The semantics of extensive quantities within geographic information (extended abstract)

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Abstract

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1. Introduction

Geo-spatial analysis involves summing, subtracting, and intersecting quantities of space, time, and substance. To determine whether such operations are meaningful, analysts interpret the meaning of the quantities, and along with these interpretations come certain assumptions. In particular, an analyst may decide that, when aggregating spatial regions, some quantities (e.g., population counts) can be summed, while others (e.g., population densities) cannot. The analyst can rely on their intuition when interpreting quantities, but to the computational brain of a geographic information (GI) system, they are indistinguishable. Consequently, current GI systems still require manual evaluation of the validity of analytical methods depending on the meaning of the data. To enable automated validity checks it is thus necessary to explicate whether quantity data represent extensive or intensive quantities.

Most existing measurement ontologies are insufficient for this purpose. Light-weight ontologies lack the formal depth required to specify the distinctions needed for capturing notions of extensivity and foundational ontologies make commitments we wish to avoid. For example, both DOLCE and FOUnt consider amounts as physical endurants, but we adopt a more basic view of amounts as quantitative nuclei. In this article we suggest a first-order formalization of quantity domains as a basis for a higher-order, relational definition of extensivity using quantities as controls and measures. In doing so, we assume that intensive quantities complement extensive quantities. We then demonstrate how this definition allows us to define various subclasses of extensive measurement across geographic information examples in terms of a Web Ontology Language (OWL) pattern with subsumption reasoning. In particular, we define two ontologies, namely the Amounts and Magnitudes Measurement Ontology (AMMO) and geo-AMMO, a specification to the domain of geo-sciences.

We distinguish two sub-quantities, namely *amounts* and *magnitudes.* Amounts are defined as quantities with mereological properties, meaning they carry notions of parthood and supplementation. Consequently, a domain of amounts is structured as an order lattice. The mereological definition entails that amounts can overlap, i.e., two regions A and B may share a part C. Magnitudes are defined as linearly ordered quantities that adhere to vector axioms, meaning they can be summed and multiplied by scalars. A domain of magnitudes is thus a vector space. However, we do not consider notions of direction. In addition to amounts and magnitudes, we adopt the notion of a *measurement function.* This

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notion is inspired by the work of Sinton, who establishes that geospatial measurement involves the three components *space*, *time*, and *content*, which take roles of *measure*, *control*, and *support*. We omit the support role in our theory and postulate that amounts are used as controls so that another amount or a magnitude can be measured. This measurement function can be used to determine whether quantities in a domain are extensive with respect to quantities in another domain. Assuming that $O(x, y)$ means x and y overlap, and m represents the measurement function, a quantity is extensive iff the following are true:

$$\forall x, y \in X(\neg O(x, y) \implies m(x) + m(y) = m(x + y)) \qquad \text{Additivity}$$
$$\forall x, y \in X(x \preccurlyeq y \implies m(y) \setminus m(x) = m(y \setminus x) \qquad \text{Subtractivity}$$

where $+$ and $\setminus$ respectively represent addition and subtraction of either a mereological or arithmetic nature, depending on whether each of X and $\{m(x) \mid x \in X\}$ is a domain of amounts or a domain of magnitudes.

We follow Sinton's semantics of *space*, *time*, and *theme* (Instead of *theme*, we speak of *content*) for amounts. Based on these semantic classes we define nine measurement functions between amount controls and amount measures:

- Capacity MF ($m : Space \rightarrow Content$)
- Occupancy MF ($m : Content \rightarrow Space$)
- Spacetime MF ($m : Space \rightarrow Time$)
- Timespace MF ($m : Time \rightarrow Space$)
- Accumulation MF ($m : Time \rightarrow Content$)
- Dynamic MF ($m : Content \rightarrow Time$)
- Space MF ($m : Space \rightarrow Space$)
- Time MF ($m : Time \rightarrow Time$)
- Content MF ($m : Content \rightarrow Content$)

For example, a measurement of population can be considered a capacity measurement and a measurement of exposure to pollution can be considered an accumulation measurement. In addition, we introduce *size*, *duration*, and *value* as semantic classes for magnitudes, together with three more measurement functions:

- Space MF ($m : Space \rightarrow Size$)
- Time MF ($m : Time \rightarrow Duration$)
- Content MF ($m : Content \rightarrow Value$)

For example, a population count is a measurement with a population amount as control and the population's cardinality as a measure and a length measurement has a space as an amount (e.g., the span of a plank) and a size as measure (e.g., 2 meters). Using these classes and measurement functions we define AMMO and GeoAMMO (c.f., full paper).