SPATIAL COGNITION

The Power of Space and Time

– how spatial structures replace computational effort

Christian Freksa
University of Bremen

Talk at The University of Melbourne, 27 February 2013

Universität Bremen

UNI FREIBURG

1 Cognitive Agents and Knowledge Representation

- Cognitive agents are immersed in space and time
  - We cannot physically escape limitations of 3D space and oriented time
  - This concerns our body including brain and other neural structures
  - This also concerns our environment
  - A severe limitation (for theoreticians)

SPATIAL COGNITION

1 Cognitive Agents and Knowledge Representation, cntd.

- Nevertheless are we able to 'think outside the box'
  - We can conceive of spaces of arbitrary extent and of arbitrary dimensionality
  - We can conceive of branching time and reversible time
- Mathematics and informatics provide us with ways to overcoming limitations of physical space and time
  - By abstraction
  - Feature: General representations for larger classes of problems

SPATIAL COGNITION

1 Cognitive Agents and Knowledge Representation, cntd.

- Abstraction comes at an expense
  - The more expressive the formalisms and the more powerful the procedures, the more expensive are formalization and reification processes
  - This cost becomes significant if new problems require new abstraction
- Multiple ontologies and formalisms allow for limiting expressiveness to what is needed
  - This requires ways of translating between various formalisms

SPATIAL COGNITION

2 Spatio-temporal tasks cognitive agents need to perform

- Navigating from A to B
  - A 3+1 D spatio-temporal problem.
  - People navigate in 2 D
  - Usually we navigate on tracks with branches => 1.5 D
  - And time? -- Not an independent dimension.
  - The environment provides the constraints options (affordances)
  - It is much easier to select from few options than to deselect from a large number of 'theoretical' cases

SPATIAL COGNITION

2 Spatio-temporal tasks cognitive agents need to perform, cntd.

- Opening doors or handling other objects
  - Rather complex spatio-temporal operations
  - Cognitively? -- Quite simple due to affordances of cognitive agents and their environments
  - We manipulate complex objects in their entirety

SPATIAL COGNITION

2 Spatio-temporal tasks cognitive agents need to perform, cntd.

- Understanding spatial expressions
  - Complex enterprise due to ambiguities on the level of individual elements
  - Almost trivial if language only refers to spatio-temporal configurations and events
  - Challenge: Extending language understanding from trivial to theoretical cases rather than constraining theoretical to real cases
  - The environment (knowledge in the world) provides the affordances for a meaningful interpretation

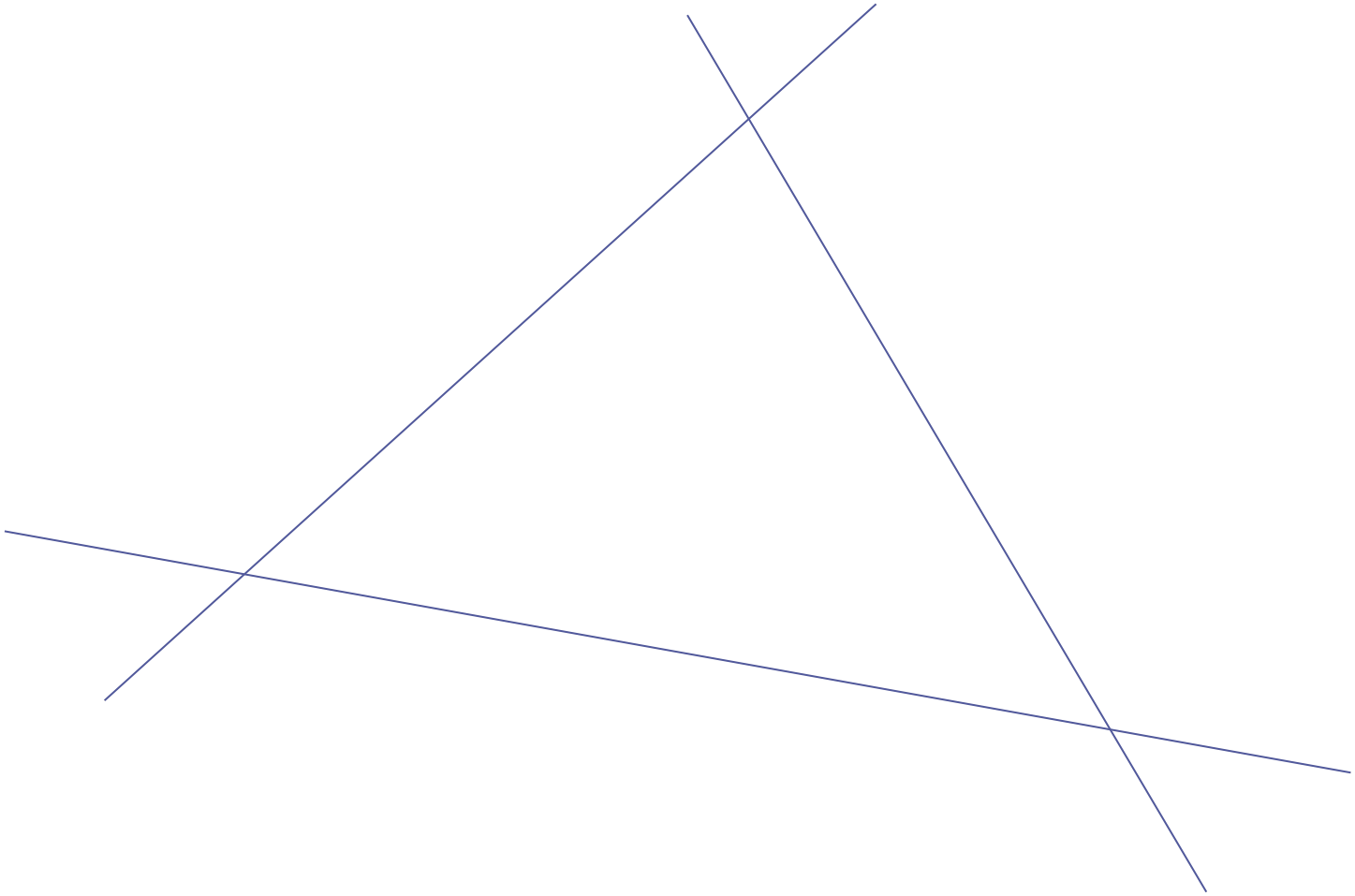
SPATIAL COGNITION

2 Spatio-temporal tasks cognitive agents need to perform, cntd.

- Transforming between spatial and temporal reference systems
  - As cognitive agents move or spatial environments change all the spatial relations between the objects have to be recomputed.
  - Is this true in natural cognitive systems?
  - No! -- The affordances of space and time do the 'computing' for us. Instantly. The cognitive agents only have to read off the relations they need.
  - Example: Showing someone a hard to see object.

SPATIAL COGNITION

3 The Power of Space: Demonstration of 'Spatial Computing'



4 What are suitable representations for affordance-oriented spatial computing?

- Logic-based or other symbolic formalisms?
  - Much too expressive.
- Diagrams?
  - Works quite well for specific sub-class of spatial tasks
  - For example maps.
- Physical Space?
  - This is what cognitive agents seem to use
  - 'Knowledge in the world'
  - Spatio-temporal processes act as operations

SPATIAL COGNITION

5 How about abstraction?

- Relational structures for spatial and temporal structures
  - Make only those relations explicit that have been derived
  - Partial and redundant knowledge
- Meta-knowledge for controlling and predicting actions

SPATIAL COGNITION

6 Advantages and disadvantages

- What do we gain?
  - Model of cognition in the *strong AI* sense: implementation of spatial cognition
  - Real-time and real-space problem solving
  - Allows for problem solving with incomplete and developing knowledge
- What do we lose?
  - The system may not 'understand' the problem solution
  - (This would require meta-level reasoning.)

SPATIAL COGNITION

7 Commonsense Reasoning

- What is commonsense?
- To what extent does commonsense require logics?
- Do we want to enable cognitive agents with commonsense reasoning abilities?
- Do we want to describe commonsense reasoning from a scientific perspective?

SPATIAL COGNITION

8 Different Objectives

- Object-level problem solving
- Meta-level understanding
- Imitation, learning, and experience

- It is best to combine the approaches

SPATIAL COGNITION

9 Towards developing a 'spatial computer' aka spatially aware cognitive agent

- Approach 0: Robotic agent [from difficult to simple]
  - Capable of moving: Transforming the subjective reference system
  - Capable of manipulating the environment: Transforming relations between spatial reference systems
  - Capable of composing and decomposing
  - Capable of inspecting spatial configurations and noting spatial relations

SPATIAL COGNITION

10 Are spatial computers restricted to solving spatial problems?

- Are natural cognitive agents restricted?
- Cognitive agents as humans and other animals employ spatial computers
  - Retina and other perception organs are spatially organized
  - Eye movement control employs spatio-temporal mechanisms
  - Memory is spatially organized -- neural maps, column structures
  - Locomotion and action apparatus are subject to spatio-temporal affordances

SPATIAL COGNITION

10 Are spatial computers restricted to solving spatial problems? ct.

- Cognitive agents are able to use spatial dimensions to stand for something else (metaphorical use of space) [at least humans]
- Cognitive agents are not good at imagining more than three or four different dimensions

SPATIAL COGNITION

11 Discussion

- Spatial laws are intrinsically represented; they do not have to be explicitly declared by scientific insight
  - Object-level common sense approach vs. logic-based meta-level reasoning
- Meta-level reasoning (or experience) is required to
  - Select suitable representation
  - Take appropriate actions
  - Get appropriate interpretation
  - [the same is true for abstract formal approaches]

SPATIAL COGNITION

Limitations of spatial computing?

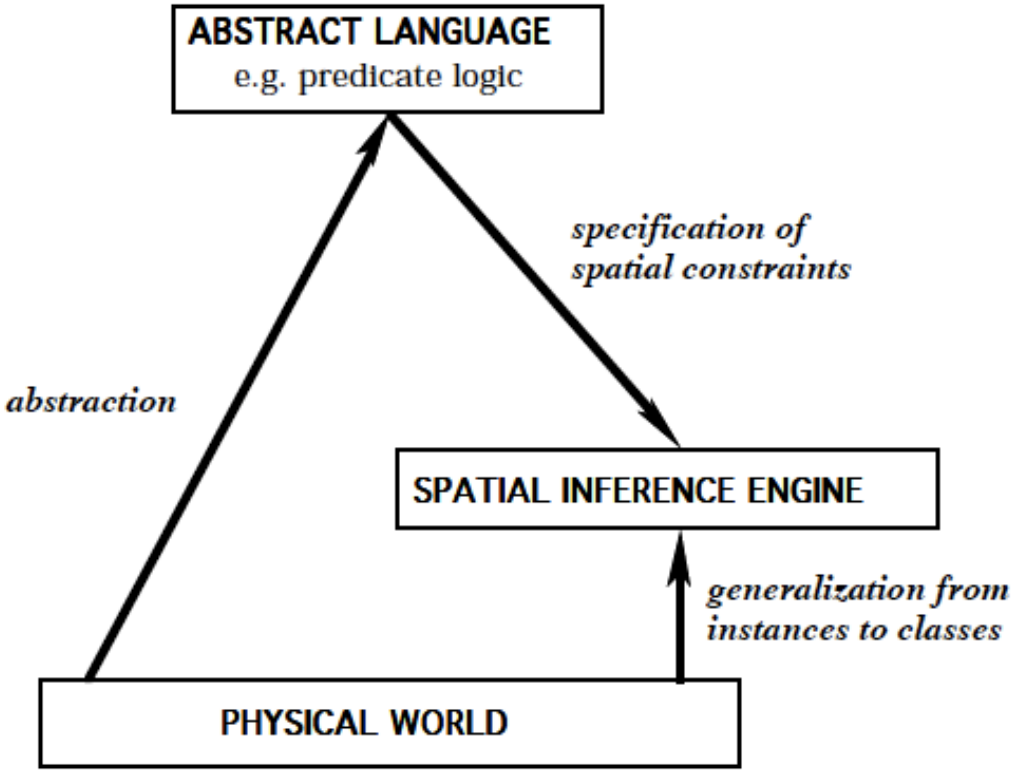


Figure 1: Spatial inference engines can be constructed by constraining very abstract formalization languages or by generalizing over the physical world.

SPATIAL COGNITION

SPATIAL COGNITION

Acknowledgments

Deutsche Forschungsgemeinschaft
DFG

DAAD
Deutscher Akademischer Austausch Dienst
German Academic Exchange Service


Alexander von Humboldt
Stiftung/Foundation


Universität Bremen