Cognitive Systems

Foundations of Information Processing
in Natural and Artificial Systems

Lecture 11

Cognitive Maps and Spatial Orientation

Universität Bremen

Cognitive Maps and Spatial Orientation

Definition: Cognitive map

- „… the body of knowledge of a large-scale environment that is acquired by integrating observations gathered over time, and is used to find routes and determine the relative position of places.“ (Kuipers, 1983)
- An agent‘s internal representation of the spatial properties of the world

Tasks for cognitive maps

- Where am I?
- Where are other places?
- How do I get there?

Introduction

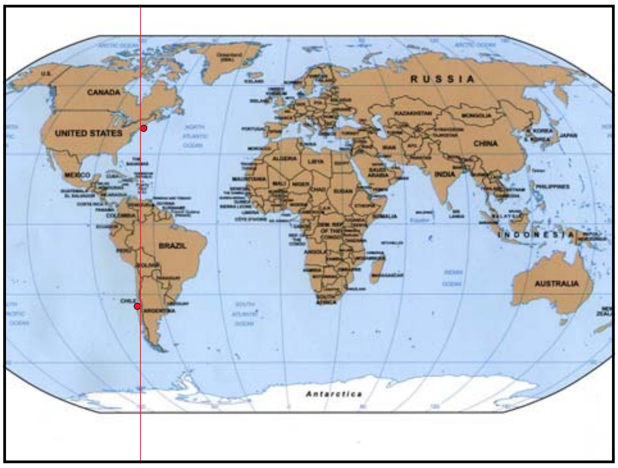
Which city is further north

London or Bremen?

Seattle or Toronto?

Which city is further west

Santiago de Chile or New York?



Cognitive Maps

Do we need spatial knowledge for spatial cognition?

- Examples of spatial problems:
  - grasping an object
  - walking along a wall ('wall following')
  - finding the shortest route to ...
  - taking a short-cut
  - walking a triangle
  - constructing a spatial configuration under constraints

Two basic methods for dealing with space

(1) Sensory-motor interaction with the environment: look – find target – move towards target – look
- requires sensory access to environment
- requires sensory-motor coupling

Knowledge in the world

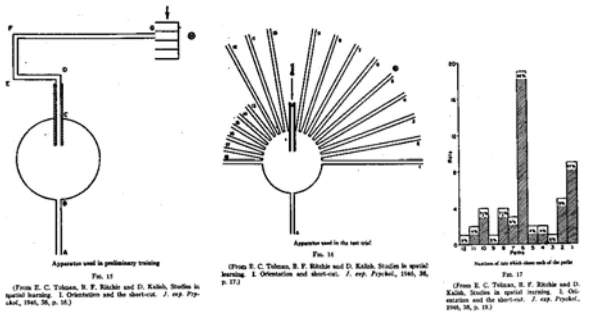
(2) Representing space in memory, representing the problem, reasoning on basis of representation
- requires spatial memory and a representation of the environment
- requires spatial inference

Knowledge in the head

The Cognitive Revolution, or: Cognitive maps in rats and men

- Tolman (1948) conducted experiments whose outcome could not be explained by simple S-R patterns
- Rats acquire complex internal representations of their environment that enable them to take smart decisions in the absence of complete sensory information about the environment
- Tolman showed that rats appear to build up an internal representation of their environment to find food in a clever way

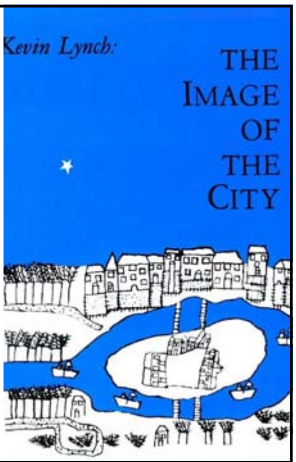
Tolman's experiment



Cognitive map of urban environment

Humans are also thought to form cognitive maps of their environments for use in navigation. Lynch developed a set of generic components which he hypothesized are used to construct cognitive maps of urban environments. They include:

- *Paths* : linear separators, examples include walkways and passages.
- *Edges* : linear separators, such as walls or fences.
- *Landmarks* : objects which are in sharp contrast to their immediate surroundings, such as a church spire.
- *Nodes* : sections of the environment with similar characteristics. For example, a group of streets with the same type of light posts.
- *Districts* : logically and physically distinct sections. In Washington, D.C., they might be Foggy Bottom, Capitol Hill, etc.

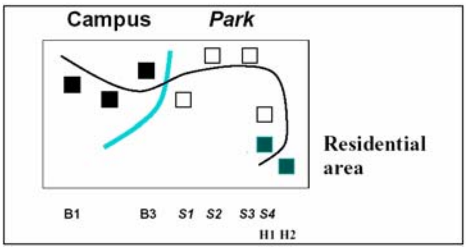


Spatial distortion

How accurately are spatial relations represented in the mind?

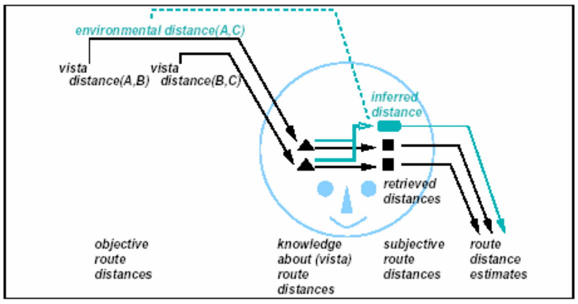
a) Distortion of distance (Berendt)
b) Distortion of orientation
c) Distortion of shape / configuration (Stevens / Coupe, Barkowsky)
d) Distortion of coherence (Kuipers / Tversky / Hirtle)

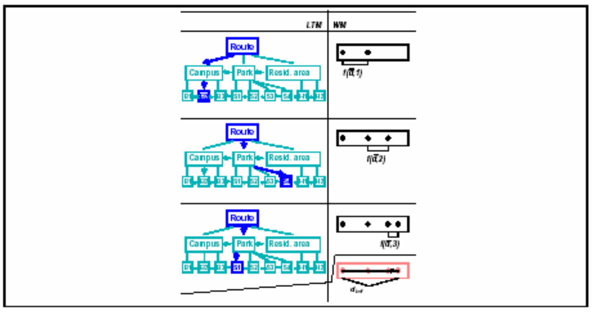
a) Distortion of distance



B. Berendt 1998

Cognitive distance ≠ spatial distance

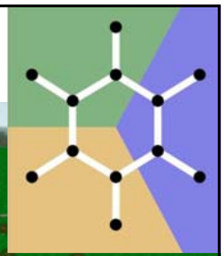




Conceptual complexity results in perceived distance

11.3.1.2 23

Cognitive Distance and Route Selection



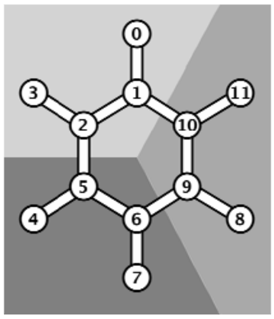
11.3.1.3

Experiment 1

Subjects view approaching a place, to the left is the landmark associated with that place.

11.3.1.4

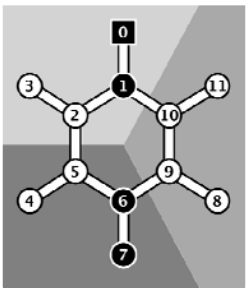
Experiment 1



Schematic map of the environment, numbered circles represent places, different shades of gray represent the different regions (all places from one region carried landmarks belonging to the same category -> there was a car-, an animal- and an art-region)

11.3.1.5

Experiment 1 – example for a test route



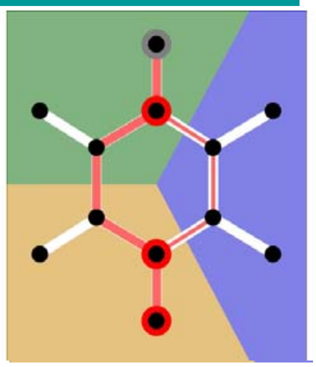
One of the critical navigation tasks in the test phase (after exploration- and test-phase) : the black rectangle represents the starting place, the black circles represent the target places. Subjects were instructed to visit all target places using the shortest possible route.

11.3.1.6

Results from 25 Subjects

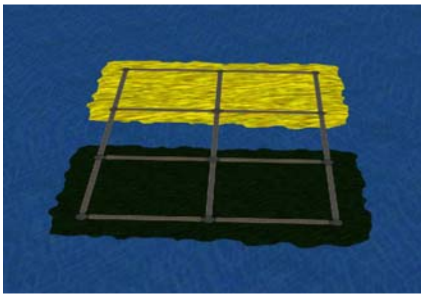
Subjects preferred routes that crossed fewer rather than more region boundaries

Jan M. Wiener



11.3.1.7

Experiment 2



Birds-eye view of the virtual environment

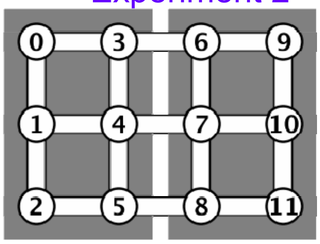
11.3.1.8

Experiment 2

Subjects view approaching a place, each place (junction) carried a unique landmark that was invisible until subjects entered the corresponding place (we call those pop-up landmarks), landmarks from one island were of the category animals, landmarks from the other island were of the category cars.

11.3.1.9

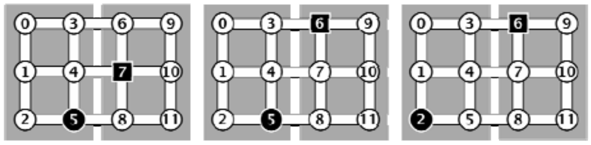
Experiment 2



Schematic map of the environment, numbered circle represent places, all places from one island carried landmarks belonging to the same category -> there was a car-, and an animal-island

11.3.1.10

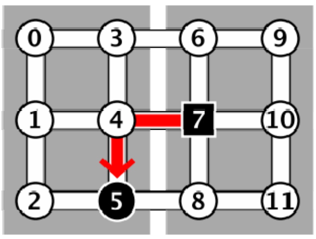
Experiment 2- Examples for test routes



Examples for the critical navigation tasks in the test phase (after exploration- and test-phase): the black rectangle represents the starting position, the black circle represents the target place. Subjects were instructed to find the shortest possible route. Note that there are at least two alternative optimal solutions

11.3.1.11

Experiment 2 - Results



Results: subjects preferred routes that allowed for fastest access to the region containing the target.

11.3.1.12

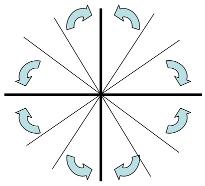
Conclusion [Distance]

- Environmental regions influence human route planning behavior
  - this suggests that regions are represented in human spatial memory (along the lines of hierarchical theories of spatial representation)
- Route planning takes into account region-connectivity and is not based on place-connectivity alone

11.3.1.13

b) Orientation

- Cognitive orientation: Categorization of spatial orientation
  – In orientation memory, we 'idealize' perceived angles to get closer to multiples of 90°



11.3.2 35

c) Distortion of shape / configuration

- Capacity restrictions do not allow us to represent all details
- Rather than leaving holes in our cognitive map, we represent coarse knowledge
- Shapes and configurations are simplified
- Representation requires fewer relations

11.3.3 36

d) Distortion of coherence

How is our overall spatial knowledge organized?

- Cognitive maps?
- Cognitive atlases?
- Cognitive collages?

11.3.4 37

'Cognitive maps' reconsidered

Cognitive map metaphor appears exaggerated

- suggests completeness
- suggests precision
- suggests homogeneity
- suggests coherence
- suggests absence of conflicts

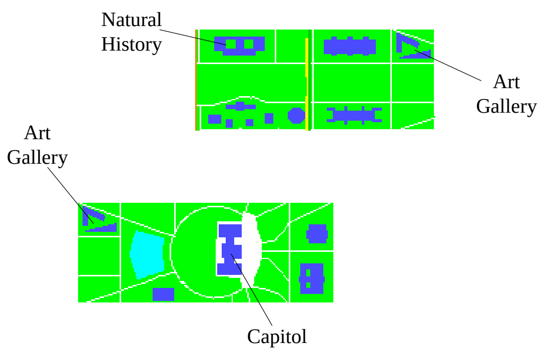
11.3.5 38

"Cognitive atlas", "cognitive collage"

- "Cognitive atlas" (Kuipers, Hirtle)
  acknowledges that knowledge is fragmented into pieces of variable scale and resolution
- "Cognitive collage" (Tversky)
  emphasizes that the knowledge fragments themselves are less than perfect and that they are not arranged in a strict geometric fashion

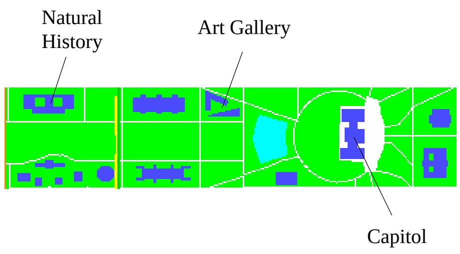
11.3.5.1 39

Take two "simple" maps…



11.3.5.2 40

…and piece them together



11.3.5.3 41

Map Integration

- Integration Hypothesis:
  - Simple maps are integrated via ***common elements***.
  - Common elements ***superimpose***.
- Evidence from:
  - Temporal maps in rats
  - Spatial maps in pigeons

11.3.5.4 42

Spatial Scale

- Definition:

  Scale is the ratio between the dimensions of a representation and those of the thing that it represents

  Scale has an important influence on how humans treat spatial information

11.4 43

Geography

"And then came the grandest idea of all! We actually made a map of the country, on the scale of a mile to the mile!"

"Have you used it much?" I enquired.

"It has never been spread out, yet," said Mein Herr: "the farmers objected: they said it would cover the whole country, and shut out the sunlight! So now we use the country itself, as its own map, and I assure you it does nearly as well."

Lewis Carroll 1893, *Sylvie and Bruno*

11.4.1 44

Psychology (I)

- Concern for the size of a space relative to a person, more precisely, to a person's body and action (e.g., looking, walking)
- Montello:
  Four major classes of psychological spaces: *figural*, *vista*, *environmental*, and *geographical* space
- On the basis of the *projective size*
- The means by which it may be apprehended and its cognitive treatment by the mind

11.4.2 45

Psychology (II)

- *Figural* space is projectively smaller than the body
- *Vista* space is projectively as large or larger than the body
- *Environmental* space is projectively larger than the body and surrounds it
- *Geographical* space is projectively much larger than the body and cannot be apprehended directly through locomotion

11.4.3 46

Empirical evidence that justifies classifying psychological space into several classes on the basis of scale

(1) The effects of learning from maps vs. from direct environmental experience,

(2) Differences in the frames-of-reference used to organize and manipulate spatial knowledge at different scales, and

(3) Attempts to measure individual differences in spatial ability at different scales

11.4.4 47

Biology, Chemistry, Engineering

- Maps much larger than objects of investigation or construction
  - drawings of plant and animal organisms
  - microscopic images
  - construction plans of miniature artifacts
    - clocks, electronic circuits, VLSI-chips

11.4.5 48

Conclusion [Spatial Scale]

- A map serves the understanding of a (spatial) configuration through visual inspection
- Visual inspection takes place in the visual field
- The visual field has a certain extension and a certain resolution
- The size of the spatial configuration to be understood must be scaled to fit the visual field and to allow resolution of items to be distinguished

11.4.6 49

Spatial abstraction

How can we represent spatial knowledge in such a way that

- most essential information is maintained
- little information is required
- graceful degradation is maintained
- dreadful interpretations are avoided
- recovery from wrong interpretations are possible
- incremental augmentation of knowledge is possible

11.5 50

Approaches to Spatial Abstraction

- Qualitative spatial knowledge / schematization
- Hierarchical organization of spatial knowledge
- Exploitation of inherent properties of spatial structures
  - topology
  - neighborhood structures
- Taking into account laws of abstraction in the interpretation of spatial knowledge

11.5.1 51

Communication about Space

- Language
  - linear structure
  - temporal sequence of linguistic utterances
- Deictics, gestures, and actions
  - semantics of spatio-temporal organization
- Sketches and maps
  - what do and what do they not mean?

11.6 52

Summary

- Spatial abilities crucially depend on spatial representations and processes
- Spatial distortions may be a feature rather than a deficiciency of spatial representations (overhead avoidance)
- Poor quality of spatial knowledge does not affect us until we need it
- When we need it, we must employ general strategies to recover partially

11.7

53

Next Semester

Cognitive Systems II

- Methods from Psychology, Neuroscience, Informatics
- Cognitive Architectures and Modeling Approaches
- Case Studies in Cognitive Modeling
- Challenges for Cognitive Science

54