A complete description (including spatial/temporal resolution, model assumptions, etc.) is required to enable community comparisons and review. By defining a target concept in terms of ontology concepts, such a representation can be articulated using the full expressive capabilities of the SWEET ontology [2].

2. **Intelligent search tools**

   Web searches for Earth science data and information are commonly hindered by syntax mismatches between information user and information provider. If the user does not enter the ‘‘correct’’ search terms, either not enough or too many results are returned. The underlying cause is that the search tool is unable to extract meaning and semantic from terms on web resources. SWEET ontology is used to search terms that are synonymous, less specific, and more specific terms than those requested. The tool then outputs the union of these terms and presents the result Ultimately the search performance will be improved by creating additional relevant search terms based on the underlying semantics.

3. **Projects using SWEET:**

- **Geo-Informatics**: It is an informatics framework for the discovery of new knowledge through integration and analysis of earth-science data and applications [18].

- **<u>Humanitarian Aid for Refugees in Emergencies (HARE) ontology</u>**: To integrate humanitarian aid in emergency information from several databases, HARE ontology has been proposed. SWEET is one of the upper ontology used to design HARE [19].

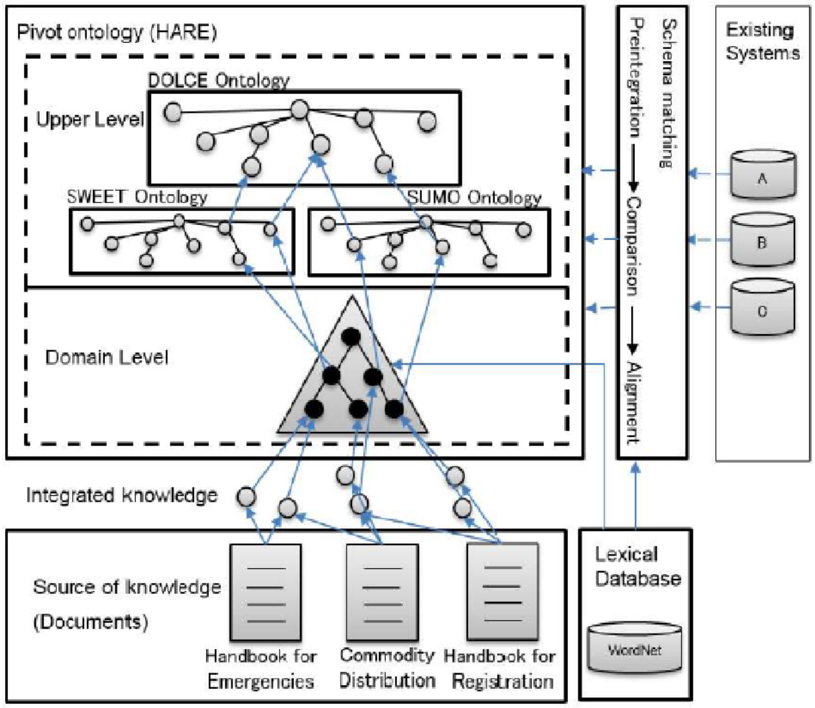

Fig 5: HARE Ontology

- **<u>GEON (Geosciences Network)</u>**: It started in 2002 as a project funded under the NSF Information Technology Research (ITR) program. The project began as a collaborative research project among a dozen PI institutions, to develop cyber infrastructure in support of data sharing and integration among the Earth Sciences community [9].
- **<u>MMI (Marine Metadata Initiative)</u>**: is a project aimed to support the exchange, integration and reuse of marine data [14].
- **<u>ESML (Earth Science Markup Language)</u>**: It is a specialized markup language for Earth science metadata based on XML [11].

- **NOESIS**: It uses domain ontologies to help the user scope the search query to ensure that the search results are both accurate and complete. It also serves as a resource aggregator. It categorizes the search results from different online resources such as education materials, publications, datasets and web search engines that might be of interest to the user [8].

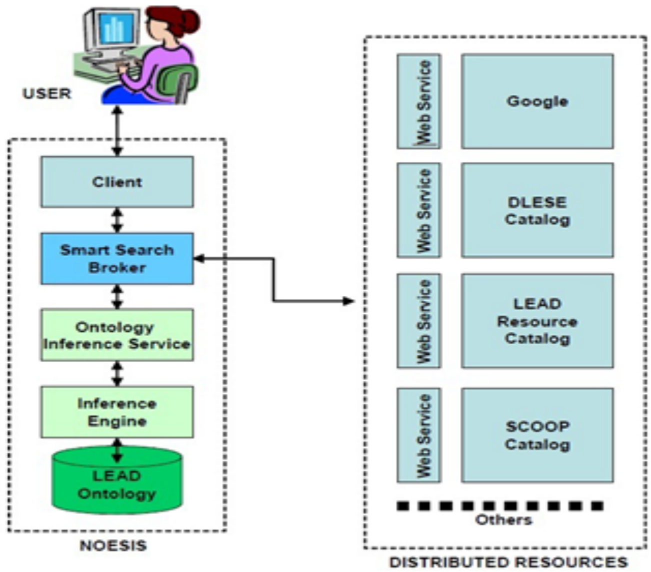

Fig 6: NOESIS Ontology

- **SESDI (Semantically Enabled Science Data Integration)**: is an ontology developed at National Center for Atmospheric Research (NCAR) to resolve interoperability issues among different Earth science sources [16].

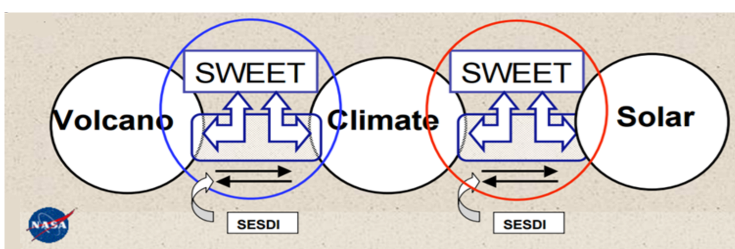

Fig 7: SESDI Ontology

- **GENESIS (Global Environmental & Earth Science Information System)**: is a NASA project that provides a database for GPS occultation observations from various spacecraft carrying NASA-supplied GPS receivers designed for atmospheric and ionosphere sounding. The flight database is augmented with GPS ground data and a variety of higher level derived products [13].

SUCCESS OF SWEET

The main factors behind the success of SWEET Ontology [24] are as follows:

1. **Common Platform** - SWEET provides a common semantic framework that enhances the understanding of dataset and science concepts to be understood by software tools. Example exchange of conceptual knowledge within between different disciplines like Earth Science Markup Language (ESML) and Earth Science Modeling Framework (ESMF) [20].
2. **Scalability** - The OWL files of the SWEET ontologies, available from are scalable, i.e., they are designed to be extended and adopted for specialized lower-level domains such as hydrogeology. SWEET ontologies are also application-independent and can be used across multiple platforms [20].
3. **Natural language-independence** - Structure should provide a representation of concepts, rather than of terms. Synonymous terms (e.g., marine, ocean, sea, oceanography, ocean science) can be indicated as such.
4. **Modularity and Knowledge Reusability** - SWEET is a modular domain ontology which prevents data redundancy, and at the same time enables optimum reusability of information since the components of the SWEET (e.g., classes and properties) are defined at the global level in a single OWL file, or in imported, reusable files. The modular architecture also ensures extensibility [1] and reusability, which are facilitated through XML’s namespace and import/include mechanisms.

5. **Orthogonality** - SWEET ontologies are a large collection of concepts (terms), they are divided into orthogonal dimensions or facets that include thousands of top-level concepts related to the Earth system. SWEET integrates many common concepts used across Earth Science disciplines (such as properties of the Earth) which provides reduced burden (and barrier to entry) on creators of specialized domain ontologies and increase incremental knowledge [20].
6. **Complex Concept Resolution** - SWEET Ontologies complex concepts can be built from simpler concepts that can be used in creating models. Building these models can help the enterprise assemble knowledge across different communities. These models can be used to explain and make predications. A model can relate primitive phenomena to one another and to more complex phenomena, which can help in providing explanations and predications about the real world.

EVALUATION OF SWEET

Some of the measures for evaluating the success of SWEET ontologies [5] are as follows:

1. **Functional measures**: These measures are used for the intended use of the SWEET ontology of the ontology and its components. The main goal of this kind of evaluation is to help Engineers or Project Managers choose the SWEET for a particular usage in a specific application.

Agreement	It is measured through the proportion of agreement that experts have with respect to the ontology elements.
User-satisfaction	It can be measured by dedicated polls, questionnaires or by means of provenance, popularity, and trust assessment.
Task:	It deals with measuring how fit an ontology is for some goals, preconditions etc.

Topic:	It deals with measuring an ontology according to its fitness to an existing knowledge repository

Table 1: SWEET Functional Measures

2. **Usability-related measures** [12]:

Metric	**Evaluation output**
User types using SWEET	Knowledge Engineer/ Project Manager Application User/ Ontology Developer
For what type of use was it conceived in first place?	Improving search for NASA Earth science data resources
How easy is it to extend SWEET?	Modular Design / Organized by Subject / Simple steps for extension
Cost of using the SWEET ontology	Free/ Open Source
SWEET Popularity	NASA/ The ESIP Federation/Taught Widely in Semantic Web Courses in Universities.

Table 2: SWEET Usability Measures

3. **Structural (content) measures**: These measures depend on the content represented in the SWEET ontology, its Knowledge coverage and popularity. Based on the fact that SWEET has a modular design we can conclude that the concepts grouped in the SWEET ontology are conceptually related for a particular domain or a sub-domain in order to achieve common goals .

Metric	**Evaluation output**
Number of classes	4233
Implementation Language	OWL
Development Methodology	Integrated top level ontology development
Methodology for extending SWEET	Incremental/Domain oriented way
DL expressivity	SHOIN(D)
Object property count	479
Data property count	42
Individual count	1851
Logical axiom count	10351
Direct popularity	188

Table 1: SWEET Structural Measures

ANALYSIS AND VISUALIZATION OF SWEET

There are several visualization tools available in order to analyze and study SWEET ontologies [1]. Two most useful tools are JPL interactive graphs and Protégé OntoGraf are explained here. JPL website provides the SWEET users with an interactive graph which makes term search and relationships study much convenient.

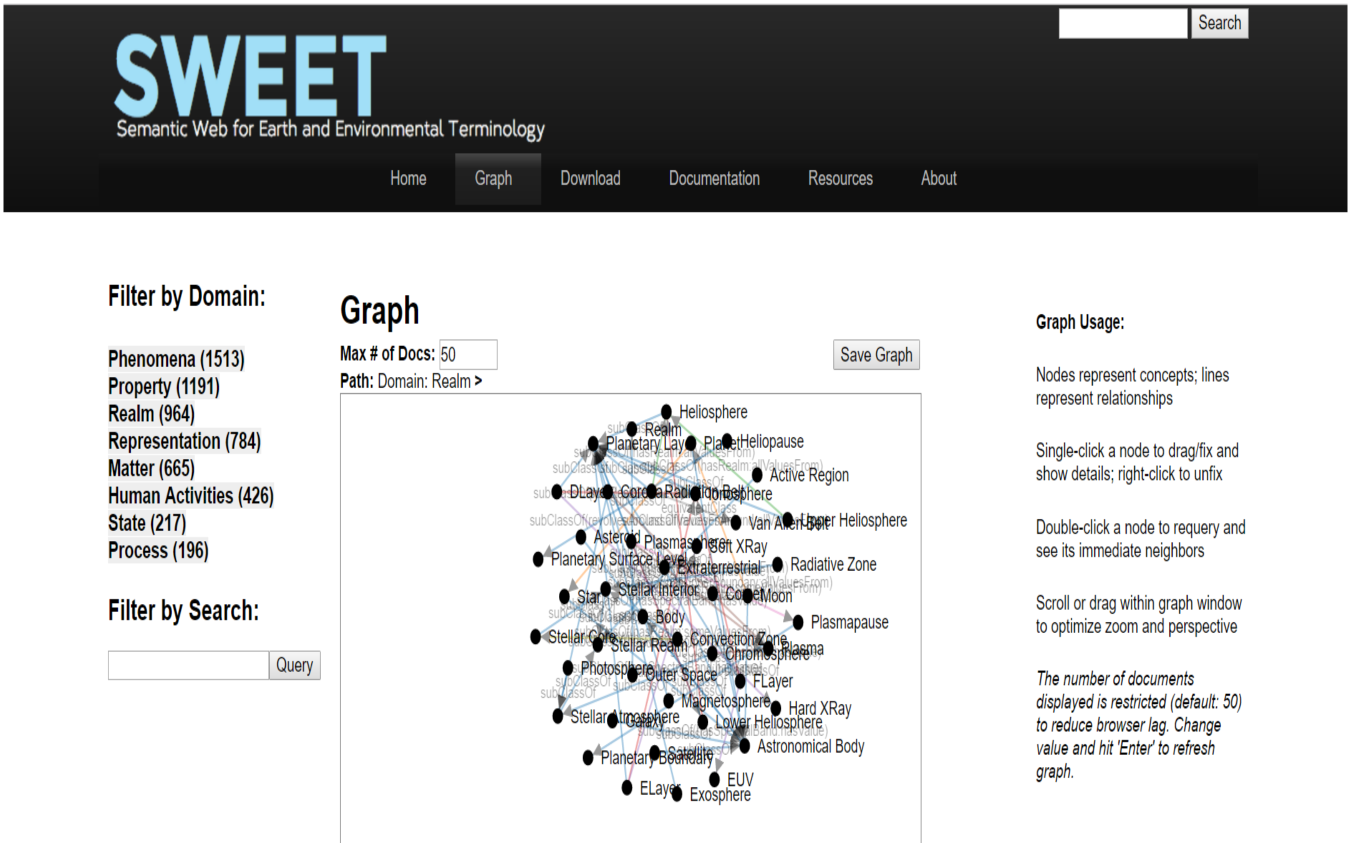

Fig 8: Interactive Ontologies Graph for SWEET ontologies

The graph consists of nodes that represent concepts, lines that represent relationships. Also, double-clicking a node will result in requery and presentation of its immediate neighbors.

In summary, these interactive graphs are a simple-to-use visualization tool, which enables the user to become familiar with SWEET modular structure [4].

Although JPL interactive graph is an appropriate tool for initial study of SWEET ontologies, other tools are needed for a more in-depth analysis of concepts and relationships. After investigation on different visualization tools, authors concluded that Protege OntoGraf is the most capable tool for this purpose. OntoGraf supports interactive navigation of the relationships in any OWL ontology like SWEET. Different layouts are supported for automatically organizing the structure of ontology. A number of relationships that are supported by OntoGraf are:

subclass, individual, domain/range object properties, and equivalence. Relationships and node types can be filtered to help create the desirable view for an improved understanding [15]. In other words, the relationship filters enable the user to hide or show different relationships in the graph based on the OWL description. Using OntoGraf Tooltips feature, further details about a class or individual could be presented.

In a nutshell, interactive graphs seem to be the appropriate visualization tool for initial study of SWEET ontology, while using Protege OntoGraf provides the user with more features to do a more in-depth study of concepts and individuals in SWEET ontologies.

EXTENSION OF SWEET

Following are the steps required to extend the SWEET ontology to make a domain specific ontology:

1. First, we need to download the SWEET ontology from [4] and save locally on our computer. Protégé [15] can be used to make further changes in the saved SWEET ontology saved locally before.
2. We understand the significant idea and concepts about the domain, which we need to formulate as ontology. This can be furthered by checking the appropriateness of the domain information and by referencing available resources. We then organize the terms as classes, properties and individuals. The classes describe the domain entities.
3. To clarify the difference between class, property and individuals consider this example. 'A Person whose name is 'Bob' hasHairColor: black''. In this example Person is a class, Bob is an individual, and hasHairColor is a property [20].
4. Form the relationships between all prevalent and new concepts through the class relationships such as owl: sub-ClassOf (e.g., Adult sub-ClassOf Person), owl:disjointWith (e.g., Adult disjointWith Child), and owl:equivalentClass.
5. After the domain specific terms are coined a thorough concept search across all the SWEET ontologies can be done. Following the search results we coin new terms under available terms in the SWEET ontologies, or re-coin the available terms in order to help

the make the new concepts more significant. The classes, properties, and individuals of pertinent parts of the ontology are visited and the required changes are applied.

6. The ontology can now be edited with editors like Protégé [15] since all the required changes have been figured out from the above steps. The domain concepts are added as new classes in the OWL files, or as subclasses of already available SWEET ontology classes. After the introduction of new classes, the relationships between concepts are maintained. Conditional and logical expressions can also be checked or added in this step. It is preferred to add individuals after the classes and properties have been successfully introduced.
7. It is a must that the new ontology does not perturb the orthogonal structure of SWEET ontologies. That is to say, if the introduction a new concept disturbs the upper-level SWEET design the new concept should be checked against inconsistency. A good practice while adding the new terms is to make it reusable by other domains which would try to extend this new ontology.
8. Validate the new ontology using OWL validators or Protégé. In post validation check, we may add individuals for domain specific constraints. After successful testing and validation of the new ontology it can be published.

Also the extension of SWEET for extending the domain ontologies can be divided in two categories [1]

1. The first group is where SWEET provides a common language for various earth science disciplines, so inconsistencies for terms and definitions between these communities are minimized.
2. Second group of applications are those where SWEET functions as a platform for more specialized domain ontologies.

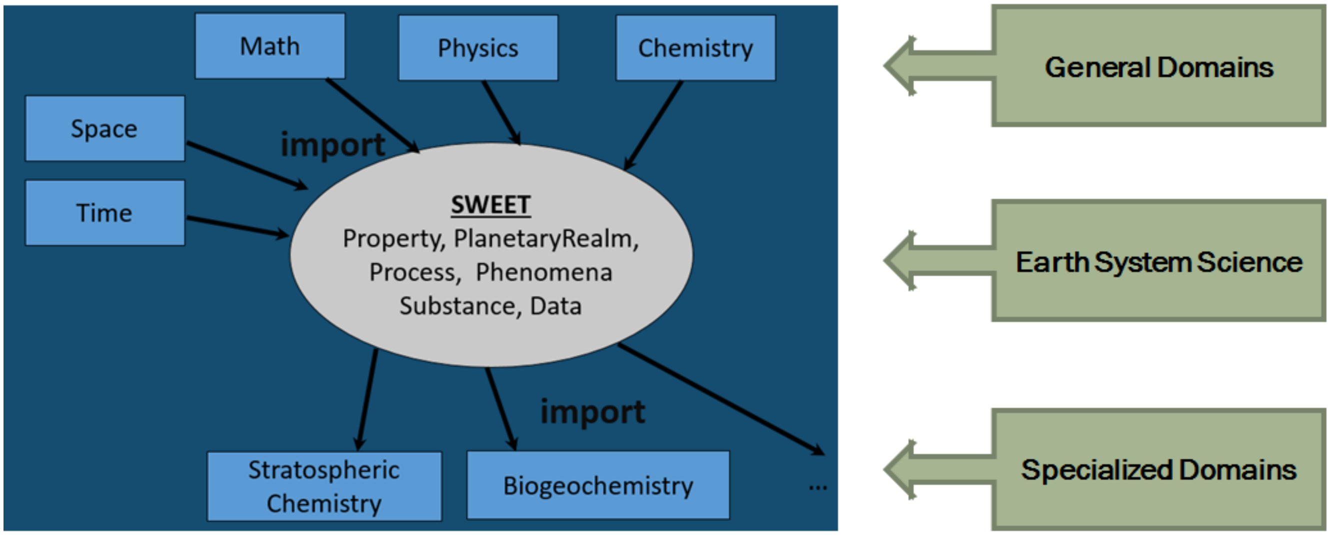

Fig 9: Extensions of SWEET

ACCOMPLISHMENTS WITH SWEET

There have been various achievements made with the SWEET ontologies and it has been evolving greatly. The accomplishments by SWEET can be attributed to shared ontologies, common vocabulary and domain semantic vocabulary that has been provided by the SWEET ontologies.

Semantic ontologies are required by almost all the environmental systems and SWEET is very essential to achieve interoperability among various types of datasets, for example SWEET is used for heterogeneous data sets where the structure is unpredictable. It provides a conceptual schema for various types of data sets and a content-based data discovery and data retrieval. Other accomplishments with SWEET ontology are its contributions related environmental models. It provides semantic descriptions for a range of environmental models.

Since SWEET ontologies are written in the OWL ontology language and are publicly available, it enables the users to use these standard languages. Also, it allows the users to reuse the languages for multiple application and this gives a great flexibility to the users and provides a stronger basis for reasoning power.

PROBLEMS ENCOUNTERED

Although SWEET is has many advantages and helpful in many ways, it has some issues involved. Firstly, OWL has a variety of constructors available and the some features of the ontology has been omitted and that results in having small modules. So, even for small and simple segments of the OWL DL, extracting such the modules becomes mathematically more sophisticated than others. Therefore, due to the minimal modules it curbs the real-world application of the ontology. Although SWEET ontology uses has many issues involved with it, there has been great improvements in these modules since their initial version of the SWEET.

Another problem with using this ontology is the complexity and disparate amount of knowledge available in SWEET, which results in handling large volume of data which is harder to control and extract from. Moreover, there have been limitations pertaining to the data interoperability due to different schemas, formats, and semantics [10]. In addition to that, correct and fast data discovery and data integration in SWEET has been a challenge, which requests domain semantics.

CLASSIFICATION OF PROBLEMS WITH SWEET

The issues with SWEET ontology can be categorized into three main pillars: 1. Numerical aspects, 2. Storage, 3. Ontology-aided search [17]. It is important to understand why each of these categories are considered as issues and how they can be addressed.

Firstly, in terms of numerical aspect, although OWL like other RDF languages is very powerful when it comes to handling numerical operations and relations, improvisations are possible. Despite OWL supporting various numerical types like float, unsigned integer etc. it has minimal operations and relations on these numbers. This is one of the critical issues as many of the scientific relations on these numbers are defined by numbers [17]. For example, “greater” is special derivation of the numerical relation greater than. The Numeric ontology provides extensions that can be used to define scientific concepts and spatial and temporal ontology concepts as well.

Secondly, the concern is with the storage of data. OWL is appropriate for exchanging data and model, whereas when it comes to large amounts of data it is less practical to store and query ontologies. There is a great need for the current storage system functionality to be improved such that it can deal with the robust ontologies. Also, the data integration and indexing can take place efficiently. There are many temporary solutions proposed for this issue such as DBMS software usage [1]. However, an effective way of addressing this issue needs to be provided. As an example, a search tool that can interpret RDF or OWL ontologies and locate resources. Here, the exact keyword match in the contents is not necessary.

Lastly, ontology-aided search needs to be further improved. There are existing tools using Perl language that finds synonymous and more specific terms in SWEET. The search results consist of clusters with parent and child matches that are present. The capabilities of these search tools can be extended to be applied to larger amount of data and return more accurate information. The output of such operations can include more general terms that is requested that can be further studied.

CONCLUSION AND FUTURE WORK

We successfully explored the different dimensions of SWEET and also gathered some evaluation metrics. We also found out the generic steps involved in extending SWEET for any other earth science related domain specific ontology. Also, we saw that SWEET ontology will help in increasing inter-agent communication in most cases of information exchange: information retrieval and extraction, semantic web services, etc. Depending on the requirements of the user , SWEET can be used either in a light version, for computationally intensive applications, or as an off-the-shelf fully axiomatized theory, to be consulted as a guiding source for more random meaning negotiation purposes.

We also inferred that SWEET is widely used at NASA and within the Earth Science Realm. It's also pretty regularly taught in Semantic Web Courses at Universities throughout the country (and abroad). It's also been adopted by the ESIP (Earth Science Information Partner) Federation, various multi-national conglomerates all focused on Earth Science Research which all tell us about the success of SWEET and it various applications in real world [15].

Our research focused on figuring out evaluation metrics for SWEET that could provide us with statistically significant information like richness, width, depth, and inheritance of an ontology schema design - specific to ontologies that can be represented as graphs- which tell us about the appropriateness and success of SWEET ontology. Future work can be to focus on enhancing the evaluation metrics techniques focusing on SWEET ontology's structural and design schema.

Also relevant to SWEET modification another future direction for research can be designing a structural approach for modifying the complex high-level SWEET ontology.

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SCREENSHOTS FROM OUR PROJECT

Dendogram Representation for a section of SWEET ontology

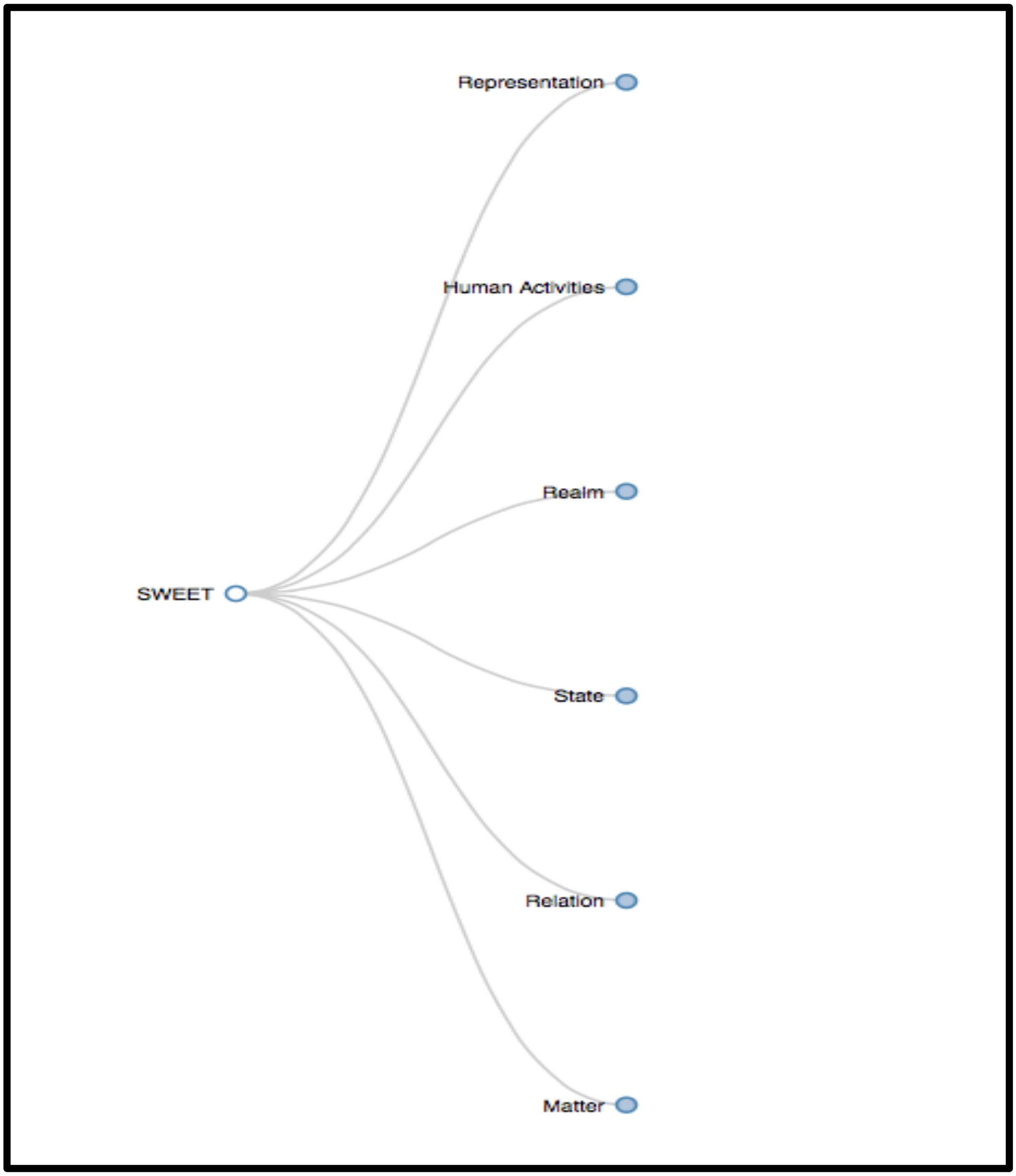

Figure 1: SWEET Ontology Representation using Dendogram

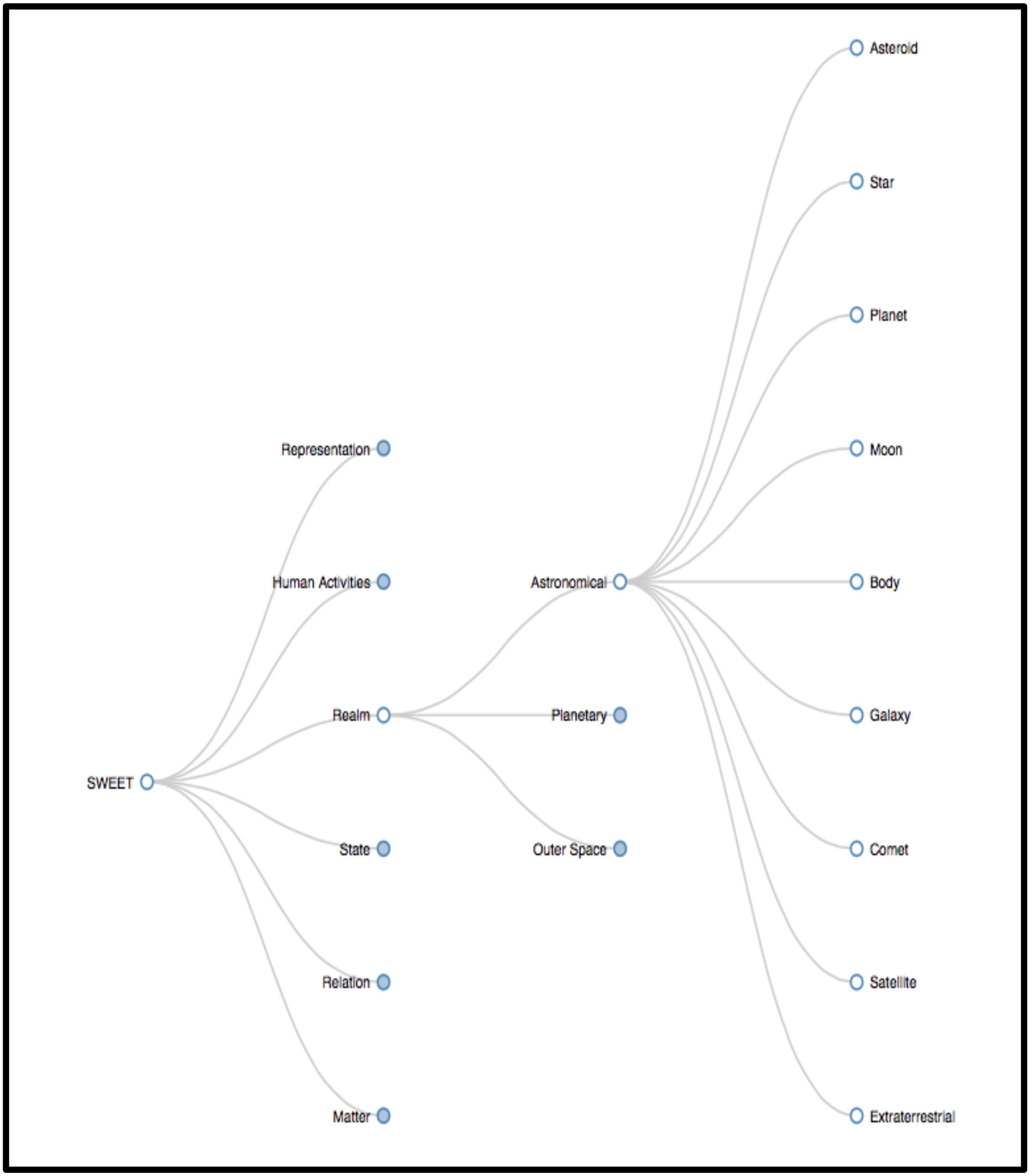

Figure 2: Expansion of Realm Ontology

sweet_data.json

```json
{"name":"SWEET",
	"children":[
		{"name":"Representation",
			"children":[{"name":"Math","size":"2122"},
					{"name":"Space","size":"2122"},
					{"name":"Science","size":"2122"},
					{"name":"Data","size":"2122"},
					{"name":"Time","size":"2122"}

				]
		},
		{"name":"Human Activities",
			"children":[{"name":"Decision","size":"2122"},
					{"name":"Commerce","size":"2122"},
					{"name":"Jurisdiction","size":"2122"},
					{"name":"Research","size":"2122"},
					{"name":"Environmental","size":"2122"}

				]
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						{"name":"Exosphere","size":"2122"},
						{"name":"Magnetospere","size":"2122"}

						]},
				{"name":"Outer Space","children":[{"name":"Realm","size":"2122"}

						]}]},
```

Figure 3: JSON Dataset used to plot D3 visualization