Internal Simulation as a Key to Cognitive Function

Lund, 2012

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Problems of the inner world

- How does the inner world arise?
- What are mental objects?
- What is the function of the inner world?
- Can animals and robots have inner worlds?
Cognitivism vs associationism

Cognitivism:

Representations
Internal models of the world
Knowledge
Information storage
Theory of mind
Understanding

In short:
Homunculus theories in a new guise
Example: how to explain anomia?

Lesion at ★ patient cannot name object but can perform appropriate action

Over there
Example: how to explain anomia?

Tree

Over there
Example: how to explain anomia?

Over there
The Simulation Hypothesis

1) *Behavioural simulation*: early stages of an action can occur without causing overt movement.

2) *Perceptual simulation*: perceptual activity can be elicited within the brain without an external stimulus.

3) *Anticipation*: simulated perception can be elicited by (simulated) behaviour.
Alexander Bain (1818-1903)

The Senses and the Intellect, 1868
Simulation of behaviour: covert, incipient behaviour

‘The tendency of the idea of an action to produce the fact, shows that the idea is already the fact in a weaker form. Thinking is restrained speaking or acting.’ (Bain, 1868 p 340)

**Analogues:**
Have the radio on but the volume turned down.
Have the car engine running but with no clutch
Hierarchical organisation of action

- Draw triangle
  - Get pen
  - Get paper
  - Draw
    - Draw horizontal line
    - Draw sloping ....
      - Contract m brachioradialis
      - Contract ....
Main signal flow
Evidence for covert behaviour

- Behavioural experiments
- Imaging studies
- Electrophysiology
Activation in motor cortex during motor imagery about 30 % of level observed during actual performance; Roth M, Decety J et al. (1996). NeuroRep 7:1280-1284
Covert behaviour – primary motor cortex

Subjects were instructed to imagine forearm flexion–extension movements with their right arm. TMS was applied to the motor cortex on one side, and the MEPs were recorded from the contralateral flexor muscle (biceps brachialis).

Fadiga et al. *Neuropsychologia*, 37:147-158, 1999
Simulation of Perception: sensory reactivation

‘What is the manner of occupation of the brain with a resuscitated feeling of resistance, a smell or a sound? There is only one answer that seems admissible. *The renewed feeling occupies the very same parts, and in the same manner, as the original feeling, and no other parts, nor in any other assignable manner.* ‘ (Bain, 1868, p. 338)

**Analogues:**
Short-circuiting measurement instruments
Perceiving a keypress
Imagining a keypress

I see K
Damage Perception - Pain
Phantom pain
Seeing

I see a tree over there
Seeing virtual tree?

I see a tree over there
Imagination, recall

I see a tree over there
Evidence for perceptual simulation

Behavioural experiments
Electrophysiology
Lesion studies
Imaging studies
Mental rotation

Shepard & Metzler (1971) Science 171, 701–703
MRI signal intensity in visual cortex during external vs imagined stimulus
fMRI dorsal occipital cortex during perception vs imagery

I am NOT suggesting

That the brain creates an *image or a representation* of the sensory input

I AM suggesting

That a complex stimulus can elicit many different behaviours, such as describing the stimulus, pointing towards it, reaching for it, drawing it…

The same is true about an internally generated stimulus.
Anticipation: action-sensation associations

‘The succession designated as *cause and effect*, are fixed in the mind by Contiguity. The simplest activity is where our own activity is the cause. We strike a blow, and there comes a noise and a fracture. … Hardly any bond of association arrives sooner at maturity, than the bond between our own actions and the sensible effects that follow from them.’ (Bain, 1868, p. 427)
Predictable consequence

$r_1$ will be associated with $s_2$
Anticipation

\[ \begin{align*}
S_1 & \rightarrow s_1 \rightarrow r_1 \rightarrow R_1 \\
S_2 & \rightarrow
\end{align*} \]
Anticipation

$r_1$ will be associated with $s_2$
Anticipation
Behavioural chain

Simulation of behavioural chain
rCBF during Tower of London task

Baker et al., Neuropsychologia. 34:515-26, 1996
Do we need cognitive maps?

LF(G) → D
RF(G) → E
Anticipation – no maps

Declarative Memory – Recall Activated by Actions

Can we account for episodic memory with associative mechanisms?

Predictions:

Declarative (episodic) memory

a) Stored in sensory cortex – disrupted by lesions, activated during recall
b) Activated by perisquires prefrontal cortex
c) Similarities between memory recall and imagining future
Episodic Future Thought: An Emerging Concept

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Abstract
The ability to mentally simulate hypothetical scenarios is a rapidly growing area of research in both psychology and neuroscience. Episodic future thought, or the ability to simulate specific personal episodes that may potentially occur in the future, represents one facet of this general capacity that continues to garner a considerable amount of interest. The purpose of this article is to elucidate current knowledge and identify a number of unresolved issues regarding this specific mental ability. In particular, this article focuses on recent research findings from neuroimaging, neuropsychology, and clinical psychology that have demonstrated a close relation between episodic future thought and the ability to remember personal episodes from one’s past. On the other hand, considerations of the role of abstracted (semantic) representations in episodic future thought have been noticeably absent in the literature. The final section of this article proposes that both episodic and semantic memory play an important role in the construction of episodic future thoughts and that their interaction in this process may be determined by the relative accessibility of information in memory.
Similarity memory recall – imagining future

A

PAST EVENT > CLINTON

FUTURE EVENT > CLINTON

B

PAST AND FUTURE EVENT ELABORATION

PAST EVENT > CONTROL

FUTURE EVENT > CONTROL

Working memory – stored information?

1. Food is placed in randomly selected well visible to monkey
2. Screen is lowered and food covered for a standard time
3. Screen is raised and monkey uncovers well containing food

Dorsolateral prefrontal cortex

Stimulus (food morsel) presented

(D) No stimulus presented

Cue Delay Response
Conversation
Talking to oneself
Simulating conversation
Why do motor structures participate in cognitive functions?

a) Thinking is covert movement
b) Abstract actions need same auxiliary systems
Working Memory as Covert Actions Extended in Time

Predictions:

Working memory

a) involves prefrontal and posterior (sensory) cortex
b) utilises the same circuitry as long-term memory
c) is modality and feature specific
Strong points of the simulation hypothesis

• Ontological parsimony: no representations, images …

• Does not require external agent

• No evolutionary leaps: same structures underlying inner world as are used for perception and movement

• Explains relationship between cognitive and motor function
Khepera robot

K trained to
a) avoid obstacle
b) predict sensor input in next step
Robot architecture

Ziemke et al. (2002).
Sensor guided movement

Ziemke et al. (2002).
Prediction guided movement

Ziemke et al. (2002).
Does $K$ have an inner world?

- Why is this not merely a causal chain?
- Why do not any internal events count as inner worlds?
Does $K$ have an inner world?

Suppose that the robot could

- Respond differentially to different inputs
- Respond in many different ways to the same input
- describing the obstacle verbally
- draw the obstacle
Does $K$ have an inner world?

Suppose that the robot could

Respond differentially to different inputs

Respond in many different ways to the same *(simulated)* input

describing the obstacle verbally

draw the obstacle
Problems of the inner world

• How does the inner world arise?
  By simulation of behaviour and perception

• What are mental objects?
  Source of image is not object but simulated seeing

• What is the function of the inner world?
  Inevitable consequence of simulation

• Can animals and robots have inner worlds?
  Yes, if their "brains" can generate their own input
References

Outline of the simulation hypothesis can be found in


For empirical evidence for covert behaviour, see papers by Jeannerod, e.g.

Evidence for simulation of perception is reviewed in

Robot simulation:

Thank you for listening!
External vs internal sensor activation

Ziemke, Jirenhed & Hesslow (2005) Neurocomputing
Stimulus prepares many responses
One response "wins".

[Diagram showing decision-making process with options such as "Red", "Down right", "Kick Point", "Catch", "Grab", "Say "red"", "say "ball"..." and a highlighted "Ball".]
At what point did subject become conscious?

It didn’t!

- Kick
- Point
- Catch
- Grab
- Say "red"
- Ball
- Down right
- Red
- Ball
- Say "ball"
Responses elicit simulated perceptions

Both overt and abortive responses elicit simulated perceptions – *these can be reported.*

I saw the ball and thought about kicking it, grabbing it, pointing…

Seeing myself kicking, pointing, catching…

Say “red”, say “ball”…

Kick
Point
Catch
Grab
The echo in the brain

Did you see the ball?

Yes

Say "red", say "ball"...

Seeing myself kicking, pointing, catching...

Kick
Point
Catch
Grab