Towards Linguistically-Grounded Spatial Logics
– Extended Abstract –

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Spatial Logics and Spatial Language. The system of Euclidean geometry is defined by geometrical axioms with points and lines as primitive entities [Hilbert, 1899, Tarski, 1959]. It provides the ground for *spatial logics*, a formal language used for describing geometrical entities and configurations [Aiello et al., 2007], interpreted over a class of geometric structures. These structures can be any kind of geometrical spaces, such as topological spaces, affine spaces, or metric spaces.

While spatial logics can specify spatial (geometry-based) entities, relations, and their axioms in a broad way, a more specific subclass are logics for *qualitative spatial reasoning*, often called *spatial calculi*. Their motivation builds on the idea that reasoning over qualitative descriptions resemble more closely human reasoning, and it may thus lead to more efficient and effective reasoning strategies than reasoning over numerical descriptions [Cohn and Hazarika, 2001]. Spatial calculi often focus on one particular qualitative spatial aspect, such as distance, shape, orientation, or topology, and on primitive types of objects in the Euclidean plane, such as points or regions. They define possible spatial relations among spatial entities and their axioms accordingly.

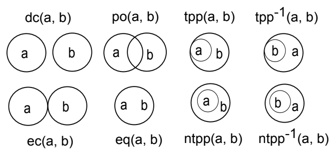
Some spatial calculi use linguistic terms to define spatial relations (e.g., [Kurata and Shi, 2008]), aiming at being cognitively adequate and suitable particularly for natural language interpretation. These calculi, however, not precisely reflect natural language semantics but meanings that are determined by the calculus' own axioms. Specifically, the diverse use of language [Bateman, 2010] requires more complex as well as more flexible logical formalizations. Such formalisms have to take into account contributing aspects for spatial language interpretations, such as context or world knowledge, in order to achieve a link or mapping from spatial language to logics [Hois and Kutz, 2008b], i.e., from a natural language sentence to an abstract spatial formalization [Kordjamshidi et al., 2010]. Even though spatial calculi might not be able to exactly reflect spatial language, they can formalize certain aspects of it, e.g., useful for spatial dialogue systems [Ross, 2008].

We propose a method to analyze the amount of coverage and adequacy a spatial calculus provides by relating the calculus to a linguistic ontology for space using similarities and linguistic corpus data. It allows evaluating whether and where a spatial calculus can be used for natural language interpretation. It can also lead to "more appropriate" spatial logics for spatial language.

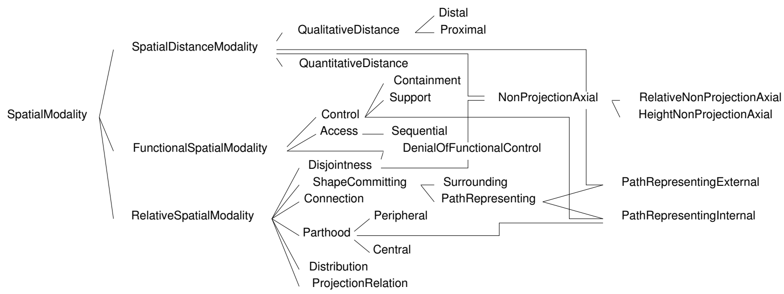
Analyzing Linguistic Coverage of Spatial Logics. For analyzing which aspects of spatial language a spatial calculus covers, the linguistic aspects have to be schematically described and categorized into spatial linguistic units of the same kind. For this purpose we use the Generalized Upper Model for spatial language (GUM-Space) [Bateman et al., 2010], which is a *linguistically-motivated ontology* that draws on findings from empirical cognitive and psycholinguistic research as well as results from theoretical language science. It basically categorizes parts of natural language sentences that contain spatial information into groups that have the same semantics. For instance, every static spatial position (e.g., 'something being on the table', 'on the ground', or 'at the wall') or every starting point of a motion (e.g., 'someone moving away from the door', 'leaving the house', or 'exiting the roundabout') is logically specified in the same way. In particular, GUM-Space is formalized as a description logic, which specifies spatial units that provide particular kinds of spatial information respectively. Hence, analyzing which parts of GUM-Space are reflected in spatial calculi can show their linguistic coverage.

Relating different logics has been investigated thoroughly (cf., e.g., [Kutz et al., 2008]) and we use some of these techniques for relating GUM-Space with a spatial calculus. In earlier work we have shown that the relationship between spatial language and logics is influenced by situational and context-dependent characteristics and can in most cases only be given with a certain likelihood. We have therefore introduced the theory of $\mathcal{S}$-Connections [Hois and Kutz, 2008a] that allows the use of similarities assigned to links from linguistic units in GUM-Space to spatial relations in a calculus. The way to examine linguistic coverage of a spatial calculus is illustrated in the following.

RCC8 and GUM-Space. The Region Connection Calculus RCC8 [Randell et al., 1992], heavily being used in qualitative spatial representation and reasoning, provides 8 basic relations (see Fig. 1a), which are mutually exclusive and exhaustive in describing the possible overlap and touching relationships between two (well-behaved[1]) regions in space. Each linguistic category in GUM-Space can be related with a similarity value to each of the 8 given relations. For example, some categories in GUM-Space distinguish static positions vs. dynamic motions implying that the first seems to be easily linkable to the RCC8 relations, while motion is not directly covered by this calculus (unless neighborhood graphs are used as a form of spatial change over time). GUM-Space also provides a thorough distinction between different types of spatial relationships, i.e., whether an entity is located relative to another entity with regard to a particular *modality*, such as projection ('left, behind, above'), direction ('south, east, up, to'), distance ('by, near, far away from'), denial of control ('outside, off'), or shape-committing ('around, across')[2]



(a) The RCC8 relations



(b) Selected GUM-Space spatial mdoalities

Figure 1: Spatial Logic and Spatial Language

While certain modalities are clearly not supported by RCC8 (e.g., projection, direction, and shape-committing), their coverage of parthood and disjoint relationships (see Fig. 1b) can be related in more detail. For this purpose, empirical data from experimental studies for spatial natural language, such as the *Rolland* Corpus [Shi and Tenbrink, 2009] for English, in which participants were asked to locate (static) objects in space in a room, can be classified by the GUM-Space schema [Hois, 2010], and determine the similarity values for the related RCC8 relations. It is thus possible to analyze whether there are clearly distinguishable similarities for relations between certain GUM-Space categories and RCC8 relations, indicating that these are more precisely covered by RCC8 than others. The similarities also indicate which RCC8 relations are 'well-defined' in terms of spatial language, e.g., how broad their coverage is. For instance, all distance-related GUM-Space modalities are linked to disjointness (dc) in RCC8 with the highest similarity but to no other relations, i.e., distance is only broadly covered by RCC8.

This analysis method between spatial language and logic furthermore supports selecting the 'most adequate' calculus for certain sets of GUM-Space categories, e.g., for natural language interpretation. This selection is strongly guided by empirical data from linguistic corpora for these sets.

[1]This is typically taken to mean regular-closed subsets of a topological space, i.e., region X such that $X = \mathbf{CI}X$.

[2]The linguistic examples given for the different spatial modalities are primarily used for illustration. In many cases, the actual use of lexical units in different sentences can lead to different classifications respectively.

References

[Aiello et al., 2007] Aiello, M., Pratt-Hartmann, I. E., and van Benthem, J. (2007). What is spatial logic? In Aiello, M., Pratt-Hartmann, I. E., and van Benthem, J., editors, *Handbook of Spatial Logics*, pages 1–11. Springer.

[Bateman, 2010] Bateman, J. (2010). Situating spatial language and the role of ontology: issues and outlook. *Linguistics and Language Compass*, page forthcoming.

[Bateman et al., 2010] Bateman, J., Hois, J., Ross, R., and Tenbrink, T. (in press, 2010). A linguistic ontology of space for natural language processing. *Artificial Intelligence*.

[Cohn and Hazarika, 2001] Cohn, A. G. and Hazarika, S. M. (2001). Qualitative spatial representation and reasoning: An overview. *Fundamenta Informaticae*, 43:2–32.

[Hilbert, 1899] Hilbert, D. (1899). The foundations of geometry. The Open Court Publishing Co.

[Hois, 2010] Hois, J. (2010). Inter-annotator agreement on a linguistic ontology for spatial language — a case study for GUM-Space. In Calzolari, N., Choukri, K., Maegaard, B., Mariani, J., Odjik, J., Piperidis, S., Rosner, M., and Tapias, D., editors, *7th International Conference on Language Resources and Evaluation (LREC'10)*, pages 3464–3469. European Language Resources Association (ELRA).

[Hois and Kutz, 2008a] Hois, J. and Kutz, O. (2008a). Counterparts in Language and Space—Similarity and $\mathcal{S}$-Connection. In *Proceedings of the International Conference on Formal Ontology in Information Systems (FOIS-2008)*, pages 266–279, Amsterdam. IOS Press.

[Hois and Kutz, 2008b] Hois, J. and Kutz, O. (2008b). Natural Language meets Spatial Calculi. In Freksa, C., Newcombe, N. S., Gärdenfors, P., and Wölfl, S., editors, *Spatial Cognition VI. Learning, Reasoning, and Talking about Space*, pages 266–282. Springer.

[Kordjamshidi et al., 2010] Kordjamshidi, P., Otterlo, M. V., and Moens, M.-F. (2010). Spatial role labeling: Task definition and annotation scheme. In Calzolari, N., Choukri, K., Maegaard, B., Mariani, J., Odjik, J., Piperidis, S., Rosner, M., and Tapias, D., editors, *7th International Conference on Language Resources and Evaluation (LREC'10)*, pages 413–420. European Language Resources Association (ELRA).

[Kurata and Shi, 2008] Kurata, Y. and Shi, H. (2008). Interpreting motion expressions in route instructions using two projection-based spatial models. In Dengel, A., Berns, K., Breuel, T. M., Bomarius, F., and Roth-Berghofer, T., editors, *KI 2008: Advances in Artificial Intelligence*, pages 258–266. Springer.

[Kutz et al., 2008] Kutz, O., Lücke, D., and Mossakowski, T. (2008). Heterogeneously Structured Ontologies—Integration, Connection, and Refinement. In Meyer, T. and Orgun, M. A., editors, *Knowledge Representation Ontology Workshop*, pages 41–50. ACS.

[Randell et al., 1992] Randell, D. A., Cui, Z., and Cohn, A. G. (1992). A Spatial Logic Based on Regions and Connection. In *Proceedings of the 3rd International Conference on the Principles of Knowledge Representation and Reasoning (KR'92)*, pages 165–176. Morgan Kaufmann, Los Altos.

[Ross, 2008] Ross, R. (2008). Tiered models of spatial language interpretation. In Freksa, C., Newcombe, N. S., Gärdenfors, P., and Wölfl, S., editors, *Spatial Cognition VI: Learning, Reasoning, and Talking about Space*, pages 233–249. Springer.

[Shi and Tenbrink, 2009] Shi, H. and Tenbrink, T. (2009). Telling rolland where to go: HRI dialogues on route navigation. In Coventry, K., Tenbrink, T., and Bateman, J., editors, *Spatial Language and Dialogue*, pages 177–189. Oxford University Press, Oxford.

[Tarski, 1959] Tarski, A. (1959). What is elementary geometry? *Studies in Logic and the Foundations of Mathematics*, 27:16–29.