Data visualization in the Semantic Web

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The widespread propagation of networked computers in Earth and space science and especially the representation of scientific data in formats that can be shared, analyzed and visualized has given rise to exciting new opportunities for exploration and discovery. *data* are the representation of some facts. We can see data of various subjects, types and dimensions, such as a geologic map of New York State, records of sulfur dioxide concentration in the plume of Turrialba Volcano, Costa Rica, and the global mean sea level time series derived from radar altimeter records of the TOPEX and Jason satellite series. A unique feature of most data in Earth and space science is that they are georeferenced, which means they contain positional values below, on, and/or above the surface of the Earth. *Information* is the meaning of data as interpreted by human beings, such as, a geologist may discover some initial clues for shale gas exploration by using a geologic map, a volcanologist may detect a few abnormal sulfur dioxide concentration values in the plume of a volcano, and a climatologist may find that the global mean sea level has been rising in the past twenty years. People use their knowledge to discover information from data. The *knowledge* is their expertise or familiarity with one or more subjects under working. The discovery process of data to information in turn may make new contribution to people's knowledge.

People not only possess knowledge implicitly in their brains, they also encode some of their knowledge in models, algorithms and programs that can be operated or run by computers and can be reused by other people. Data visualization plays an increasingly important role in the interactions between human and computer, and the Semantic Web provides a broader space for people to share both data and knowledge. This chapter will introduce research topics and applications associated with data visualization in the Semantic Web, with a focus on subjects in the Earth and space science. The text is organized as two parts: the first part is about concepts and theories and the second is about technologies and applications.

1 Concepts and theories
1.1 Data visualization and geovisualization
Visualization literally means to form a mental picture or vision of something not present to the sight, or in simple words, to make something visible. The meaning has two levels: first to make something to be seen and second to make it apparent. Daily experience tells us that graphics are easier to read and understand than words and numbers. Readers may do a small experiment by

reading the table and diagram in Figure 1. The differentiation in reading graphics and texts/numbers has been explained by studies on visual object perceptions [1], which show that the human brain deciphers image elements simultaneously, and decodes language in a linear and sequential manner that takes more time to process.
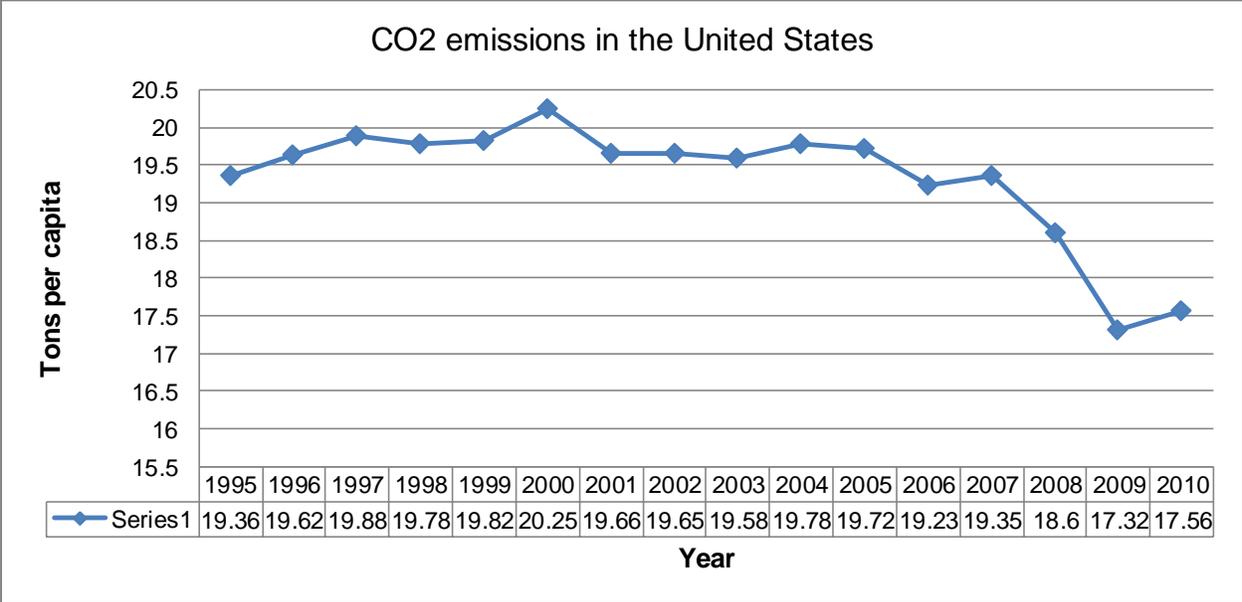

Figure 1. A simple example of data visualization: CO2 emissions (metric tons per capita) in the United States. Source of data: The World Bank: United States: http://data.worldbank.org/country/united-states

Visualization helps people understand data's meaning from the visual representations. *Data visualization* is the study of creating visual representations of data. In practice, especially for quantitative data, data visualization means to visually display measured quantities by "combined use of points, lines, a coordinate system, numbers, symbols, words, shading, and color" [2]. We can understand the functionality of data visualization by putting it in the context of data processing and information gaining. As we discussed in above words, data are representations of facts and information is the meaning worked out from data. The procedure from data to information is analogous to storytelling, and data visualization is one of the mostly used methods in that procedure [3, 4]. For example, the diagram in Figure 1 shows that the CO_2 emission per capita in the United States has a trend of increasing between 1995 and 2000, and a trend of decreasing between 2000 and 2010. The year of 2000 presents a highest value of CO_2 emission per capita during the whole period of 1995-2010. A further investigation on the total population in the United States, governmental policies, new technological and management efforts for reducing CO_2 emission, etc. may show more background stories about the information revealed by the diagram.

A unique feature of most Earth and space science data is that they are georeferenced. Yet, here we want to address that the spatial features of Earth and space science data cover those below, on and above the surface of the Earth, and for geographical data their spatial features are primarily on the surface of the Earth. In the domain of cartography and geographical information science, there is a major research topic called *geovisualization*, which is "the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions and construct knowledge" [5]. The concept of geovisualization was derived from cartography so we can often see maps used as the media for geovisualization, such as the example in Figure 2. Furthermore, geovisualization addresses exploration and interaction [5, 6], it requires interactive and dynamic map applications to be developed and reused beyond the traditional static maps [7, 8].
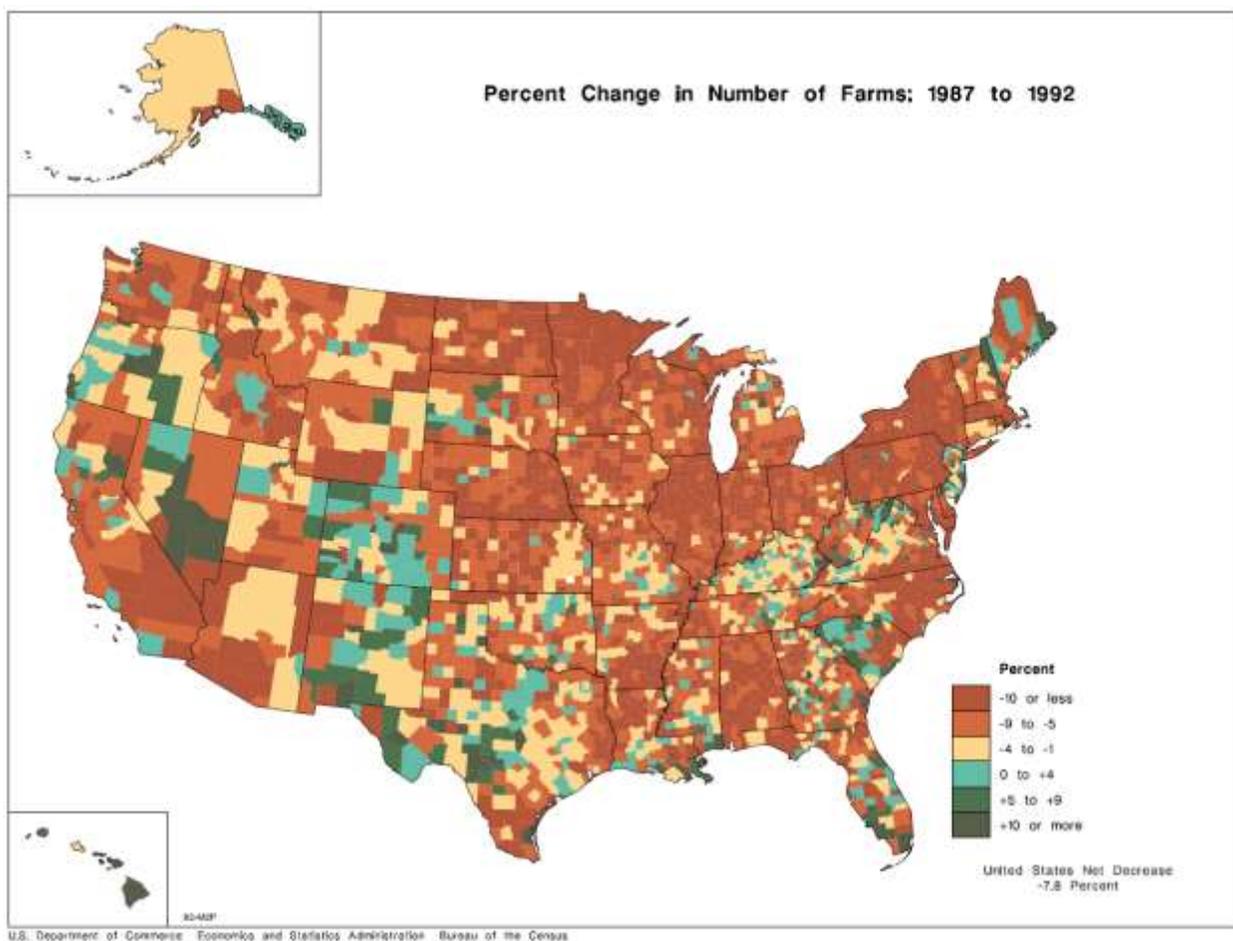

Figure 2. A sample of geovisualization: percent change in number of farms in the United States during the period 1987 to 1992. Source of image: United States Census Bureau: https://www.census.gov/geo/maps-data/maps/pdfs/thematic/ag_003.pdf

Through primarily facing geographical data, methods and technologies of geovisualization are also useful for Earth and space science data visualization and have already been applied in

practices. Figure 3 shows an example of Earth science data visualization in the GPlates program [9]. It is a three dimensional animation for spatial features in a subsurface environment. Users can interact with the visualized data through the program window. The interactive, flexible, expressive and interoperable features of data and visualization in GPlates are very similar to the specified features of exploration and interaction in geovisualization.
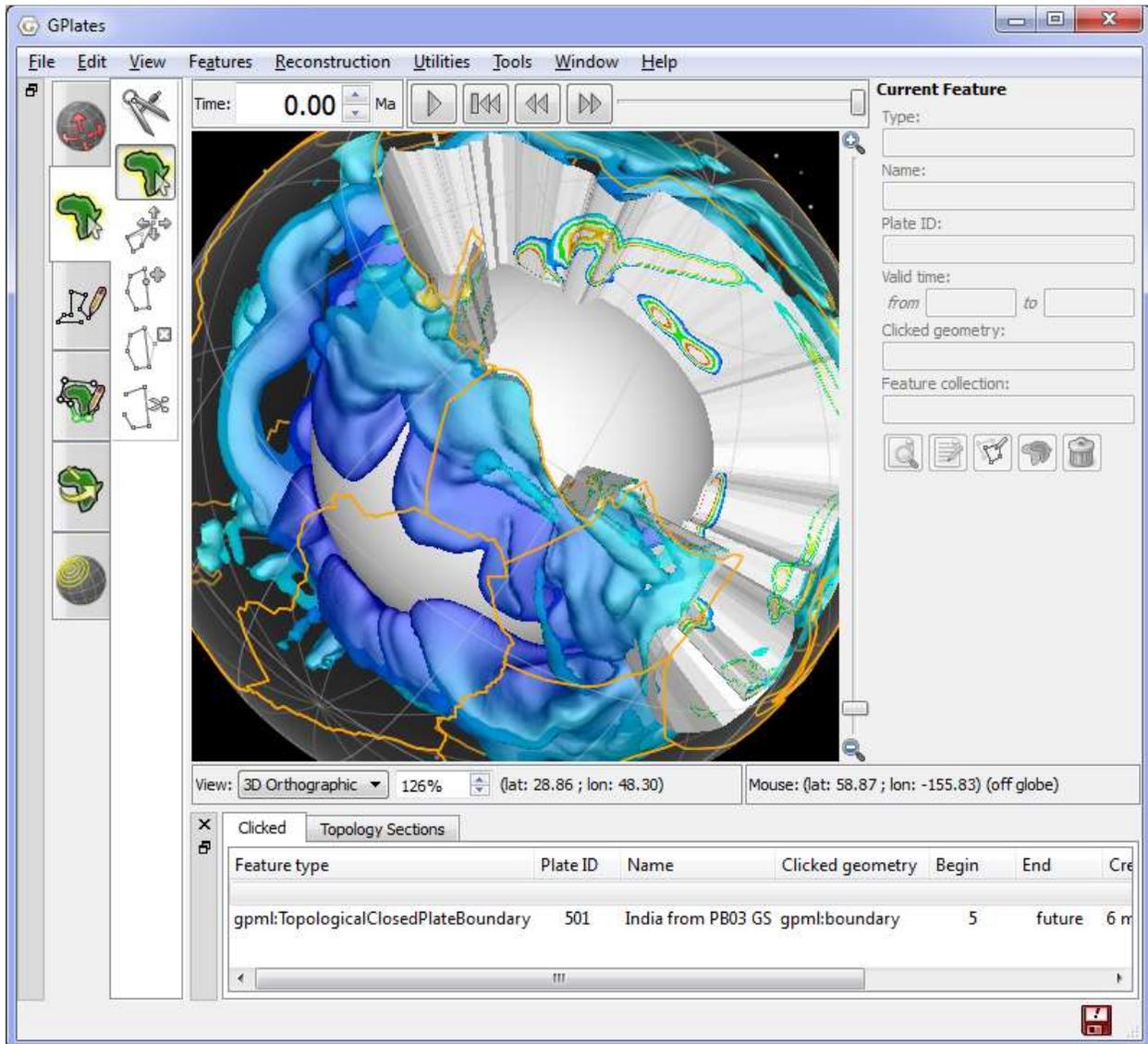

Figure 3. An example of Earth science data visualization: mantle temperature isosurface with semi-transparent deviation window in the GPlates program (version 1.3.0). Source of image: GPlates:
http://www.gplates.org/screenshots/1.3.0/GPlates_MantleTemperature_isosurface_walls_deviation.png

1.2 Semantic Web and Linked Data

The Semantic Web provides a broader space for sharing data and conducting data visualization. *Semantic Web* is an extension of the current World Wide Web (the Web). The Semantic Web is a "Web of Data" in addition to the classic "Web of Documents" [10]. To enhance the use of the "Web of Data", semantic technologies leverage extant ontologies that define important concepts and relationships in domains of relevance, such as the SWEET ontology [11] in Earth and space science. By giving well-defined structure and meaning to document and data in the Web, Semantic Web better enables computers to read the data and work in cooperation with people. As a result, documents and data can be linked together to provide clues to the computer, such as whether two datasets share a common subject, a professional term in one document represents a sub-concept of a term in another document, one dataset was derived from another dataset, or a tool is recommended for processing a dataset based on the tool description, etc. Semantic Web uses Web languages based on the Resource Description Framework (RDF) [12] to achieve those features, which not only improves the interoperability between datasets and communication between people, but also provides new mechanisms that allow people and machines work more interactively [13].

A recent effort underpinning the evolution of Semantic Web is the *Linked Data*, which promotes the best practices for publishing and connecting structured data in the Semantic Web [14]. By using semantic technologies, people are able to identify, categorize, annotate and link data from various domains, such as geology, oceanography, climatology and biology, as well as records at detailed levels, such as people, organizations, publications, and activities, etc. Tim Berners-Lee [15] describes a star rating system for Linked Open Data, which includes five stages from one star to five stars: (1) on the Web and with an open license, (2) a machine-readable data structure, (3) a non-proprietary format, (4) use open standards from W3C (RDF and SPARQL) to identify things, and (5) link data to other people's data. Those guidelines have been adopted by an increasing number of data providers in their data sharing practices, creating a global data space in the Web [16].

For Earth and space science researchers, Semantic Web and Linked Data provide a new environment for retrieving datasets, conducting scientific studies and communicating research findings. Data visualization, as a general method in scientific works, benefits from the global data space enabled by Semantic Web and Linked Data. Especially, for individual or collaborating researchers who use datasets from multiple sources, the heterogeneities among data models, vocabularies and access methods are being diminished by the efforts of Linked Data. The improved data interoperability allows applications, including data visualization, to operate on top of various data sources via standardized access mechanisms [16]. Moreover, as science is driven by data, the increasing accessibility to data of interest through the Linked Data will help researchers find interesting patterns, generate hypotheses and explore new research topics. Data visualization's role of promoting exploration and interaction will contribute to that procedure. We will discuss this in more detail in the next section.

1.3 Data visualization in a data life cycle

In the above two sections we introduced a number of concepts relevant to data visualization and Semantic Web. Especially, we addressed the role of data visualization in the procedure from data to information and the innovation of Linked Data for creating a global data space. The procedure from data to information, in our understanding, is equivalent to the step of data analysis in a *data life cycle*, which represents the whole process of data management and use (Figure 4). The data life cycle is a general model and is applicable to various environments, such as a relational database or the Linked Data. Concept articulation and definition can be, but is not always, a primary part in the first step of the data life cycle. For a relational database, the concept study is the construction of conceptual models, logical models and physical models, and for a data center in the Linked Data, the concept study is building ontologies and vocabularies. The life cycle is open-ended, as data are continually repurposed, creating new data products that may be processed, distributed, discovered, analyzed and archived.
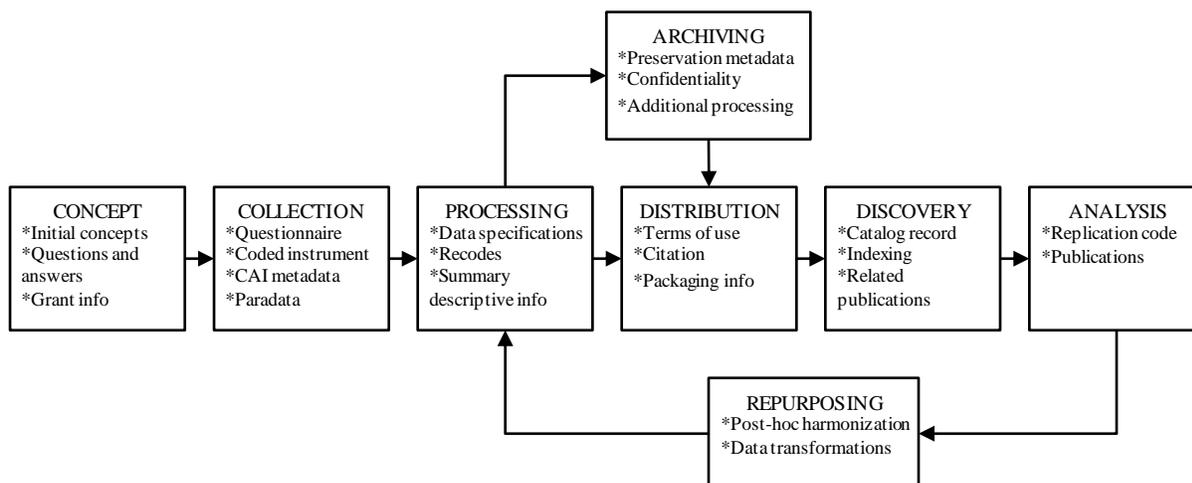

Figure 4. Data life cycle [17].

Data visualization can provide support to different steps in the data life cycle [18]. For example, concept maps are a kind of graphical tools for organizing and representing knowledge [19]. Recently they have been increasingly used in works building ontologies and vocabularies for the Semantic Web (the first step in the data life cycle). Figure 5 shows a part of the concept map we recently created for the Ontology of the Global Change Information System (GCIS Ontology, version 1.2) [20]. In that diagram the report is a subclass of publication, and there are a number of components in a report, such as chapter, figure, table, image, array, and the relationships among those concepts. Also shown in Figure 5 are concepts such as committee, group, agent and their relationships with the report or publication. MacEachren et al. [21] developed visualized tools that can capture and explore concepts underlying collaborative science activities. Their visualization approach links geovisualization methods with concept mapping tools and the work is conducted in a Web-based collaborative environment. Our work with the GCIS Ontology

concept map [20] and the work of MacEachren et al. [21] both show that the visualization approach of concept maps greatly improve the collaboration between domain experts and computer scientists.
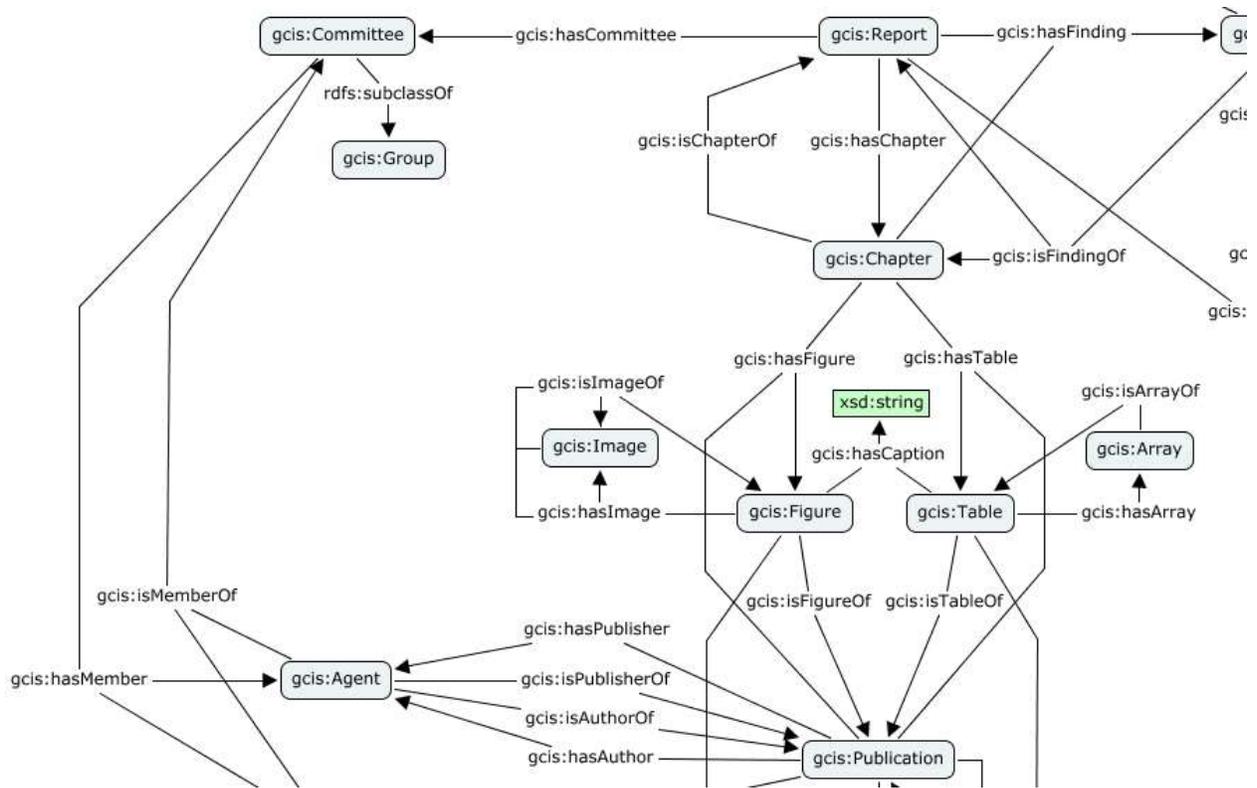

Figure 5. A part of the GCIS Ontology (version 1.2) concept map. Boxes in the figure are classes or data types, and arrows with annotation are properties describing relationships. Source of image: http://cmapspublic3.ihmc.us/rid=1MCJMLST0-1G0CSWH-2YH4/GCIS_Ontology_v1_2.cmap

Visualization has also been used to support data discovery. For example, in the International Open Government Dataset Catalog (IOGDC) developed by the Tetherless World Constellation at Rensselaer Polytechnic Institute, a scalable, Web-based faceted browsing and search interface was built to help users find datasets of interest [22]. Faceted classification allows the assignment of a dataset to multiple taxonomies, that is, sets of attributes or facets, so datasets can be classified and ordered in different ways. Figure 6 shows the user interface of a demo for faceted data browsing and search in IOGDC. The visualized user interface allows the data center to hide the implementation of semantic technologies on server side from the front end. It uses the S2S faceted browser [23] and Cascading Style Sheets (CSS) to control the layout of facets and the arrangement of contents in each facet.

Figure 6. A demo in IOGDC for faceted browsing and search of data. Source of image:
http://logd.tw.rpi.edu/demo/international_dataset_catalog_search

In the context of Semantic Web, ontologies and vocabularies built in the earlier stage of a data life cycle can be incorporated with data visualization and provide efficient support to the data analysis stage. Kemp [24] studied the ontologies in the geographical information science community and discussed that the ontologies can facilitate interoperable access to separate data sources by mapping the ontological terms to individual database schemas. In this way the common ontologies underlying various data sources enable users to specify parameters and drive visualizations over the data space.

1.4 A vision on the future: Linked Science

With increasingly deployment of new platforms, instruments, sensors and computer programs in an emerging cyberinfrastructure, Earth and space science data are growing in volume, variety and complexity. Semantic Web and Linked Data provide a global data space for scientific data stakeholders to reorganize data legacy, design and develop new-generation data infrastructure, coordinate with each other and to share data in the Web. In the meantime, scientists are becoming more dependent on the Web for retrieving and sharing research data, collaborating on research and communicating findings. A major challenge in current scientific facilities is that they are developed independently and thus are separated to each other. It is hard for a journal article reader to access the data and software program used in that article, not to mention the instrument used for collecting the data. Brodlie et al. [25] discussed linking people, data and resources for distributed geovisualization works. We can extend their view to a broader vision of *Linked Science*, by leveraging the functionalities of identifying, categorizing, annotating, and

linking enabled by the Semantic Web. In the context of Linked Science, not only datasets, but various agents, entities and activities will be identified, annotated and linked, including researchers, organizations, samples, datasets, methods, instruments, computer programs, publications, projects, workshops, conferences, research subjects, etc.

In such a context of Linked Science, data visualization's role will be similar to what it works in a data life cycle. For example, in our recent work with the Deep Carbon Observatory – Data Science [26], we adapted and assembled several platforms to develop an interdisciplinary network platform for the Deep Carbon Observatory community [27], which bears some features of the above-mentioned Linked Science. Figure 7 illustrates one of the visualization functions in the developed platform. The figure is about the disciplinary distribution of the publications. What is not shown in the figure is that each publication has a unique identifier and detailed annotation, and the publications are linked to journals, books or conferences.
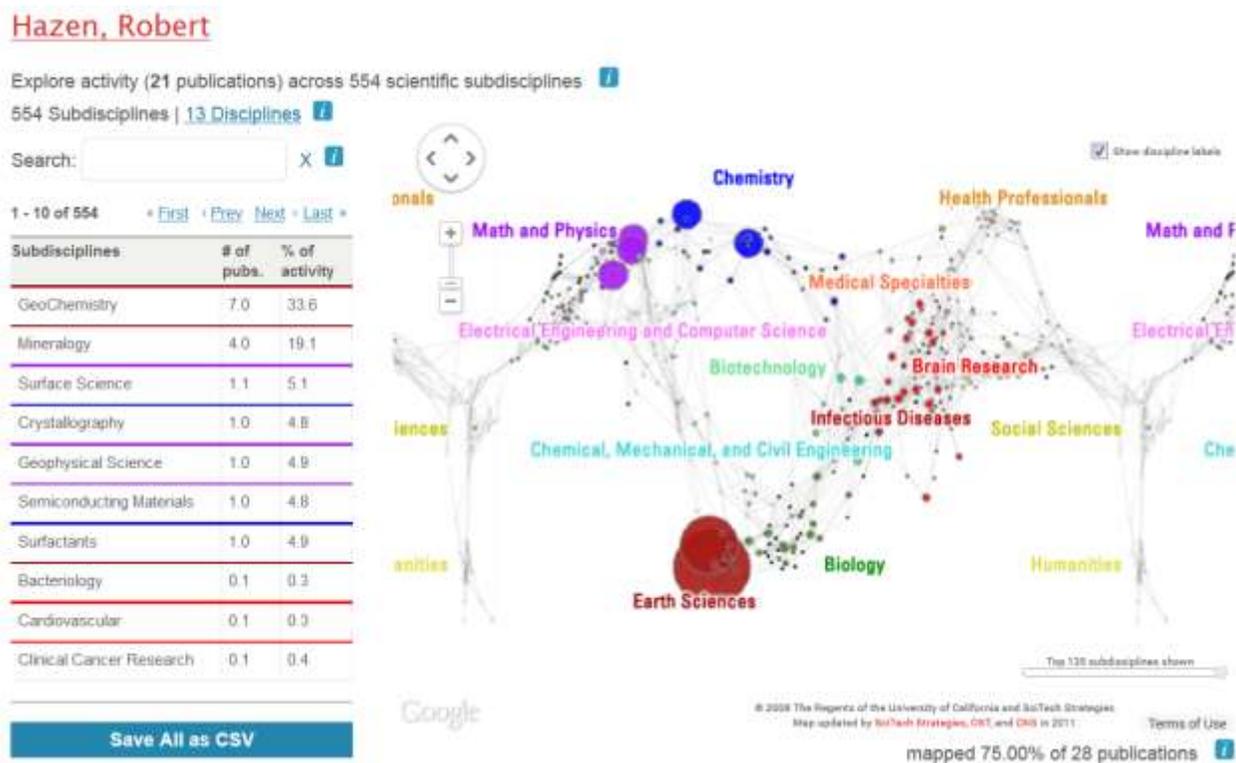

Figure 7. An visualization example showing disciplinary distribution of a researcher's publication. Here we collected information of 28 publications of Dr. Robert Hazen and encoded them into RDF format.

2 Technologies and applications
2.1 Web-based data visualization
Earth and space science researchers use various computer programs and programming languages in their daily work. Most programs and languages have data visualization modules, and some

visualization functions are specifically designed for georeferenced data. There are both proprietary and open-source software available for use, such as MATLAB® and R for numerical analysis, ArcGIS® and QGIS for geospatial analysis, ERDAS® and ILWIS for remote sensing image processing, Google Maps® and OpenStreetMap for online map browsing, GOCAD® and GPlates for subsurface modeling, and Google Earth® and NASA World Wind for the virtual globe. Yet, here we want to focus on languages, programs and libraries that face the Web or provide interfaces to communicate with the Web. Especially, we want to address the feature of open-source because for data analysis and visualization in the Web we are able to present not only the results but also the methods and the datasets used, and the Semantic Web provides a space to identify, categorize and annotate all those components, and to link and present them.

(1) General-purpose data visualization libraries
D3.js [28] is a JavaScript library for manipulating documents based on data. The name D3 comes from the abbreviation of Data-Driven Documents. D3 can bind arbitrary data to a Document Object Model (DOM), and then apply data-driven transformations to the document. D3 can be used to created many feature online data visualizations. Readers can refer to its website [28] for tutorials and examples. D3 also includes functionality for visualizing geospatial data. For example, Mike Bostock [29] and Jason Davis [30] developed visualizations illustrating the auto transition among a list of map projections (Figure 8). Other libraries enabling online data visualization include Processing.js [31], Dygraphs [32], Paper.js [33], jqPlot [34], Google Charts [35], and more.
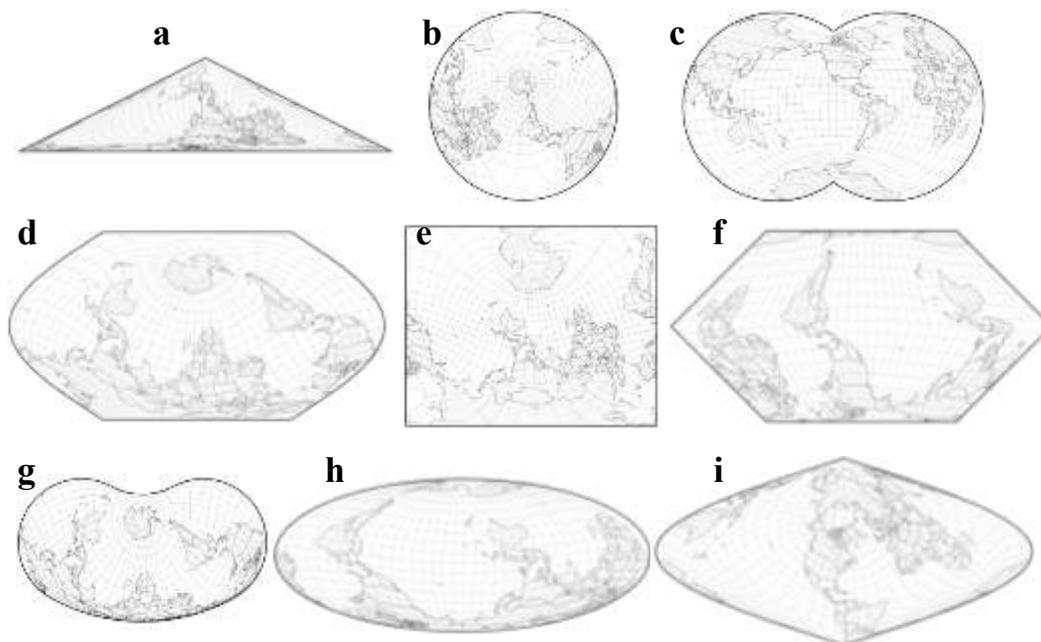

Figure 8. A number of map projections enabled in Jason Davis's visualization work with D3. (a) Collignon, (b) Van der Grinten II, (c) Van der Grinten IV, (d) Eckert V, (e) Mercator, (f) Eckert II, (g) Hill, (h) Bromley, and (i) Sinusoidal. Source of data: [30].

(2) Numerical analysis and visualization tools

A widely used open-source tool in numerical analysis and data visualization is the R environment [36]. R provides various statistical and graphical techniques, and is still extending with contributions from a big community. There are a number of library packages in R that handle and process georeferenced data, such as the sp [37] and the gstat [38]. sp provides classes and methods for two- and three-dimensional spatial data, and gstat is for spatial and spatio-temporal geostatistical modeling, prediction and simulation. David Rossiter developed well-organized materials with the R environment for a geostatistical course, with fundamental to higher level topics [39]. Recently, Markus Gesmann et al. developed the googleVis [40] package which establishes an interface between R and the Google Charts API. It allows users to create interactive charts in a web page based on R data frames. Python [41] is a general purpose language and it also covers numerical analysis functionalities. The IPython [42] provides a web browser-based notebook with support for codes, texts, mathematical formulas, inline plots and other media, including interactive data visualization.

(3) Libraries for developing interactive maps

Web-based mapping services such as Google Maps®, Bing Maps® and OpenStreetMap already present layers of rich information. Interesting mash-ups can be built by overlaying other data over them and developing interactive functiones. Libraries such as OpenLayers [43], Leaflet [44] and Google Maps API [45] make it possible to develop such mash-ups. A recent example is the OnTheMap for Emergency Management project enabled by the U.S. Census Bureau [46]. It provides an interactive map with data about current natural hazard and emergency related events, such as hurricanes, storms, wildfires, folds, snow and freezing rains. Figure 9 shows a screen shot of this project on April 05, 2014.
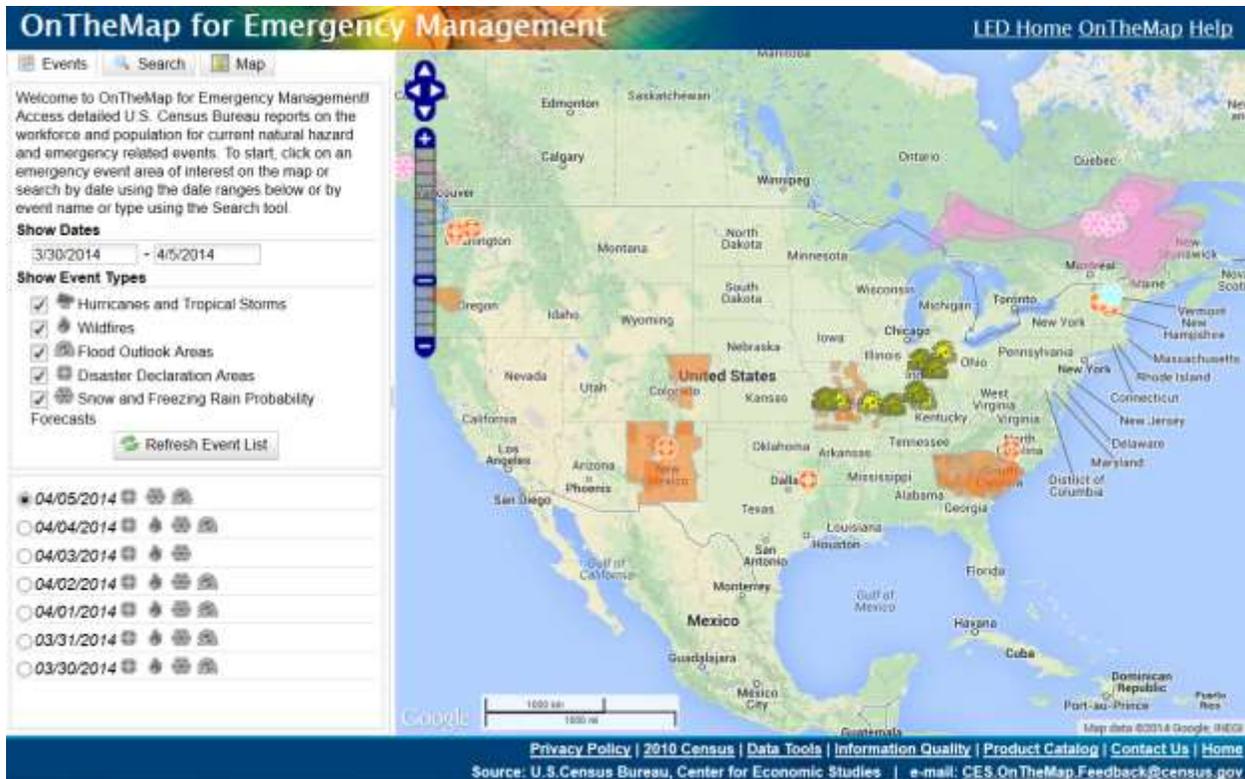
Figure 9. Interactive mapping developed with OpenLayers in OnTheMap [46].

(4) Data visualization and service with virtual globes

Virtual globes such as Google Earth® and NASA World Wind provide even more attractive platforms for mash-ups, especially if the applications face a regional and global scale. Many research topics in Earth and space are at such broad scales so virtual globe is often used for presenting researches. For example, in Google Earth® there are already layers of data with live data streams, such as those centered on ocean animal tracking, clouds, earthquakes and volcano eruptions. Figure 10 shows the layer of Census of Marine Life [47] in Google Earth®.
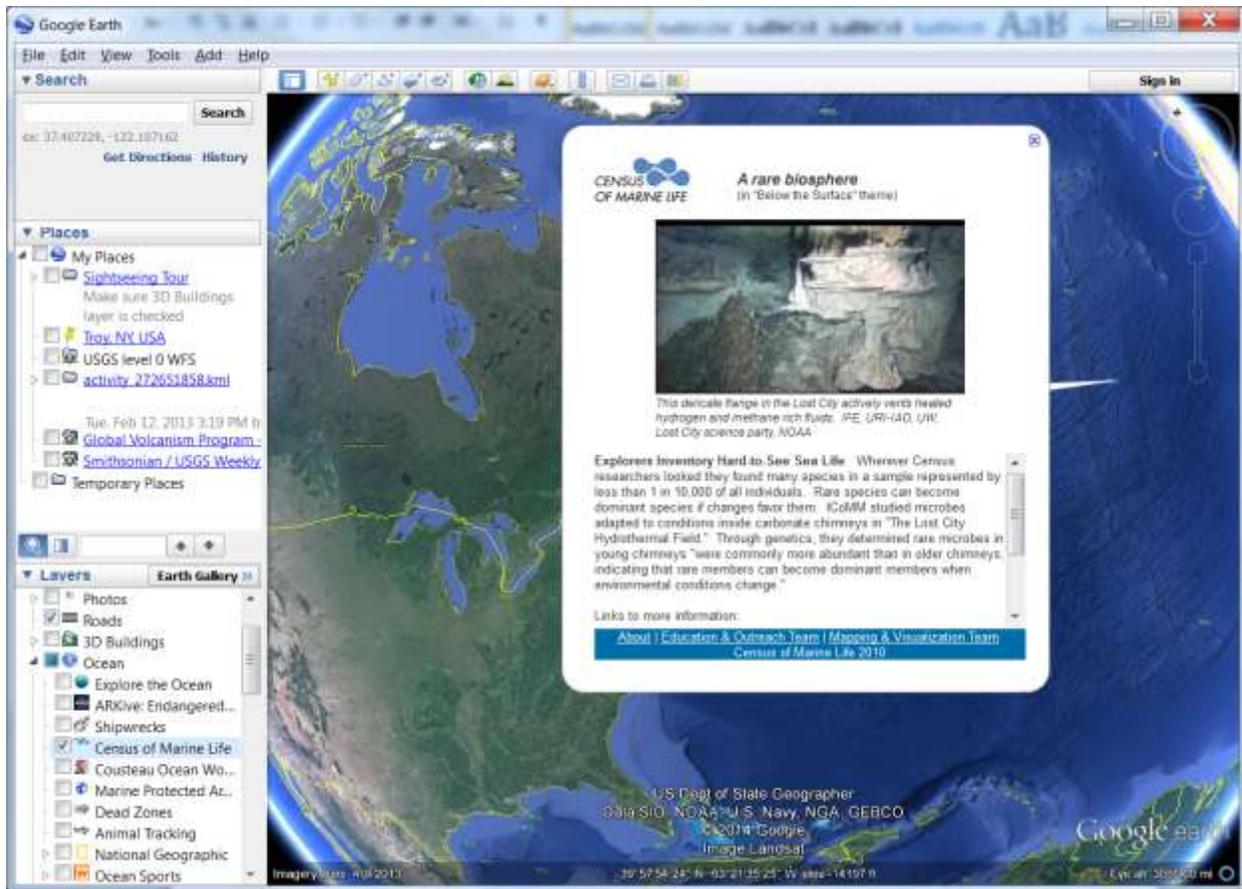
Figure 10. The layer of Census of Marine Life in Google Earth®.

2.2 Standard development and best practices

Scientific and engineering works using multi-source datasets desire standards or community consensus to reduce the heterogeneities between datasets under work. In Earth and space science, we can see various standards used. General standards include the JavaScript Object Notation (JSON) [48] for transmitting data with human-readable text, the Scalable Vector Graphics (SVG) [49] for two dimensional vector graphics, and the GeoJSON [50] for encoding collections of georeferenced features. The Open Geospatial Consortium (OGC) [51] coordinates the development and revision of many data standards, such as the Keyhole Markup Language (KML) [52] for presenting geospatial features with Web-based maps and virtual globes, the Network Common Data Form (netCDF) [53] for creating, sharing and accessing array-oriented data, and the GeoSPARQL [54] for representing and querying geospatial data in the Semantic Web. OGC also developed several geospatial data service standards which are widely used in Earth and space science, such as the Web Map Service (WMS) [55], Web Feature Service (WFS) [56] and Web Coverage Service (WCS) [57]. For three dimensional modeling in the Web there are languages and libraries such as the Web Graphics Library (WebGL) [58], the Virtual Reality Modeling Language (VRML) [59] and the X3D [60]. The WebGL has been used in GPlates [9].

The World Wide Web Consortium (W3C) [61] leads the development of standards for the Web, including those for the Semantic Web. General W3C standards include the Extensible Markup Language (XML) [62], the SVG [49], the RDF [12], the Web Ontology Language (OWL) [63] and the Simple Knowledge Organization System (SKOS) [64], etc. W3C also develops domain specific ontologies, such as the provenance ontology (PROV-O) [65] and the Data Catalog Vocabulary (DCAT) [66]. Besides W3C, there are also other communities developing standards and ontologies facing the Semantic Web, such as the Dublin Core Metadata Initiative (DCMI) Metadata Terms [67] and the Bibliographic Ontology [68].

We introduced a number of standards in the above words because many of them are used throughout a data life cycle in the Web. Yet, standards are the initial elements, to put standards into practice, domain expertise and innovative ideas are needed. For example, Hans Rosling's work on motion charts [69] brought up a fresh idea to extend the traditional static charts. Google Motion Chart [70] adapted Rosling's work and makes it applicable to more topics. Here below we will introduce a few best practices of using those standards in data visualization, with a focus on georeferenced data.

The D3-based map projection transition demos developed by Mike Bostock [29] and Jason Davis [30] are good works using JSON as format of input data and SVG as format for the output graphics. The portal of the OneGeology project [71] provides a platform to browse geological map services across the world, using WMS and WFS standards. OneGeology also promotes the use of common conceptual schemas (e.g., GeoSciML [72]) and vocabularies [73]. By 2014 there have been 172 organizations from 117 countries participate in OneGeology, and many of them provide geological map services (Figure 11). The U.S. Geological Survey also uses WMS, WFS and other standards in its data services, such as the Mineral Resources On-Line Spatial Data [74]. The data portal of the Group on Earth Observations (GEO) [75] provides OGC standard-based services to more comprehensive Earth and space science subjects, including disasters, health, energy, climate, water, weather, ecosystems, agriculture and biodiversity. GeoSPARQL is a relatively newer standard and there are already feature applications with it. For example, a recent work is the Dutch Heritage and Location demo [76], which shows the linked open dataset of the National Cultural Heritage (Rijksdienst voor het Cultureel Erfgoed, RCE) with 13,000 archaeological monuments in the Netherlands. Besides the GeoSPARQL, the OpenStreetMap, OpenLayers and GeoJSON are used in that demo.
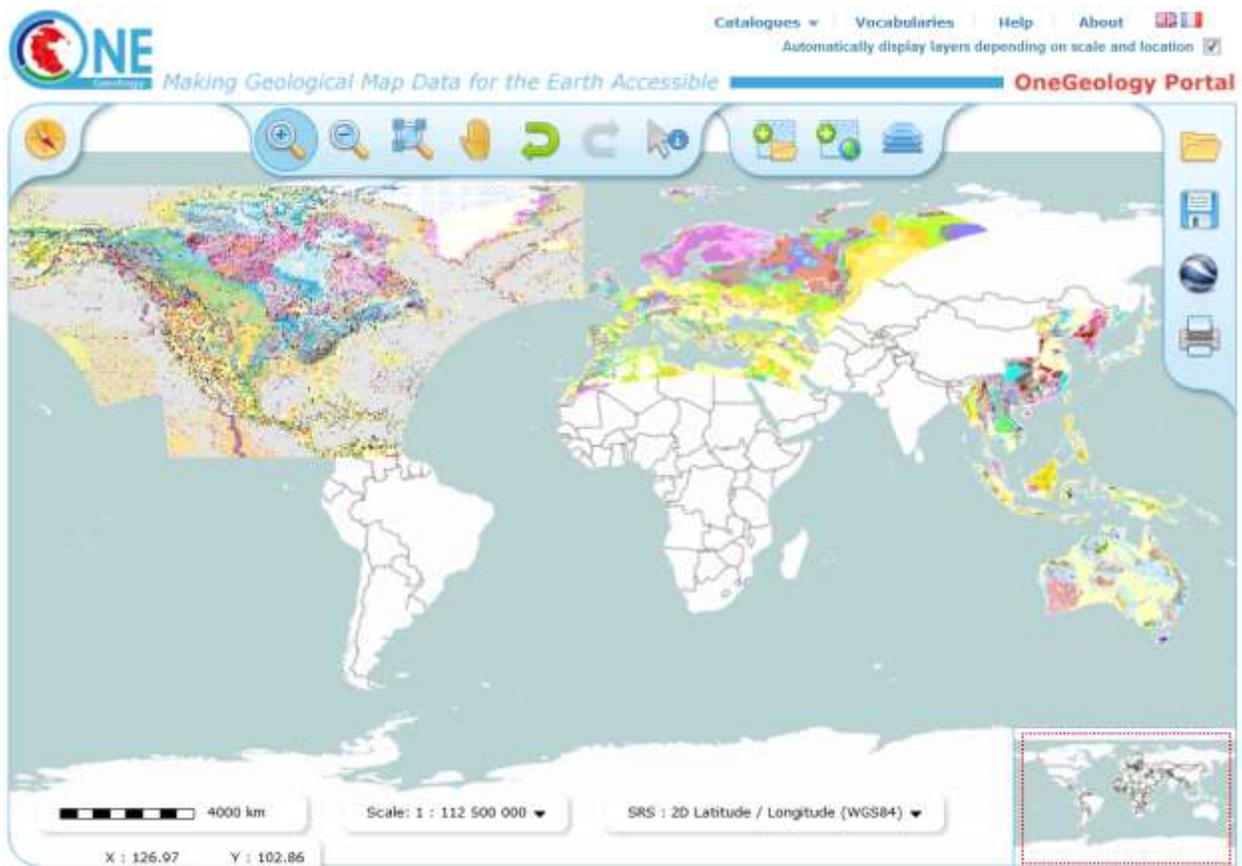
Figure 11. User interface of OneGeology portal with geological map services from four sources connected.

2.3 Earth and space science applications facing the Semantic Web

In current Earth and space science works, semantic technologies have been put into practice in various applications. We already mentioned a few of them in above sections. Data and service standards, semantic technologies and data visualization methods and tools are incorporated into those applications. In this section we will introduce more examples of data visualization in the Sematic Web.

(1) Solar-terrestrial physics

The Virtual Solar Terrestrial Observatory (VSTO) project [77] develops a semantic data framework serving data from diverse data archives in the fields of solar physics, space physics and solar-terrestrial physics. VSTO allows users to query data of interest without having to understand the complexity inherent in heterogeneous data. It also provides functions to visualize the query results [78].

(2) Geology

In the portal of OneGeology-Europe [79], a sister project of OneGeology, in addition to the common data schemas and vocabularies, common color codes are also applied to the geological

map services provided by participating European countries. Users can send queries to all the data sources concurrently and create a customized online map layer. Ma et al. [80] built a visualization of geologic time scale and developed interactive functions between the visualization and geological map services (Figure 12).
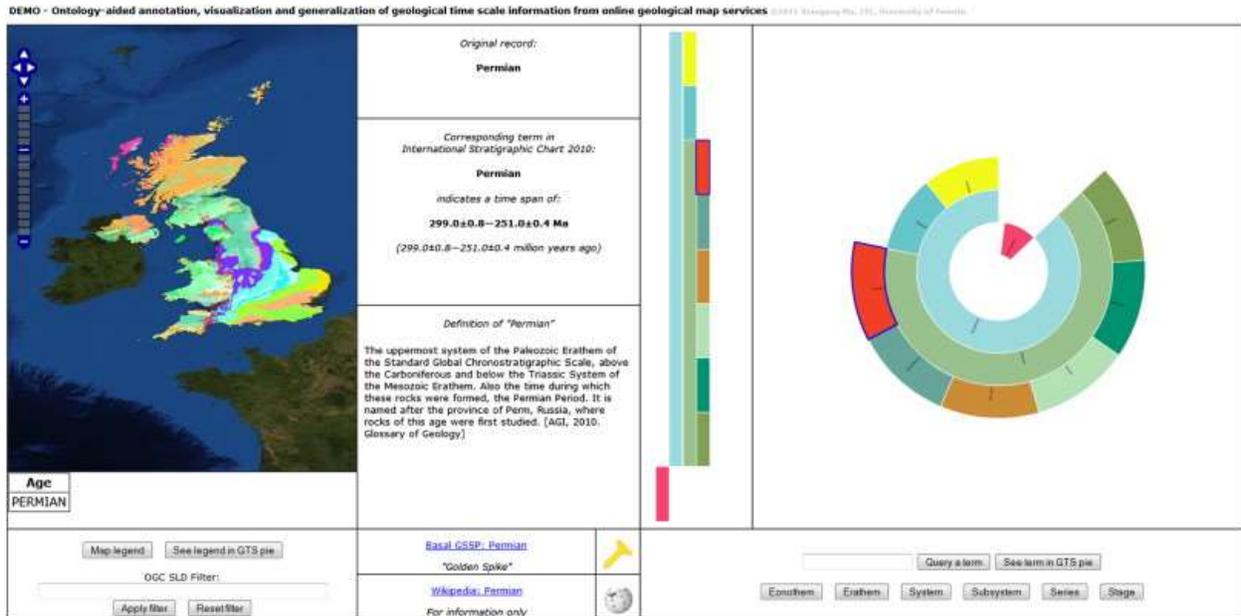

Figure 12. A visualization of geologic time scale and its interactions with geological map services. Source of image: [80].

(3) Oceanography
In the portal of the Biological and Chemical Oceanography Data Management Office (BCO-DMO) [81], Semantic technologies have been used for describing the semantics of data services, as well as the semantics of user interface components. A faceted user interface was developed for users to browse and search datasets and a map window was used to visualize and show the search results.

(4) Environmental science and ecology
In the Semantic Ecology and Environmental Portal (SemantEco) project [82], a semantically enabled environmental monitoring framework has been developed and used to build a water quality portal called SemantAqua. SemantEco supports modular extensions so it is easier to be used for other domains. In the recent works [83] of SemantEco, Google Maps® was used to display the sources of water pollution together with species habitat, and D3 was used to visualize species count over time in a specific geographical region.

(5) Climate Change
The Global Change Information System (GCIS) is an initiative within the U.S. Global Change Research Program (USGCRP) [84]. The data portal of the Global Change Information System

has adopted semantic technologies to build ontologies [20] and set up a triple store to serve linked data of the recent National Climate Assessment. Data visualization standards and tools, such as SVG and conceptual maps were used in ontology engineering and data browsing in GCIS [86].

(6) Geography

Geographical data are often used as basic layers in Earth and space science works. Recently, the Ordnance Survey has built a Linked Data Platform to serve geographical data in Linked Data formats [87]. As the datasets are georeferenced, it is easier to develop visualized mash-ups with other online mapping services, such as Google Maps® and OpenStreeMap.

(7) Research community

In our recent project Deep Carbon Observatory – Data Science [26], semantic technologies have been applied in data and metadata management. We adapted and assembled a few platforms to realize the data management functionality. The Handle System [89] was used to assign a unique identifier (i.e., DCO ID) to each agent, entity or activity in the Deep Carbon Observatory community. VIVO [90] was used to manage and visualize metadata, such as the example in Figure 7. CKAN [91] was used to archive datasets. The metadata in VIVO are stored as RDF triples and we are developing visualizations to make the data browsing user friendly. Figure 13 shows an example of visualized community metadata.
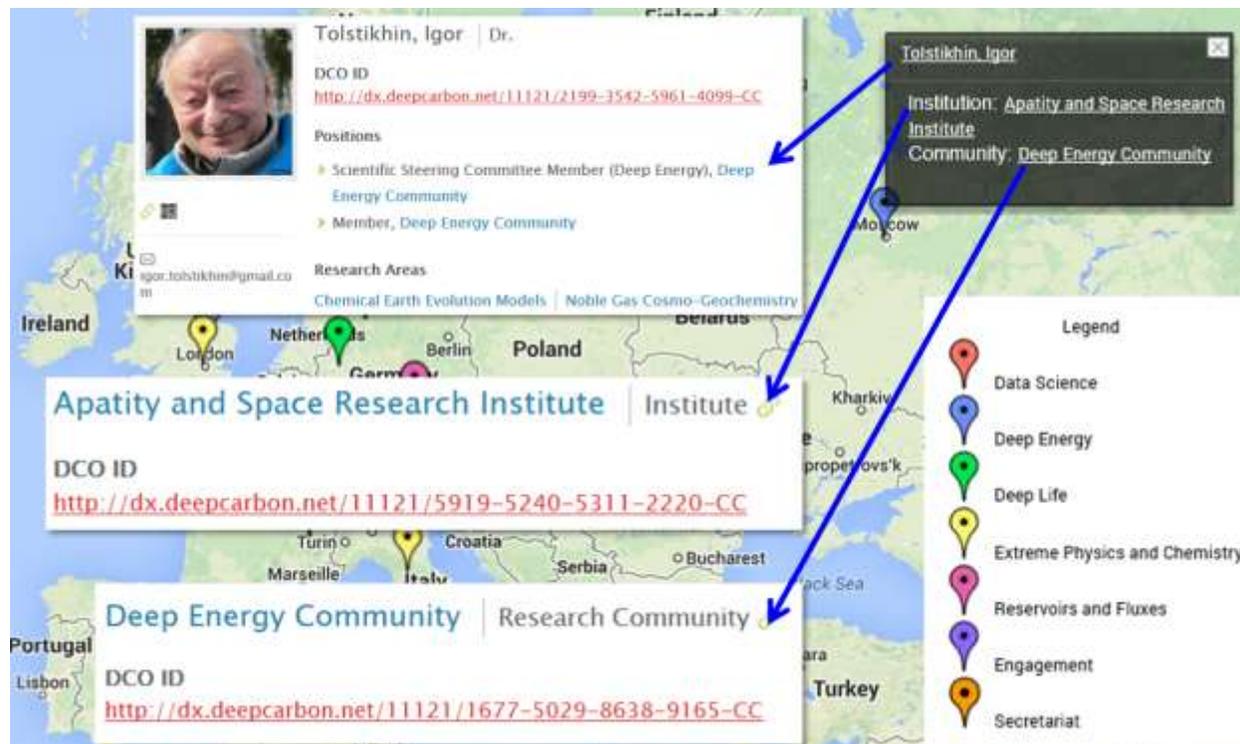

Figure 13. Visualizing and browsing the Deep Carbon Observatory community metadata through Google Maps®. Each pin in the map represents an individual researcher. Clicking a pin will

initiate a pop-up window showing links to the researcher webpage, his/her affiliation and his/her sub-community in the Deep Carbon Observatory.

(8) General topics
The Linking Open Governmental Data (LOGD) project provides a list of data visualization demos based on semantic technologies [92]. Various standards, data visualization tools and platforms are used in those demos, such as RDF, SPARQL, JSON, Google Charts, Google Maps®, etc.

2.4 A broader space for technological innovations
The Web as an open space brings both advantages and challenges to scientific researchers. A major advantage is the fast accessibility to resources. For example, it is now possible to find and download a piece of interested dataset in a few minutes. A major challenge of the current Web is the heterogeneity of datasets available in the Web. For regional and global researches, the use of multi-source datasets and the heterogeneity in data formats, terminologies and conceptual schemas cost researchers too much time. Through efforts on the Semantic Web and the Linked Data people are building a global data space to reduce such heterogeneities. By using common ontologies, vocabularies and data formats, the interoperability between datasets will be significantly improved. We can already see some initial results of improved data interoperability in projects such as VSTO, OneGeology, BCO-DMO and LOGD, etc.

Data interoperability was also discussed as the essential feature of the Web in Berners-Lee and Fishetti's view [93]. They further discussed that the Web should also be a place for interactions between people and data, as well as the interactions among people. They also wish such interactions can finally bring intercreativity, not only in science but also in the daily life of human beings. The visual representation, interaction and exploration enabled by data visualization will be a powerful support in people's activities in the Semantic Web. We already discussed many feature tools and applications, and there are new ones rising up to support people's work in the Semantic Web. While this chapter was under drafting in late 2013 and early 2014, a few new tools already showed up, such as the JSON-LD [94] as a JSON-based serialization format for Linked Data (and the GeoJSON-LD is under development [95]), the SPARQL package in R [94] that enables people retrieve data from data end-points in the Semantic Web, and the IPython Notebook [95] that enables people assemble, analyze and visualize datasets in the Web and generate research documents directly.

We hope the concepts, methods, tools and applications introduced in this chapter offer readers a general idea about data visualization in the Semantic Web, especially the works in Earth and space science. The best way to learn is by practicing, which is specifically true for data visualization tools and applications. More innovative data visualization works are yet to be explored by people in the global data space enabled by the Semantic Web.

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