Dagstuhl Seminar 10131 Proceedings: Spatial Representation and Reasoning in Language: Ontologies and Logics of Space

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1 Executive Summary

The goal of this seminar was to bring together researchers from diverse disciplines to address the spatial semantics of natural language, the interface between spatial semantics and geospatial representations, and the role of ontologies in reasoning about spatial concepts in language and thought. There are five themes that were addressed in this seminar:

1. Designing and reasoning with spatial ontologies;
2. Representing and processing spatial information in language;
3. Identifying appropriate spatial logics for linguistic expressiveness;
4. Mapping and normalizing spatial representations for geospatial tasks and domains;
5. Integrating temporal and spatial ontologies and logics for reasoning about motion and change.

To this end, we invited researchers from the following areas: spatial and temporal logics, qualitative reasoning, ontologies and knowledge representation, natural language processing, geographic information systems, and computational semantics. As a result of the discussion from this seminar, we expect the following milestones and agreements to emerge:

1. Coordination on ontologies for space and time;
2. Initial consensus on spatial representations derived from language;

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3. Strategies for mapping linguistically derived spatial information to GIS baseline representations.

The relation between language and space has long been an area of active research. Human languages impose particular linguistic constructions of space, of spatially-anchored events, and of spatial configurations that relate in complex ways to the spatial situations in which they are used. Establishing tighter formal specifications of this relationship has proved a considerable challenge and has so far eluded general solutions. One reason for this is that the complexity of spatial language has often been ignored. In much earlier and ongoing work, language is assumed to offer a relatively simple inventory of terms for which spatial interpretations can be directly stated. Examples of this can be found not only in accounts that focus on formalizations of particular tasks, such as path and scene descriptions, navigation and way-finding, but also in foundational work on the formal ontology of space, on qualitative spatial calculi, and on cognitive approaches.

In all of these approaches the principal burden of explanation is located within the non-linguistic formalizations pursued. This produces characterizations of spatial semantics that mirror the tasks and formal criteria addressed rather than the properties required for treating spatial language. These characterizations turn out to be ill-suited for dealing with the extreme flexibility of spatial language as used in real contexts. To bring the flexibility of spatial language use under control, we pursue a detailed formalization of what language itself brings to the interpretation of space. In particular, we consider language as contributing a structure of the spatial world that can be formulated as an ontology. This organization provides an additional layer of ontological information that formalizes the semantic commitments entered into by any linguistic spatial construction. Such semantic commitments are intended to capture precisely the degree of formalization required to explain the linguistic options taken up while at the same time avoiding over-commitment with respect to the physical or conceptual spatial situations in which those linguistic options may be exercised. These commitments are a reflection of the underlying semantic ontologies being referenced by language, and at the same time are an image of the specific structures assumed in the spatial logics allowing us to reason about objects in space and through time.

A distinct, well-defined and empirically-motivated layer of semantics for spatial language of this kind has direct applications for many currently relevant tasks involving spatial language. These include attempts to support communication via natural language with the human users of Geographic Information Systems and of context-based services. GIS traditionally includes fields such as cartography and surveying, but recently work in this area has expanded to include photogrammetry, remote sensing, spatial databases, spatial cognition, and spatial statistics. The application of geographical information systems is far reaching, including topics such as geodemographics, demographic segregation, evacuation, impact of disasters such as flooding, and medical geography. In addition to these systems, there is also interest in studying the underlying principles of geospatial technologies, including analysis and simulation of pedestrian movement. In fact, computing dynamic information has recently become an important part of emerging GIS technologies.

A further area in which a better understanding of the connection between natural language and formal representations of space is required is the automatic enrichment of textual data with spatial annotations. There is a growing demand for such annotated data, particularly in the context of the semantic web. Moreover, textual data routinely make reference to objects moving through space over time. Integrating such information derived from textual sources into a geosensor data system can enhance the overall spatiotemporal representation in changing and evolving situations, such as when tracking objects through space with limited image data. Hence, verbal subjective descriptions of spatial relations need to be translated into metrically meaningful positional information. A central research question currently hindering progress in interpreting textual data is the lack of a clear separation of the information that can be derived directly from linguistic interpretation and further information that requires contextual interpretation. Markup schemes should avoid over-annotating the text, in order to avoid building incorrect deductions into the annotations themselves. Solutions to the language-space mapping problem and its grounding in geospatial data are urgently required for this. To this end, another goal of this seminar is to discuss recent advances in the spatial semantics of natural language and the interface between spatial semantics and geospatial representations.

Given the explosion in the range of distinct treatments of spatial information, particularly in axiomatizations of distinct spatial calculi, it becomes a challenging research issue to consider just which of these proposals are appropriate for describing the semantics of spatial language and which less so. This may serve as a useful guide for further directions of formalization for space which offers evaluation metrics for competing axiomatizations.

Finally, we addressed the problem of integrating spatial representations with temporal knowledge in the service of modeling motion and change. The recognition of spatial entities in natural language is an important component of understanding a text. However, simply identifying fixed geospatial regions and specific facilities is not enough to achieve a complete representation of all the spatial phenomena present. In fact, this leaves out one of the most crucial aspects of spatial information, i.e., motion. To capture motion, we must integrate temporal and spatial information with the lexical semantics of motion predicates and prepositions. The goal of this line of research is to further the representational support for spatio-temporal reasoning from natural language text in the service of reasoning. If we are to successfully capture motion phenomena in text, annotations for temporal and spatial information must be merged, just as a topological base and a temporal calculus need to be combined to model motion predicates.

2 Presentations

Below is a listing of the researchers attending the Seminar, followed by abstracts for those presenting.

1. John Bateman, Universität Bremen, Germany
2. Brandon Bennett: Division of Artificial Intelligence, School of Computing, University of Leeds, UK, brandon@comp.leeds.ac.uk
3. Nate Blaylock: Institute for Human and Machine Cognition, Pensacola, FL, blaylock@ihmc.us
4. Robert J. Bobrow: Division Scientist, BBN Technologies, Cambridge, MA, rusty@bbn.com
5. Stefano Borgo: Laboratory for Applied Ontology, ISTC-CNR, Trento, Italy, stefano@loa-cnr.it

6. Max Egenhofer: Spatial Information Science and Engineering, University of Maine, Orono, Maine, max@spatial.maine.edu

7. Carola Eschenbach: Knowledge and Language Processing, University of Hamburg, Germany, eschenbach@informatik.uni-hamburg.de

8. Kenneth D. Forbus: EECS Department Northwestern University, IL. forbus@northwestern.edu

9. Andrew Frank: Institute for Geoinformation and Cartography, Technical Universtiy of Vienna, frank@geoinfo.tuwien.ac.at

10. Christian Freksa: Informatics, Universität Bremen, Bremen, Germany, freksa@informatik.uni-bremen.de

11. Christopher Habel , Universität Hamburg

12. Jerry R. Hobbs: USC/ISI, Marina del Rey, CA, USA. hobbs@isi.edu

13. Joana Hois: Universität Bremen, Bremen, Germany, joana@informatik.uni-bremen.de

14. Oliver Kutz: Universität Bremen, Bremen, Germany, okutz@informatik.uni-bremen.de

15. Inderjeet Mani: MITRE corporation, Bedford, MA, imani@mitre.org

16. David McDonald, BBN, Cambridge, MA

17. Till Mossakowski: DFKI-Lab Bremen, Bremen, Germany. till@informatik.uni-bremen.de

18. Jessica Moszkowicz: Laboratory for Linguistics and Computation, Brandeis University, Waltham, Massachusetts, jlittman@cs.brandeis.edu

19. Amitabha Mukerjee , Indian Inst. of Technology - Kanpur

20. Philippe Muller: Computer Science, Université Paul Sabatier, Toulouse, France, muller@irit.fr

21. Ian Pratt-Hartmann: School of Computer Science, The University of Manchester, Manchester, United Kingdom, ian.pratt@manchester.ac.uk

22. James Pustejovsky, Brandeis University, Waltham, MA

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24. Marc Verhagen: Computer Science Department, Brandeis University, Waltham, MA. 02254, marc@cs.brandeis.edu

25. Laure Vieu: Logic, Language, and Computation Group, Université Paul Sabatier, Toulouse, France, Laure.Vieu@irit.fr

26. Stephan Winter: Department of Geomatics, The University of Melbourne, Australia, winter@unimelb.edu.au

27. Stefan Wölfl: Institut für Informatik, Universität Freiburg, Germany, woelfl@informatik.uni-freiburg.de

28. Yunhui Wu, The University of Melbourne

29. Joost Zwarts: Departement Moderne Talen Faculteit Geesteswetenschappen, Universiteit Utrecht. j.zwarts@uu.nl

2.1 John Bateman: Ontological diversity: the case from space

The situated interpretation of natural language concerning space, spatial relationships and spatial activities is a complex problem spanning contributions from several disciplines. Space plays a central role in many theories of cognition and the spatial language observed in actual contexts of use is extremely flexible. In our work on spatial representations of all kinds, principles drawn from ontological engineering play a central role. Moreover, we have been led to augment those principles in particular ways: most specifically with respect to ontological modularity, ontological heterogeneity, and multiple ontological levels or strata.

2.2 Nate Blaylock: Resources and Representations for Geospatial Language Processing

Introduction I am interested in the understanding of what I call geospatial language. Formulating an exact definition of geospatial language is difficult, but intuitively, I mean language which makes references to objects and events situated at latitudes and longitudes (lat/lons) in the real world, where the goal is often to ground the references to real-world entities (such as streets, buildings, mountains, etc.) Recently, we have been engaged in research on a subproblem of geospatial language understanding called geospatial path understanding, which is the problem of taking a natural language description of a path and recovering the path in lat/lon coordinates. As part of this research, we have gathered a small corpus (the PURSUIT Corpus) of real-time descriptions of paths by participants driving in cars in a city area. I describe more below about the annotation of the corpus, but to give a feel for its contents, here is a sample utterance: ...and were going under the I-110 overpass I believe and the Civic Center is on the right side on the corner of Alcaniz and East Gregory Street where we are going to be taking a left turn... Note the many references to geospatial entities such as streets and businesses, and geospatial movement events (and situations) such as going under an overpass, turning, and the relative positions of entities. Many of the issues here overlap with traditional research on spatial language, but I believe the geospatial natural of the problem both imposes additional needs as well as provides potential solutions over purely (non-geospatial) spatial language understanding. In this paper, I will reference two areas of needs that I have found in my research: the need for geospatial ontologies, and the need for data resources.

Ontologies for Geospatial Entities and Events The PURSUIT Corpus (described above) contains almost 4 hours of 13 spontaneous auto route descriptions within a small city (Pensacola, Florida) environment, coupled with the GPS tracks from those routes. In the corpus, we have hand-annotated references (both named and not) to geospatial entities such as streets, intersections, addresses, businesses, parks, bodies of water, etc., with name, address (where applicable) and lat/lon information. We are also interested in annotating the corpus with other geospatial information, especially references movement events.

I believe that there is a need for ontologies of these geospatial concepts. From my experience with the PURSUIT Corpus, I see this ontology being divided into at least four major areas: entities, situations, events, and orientation.

Entities These are the types of geospatial objects in the world. This category would include both natural objects (e.g., mountains, bodies of water, forests) as well as man-made objects (e.g., streets, intersections, addresses, parks, cemeteries, buildings, businesses). Work on this ontology (especially for businesses) can start to overflow into other ontologies, such as for company types. (In PURSUIT, there are many references to business categories such as a Mexican restaurant.)

Situations By this I mean descriptions of relationships between two or more entities (such as the relative location of two buildings). Much of the work done in spatial relations can likely be used here.

Movement events There is a great need for ontologies that describe the types and arguments of movement events. For movement in a graph1 examples include events such as stopping, turning and passing other entities. As these are events, there is also a temporal component to this. Arguments to these can be entities, and also orientations (to be mentioned next).

Orientation There are several types of orientation frames that appear in the PURSUIT Corpus. First, there is directionality (north, south, east, west). Second, is object-centric (right vs. left) (note that this appears both for turn information (e.g., turning left) as well as passing (e.g., Im passing the Civic Center on my left). Note that the latter also requires a knowledge of going up or down a street. Orientation information is probably the best understood of these in terms of an ontology, but the role played in geospatial events and situations may not be.

As most of my work has been on movement in a street network, I will mention that here. It is not clear to me if there is also a need for a more generalized ontology for movement in this area, although there probably is a need.

Data Resources Access to and reasoning about these geospatial concepts also quickly becomes an issue. The amount of geospatial data available electronically is ever-increasing. The gathering of such data is outside the scope of this workshop. What I will discuss here is the types of queries one would like to make to a geospatial database. This is just a representative grab bag from my experience:

- Streets as entities: the databases we looked at represented street segments, but not a street as its own concept (i.e., a collection of street segments).
- Entities on streets: The on concept is important here. I would like to be able to query the entities on a given street (or section of it). Note that we need to know of entities which are on the corner of the street but may have an address on the cross street. Also, knowing which side of the street something is on, given which direction on the street a car is headed.
- Entities as polygons: this becomes an issue especially when an entity is large (such as a park or a neighborhood).
- Streets as lines: our path understanding system basically gathers constraints on the path from the language description and timing and uses that to rule out impossible paths. In this type of scenario, you can know that a certain street was crossed (but not at which point),

and being able to reason about if any part of that street was within x distance to another point would be very convenient.

- Entity visibility from a point: there are several mentions in the corpus of being able to see something (e.g., a tall building or water tower) in the distance.

I will close with one mention of data availability and the continuing need for it. Our corpus contains mentions of things we didnt have available such as fire hydrants, fields and wooded areas, parking lots, and neighborhoods. Although a lot of data is available, there is much more that could be useful.

2.3 Carola Eschenbach: Spatial dynamics and diachronic identity

The systematic treatment of change in time is a challenge to any formal approach. In the spatial domain, a broad variety of phenomena can be collected under the notion of spatial dynamics, starting from the motion of people traveling from home to Dagstuhl, up to long- term climatic changes, often called global warming that might result in the cooling down of certain parts of Europe. The example elaborated in my talk is based on changes combining population of spatial regions, administration and state identity.

(Q) How did the size of the population of the European capitals develop from 1900 to 2000?

At the first glance, this query concerns population data and, thus, the answer should report for any European capital the mapping of time to the number of inhabitants. However, such a report presupposes a treatment of capitals (and states) as persistent individuals. Looking closer into German history, we find that there are several options of reconstructing such a persistent entity that we might call the German capital for the time interval mentioned in query (Q).

Diachronic identity is a tough challenge for any ontological analysis. Obviously, humans have a strong intuition on the possibility to define criteria of diachronic identity for humans and many types of animals (which might be challenged in the context of thought experiments or science fiction). For other cases such as amoebae or the ship of Theseus, the clear and unique intuition on diachronic identity is replaced by a spectrum of options where each option can be supported by systematic arguments. Correspondingly, for many cases of juristic or social importance (land register, juristic succession of organizations) there are specific regulations that define the diachronic identity of entities. However, few people are aware of the specific regulations regarding formal criteria.

In my talk, I will outline the options of using diachronic identity or using time-varying functions for evaluating queries such as (Q). This evaluation aims at clarifying the interface between (natural) language semantics and ontological modeling.

2.4 Christian Freksa: Abstract Relations and Grounding

In my contribution I argue that we have representations for cognitive concepts that are not grounded in elementary geometric entities like point, lines, or areas, but rather in relation to other cognitively more meaningful concepts. Limited reasoning can take place on this basic level representation; for more elaborate reasoning about details of these concepts or about their embedding into larger structures, additional relations have to be retrieved from memory or constructed through perception and / or reasoning. The basic level concepts correspond to Eleanor Roschs (1978) basic level concepts. This view explains why we are able to conceptualize / imagine underspecified entities like a person even if we do not know his or her sex, color, size, etc., or a large wrdlbrmft vs. a small wrdlbrmft, even if we do not know the typical size or shape of a wrdlbrmft. Thus, rather sparse relational representations suffice to reason about specific feature dimensions that may be relevant in a given context.

2.5 Christopher Habel: The Role of Spatial Representations in Multimodal Language-Graphic Comprehension

Documents combining different representational modalities (e.g. language, tables, pictorial representations, graphs) are widespread in both printed forms and in electronic media. In particular we focus on multimodal comprehension of expository text accompanied by graphics of a specific type, namely line graphs of functions with time-arguments and numbers as values. In this talk, we exemplify our approach with multimodal constellation from a waterbird census report.

The computational architecture for multimodal comprehension of text-graphics documents we present in the seminar employs the parallelity of language comprehension and graph comprehension by use of a common representational formatfor conceptual and spatial representations, and of kindred types of spatial reference systems. Empirical evidence for this approach and for the core role of spatial representations has been given by a series of experimental studies mainly using the Eye-tracking paradigm.

2.6 Joana Hois: Interpreting Spatial Language by using Modular Ontologies

Interpreting spatial language requires that we translate meanings of linguistic units into spatial units. On the linguistic side, information about direction, topology, distance, perspective, shape, or path and motion provide the spatial meaning that has to be interpreted. A formal model that formally groups such linguistic units into logical categories is, for instance, given by the spatial extension of the Generalized Upper Model, GUM-Space. On the spatial side, the same types of information are given together with geometrical or even functional aspects. Today, many formal models exist that represent and reason about orientations, regions, distances, shapes, or motion, in particular specified as so-called spatial calculi.

We primarily investigate connections between such formal models of language and formal models of space. Given GUM-Space, we are interested in mapping certain GUM categories to models of spatial calculi. We therefore analyze how a link relation between GUM and a spatial calculus can be specified, that allows the interpretation of spatial language. In particular, we address the question what this 'linking logic' has to provide. Furthermore, information that is relevant for concrete links has to be taken into account as well. We study how vagueness and ambiguity, context information and commonsense knowledge can be formalized along the link relations.

2.7 Inderjeet Mani: The Creeping Virtuality of Place

Places are inherently dynamic. They also mediate between entities and events of significance to us, and space. They reflect a network of associations, involving landmarks deemed salient for various reasons. These are all properties assigned to a place by a speaker, and may or may not correspond to the properties assigned to a place by any other speaker. As a result, places have a subjective quality. These properties of dynamicity and subjectivity present interesting challenges when producing mashups that align different data sources. I propose addressing this by assuming that entities, following Hornsby & Egenhofer (2000), have histories, namely sequences of time intervals when they are predicated to exist. Places are entities with spatial properties that include topological relationships to other places, represented in terms of RCC-8 or the 9-intersection calculus, as well as distance and orientation relations. This spatio-temporal integration can avail of existing annotation schemes for space and time in natural language, but it leaves some open issues related to the representation of subjectivity.

2.8 David McDonald: Desiderata for the representation of incomplete spatial information

Spatial descriptions in natural language can rarely supply an exact specification for a GIS system. They are instead deliberately incomplete, and draw on their interlocutors' shared context and general knowledge to provide enough information for the speaker's purposes. In this paper I illustrate how information can be missing or simply irrelevant and pose this as a problem that must be met by the representations sitting between the natural language and cartographic or other sorts of specific models.

We are in the earliest stages of developing a system for interpreting and representing the descriptions of spatial relationships that are found in naturally occurring texts. Our goal is to assemble models that we can stand up in a game engine for our avatar to walk through that are thorough enough for NPCs to know what they are going to see as they move from one place to the next. At this point we have concluded that interpreting the spatial descriptions in a text require co-composition, a context-sensitive model of word meanings, and a prototype-based representation for modeling that can provide the basis for applying defaults and inferences.

2.9 Amitabha Mukerjee: Sensorimotor Emergence for Grounded Action Structures

Image schemas based on sensorimotor learning subsume logical predicate structures, encode the action categorization scheme and are defeasible. We consider how a developmental agent may learn action structures based on different Machine Learning algorithms, some prior skill sets such as bottom-up attention, and some intrinsic motivation for exploration and simplification. We investigate how such an agent may learn concepts from multimedia data, and relate them to units in language, and go on to discover structures in grammar such as word order and anaphora.

Consider linguistic descriptions for spatial actions, e.g. "The square is hitting the circle. Now it chases it around the box"

In this, any action models we construct for hit(x,y) or for chase(x,y) must, in the end, encode sensorimotor inputs to distinguish core elements based on which one can a) recognize and b) execute the action. The same sensorimotor models will also encode the categories of the arguments of the action, albeit probabilistically, and many other relations that must hold for these actions.

Thus, these models subsume Logical predicates such as chase(x,y); they encode the action categorization schemes as well as argument category preference, but are defeasible and most importantly, are defined on the sensorimotor stratum, which enables it to determine whether a given input is an instance of this action or not. Furthermore, the same model can also be used in executing the action.

Here, we consider how a developmental agent may learn action structures based on different Machine Learning algorithms, some prior skill sets such as bottom-up attention, and some intrinsic motivation for exploration and simplification. We also assume that the agent has some phonological and morphological familiarity with its language environment (is able to separate words). We show how such a system, when presented with only perceptual input, can construct models for 2-agent actions such as come-closer() or chase(). Further, we show that such a system use the action signature to determine that come-closer (A,B) is commutative, whereas chase(A,B) is not.

Next, we expose such a system to linguistic commentaries for the same scenes that it has used for learning these action categories. By noting which objects / actions are being attended to during an utterance, the system relates these entities with the words in the word-separated input, without any knowledge of syntax, part of speech, etc. We show that it is able to learn the names of objects, and also the labels for actions.

Then we show that for non-commutative actions like chase, it is able to discover that, at least for English, these are encoded in terms of word order. Next, we show that by looking at arguments that are absent, it can discover the notion of anaphorical reference (dynamic vs static reference).

We also show how this process may work for more than two languages by considering the learning of English and Telugu primitives.

2.10 Ian Pratt-Hartmann: Survey of Spatial Logics

This talk presents a survey of spatial logics. It is aimed at people who have had some exposure to the subject, but who do not see themselves primarily as logicians. The object of the talk is to help those people navigate through the maze of spatial logics in the literature.

2.11 James Pustejovsky: ISO-Space: A Language for Annotating Spatial Information in Language

We introduce ISO-Space, an annotation specification for capturing spatial and spatiotemporal information in natural language. We discuss many of the issues found in spatial language and show how ISO-Space aims to address these problems. ISO-Space is an emerging resource that is still in its early stages of development. We describe the genres of text that will be used in a pilot annotation study, in order to refine and enrich the specification language.

Motivation and Problem Definition Natural languages are filled with particular constructions for talking about spatial information, including spatially anchored events, locations that are described in relation to other locations, and movement along a path. While representing and reasoning about spatial information has recently received ample attention, particularly from the qualitative reasoning community, that work often overlooks the complexity that language brings to the problem. In fact, establishing tighter formal specifications of the relationship between language and space has proved to be a considerable challenge. In this paper, we propose an annotation framework called ISO-Space that aims to be such a specification. ISO-Space incorporates the annotations of static spatial information, borrowing from the SpatialML scheme, along with a new markup language called Spatiotemporal Markup Language (STML) that focuses on locating events in space.

The name "ISO-Space" is used in particular because this markup language is being developed within the ISO TC37/SC4 technical subcommittee on language resource management as part six of the Semantic Annotation Framework, where the goal is to create a new standard for capturing spatial and spatiotemporal information.

In previous analyses of spatial information, it has been assumed that language makes use of a relatively simple inventory of terms in order to describe spatial information. In approaches such as these, the principle burden of explanation is located within non-linguistic formalisms, but such characterizations are ill-suited for dealing with the extreme flexibility of spatial language as used in real contexts.

There are many applications and tasks which would benefit from a robust spatial markup language such as ISO-Space. These include:

- Building a spatial map of objects relative to one another.
- Reconstructing spatial information associated with a sequence of events.

- Determining object location given a verbal description.
- Translating viewer-centric verbal descriptions into other relative descriptions or absolute coordinate descriptions.
- Constructing a route given a route description.
- Constructing a spatial model of an interior or exterior space given a verbal description.
- Integrating spatial descriptions with information from other media.

To this end, the goal of ISO-Space is not to provide a formalism that fully represents the complexity of spatial language, but rather to capture these complex constructions in text to provide an inventory of how spatial information is presented in natural language. The framework is built on previous and ongoing work on annotations for spatial, temporal, and spatiotemporal information, but we also follow the MATTER cycle. Following that strategy, we aim to look frequently at real text and adjust the specification of ISO-Space accordingly after several rounds of annotation.

In this paper, we first describe the semantic requirements for the annotation language, and then discuss the structure of the annotation framework. We then outline the basic elements of the current version of ISO-Space, followed by explicit examples of how these elements are used for markup. We briefly discuss our strategy of corpus-driven development of the specification, and conclude with remaining issues and outstanding questions of interpretation.

2.12 Angela Schwering: Capturing, Representing, Processing Spatial Information - Overview of Tasks and Problems

Spatial Cognition and Human Computer Interaction Sketch map is an important representation of spatial information often used in human-human communication. Compared with verbal or textual language, it is easier to express (complex) spatial relations in a sketch map. Sketch maps are intuitive and support human spatial thinking and thus are a very natural way to reflect how people perceive properties of spatial objects and their spatial relations. However, during sketch map drawing, errors due to human spatial cognition may occur: e.g. distance judgments for routes are judged longer when the route has many turns. Shape and directions get straightened up. Similarly, buildings and streets with different shapes are often simplified and depicted as schematic figures like blobs and lines. These errors are not random; rather they appear to be a consequence of ordinary perceptual and cognitive processes. We aim to develop an approach that analyzes sketch maps formally accounting for distortion and schematization effects mentioned above. We aim to develop a system which allows a user to formulate a spatial query by drawing the desired spatial configuration and get it translated into a symbolic representation to be processed against a geographic database.

Semantics and Usability Our research focuses on capturing and representing the semantics of spatial information in order to enable effective and accurate information processing. Intelligent methods are required to provide optimal support of users' needs and overcome semantic interoperability problems. Our research focuses on semantic annotation of spatial data and the development of models to measure semantic similarity of natural language expressions.

Consistent and flawless communication between humans and machines is the precondition for a computer to process instructions correctly. While machines use well-defined languages and formal rules to process information, humans prefer natural-language expressions with vague semantics. We investigate experimentally the meaning of natural-language spatial relations and develop a computational model to specify the semantics and reason on spatial relations. Natural-language relations and cognitively plausible operations shall improve query languages of geographic information systems and increase the usability for humans.

2.13 Yunhui Wu: Interpreting place descriptions for navigation services

We see a need for research bringing spatial intelligence into the fundamental mechanisms of parsing and interpreting place descriptions. An intelligent navigation service will have capabilities to imitate human route communication behavior (Winter and Wu, 2009), thus, at least the capabilities to make sense of place descriptions.

2.14 Joost Zwarts: The semantics of cardinal directions in English

The cardinal directions (north, east, south, and west) form the basis of a relatively rich subdomain of expressions in English. Different formal models for cardinal directions have been developed for geographic information systems (e.g. Frank 1996), but these have not been directly applied to the semantics of these expressions. On the other hand, the many discussions of directionality in natural language have mostly focussed on non-compass expressions, like up, behind, and left, even though cardinal directions are the primary example of one of the three types of directional frames, the absolute frame of reference (e.g. Levinson 2003). Against this background, this paper explores the formal semantics of cardinal directions in English. The aim is not so much to provide a complete and fully formalized account, but rather, to discuss some general issues in the formal semantics of spatial language, using cardinal direction expressions as a extended case study.

3 Additional Materials

3.1 Working Groups

Five working groups were organized to discuss in more depth the issues arising from the first day. These were as follows:

1. Space and Vagueness
2. The Notion of *Location* vs. *Place*
3. Representing Motion

4. Ontology of Space
5. Orientation and Direction

3.2 Consensus and Future Directions

The discussion from the present Seminar were fruitful in several respects. One major result involved the consensus relating to what conceptual inventory is required for representing space in language. Linguists traditionally divide spatial expressions into at least four grammatically defined classes:

a. Spatial Prepositions and Particles: *on*, *in*, *under*, *over*, *up*, *down*, *left of*;

b. Verbs of position and movement: *lean over*, *sit*, *run*, *swim*, *arrive*;

c. Spatial attributes: *tall*, *long*, *wide*, *deep*;

d. Spatial Nominals: *area*, *room*, *center*, *corner*, *front*, *hallway*.

Unlike the fairly well-behaved list of 13 values for temporal relations in language (as encoded in ISO-TimeML), spatial prepositions are notoriously ambiguous and context dependent. Not only are there vastly more configurations possible between objects construed as spatial regions, but languages are idiosyncratic in how spatial information is encoded through different linguistic expressions. For this reason, we will have to define constraints that allow for underspecified semantic interpretations for several of the concepts introduced in our abstract syntax. These will need to communicate with various lexical and spatial ontological resources, in order to help disambiguate and more fully determine the semantics of relation types from the specification.

It was agreed that any representation for spatial information must include (at least) the following notions:

- Locations (regions, spatial objects): Geographic, Geopolitical Places, Functional Locations.
- Entities viewed as Spatial Objects.
- Paths as Objects: routes, lines, turns, arcs
- Topological relations: *inside*, *connected*, *disconnected*.
- Direction and Orientation: *North*, *downstream*.
- Time and space measurements: units and quantities for spatial and temporal concepts.
- Object properties: intrinsic orientation, dimensionality, size, shape.
- Frames of reference: absolute, intrinsic, relative.
- Spatial Functions: *behind the building*, *twenty miles from Boulder*.
- Motion: tracking moving objects over time.

It is these concepts which must be specified set-theoretically in an abstract syntax, and for which a formal semantics must be provided.