Semantic Representation of Cartography

A Map Projections Example

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Motivation

Make cartographic knowledge more accessible to people and provide automated (machine) access to knowledge elements for incorporation in artificial intelligence solutions

Provide access to map projections knowledge from semantic knowledge base
Outline

Semantic Knowledge Representation and the Semantic Web
Cartographic Knowledge
Map Projections Knowledge - What knowledge to represent
Semantic Representation of Map Projections Knowledge
Ontology for Map Projections
Implementation Methods
Conclusions
Semantic Knowledge Representation

Represents meaning of data elements
Built as a knowledge graph (ontology)
  Graph data structure of node-edge-node

Allows query of knowledge or browsing the knowledge graph, following links from node to node in the graph for access to additional knowledge

Supports logic and inference with machine interpretation
World Wide Web

Web of documents
Access is through Web pages which are documents
Search is a search for documents, perhaps containing specific words, phrases, concepts
Each page or set of pages is accessed by a Uniform Resource Locator (URL)
Semantic Web

Semantic Web is a web of data that can be processed by machines. Data are linked, access is through data links. Format is not pages, but data are stored as Resource Description Framework (RDF) triples. A triple is subject, predicate, object. Data elements linked by Uniform Resource Identifier (URI). Information is queried by SPARQL Protocol and RDF Query Language (SPARQL).

URIs are often internationalized (to the Universal Coded Character Set) and become IRIs.
Semantic Web RDF format

An RDF triple contains three components:

- the subject, which is an RDF IRI reference or a blank node
- the predicate, which is an RDF IRI reference
- the object, which is an RDF IRI reference, a literal or a blank node

An RDF graph is a set of RDF triples

A collection of triples is known as a triplestore and functions as a database and knowledgebase

Triplestore is queried with the SPARQL Protocol and RDF Query Language

An example IRI:

<http://cegis.usgs.gov/TopoVocab/1.0/Terrain#/crater>

Semantic Web RDF is the basis for Linked Open Data
The sky is blue.

- If we want to store the idea of a blue sky we choose a subject to represent “the sky”
- We select a predicate to represent “has the color”
- And we choose an object that represents the concept of “blue”
Triple Example

- “The sky is blue” in triple form might look like this:
  

- Each part is called an “RDF term”
- Each RDF term is separated by (at least) a space
- The triple ends with a period
Another example

@prefix gu:  <http://cegis.usgs.gov/rdf/gu/> .
@prefix rdf:  <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .


- Same “Subject Predicate Object” structure
- But now we have two triples
  - The first describes a “type”
  - The second describes the name or label of the feature
Triplestores

- A collection of triples is called a “graph”
- A program that stores graphs is called a “triplestore”
- Triplestores also execute queries on graphs
- The RDF query language is called SPARQL (sparkle)
- Collection of triplestores on Semantic Web all linked form Linked Open Data
Circle size indicates number of triples
Cartographic Knowledge

Cartography consists of subfields of knowledge areas
One approach to organizing cartographic knowledge as subfields of knowledge areas follows
Cartography Subfields

Theoretical Underpinnings

• Theories of Space & Spatial Representations (Philosophy, Psychology, Geography, Mathematics)
• Spatial Cognition (→ Cognitive Science)
• History of Cartography & Cartographic Heritage
• Cartographic Paradigms & Theories
• Maps & Power / Critical Cartography
  o Gender, Race, Underrepresented Groups & Cartography

Measuring the Earth

• Geodesy & Spatial Reference Systems (→ Geodesy)
• Earth Observation & Satellite Imagery (→ Remote Sensing)
• Remote Sensing Technologies (→ Remote Sensing)
• Measurement Theory & Statistics (→ Statistics)
• Field Research & Qualitative Methods (→ Geography)
• Toponymy (→ Geography)
Cartography Subfields

Cartographic Data

- Data Models: Conceptual, Logical, Physical
- Data Formats: Raster, Vector (→ Geographic Information Science)
- Geospatial Semantics
- Spatial & Cartographic Databases (→ Geographic Information Science)
- Uncertainty & Error Propagation (→ Geographic Information Science)
- Data Quality, Trust & Provenance
- Volunteered Geographic Information
- Online Data Retrieval (Scraping, Social Media) (→ Web Engineering)
Cartography Subfields

Cartographic Transformations

- Horizontal and Vertical Datums
- Geographic Reference and Coordinate Systems
- Map Projections
- Cartograms
- Generalization Foundations
- Digital Generalization
- Classification, Value Scales (→ Statistics)
- Scale
- Symbolization & Visual Variables
- Thematic Mapping Techniques
Cartography Subfields

Map Design

- Cognitive Foundations of Map Perception (→ Cognitive Science)
- User Interface Design
- Design Basics: Color Theory, Typography, Grids, Visual Hierarchy (→ Design)
- Map Layout, Legends & Perimap Design
- Terrain Representation
- Planetary Cartography
- Atlas Design
- Art & Cartography (→ Visual Arts)
- Mapping Time
- Flowmaps
- 3D Mapping
- Geovisual Analytics
Cartography Subfields

Media Technology for Cartography

- Visual Media Technologies (Print & Digital Output Media) (-> Printing, Media Informatics)
- Foundations of Computer-Generated Graphical Output (-> Computer Graphics)
- Web Cartography (-> Web Engineering)
- Mobile & Uniquitous Cartography (-> Uniquitous Computing)
- Sensors & Location Based Services (-> Uniquitous Computing)
- Multimedia & Multisensory Spatial Representations
- Maps for the Blind and Partially Sighted
- Cartography in Virtual, Augmented Reality, Immersive Environments (-> Computer Graphics)

Map Use

- Map Reading and Interpretation
- Map Analysis
- Statistical Mapping
- Usability Engineering and Evaluation
- User-Centered Design (-> Design, Interactive Systems)
- Map Use & User Studies (-> Cognitive Science)
- Sketch Maps, Mental Maps (-> Cognitive Science)
Cartography Subfields

Specialist Application Fields

• Topographic Maps & Mountain Cartography
• Marine Cartography
• Maps in Crisis Management
• Military Cartography
• Aviation Cartography

Interactive Cartography

• Cartographic Animation
• Geovisualization & Geovisual Analytics
• Digital Atlases
• Storytelling & Narrative Maps (→ Literature Studies)
• Context-Sensitive Cartography
Cartography Subfields

Map Production & Cartographic Information Management

- Digital Map Production Technologies (GIS etc.)
- Map Production Workflows
- Spatial Data Infrastructures & Standards, Metadata
- Data Warehousing & Big Data Technologies (-> Systems Engineering)
- Cartographic Institutions

Cartography Outreach & Education

- Cartography and Children
- Cartographic Education
- Cartography & Other Disciplines
Semantic Representation of CartoBoK

Represent as Resource Description Framework (RDF) triples

Ontology of Cartographic Knowledge
  Classification of knowledge elements
  Build as RDF triples
  Support logic and inference to build knowledge representation
  Access by humans and machines
Map Projections

Well-defined sub area of cartography
  Semantically simple with a few basic concepts
  Wealth of applications of concepts and implementations
  Users and machines need help to automatically select correct projection needed

A few major concepts to model semantically
  All map projections are coordinate transformations of form:
    \[ x = f_1(\phi, \lambda) \]
    \[ y = f_2(\phi, \lambda) \]

Constraints on map projection modeled as properties:
  Scale determines sphere or ellipsoid equations
  Preserve angles (conformal)
  Preserve area (equal area, or authalic)
  Preserve distance (equidistant)
  Preserve graphical look
  Compromise
Map Projections – What Knowledge to Model

Classes based on class characteristics
Preservation of characteristics from spherical representation
Distortion characteristics
Usage for specific areas
History of projection

Represent metaknowledge in an ontology based on classification and projection characteristics
Not represent actual equations but concepts
Use a Simple Map Projection Classification

Cylindrical
Pseudocylindrical
Conical
Azimuthal
Space Projections
Semantic Modeling of Map Projections

Subjects
- Projection classes
- Individual projections

Predicates:
- Has transformation
- Preserves angles
- Preserves area
- Preserves distance
- Preserves global look

Objects
- Projection classes and subclasses
- Individual Projections
Projection Knowledge Graph Triples

Projection Summary Description – Example triples of Map Projection Knowledge

:EqualArea rdfs:subClassOf :CoordinateTransformation
:Mollweide rdf:type :EqualArea
:Mollweide rdfs:comment :SummaryDescription
:CoordinateTransformation :hasSphericalFormulas :SF

Formulas for Ellipsoid
Graphic of projection
History
Usage
Features
Ontology Design Pattern for Coordinate Transformation
Ontology Design Pattern for Mollweide Projection

Mollweide
  ^
 /       
|        |
|        |
|        |
MollweideSummary       MollweideHistory       MollweideGraphic

   ^              ^              ^
   |              |              |
   hasSummary    hasHistory    hasGraphic

Mollweide

    ^
    |
    hasUsage

MollweideUsage

    ^
    |
    hasFeatures

MollweideFeatures
### Summary

| Projection                      | Type          | Conformal | World                  | Topographic Maps | Geological Maps | Thematic Maps | Presentations | General Use | USGS Maps |
|--------------------------------|---------------|-----------|------------------------|------------------|----------------|--------------|---------------|-------------|-----------|-----------|
| Globe                          | Sphere        | ✓         | ✓                      |                  |                |              |               |             |           |
| Mercator                       | Cylindrical   |           |                        |                  |                |              |               |             |           |
| Transverse Mercator            | Cylindrical   |           |                        |                  |                |              |               |             |           |
| Oblique Mercator               | Cylindrical   |           |                        |                  |                |              |               |             |           |
| Space Oblique Mercator         | Cylindrical   |           |                        |                  |                |              |               |             |           |
| Kail Cartographic             | Cylindrical   |           |                        |                  |                |              |               |             |           |
| Robinson                       | Pseudocylindrical |         |                        |                  |                |              |               |             |           |
| Sinusoidal Equal Area          | Pseudocylindrical |         |                        |                  |                |              |               |             |           |
| Orthographic                   | Azimuthal     |           |                        |                  |                |              |               |             |           |
| Stereographic                  | Azimuthal     |           |                        |                  |                |              |               |             |           |
| Geometric                      | Azimuthal     |           |                        |                  |                |              |               |             |           |
| Azimuthal Equal Area           | Azimuthal     |           |                        |                  |                |              |               |             |           |
| Lambert Equal Area             | Azimuthal     |           |                        |                  |                |              |               |             |           |
| Albers Equal Area Conic        | Conic         |           |                        |                  |                |              |               |             |           |
| Lambert Conformal Conic        | Conic         |           |                        |                  |                |              |               |             |           |
| Equidistant Conic (Simple Conic)| Conic         |           |                        |                  |                |              |               |             |           |
| Polyconic                      | Conic         |           |                        |                  |                |              |               |             |           |
| Bipolar Oblique Conformal      | Conic         |           |                        |                  |                |              |               |             |           |

### General Notes:

**Azimuth** - The angle measured in degrees between a base line radiating from a center point and another line radiating from the same point. Normally, the base line points North, and degrees are measured clockwise from the base line.

**Aspect** - Individual azimuthal map projections are divided into three aspects: the polar aspect which is tangent at the pole, the equatorial aspect which is tangent at the Equator, and the oblique aspect which is tangent anywhere else. The word “aspect” has replaced the word “case” in the modern cartographic literature.

and the shapes of very small areas and angles with very short sides are preserved. The size of most areas, however, is distorted.

**Developable surface** - A developable surface is a simple geometric form capable of being flattened without stretching. Many map projections can then be grouped by a particular developable surface: cylinder, cone, or plane.

**Equal area** - A map projection is equal area if every part, as well as the whole, has the same area as the corresponding part on the Earth, at the same reduced scale. No flat map can be both equal area and conformal.

between Washington and any other point on the projection. It shows the correct distance between Washington and San Diego and between Washington and Seattle. But it does not show the correct distance between San Diego and Seattle. No flat map can be both equal area and conformal.

**Graticule** - The graticule is the spherical coordinate system based on lines of latitude and longitude.

**Great circle** - A circle formed on the surface of a sphere by a plane that passes through the center of the sphere. The Equator, each meridian, and each full circumferential of the Earth forms a great circle. The arc of a great circle shows the shortest distance between points on the Earth. Scale varies from place to place on every map. The degree of variation depends on the projection used in making the map.

**Map projection** - A map projection is a systematic representation of a round body such as the Earth on a flat (plane) surface. Each map projection has specific properties that make it useful for specific purposes.

**Rhumb line** - A rhumb line is a line on the surface of the Earth cutting all meridians at the same angle. A rhumb line shows true direction. Parallels and meridians, which also maintain constant true directions, may be considered special cases of the rhumb line. A straight rhumb line crossing the Equator at any point must eventually cross all parallels and ultimately close on itself. A spiral or logarithmic rhumb line is a curved line that approaches a given line to an infinite value in finite distance. A rhumb line on a Mercator projection is a straight line.
Usage: Mercator

Found 14 uses of Mercator

- Mercator SubClassOf Cylindrical
- Class: Mercator

- Mercator Type Cylindrical
- Mercator preserves StraightRhumb
- Individual: Mercator
- Mercator regionMapped ContinentOcean
- Mercator usedFor Navigation
- Mercator preserves Angle

Description: Mercator

Types
- Cylindrical

Same Individual As

Different Individuals

Property assertions: Mercator

Object property assertions
- preserves StraightRhumb
- regionMapped ContinentOcean
- usedFor Navigation
- preserves Angle

Data property assertions

Negative object property assertions

Negative data property assertions
**FEATURES**

The Lambert Azimuthal Equal-Area projection is a perspective projection. It is a "synthetic" azimuthal in that it was derived for the specific purpose of maintaining equal area. The ellipsoidal form maintains equal area, but it is not quite azimuthal except in the polar aspect, for the name for the general ellipsoidal form is a slight misnomer, although it looks like the spherical azimuthal form and has most of its other characteristics. The polar aspect (fig. 39A), like that of the Orthographic and Stereographic, shows circles for parallels of latitude, all centered about the North or South Pole, and straight equally spaced radii of these circles for meridians. The difference is, as before, in the spacing of the parallels. For the Lambert, the spacing between the parallels gradually decreases with increasing distance from the pole. The opposite pole, not visible on either the Orthographic or Stereographic, may be shown on the Lambert as a large circle surrounding the map, almost half as far from the center as the Equator from the center. Normally, the projection is not shown beyond one hemisphere (or beyond the Equator in the polar aspect).

The equatorial aspect (fig. 39B) has, like the other azimuthals, a straight Equator and straight central meridian, with a circle representing the 90th meridian east and west of the central meridian. Unlike those for the Orthographic and Stereographic, the remaining meridians and parallels are uncommon complex curves. The chief visual distinguishing characteristic is that the spacing of the meridians near the 90th meridian and of the parallels near the poles is about 0.7 of the spacing at the center of the projection, or moderately less to the eye. The parallels of latitude look considerably like circular arcs, except near the 90th meridians, where they exhibit a noticeable turn toward the nearest pole.

The oblique aspect (fig. 39C) of the Lambert Azimuthal Equal-Area resembles the Orthographic to some extent, until it is seen that crowding is far less pronounced as the distance from the center increases. Aside from the straight central meridian, all meridians and parallels are complex curves, not ellipses.

In both the equatorial and oblique aspects, the point opposite the center may be shown as a circle surrounding the map, corresponding to the opposite pole in the polar aspect. Except for the advantage of showing the entire Earth in an equal-area projection from one point, the distortion is so great beyond the inner hemisphere that for world maps the Earth should be shown as two separate hemispherical maps; the second map centered on the point opposite the center of the first map.

**GEOMETRIC CONSTRUCTION**

The polar aspect (for the sphere) may be drawn with a simple geometric construction: In figure 40, if angle AOR is the latitude φ, and P is the pole at the center, PA is the radius of that latitude on the polar map. The oblique and equatorial aspects have no direct geometric construction. They may be prepared indirectly by using other azimuthal projections (Harrison, 1945), but it is now simpler to plot directly or manually from rectangular coordinates which are generated by a relatively simple computer program.
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT ?subject ?object
WHERE {?subject rdfs.subClassOf ?object}
Conclusions

Map projections is a sub-area of a Cartographic Body of Knowledge (CartoBoK) that can be modeled semantically.

Cartographic knowledge can be built as a semantic knowledge graph

Makes map projection knowledge available in a form to be accessed automatically by machines or to assist humans
Semantic Representation of Cartography

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