The Power of Space and Time

– how spatial structures replace computational effort

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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)
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
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
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
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
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
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.
The Power of Space: Demonstration of 'Spatial Computing'
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
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
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.)
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?
Different Objectives

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

- It is best to combine the approaches
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
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
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 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]
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.
Acknowledgments