Grounding Geographic Information

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MOTIVATION

Ontologies need to introduce some primitive symbols used for the definition of more complex ones. These primitive symbols have no formal definitions in the ontology, and as ontologies usually are incomplete axiomatizations, the semantics of the primitives remain ambiguous (Guarino 1998). This shifts the problem of semantic interoperability to the problem of how to ground such primitives. Grounding gives meaning to ontological primitives by *relating them to qualities* outside the symbol system, and thus stopping infinite regress. In analogy to spatial reference systems, we propose to do so by introducing semantic datums (Kuhn and Raubal 2003) that anchor primitives in *physical and reproducible observations*.

In particular we address the problem of how the qualia of geographic entities, the 'values' of their particular qualities, can be reproducibly mapped to symbols as a result of conscious experience. Measurement theory (Suppes 1963) merely provides us with some formal constraints for such mappings, but does not account for reproducibility (see also (Boumans 2005)). From an ontological point of view, this raises two questions, which are at the core of our research agenda on semantic interoperability:

a. How are qualia related to spatial entities?
b. How do we get from qualia to symbols?

We suggest that an answer to the first question is crucial for the second one, as inherent qualities are ontologically dependent on their host (Masolo *et al.* 2004). We first introduce a simplified scenario to improve readability.

Several characteristics can be used to describe the notion of *river* or *lake*, such as *water depth* or *salinity*. Dependent on the application area (e.g., navigation versus fishing, or diving versus swimming), particular ranges of *water depth* are categorized by introducing the symbols *deep* or *shallow*. To enable interoperability between different communities, we have to introduce semantic datums for these symbols.

HOW ARE QUALIA RELATED TO SPATIAL ENTITIES?

How could a semantic datum for 'water depth of a lake' look like? The identification of this particular depth is dependent on its host. Probst and Espeter (2006) have given an answer to this question based on the host's dimensionality. We extend this work by showing observable individuation criteria for lakes, and then how other qualities, like its depth, can be derived from observable primitives. (Gibson 1986) described the *meaningful environment* in terms of 'media', 'substances' and their 'surfaces'. Media are separated from substances of the environment by surfaces. A medium can be identified by affordance characteristics, for instance, it permits unimpeded locomotion and transmits light, and so on, whereas substances do not. These distinctions are relative: for example, water is medium for fish, whereas it is, by and large, a substance for us. Humans are able to identify and distinguish different substances by observing qualities of surfaces, like the length, the texture, its shape, and more.

Looking at a particular lake, e.g. Lake Constance at the German, Swiss, and Austrian border, we may perceive its flat surface, on which events such as ripples, freezing, and evaporation may occur. We experienced this observation as ‘stable’ – the surface of a lake doesn’t change dramatically over time, thus humans can use the surface quality to identify the lake. Entities resulting in similar observations can be grouped into the same category; and this category is named by *pointing* at it. But how can we communicate how deep the lake is? A human's perception of *deep* or *shallow* depends on his planned activities. The diver may call a lake’s water depth of ten meters 'shallow', whereas the novice swimmer would call two meters too deep. If we want to create a reproducible classification of depth, we need to define these categories in terms of surfaces and their directly perceivable properties. The authors have formally outlined how this can be done (based on formalisms like that in Borgo *et al.* 1997) in another paper (Scheider *et al.* 2009).

In a nutshell, we propose to ground symbols for qualities like 'depth of Lake Constance' by defining them from perceptual primitives in Gibson’s *meaningful environment*. These primitives can be directly observed and be given agreed names. In the next section we explore on how to link from qualia to symbols using our example.

HOW DO WE GET FROM QUALIA TO SYMBOLS?

We consider a sensor to be a device to *reproducibly transform a particular quality into symbols*. This means sensors are physical implementations of semantic datums. The one-dimensional water depth quality of a lake at a certain region of its water body is considered to have the quale *d*. A water body has more than one such quale (Probst and Espeter 2006). But all these qualia *do not have direct sensors* available. So which qualities provide sensors? The answer to this question was partly given in the last section: All primitive qualities of the Gibson environment. Water depth is definable in terms of the location of the lake’s water surface. A sensor for depth would be a function *f* (called scale in measurement theory) from the *vertically aligned diametrical paths* '*p*' inside of the lake’s water body to the *meter symbol space* '*s*', *that is* $f(p) = s$ (see Figure 1). The symbol *s* is a meter length, e.g. $s=1$. The function is not injective, it has some uncertainty, and it is based on convention. The possible functions from paths into symbol space are restricted to the unique intended one, because the *units of measurement* for this scale, e.g. the straight path denoting 1 meter, can be compared e.g. to a platinum bar called 'Mètre des archives' (nowadays, this would be the distance of a ray of light in a certain time interval).

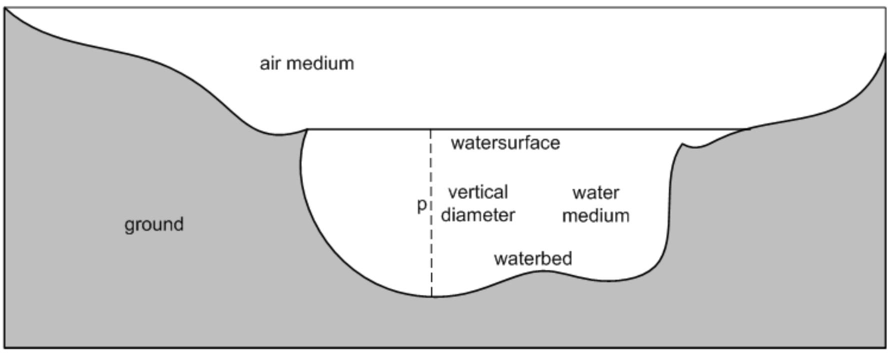

Figure 1: Water depth is the perceivable length of a vertically aligned path from the water surface to the bed of a particular water body.

Summing up, we arrive from qualia of spatial entities to symbols by using observable primitives to first individuate bodies and their surfaces, and second by deriving new quality symbols, like water depth, from them. Using such sensor data, particular information communities categorize lakes or rivers by their specific regions in the water depth space using the symbols *deep* or *shallow*. It is still an open question which ontologies are amenable to our method. The general applicability to geospatial concepts needs to be demonstrated with additional case studies. We are currently working on flow velocity and street network categories.

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