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# HOW DO PEOPLE THINK ABOUT SPACE?

Position paper for
Dagstuhl Seminar 10131: Spatial Representation and Reasoning in Language
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## 1. My Past

I read the collection of papers in "Formal Theories of the Commonsense World" by Hobbs and Moore [1985] in the 1980s. The "Naive Physics Manifest" by Hayes [1978] and its application to geography and GIS has been a challenge since: How do people think about space? How does common spatial thinking work?

In Max Egenhofer's PhD thesis we explored topological, qualitative spatial reasoning [1989][Egenhofer and Franzosa, 1991]; later I worked on qualitative distances and directions[Frank, 1996][Frank, 1992]. David Mark and I organized the "Las Navas" meeting on "Cognitive and Linguistic Aspects of Geographic Space" [Mark and Frank, 1991] heavily influenced by Talmy's "How Language Structures Space" [1983] and the Image Schemata concept of Johnson [1987]. Later I formalized spatial prepositions [Frank and Raubal, 1999, Frank, 1998].

My GIScience oriented ontology work convinced me that the usual static approach is not fruitful and I have recently shown how to combine spatial and task planing in a formally elegant way Frank [2009].

## 2. Open Problems

(1) I do not know of an elegant formalization for topological relations between regions of different dimension, regions with holes, etc.; the limitations of Egenhofer relations or the equivalent RCC-8 relations by Cui et al. [1993], which remain a vexing problem.

(2) Geometry of real objects does not consist of dimensionless points and infinitely thin lines. How to reason formally with wide lines and extended points? [Rosenfeld, 1994, Buckley and E.Eslami, 1997] The "Egg and Yolk" approach by Clementini and Di Felice [1996] and Cohn and Gotts [1996] and its extension to fuzzy boundaries [Dilo et al., 2004] does not cover geometric constructions like intersection, bisector, etc. of lines. Wilke investigates currently if a subset of Euclidean geometry can be formalized for extended "spray can" geometry [Wilke and Frank, 2009] with objects using Pavelka algebra[Pavelka, 1979].

(3) An effort to build representations for geometric objects that are valid for any dimension are underway by Karimipour et al. [2008a,b]; we have a representation, which supports gradual refinement (i.e., level of detail), and gives elegant algorithms for union and intersection of two regions of n-dimension (n=2, 3, ...) Bulbul and Frank [2009], Bulbul et al. [2009]. The representation gives, similar to region quadtrees, an approximation with an outer and an inner limit; Egg-Yolk reasoning would bne applicable.

## 3. Challenges

### 3.1. Level of Detail.

Reasoning with multiple levels of detail (and generally with multiple representations were discussed by Buttenfield and Delotto [1989], Buttenfield [1993]. People switch effortless between the conceptualization of a city as a point ("I flew to London") and an extended object ("I found a hotel in London").

This challenge seems to be related to the next:

### 3.2. Realistic Ontology for Space AND Time.

Constructing an ontology with spatial objects or assigning geometries to objects is possible [Bennett, 2001], even when enforcing spatial constraints (e.g., some object collections, like ownership parcels must be jointly exhaustive, pairwise disjointed, often abbreviated as JEPD). Including eminently spatial aspects like movement or subdivision of objects cannot be included in current ontological formalism because they are static representations and do not include operations to change the values of the relations modeled.

I assume today that the plan to address first static space and later combine it with time – as for example, proposed by the NCGIA initially [1989] – does not work. Movement in space is a fundamental part of spatial thinking and without motion we will not capture how people think about space. Note, that I focus on movement here as the, perhaps most prominent, aspect of physical operations, occuring in space. Movement is just one of the Image Schemata, which capture on a very general level the concept of space and operations in space.

## 4. How to Proceed

I strongly believe in use cases, preferably not constructing "academic" use cases, but real cases the researcher experiences daily. This should not be too difficult for spatial reasoning, as we all live and move in space.

In the seminal paper "Naive Geography" by Egenhofer and Mark [1995] many of the above mentioned problems were already listed; they dreamt of a "GIS that can be used without major training by a new user community such as average citizens". I, and perhaps others, derived from this two use cases on which I see research concentrated:

- Giving instructions for navigation: I find, however, that I, at least, readily adapt to whatever linguistic expression a car navigation system selects; "naturalness" is not really required, consistency is all that counts. Difficulties occur when my visual conceptualization of the objects in the world differs from the navigation systems notion of, e.g., the continuation of a road by road name, which is an issue of semantic classification of objects [Frank, to appear 2006]
- Understanding human descriptions of spatial situation: Limited cases are solvable, e.g., Pierre Loustau (PhD University of Pau) built a system to analyze the extensive travel descriptions of the 19th century and produce geometric representations that can be visualized on a map and queried. Integrating descriptions from different sources, with different liability remains a problem (already attached and partially solved in Werner Kuhn's PhD thesis [1989]).

## 5. Approaches

The difficulty is to ask the right question. Small improvements to existing theories are possible (e.g., extensions to RCC or Egenhofer 4- or 9-intersections, a fuzzyfication of x, etc.) but do not likely yield novel insight to the fundamental question: What is space? How do people think about space, i.e. how do humans conceptualize space, time and operations in space.

I follow at the moment a tiered approach [Frank, 2001], where in the first tier I posit an Euclidean 3D world with linear time and continuous physical processes. Human reasoning is, however, with physical objects and discrete operations that form tier 2. Social meaning of objects and operations is in tier 3, including linguistic descriptions of spatial simulations in tier 2, which have a physical existence in tier 1. The operations at the different tiers are connected, as the lower tier 'implements' the operation of the next higher tier (note, that I exclude 'freestanding Y terms' meaning, that every X, which counts as Y in the context Z [Smith and Searle, 2001] is eventually grounded in a physical object of tier 2). Formalization in a computer checkable form helps to avoid ones own misconception and the unnecessary ballast of 2000 years of metaphysics.

## References

Brandon Bennett. Space, time, matter and things. In C. Welty and B. Smith, editors, *Proceedings of the 2nd international conference on Formal Ontology in Information Systems (FOIS'01)*, pages 105–116, Ogunquit, Maine, USA, 2001. ACM.

J.J. Buckley and E.Eslami. Fuzzy plane geometry i: Points and lines. *Fuzzy Sets and Systems*, 86:179–187, 1997.

R. Bulbul and A.U. Frank. AHD: The Alternate Hierarchical Decomposition of Nonconvex Polytopes (Generalization of a Convex Polytope Based Spatial Data Model). In *17th International Conference on Geoinformatics. Fairfax, USA*, 2009.

R. Bulbul, F. Karimipour, and A.U. Frank. A Simplex based Dimension Independent Approach for Convex Decomposition of Nonconvex polytopes. 2009.

Barbara P. Buttenfield. Multiple representations - closing report. Technical report, Buffalo, 1993.

B.P. Buttenfield and J. Delotto. Multiple representations: Report on the specialist meeting. Technical report, 1989.

Eliseo Clementini and Paolino Di Felice. An algebraic model for spatial objects with indeterminate boundaries. In Peter A. Burrough and Andrew U. Frank, editors, *Geographic Objects with Indeterminate Boundaries European Science Foundation*, volume 2, pages 155–169. Taylor & Francis, 1996.

A.G. Cohn and N.M. Gotts. The 'egg-yolk' representation of regions with indeterminate boundaries. In Peter Burrough and Andrew U. Frank, editors, *Geographic Objects with Indeterminate Boundaries*, volume GISDATA II. Taylor & Francis, London, 1996.

Z. Cui, A. G. Cohn, and D. A. Randell. Qualitative and topological relationships in spatial databases. In David Abel and Beng Chin Ooi, editors, *Advances in Spatial Databases (Third Symposium on Large Spatial Databases, SSD '93, Singapore)*, volume 692, pages 296–315. Springer-Verlag, Berlin, 1993.

A. Dilo, R. A. de By, and A. Stein. Definition and implementation of vague objects. In Andrew U. Frank and Eva Grum, editors, *ISSDQ '04*, volume 28a (Volume

1), pages 139–145, Bruck a.d. Leitha, 2004. Department of Geoinformation and Cartography.

Max J. Egenhofer. *Spatial Query Languages.* PhD thesis, University of Maine, 1989.

Max J. Egenhofer and Robert D. Franzosa. Point-set topological spatial relations. *International Journal of Geographical Information Systems*, 5(2):161–174, 1991.

Max J. Egenhofer and David M. Mark. Naive geography. In Andrew U. Frank and Werner Kuhn, editors, *Spatial Information Theory - A Theoretical Basis for GIS*, volume 988, pages 1–15. Springer-Verlag, Berlin, 1995.

A Frank. Formal models for cognition - taxonomy of spatial location description and frames of reference. In *In C. Freksa, C. Habel, K. F. Wender (Eds.), Spatial Cognition*, pages 293–312. Springer Verlag, 1998.

A. Frank. Distinctions - a common base for a taxonomic calculus for objects and actions. *Spatial Cognition and Computation*, to appear 2006.

A. U. Frank. Tiers of ontology and consistency constraints in geographic information systems. *International Journal of Geographical Information Science*, 75 (5 (Special Issue on Ontology of Geographic Information)):667–678, 2001. URL ftp://ftp.geoinfo.tuwien.ac.at/frank/3465tiers-of-ontology.PDF.

A U Frank and M Raubal. Formal specifications of image schemata - a step to interoperability in geographic information systems. *Spatial Cognition and Computation*, (1):67–101, 1999.

Andrew U. Frank. Qualitative spatial reasoning about distances and directions in geographic space. *Journal of Visual Languages and Computing*, 1992(3):343–371, 1992. URL ftp://ftp.geoinfo.tuwien.ac.at/frank/afqualspatrddgs92.pdf.

Andrew U. Frank. Qualitative spatial reasoning: Cardinal directions as an example. *IJGIS*, 10(3):269–290, 1996. URL ftp://ftp.geoinfo.tuwien.ac.at/frank/ijgis-frank.ps.

Andrew U. Frank. Wayfinding for public transportation users as navigation in a product of graphs. *VGI*, 95 (2):195–200, 2009.

Patrick J. Hayes. The naive physics manifesto. In D. Mitchie, editor, *Expert Systems in the Microelectronic Age*, pages 242–270. Edinburgh University Press, Edinburgh, 1978.

J. Hobbs and R. C. Moore, editors. *Formal Theories of the Commonsense World*. Ablex Series in Artificial Intelligence. Ablex Publishing Corp., Norwood, NJ, 1985.

M. Johnson. *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason.* University of Chicago Press, Chicago, 1987.

F. Karimipour, M.R. Delavar, and A.U. Frank. A mathematical tool to extend 2d spatial operations to higher dimensions. 5072/2008:153–164, 2008a. URL http://www.springerlink.com/content/42n52184650r27q5.

Farid Karimipour, Andrew U. Frank, and Mahmoud R. Delavar. An operation-independent approach to extend 2d spatial operations to 3d and moving objects. In *GIS '08: Proceedings of the 16th ACM SIGSPATIAL international conference on Advances in geographic information systems*, pages 1–6, New York, NY, USA, 2008b. ACM. ISBN 978-1-60558-323-5.

W. Kuhn. *Interaktion mit raumbezogenen Informationssystemen - Vom Konstruieren zum Editieren geometrischer Modelle*, volume Mitteilung Nr. 44. Institut fÃŒr Geodaesie und Photogrammetrie, ETH ZÃŒrich, ZÃŒrich, 1989.

David M. Mark and Andrew U. Frank, editors. *Cognitive and Linguistic Aspects of Geographic Space*, volume 63 of *NATO ASI Series D*. Kluwer Academic Publishers, Dordrecht, The Netherlands, 1991.

NCGIA. The u.s. national center for geographic information and analysis: An overview of the agenda for research and education. *IJGIS*, 2(3):117–136, 1989. International Journal of Geographic Information and Analysis.

Jan Pavelka. On fuzzy logic i, ii, iii. *Zeitschrift fur Mathematische Logik und Grundlagen der Mathematik*, 25:45–52, 119–134, 447–464, 1979.

Azriel Rosenfeld. Fuzzy plane geometry: Triangles. *Fuzzy Systems. IEEE World Congress on Computational Intelligence.*, vol.2:891–893, 1994.

Barry Smith and John Searle. The construction of social reality: An exchange. *American Journal of Economics and Sociology*, 60, 2001.

L. Talmy. How language structures space. In H.Pick and L. Acredolo, editors, *Spatial Orientation: Theory, Research, and Application*. Plenum Press, New York, NY, 1983.

G. Wilke and A.U. Frank. Projective spray can geometry-towards an axiomatic approach to error modelling for vector based geographic information systems. *Currently under Review for GEOWS*, 2009.