Semantic Reference Systems*

Geographic Information Systems (GIS) operate on spatial, temporal, and thematic data. The interpretation of the first two kinds of data is given by well known spatial and temporal reference systems such as coordinate systems and calendars. Based on these reference systems, we can transform between coordinates and timestamps or measure distance in space and time. We can also project three dimensional coordinates into two dimensional representations for paper maps. What is missing so far, is a reference system for the third kind of data. In analogy to spatial and temporal reference systems, semantic reference systems (SRS) should allow to transform and project thematic data, or to measure semantic distance (called semantic similarity). Typical applications for such a semantic reference system include the transformation or comparison of different conceptualizations between information communities, and information retrieval in general. In the first case, this would allow to mediate between the conceptualization of water bodies as used in hydrology to the one used in tourism. In the second case, one could retrieve similar water bodies or kinds of water bodies (such as lake, river, or reservoir) based on a users query. A semantic reference system consists of two parts, the semantic reference frame, i.e., a formal system such as an ontology, and particular semantic datums to ground the meaning of the terms used in the reference frame.

Ontologies as Reference Frames

An ontology specifies the conceptualization of a particular information community by providing formal definitions for the terms used in this community. To do so, ontologies need to introduce primitive terms used for the definition of more complex ones. For instance, the term *River* could be specified by introducing the term *Spring* and the relation *has_Origin* between rivers and springs. One could also define attributes such as *flow_velocity* and *water_gauge,* and introduce kinds of

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rivers such as *Forest_River*. In turn, we also have to specify the meaning of terms such as *Spring* and also the attributes and relations used to specify the meaning of *River*. We continue with the specification process until only primitives are left, i.e., terms, relation, and attributes for which no formal definition can be given within our ontology. To ensure consistency in the interpretation of these terms, and hence to achieve semantic interoperability, we need to ground these primitives in observable reality by introducing semantic datums. Summing up, ontologies restrict the potential meanings of terms used in an information community. However, in order to restrict the possible interpretations exactly to the intended ones, a semantic datum is needed. Besides specifying a vocabulary, ontologies support logical reasoning which is a prerequisite for information retrieval. For instance, if we define particular attributes such as *flow_velocity* for *River* we can infer that each water body which has been classified as a river has a flow velocity. Semantics-aware search engines use reasoning to deliver more flexible results. If a user types in *Stream* as keyword, the search engine would also include kinds of streams such as rivers and creeks, and also similar water bodies (such as reservoir if the user is querying for *Lake*) in the result set.

Semantic Datums and Sensors

A semantic datum provides a particular interpretation for the primitives of a reference frame to something outside of it. An interpretation is a function from all symbols (terms, attributes, and relations) in an ontology to some particular other structure which preserves the truth of its sentences. Typically, ontologies allow for more than one interpretation that satisfies its sentences, and therefore it has an ambiguous meaning. As all non-primitive symbols in an ontology are definable from the primitive ones, a semantic datum can fix one particular interpretation. The structure in which the symbols are interpreted can be other ontologies as well as observable real world structures. We say that an ontology is grounded, if there exists a semantic datum for an interpretation into observable real world structures. Examples of interpretations into observable real world structures are measurement scales. This can be illustrated by the analogy to spatial reference systems. Spatial reference frames are grounded. A datum in a spatial reference frame fixes the position of the origin, the orientation of coordinate axes of the reference frame relative to the earth, and the length measurement scale which fixes the units of measurement. All coordinates and their relative locations are defined in origins and units of such reference frame.

There are two ways of establishing a semantic datum for a semantic reference frame. Either there is a physical sensor available which grounds primitive symbols directly into observable real world structures. A sensor can be considered as a physical device that implements such an interpretation. In our example, a directly observable semantic datum for the Bessel ellipsoid is for instance a named spot on the earth's surface like "Rauenberg" near Berlin (Potsdam Datum). Or there is a criterion available to define the primitive in a second reference frame. The point of origin and the units of a map projection, like a Gauss-Krüger strip, are e.g. definable from a reference ellipsoid, like Bessel. In terms of the water body example, a river's gauge is defined in reference to its bankfull stage (as datum). The bankfull stage is the level of the water surface measured when the river's banks are under water. The level of water surface in turn is the vertical distance measured between the idealized water body surface to the air and the idealized surface to the river bed.

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See also Semantic Interoperability, Ontology, Ontological Foundations for Geographical Data, and Spatial Data Mining

Further Readings

Kuhn, W., 2003. Semantic Reference Systems. International Journal of Geographical Information Science, Guest Editorial, 17(5), pp. 405-409

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