AN ONTOLOGICAL ANALYSIS OF WATER FEATURES

Boyan Brodaric[1], Torsten Hahmann[2], Michael Gruninger[3]

[1]Geological Survey of Canada, Ottawa, Canada K1A0E9
Email: boyan.brodaric@canada.ca
[2]School of Computing and Information Science, University of Maine, Orono, ME 04469, USA
Email: torsten.hahmann@maine.edu
[3]University of Toronto, Toronto, Canada M5S3GB
Email: gruninger@mie.utoronto.ca

Abstract

Water features are understood and represented heterogeneously in a wide variety of settings, including in data standards, polices and regulations, and amongst different cultures and languages. Ontologies aim to reduce this heterogeneity by representing commonalities across such settings. In this paper we build upon existing work in hydro ontologies and philosophical ontology to enhance the conceptualization and representation of water features. This results in a new taxonomy for water features, which helps identify and organize their essential parts. The results are represented as a first-order logic extension of the DOLCE ontology as well as an independent ontology fragment, and these are intended to serve as a reference ontology for the hydro domain as well as an aid to data interoperability.

1. Introduction

Water features are entities that are essentially composed of water and variably other things. Prototypical examples include lakes, rivers, puddles, and clouds, but can also include aquifers. They play a key role in many human activities, such as those related to health, climate and weather, agriculture, energy, recreation, and transportation. Research and operations in these domains are heavily dependent on digital representations of water features, but the inherent conceptualizations can vary widely. Examples of heterogeneity abound, and can be found when comparing international water data standards (Boisvert & Brodaric 2012; Dornblut & Atkinson 2013; INSPIRE 2013; 2014), national catalogs of hydrographic features (Duce & Janowicz 2010), ontological considerations (Galton & Mizoguchi 2009; Santos *et al*. 2005; Sinha *et al*. 2014; Wellen & Sieber 2013), and database structures (Maidment, 2002; Strassberg, *et al*., 2011). This is problematic as it inhibits some uses, especially their integration, which is typically an important precursor to regional scientific analysis such as water availability, or complex societal decision-making such as water allotment. At the heart of the problem is a disparity about the fundamental nature of a water feature, as different aspects are variously emphasized in distinct conceptualizations. These aspects include most notably the water body, its water matter, its container or void (the space it occupies), or even an immaterial spiritual entity (Mark *et al*. 2007; Wellen & Sieber 2013). The emphases exist perhaps to enable diverse uses, for example, reasoning about the presence of a water body facilitates navigation of rivers that might have wet or dry segments; reasoning about the constitution and flow of water matter informs contamination scenarios, as does reasoning about the permeability of the container; and reasoning about the container's void informs storage and overflow scenarios. Yet, it is still somewhat surprising that an entity of such significance is so widely construed and often vaguely defined. In this paper we undertake an ontological analysis of water features and develop a new conceptualization and representation that encompass the key aspects. This is achieved by extending and uniting two significant approaches to physical ontology, namely Hayes' ontology of liquids (1978) and Fine's theory of parts (1999). The results contribute to the design of the HyFO reference

ontology, which is being developed for the hydro domain to help identify semantic heterogeneities, aid interoperability, and inform ongoing representation initiatives.

2. Background and Related Work

As part of Hayes' seminal ontological analysis, liquid features are delineated using several criteria, chief amongst them being containment and support. Containment refers to liquid being topologically surrounded, while support refers to it being held against a surface. These criteria help distinguish most of the representative examples: water bodies in lakes and rivers are contained and supported, in puddles they are uncontained and supported (assuming puddles are spills resting on relatively flat surfaces), while in clouds they are uncontained and unsupported. Note that essential aspects can then be identified for different water features: contained water features must have a container and a void, but uncontained features must not; supported water features must have a supporting boundary, but unsupported features must not. However, aquifers are not distinguished from rivers using these criteria, inasmuch as water bodies can be contained and supported by both aquifers and rivers, under general notions of containment and support. Hence, these notions alone are insufficient to delineate all the representative water features.

In addition to its failure to delineate the full range of water features, Hayes' ontology of liquids also does not provide great detail about the inner structure of a water feature, that is, its main components, their relations, and the relation to the water feature itself. This is advanced somewhat by Fine's notions of temporary and timeless parts, which respectively form variable and rigid wholes. Using rivers as a prototypical example, Fine segments the wet aspect of a water feature into two things linked as whole to part: (1) a persistent water body comprising a variable whole, and (2) its changing (temporary) water matter parts. It is the water body that, over time, persists and rises or falls within a container, and which consists of all the water matter in the container at a timepoint, while it is some specific water matter part that moves at variable speed within the container. However, several things remain unaddressed by Fine. Most notably, the relation of a water body to other aspects is unanswered, such as the relation to a container or to the water feature itself, and rigid wholes are not considered in relation to water features despite their potential application.

Related work on water feature ontologies (e.g. Galton & Mizoguchi 2009; Santos *et al*. 2005; Sinha *et al*. 2014; Wellen & Sieber, 2013) individually incorporate some, but not all, of the seemingly fundamental distinctions made by Hayes and Fine. In particular, the three entities emerging from the above work, namely the water feature, water body and water matter, are not distinguished by any one approach, and the complete range of representative water features is also not delineated. This work then complements the related efforts, by encompassing the full range of representative features and refining their internal structure.

3. Water Feature Conceptualization and Representation

A new conceptualization for water features is achieved by two additions to Hayes' and Fine's efforts: a notion of dependence is introduced to further categorize contained water features, and water features themselves are distinctly recognized and characterized as rigid wholes.

In previous work (Hahmann & Brodaric 2013), detachable and dependent containment denote whether the topological attachment between physical entities is accidental or necessary, respectively: for example, an amount of water matter is accidently contained by a riverbed because it could possibly be in a different riverbed, but the river channel (the void) is necessarily contained by its host riverbed and could not possibly be displaced elsewhere without being a different channel. Likewise, an aquifer and the stuff that it is made of—the rock plus water matter—are dependently contained, because they are necessarily spatially co-located such that if one boundary changes then so does the other. Using this distinction,

aquifers can be distinguished from rivers, because the water in aquifers is dependently contained, and the water in rivers is detachably contained. Interestingly, aquifers also can be variably supported (confined) or unsupported (unconfined) as per the permeability of their boundaries. This leads to an enhanced taxonomy of water features, as shown in Figure 1, in which the representative examples are delineated first by whether the water matter is contained or not, then supported or not, and finally by the type of dependence.

Further understanding of water features as rigid wholes rigorously grounds the water feature-body-matter distinction in Fine's whole-part theory, and it means that each water feature has a stable configuration of specific essential parts. In particular, each water feature has a water body as an essential part, but as implied by the taxonomy below, different water features can also have other essential parts. A cloud has a water body as its only essential part, whereas a puddle has a water body and supporting surface as essential parts, and a river and aquifer have their container, void, supporting surface, and water body as essential parts, all arranged in a particular topological relation unique to each type of feature. Importantly, rigid and variable wholes can be nested: indeed, each of the stable water feature parts is in turn a variable whole, meaning that each can itself have changing parts in time, such as a water body with changing water matter, or a riverbed with changing segments due to the effect of physical processes over time. In essence, while a water feature has fixed essential parts configured uniquely, each such part can be dynamically exchanged over time.

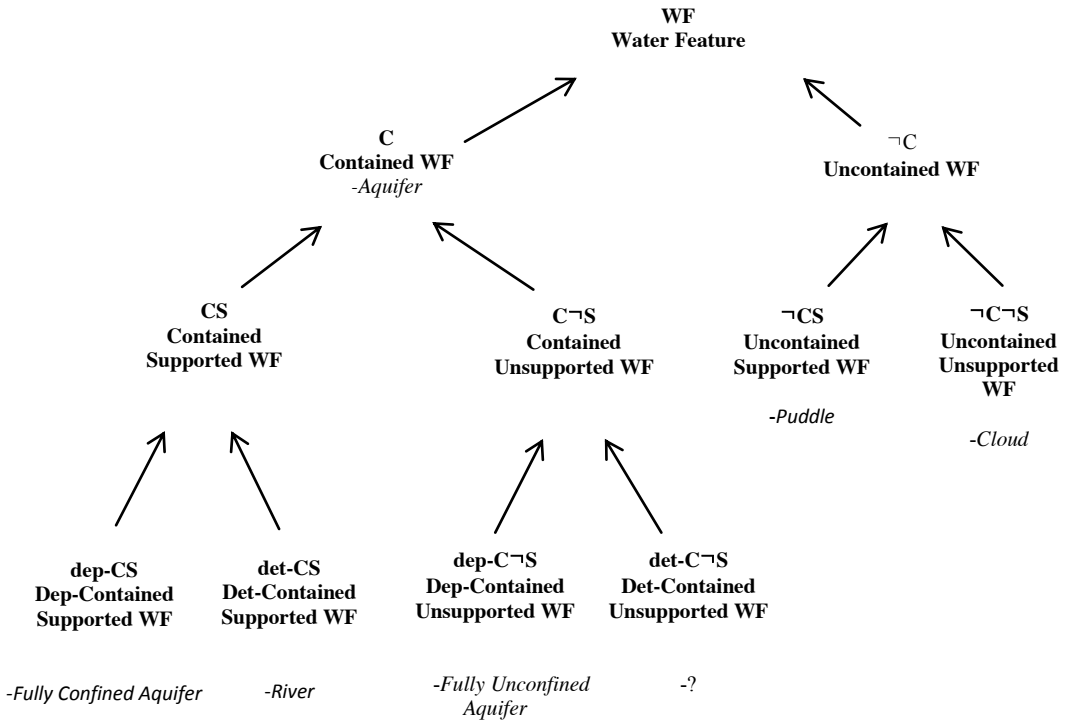

Figure 1. Taxonomy of water features.

This conceptualization of water features is being incorporated into the HyFO ontology, which is expressed in first-order logic as an extension of the DOLCE foundational ontology (Masolo *et al*. 2003): water features and bodies specialize DOLCE physical objects, water matter specializes DOLCE matter, while voids and supporting boundaries specialize DOLCE features. Important relations that bind these entities together include containment, void hosting, constitution, and dependence. The conceptualization can also be represented independently of DOLCE, as a so-called ontology design pattern. Unfortunately, neither representation can be adequately elaborated or illustrated here due to lack of space.

4. Summary and Future Directions

A new conceptualization for water features is developed by extending Hayes' ontology of liquids and applying Fine's theory of parts. The conceptualization is represented as a first-order logic extension of the DOLCE foundational ontology and as a lightweight ontology design pattern. It forms the core of the HyFO ontology, which is being developed as a reference ontology for the hydro domain and as an aid to interoperability. The conceptualization, via HyFO, is currently being tested in various ways, including via mappings with other hydro representations. Two interesting avenues remain to be explored in its design: applying dependence to the notion of support, to further distinguish types of support, and the inclusion of immaterial essential parts such as spiritual entities, as identified in ethnophysiographic studies. The conceptualization seems to be well positioned for enhancement in these directions. It remains to be seen, though, upon further testing, whether other notions deemed insufficiently fundamental will warrant inclusion, such as rate of water flow or degree of water consolidation, as originally suggested by Hayes.

Acknowledgements

The authors gratefully acknowledge support for this work obtained from the Groundwater Program of Natural Resources Canada and the Maine Economic Improvement Fund.

References

Boisvert E and Brodaric B, 2012, GroundWater Markup Language (GWML) – enabling groundwater data interoperability in spatial data infrastructures. *Journal of Hydroinformatics*, 14(1):93–107.

Dornblut I and Atkinson R, 2013, *Hy_features: a geographic information model for the hydrology domain*. Technical Report GRDC 43r1, Global Runoff Data Centre, November 2013.

Duce S and Janowicz K, 2010, Microtheories for Spatial Data Infrastructures – Accounting for Diversity of Local Conceptualizations at a Global Level. In: SI Fabrikant, T Reichenbacher, MV Kreveld and C Schlieder (Eds), *6th International Conference, GIScience 2010*, Springer, LNCS 6992, 27-41.

Fine K, 1999, Things and Their Parts. *Midwest Studies in Philosophy*, XXIII, 61-74.

Galton A and Mizoguchi R, 2009, The Water Falls but the Waterfall does not Fall: New perspectives on Objects, Processes, and Events. *Applied Ontology*, 4(2):71-107.

Hahmann T and Brodaric B, 2013, Kinds of full physical containment. In: T Tenbrink, J Stell, A Galton and Z Wood (Eds), *11th International Conference on Spatial Information Theory, COSIT-13*. LNCS 8116, Springer, 397-417.

Hayes PJ, 1978, *Naive Physics I: Ontology for Liquids*. Working Papers, No. 35, University of Geneva, 66 pp.

INSPIRE Thematic Working Group Geology, 2013, *D2.8.II.4 INSPIRE Data Specification on Geology – Draft Guidelines, v3.0 rc3*. Technical report, INSPIRE, 369 pp.

INSPIRE Thematic Working Group Hydrography, 2009, *D2.8.I.8 INSPIRE Data Specification on Hydrography – Guidelines, v3.0*. Technical report, INSPIRE, 175 pp.

Maidment DR, 2002, *Arc Hydro: GIS for Water Resources*. ESRI Inc, 203 pp.

Mark DM, Turk AG and Stea D, 2007, Progress on yindjibarndi ethnophysiography. In: S Winter, M Duckham, L Kulik and B Kuipers (Eds), *8th International Conference on Spatial Information Theory, COSIT 2007*. LNCS 4736, Springer, 1–19.

Masolo C, Borgo S, Gangemi A, Guarino N and Oltramari A, 2003, *Wonderweb Deliverable D18 – Ontology Library (Final Report)*. Technical report, National Research Council - Institute of Cognitive Sci. and Technology, Trento, 349 pp.

Santos P, Bennett B and Sakellariou G, 2005, Supervaluation Semantics for an Inland Water Feature Ontology. In: *Proceedings International Joint Conference on Artificial Intelligence*, *IJCAI-05*, 564–569.

Sinha G, Mark D, Kolas D, Varanka D, Boleslo ER, Feng C-C, Usery E, Lieberman J and Sorokine A, 2014, An Ontology Design Pattern for Surface Water Features. In: M Duckham, E Pebesma and K Stewart (Eds), *8th International Conference, GIScience 2014*. LNCS 8728, Springer, 187-203.

Strassberg G, Jones NL and Maidment DR, 2011, *Arc Hydro Groundwater : GIS for Hydrogeology*. ESRI Inc, 160 pp.

Wellen CC and Sieber RE, 2013, Toward an Inclusive Semantic Interoperability: The Case of Cree Hydrographic Features. *International Journal of Geographical Information Science*, 27(1):168-191.