Space for Space
SpacePortal: the 21st Century Home for Spatial Ontologies

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As the continued vibrancy of the field of 'space', 'spatial cognition', 'spatial qualitative reasoning and representation', 'spatial intelligence' and so on amply demonstrates, there is now considerable awareness that accounts of space and human abilities to deal with space constitute a key area of research. Space and our dealings with space provide for many of the skills essential for intelligent behaviour. Against this background, the Collaborative Research Center on Spatial Cognition at the Universities of Bremen and Freiburg supported by the German Research Council (DFG) from 2002 until 2014 has been seeking new inroads into the diverse phenomena of spatial cognition and the use of spatial skills for activities such as design, way-finding, spatial verbal communication, maps and other visual spatial information sources, as well as probing both the underlying neurocognitive mechanisms and the formal properties of spatial descriptions that make such skills possible.

A striking result of this work has been the recognition of the sheer diversity of spatial representations that can be usefully employed. Spatial intelligence appears to involve both heterogeneous specifications and combinations of such specifications according to the needs of specific tasks and situations. To deal with this compexity, we have adopted and extended methods from ontological engineering and are currently proposing new standards for the development and application of spatial (and other) ontologies. This new generation of methods involves both ontological content, in that we address a very broad range of ways of 'conceptualizing' space, and ontological formalisms, in that we actively explore use and integration of a variety of formalisms for ontological specifications. Examples of the former include ontological notions of region captured by region-based calculi [10, 6], extensions to include metric information, different kinds of objects, directions and movement, as well as foundational work on notions on mereology, formalizations of space, perspectivalization and much more [3, 2, 4, 5, 7]. Examples of the latter range from classes of formalizations lying broadly within the expressive capabilities of description logic [8] up to the more expressive possibilities of first order logic and beyond for axiomatisations of many of the basic theories of space. Bateman and Farrar offered an early catalogue of these formalizations and their potential relation to ontological specifications [1].

Our exploration and development of tools and content has now reached the stage where the techniques and supporting software are ready for more general application. For expressing heterogeneous specifications and formally capturing diverse theories of space potentially expressed in quite different logical languages, we adopted the Hetereogenous Toolset (HETS [9]) and its notions of heterogeneous specifications. These now shape the Distributed Ontology Language DOL, part of the emerging Ontology Integration and Interoperability standard (OntoIOp) at the Object Management Group (OMG).[4]. Building on this further, a new foundation has now been achieved for collecting the diverse formal specifications developed for space over the years. A framework for a semantically sophisticated repository for spatial ontologies has been defined and we are currently engaged both in populating this repository and in exploring mappings between possibly quite heterogeneous specifications.

The value and potential significance of this initiative can be brought out dramatically by considering the state of the art in the biology domain. Several years ago a persistent repository called BioPortal was established with considerable input on ontology design and principles from Barry Smith (Buffalo). This provided a central point worldwide for depositing and sharing ontologies in the biomedical area: it is the one clear example of large-scale ontology sharing across an entire community to exist at this time. We believe that the time is now ripe to undertake a parallel effort in the related areas of spatial cognition, GIS and spatial specifications in general. Our repository, called SpacePortal, is intended to act as a point of crystallization for a large-scale sustainable orientation to qualitative and ontological accounts of space, while still preserving the strong formal foundation necessary for using such resources in reasoning.

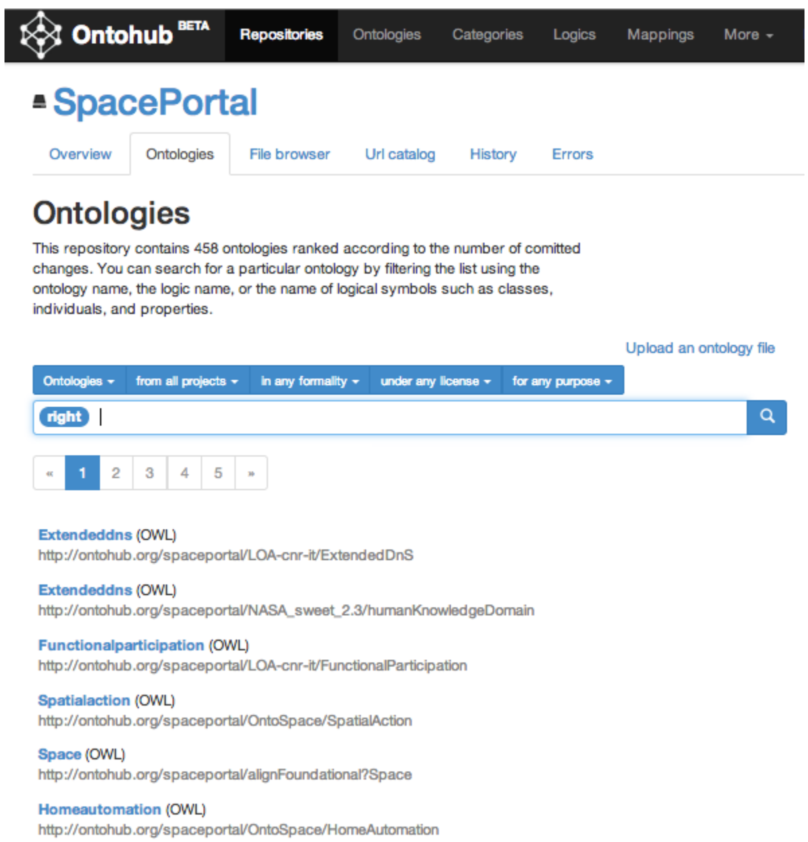
A usable ontology repository needs to support several critical features that go beyond a simple 'storage' place for ontological specifications. Of particular importance is the need to operate semantically, i.e., with an understanding of the specifications maintained, rather than merely acting as a store for uninterpreted texts. This becomes an increasing challenge when the specifications are drawn from different logics and diverse perspectives. In addition, to support and explore synergies and reuse across modular ontologies it is necessary to provide formal connections or mappings between ontologies. Considered formally such connections are best seen as 'alignment' relations that are used to relate terms living in different ontologies. The basic purpose of alignments is to support better the re-use of existing ontologies, and to understand their relationship better. However, several problems are immediate: (1) alignments across (heterogeneous) specifications are meaningless without proper semantics and provide little in terms of re-use; (2) alignments need to be complemented with means to *use* the alignments in order to extract desired information; and (3) the combined consistency and the sheer size of aligned ontologies need to be taken into account. All these problems have sound solutions in the DOL/Ontohub context that we are developing. The Ontohub platform now supports multiple (onto)logical formalisms (e.g. OWL, CL, OBO, RDF, CASL, etc) as well as various mappings between ontologies. The repository engine is designed to manage distributed and heterogeneous ontologies. The heterogeneous nature makes it possible to integrate ontologies written in various ontology languages. And the distributed nature of the system is intended to enable communities to

[4] `http://www.omg.org/cgi-bin/doc?ad/2013-12-02`

share and exchange their contributions easily. SpacePortal builds on these formal underpinnings and technological infrastructure and so can support the collection and re-use of ontologies across the large array of space-related domains.
Currently, SpacePortal comprises the following folders of ontologies (sometimes as mirrors, sometimes genuinely hosted as SpacePortal), expressed not only in OWL (e.g. GUM-Space), but also in first-order logic (e.g. GFO spatial ontology and COLORE):

- GeoNames, an ontology for geospatial semantic information,
- LOA-cnr-it, containing ontologies developed at LOA in Trento, in particular the upper ontology DOLCE featuring fundamental spatial concepts,
- NASA_sweet_2.3, the Semantic Web for Earth and Environmental Terminology ontologies,
- OntoSpace, containing ontologies developed in the SFB/TR "Spatial Cognition", in particular GUM-Space, as well as ontologies for architecture, home automation, as well as spatial calculi,
- SESAME-S, providing an ontology for smart buildings,
- SOCoP, a repository of geo-spatial OWL ontologies maintained by the Open Ontology Repository (OOR) community. SOCoP is currently hosted using BioPortal technology, but has been unavailable recently—indeed, the SoCOP mirror at `ontohub.org/socop` may turn into a replacement in the near future.
- COLORE, a repository of richly-axiomatized ontologies, written in Common Logic, including concepts from geometry, mereology, and processes in time and space. The COLORE maintainers have announced to host COLORE at Ontohub in the future.

In order to achieve a sustainable and comprehensive integration of such diverse heterogeneous ontologies as SpacePortal content, we implement two orthogonal approaches: 1) horizontal categorization of domains for spatial ontologies and 2) vertical interconnection of spatial concepts that supports interoperability and a flexible 'communication' across heterogeneous spatial ontologies. This in turn is leading to a deeper consideration of contributing ontologies so as to find sophisticated alignments beyond that which can be isolated by surface means, such as



databases of synonyms with applications of WordNet. Using these alignments, we aim at an integrated upper ontology by formal combination of ontologies as defined above. This combination will naturally cover more aspects of space than the ontologies individually.
SpacePortal ontologies are also categorised according to criteria that distinguish specific fields in which a spatial ontology might be being applied. For example, *Shape* is a spatial concept that is addressed in different ways across diverse fields of spatial representation and with varying formalisations and so provides a useful cross-ontology access category. The category system adopted is also maintained as an OWL ontology in Ontohub.[5] With the establishment of integrated upper ontologies and broadly relevant classifications for spatial categories, we are also considering further applications of this information beyond the narrow confines of spatial reasoning as such — including, for example, the possibility of using ontological categories as indexes into document collections.
Work on SpacePortal continues and now seeks a broader involvement and input from the research community as a whole. Space-related ontologies can be uploaded through the file system at `http://ontohub.org/spaceportal` in any of the supported formats (See `http://wiki.ontohub.org/index.php/Logic`). Detailed instructions for new users of SpacePortal are available at `http://wiki.ontohub.org/index.php/SpacePortal`.

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[5] `http://ontohub.org/meta`