

Cognitive Systems

Foundations of Information Processing
in Natural and Artificial Systems

Lecture 10

Mental Images, Rotation, Scanning,
and Attention



What is a Mental Image?

- The trunk example
 - you have numerous pieces of baggage, sports equipment, ...; do they fit into the car?
- A geographic example
 - in which direction with respect to Bremen are located:
 - Berlin?
 - London?
 - Vienna? ...

10.0.1

2

Outline

1. Mental imagery
 - definition
 - rotation and scanning
 - characteristics and properties
2. Human memory
 - working memory recap
 - memory for mental images
3. Imagery Models
 - psychological models
 - AI models

10.0.2

3

Mental Imagery – A Definition

- Mental imagery is "the **mental invention or recreation** of an **experience** that in at least some respects resembles the experience of actually **perceiving** an object or an event, either **in conjunction with, or in absence of**, direct sensory stimulation" (Finke, 1989)

10.1.1

4

... invention or recreation ...

- mental image construction
 - based on memory
 - combined from elements
- image inspection
 - utilization of image
- image modification
 - alternatives in constructed and inspected images

10.1.1

5

... of an experience ...

- issue of interest: cognitive principles (not experience!)
- indirect measurement!
- are mental images 'real'?
- cf. imagery debate

10.1.1

6

... visual perception ...

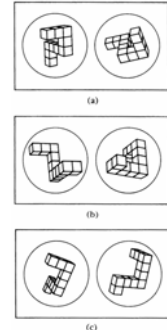
- imagery tightly coupled with vision
 - imagery with perception
 - e.g. combination of seen and mentally constructed elements
 - imagery without perception
 - pure construction from memory
 - no perception without imagery
 - imagery precondition for vision processes

10.1.1

7

Mental Rotation

- Subjects were presented with pictures of 3-dimensional objects
- Task: determine if two objects are identical except for orientation
- Subjects have the impression of mentally rotating the objects



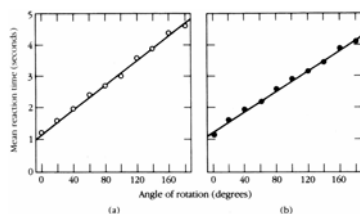
[Shepard & Metzler, 1971]

10.1.2

8

Mental Rotation

- Time required to decide whether figures are identical depends on rotation angle?
- Linear relationship between rotation angle and reaction time as evidence for mental rotation
- Mental operation analogical to physical rotation



10.1.2

9

Mental Scanning

- Subjects memorized a fictional map
- Then they were presented with a pair of entities on the map
- Task: imagine a spot moving from the first entity to the second one



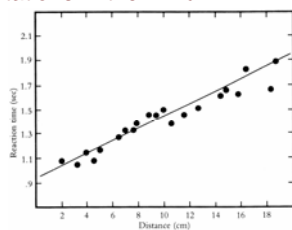
[Kosslyn et al., 1978]

10.1.3

10

Mental Scanning

- Linear relationship between distance on the map and scanning time
- Support for the assumption of spatio-analogical representations in the mind



10.1.3

11

Conclusion

- Spatio-analogical representation in the mind
- Critics: difference between
 - experience
 - experimental behavior
 - physical realization in the mind / brain

10.1.4

12

The Imagery Debate

- Do 'mental images' have a specific representation format?
 - dual coding
 - just propositional coding
- e.g. "who 'looks' at the internal picture?"
- Evidence from patients with brain damages
- Mental imagery widely accepted in cognitive science

10.1.4

13

Mental Images: Characteristics

- Fundamental - not epiphenomenal
 - quasi-pictorial mental representation structures
- Mental constructions
 - use of pieces of knowledge
 - mental storage differs from form in usage
 - not retrieved in a ready-made form

10.1.4

14

Mental Images: Characteristics

- Composition from well-organized pieces of knowledge
 - hierarchical structure in long-term memory
 - organization in mental storage influences image construction process
- Image construction from pictorial and propositional information
 - e.g. image construction from verbal descriptions

10.1.4

15

Unifying Principles

overview

- Implicit encoding
- Perceptual equivalence
- Spatial equivalence
- Transformational equivalence
- Structural equivalence

[Finke, 1989]

10.1.5

16

Implicit Encoding

- Imagery allows to exhibit information not explicitly stored in memory
- Retrieve implicit information from memory
- Advantageous w.r.t. space requirement
- cf. *diagrammatic reasoning* in AI

10.1.5

17

Perceptual Equivalence

- "Imagery is functionally equivalent to perception to the extent that similar mechanisms in the visual system are activated when objects or events are imagined as when the same objects or events are actually perceived"
- Imagery is essential for vision, not the other way around!

10.1.5

18

Spatial Equivalence

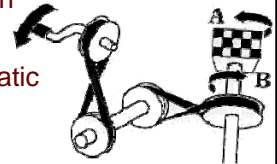
- "The spatial arrangement of the elements of a mental image corresponds to the way objects and their parts are arranged on actual physical surfaces or in an actual physical space"
- *Visual buffer* structure both in vision and in imagery

10.1.5

19

Transformational Equivalence

- Cf. mental rotation
- "Imagined transformations and physical transformations exhibit corresponding dynamic characteristics and are governed by the same laws of motion"
- Cf. mental animation
- Also used in diagrammatic reasoning systems



10.1.5

20

Structural Equivalence

- Structure of images corresponds to that of real objects
 - organized, coherent structure
 - reorganization
 - reinterpretation
- e.g. in configuration tasks, anticipation and planning of motion and change

10.1.5

21

Outline

1. Mental imagery
 - definition
 - rotation and scanning
 - characteristics and properties
2. Human memory
 - working memory recap
 - memory for mental images
3. Imagery Models
 - psychological models
 - AI models

10.2.0

22

Human Memory

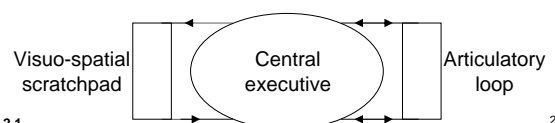
- long-term memory
- working memory
- short-term memory

10.2.1

23

Working Memory [Baddeley 1986]

- information from the senses
- information from long-term memory
- (at least) 2 sub-systems
 - visuo-spatial sketchpad
 - articulatory loop



10.2.1

24

Central Executive

- mediates between
 - working memory subsystems
 - long-term memory
- controls rehearsal processes
- translates between modalities

10.2.1

25

Visuo-Spatial Sketchpad

- short-term memory
- transient structure
 - fading (approx 1.5 sec)
 - rehearsal
- subdivision by Logie, 1995
 - visual information
 - spatial information

10.2.1

26

Capacity Restriction in Working Memory

- 7 +/- 2 items (Miller, 1956)
- 4 items (Cowan, 2001)
- swapping with long-term memory
- chunking in working memory

10.2.1

27

Long-Term Memory

- Network structure
- Spreading activation
- Hierarchical organization
 - conceptual hierarchies
 - individual hierarchies

10.2.1

28

Memory for Mental Imagery

- Imagery is performed in working memory
 - image construction and modification
- Information used in imagery stems from long-term memory
 - activation of information

10.2.2

29

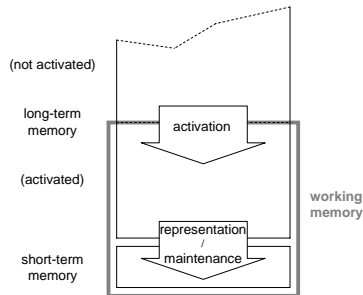
Memory for Mental Imagery (contd.)

- working memory consists of long-term memory and short-term memory
- image construction in visual buffer = visuo-spatial sketchpad
- image inspection in visual buffer
- imagery processes in central executive

10.2.2

30

Integration of Memory Systems



10.2.2

31

Outline

1. Mental imagery
 - definition
 - rotation and scanning
 - characteristics and properties
2. Human memory
 - working memory recap
 - memory for mental images
3. Imagery Models
 - psychological models
 - AI models

10.3.0

32

Imagery Models

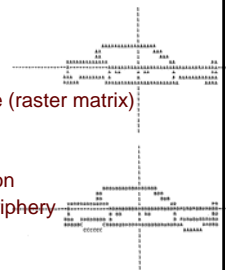
- Psychological models
 - implemented (Kosslyn, 1980)
 - conceptual (Kosslyn, 1994)
- Artificial intelligence models
 - simulation (Funt, 1980)
 - spatial reasoning (Khenkhar, 1991)
 - computational imagery (Glasgow & Papadias, 1992)

10.3.0

33

Kosslyn, 1980

- cathode-ray tube metaphor
 - surface vs. deep representation
- surface representation
 - short-term / working memory
 - quasi-pictorial positional structure (raster matrix)
 - limited spatial extent
 - approx. circular shape
 - definite grain and limited resolution
 - resolution decreases towards periphery
 - fading of image parts



10.3.1

34

Kosslyn, 1980 (contd.)

- deep representation
 - long-term memory
 - 2 kinds of deep representations
 - perceptual / literal image representation
 - skeletal encodings
 - individual encodings
 - hierarchical organization
 - discursive description (propositions)
 - qualitative spatial descriptions
 - information about parts, location, and category

10.3.1

35

Kosslyn, 1980 (contd.)

- image construction
 - PICTURE, FIND, PUT, IMAGE (control)
- image inspection
 - LOOKFOR (control), RESOLUTION, REGENERATE
- image modification
 - ZOOM, PAN, ROTATE, SCAN

10.3.1

36

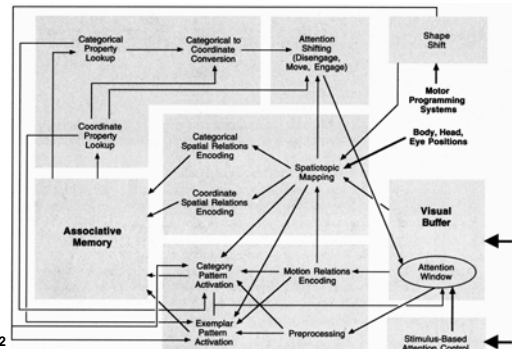
Kosslyn, 1994

- conceptual model
 - based on high-level vision processes (neuropsychology)
 - interaction between subsystems
 - implementation only of partial aspects

10.3.2

37

Kosslyn, 1994 (contd.)

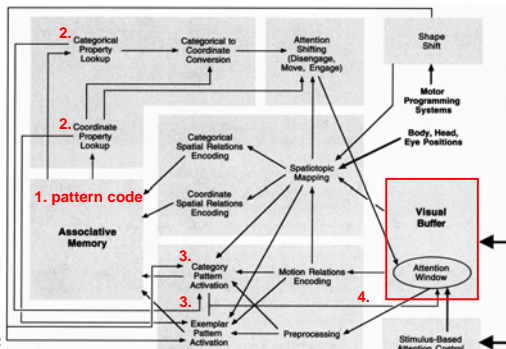


10.3.2

38

Kosslyn, 1994 (contd.)

image construction

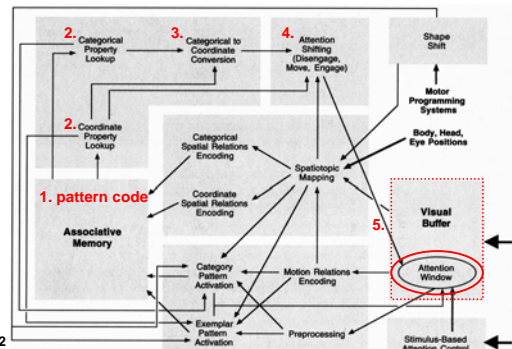


10.3.2

39

Kosslyn, 1994 (contd.)

adding additional parts

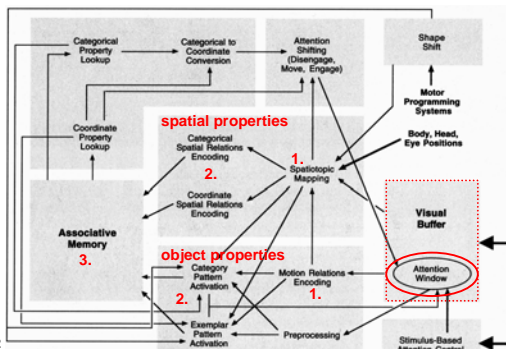


10.3.2

40

Kosslyn, 1994 (contd.)

image inspection

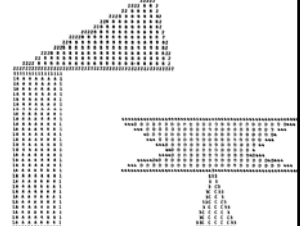


10.3.2

41

Funt, 1980 (WHISPER)

- Reasoning about mechanics
- Prediction of motion
- Positional representation of initial state
- Representation of intermediate states
- Components
 - diagram
 - high-level reasoner
 - 'retina'



10.3.3

Funt, 1980 (contd.)

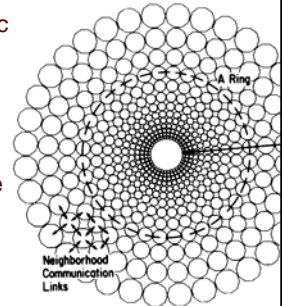
- high-level reasoner
 - procedural propositional problem solver
 - qualitative physical knowledge

10.3.3

43

Funt, 1980 (contd.)

- 'retina'
 - positional diagrammatic structure
 - circular structure of concentric rings
 - parallel processors
 - neighborhood structure
 - supervising processor
 - variable position



10.3.3

Funt, 1980 (contd.)

- retina: perceptual primitives
 - focus center of entity
 - check for symmetry
 - check for congruence
 - scaling, rotation
 - connections, collisions
 - boundary features (convexity, slope)
 - identify neighboring entities
- simulation of tentative movement of objects

10.3.3

45

Depic-2D (Khenkhar, 1991)

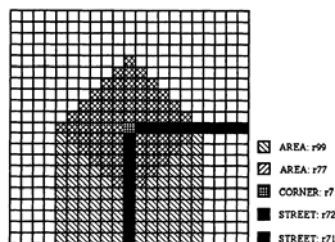
- hybrid system:
 - propositional and pictorial reasoning
- regular rectangular cell structure
- depiction of objects in cells

10.3.4

46

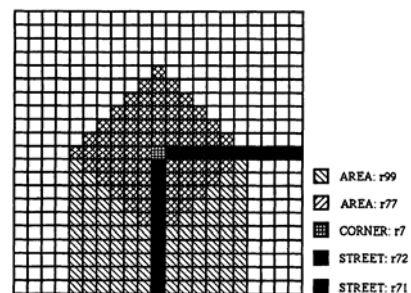
Depic-2D (Khenkhar, 1991)

- depiction of objects in cells
- use of neighborhood structure
 - spreading activation
 - e.g. buffering



10.3.4

Depic-2D (Khenkhar, 1991)

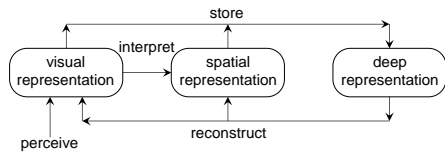


10.3.4

48

Computational Imagery (Glasgow & Papadias, 1992)

- diagrammatic reasoning architecture for technical applications
 - chemistry
 - geography
- 3 subsystems

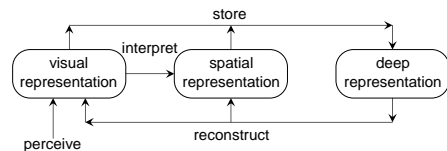


10.3.5

49

Computational Imagery (contd.)

- surface representation subdivided
 - spatial representation
 - 'where' aspects: location w.r.t. other objects
 - visual representation
 - 'what' aspects: shape, color, texture



10.3.5

50

Computational Imagery (contd.)

- deep representation
 - long-term storage (before and after processing)
 - hierarchical organization

10.3.5

51

Computational Imagery (contd.)

- visual representation
 - positional structure: occupancy arrays
 - shape, distance, (relative) distances
 - texture, color, surface orientation
 - 3D, viewer independent
 - standard computer graphics operations

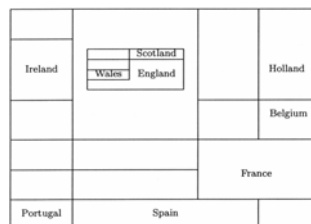


10.3.5

52

Computational Imagery (contd.)

- spatial representation
 - qualitative relationships between objects
 - relational structure: symbolic arrays

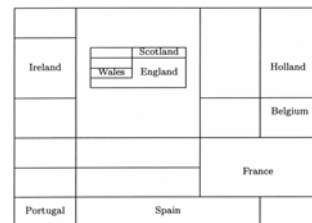


10.3.5

53

Computational Imagery (contd.)

- topology and (coarse) orientation
- no exact shapes and sizes
- hierarchies
- processes for
 - information transfer
 - placing, detecting, moving, deleting
 - checking for adjacency
 - pattern recognition by attention control



10.3.5

54

Next Week

Learning and Action:

Cognitive Maps and Spatial Orientation

10.4.0

55