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Cognition and Emotion

Lecture 5: Computational Cognitive Science

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Lecture Overview

- ▶ What is Computational Cognitive science
- ▶ The Computer Metaphor
- ▶ Computational Cognitive Modelling
- ▶ Examples of Models
- ▶ Strengths
- ▶ Limitations

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What is Computational Cognitive Science?

- ▶ The study of behaviour through computational mechanisms.
- ▶ It aims to understand the basis behind human information processing.
- ▶ Incorporates mathematics, computer simulation, behavioural experiments, Artificial Intelligence (AI).

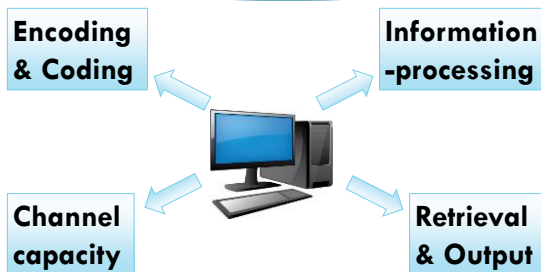
Computational Cognitive Science

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- Relies on the **computational metaphor**.
 - Brain is considered as similar to a computer, with groups of neurons performing computations.
- Cognition is then simulated through software and programmes
- Neisser (1967): "The task of trying to understand human cognition is analogous to trying to understand how a computer has been programmed" (p.6).

Computer Metaphor

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Computer Metaphor

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- Fundamental aspect of the metaphor is the description of human cognition in terms of **information processing**
- To understand this we must differentiate between **content** of information and the **process** by which it is transmitted.
- Other important factors about the computer metaphor
 1. Information processing can be described by a number of stages.
 2. The form of information can change during the processing.

Computational Cognitive Science

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- ▶ Makes use of Modelling
 - ▶ Not that type of modelling
- ▶ Uses **Computational models**
 - ▶ Developing computer programmes that mimic human thought and cognitive processing.
 - ▶ A good model shows how a theory can be specified
 - ▶ It allows behaviour to be predicted in a new situation



Cognitive Modelling

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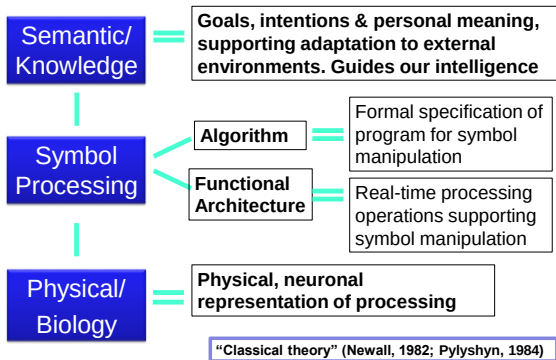
- Aims to scientifically explain cognitive processes and how they interact.
- We want to know how the mind works:
- How we process information and act on it.
 - How we learn, generalize, and memorize.
 - How we think, reason, plan, and make decisions
- ☐ Comparing the principles of a model to human behaviour allows us to test and refine theories.

Cognitive Modelling

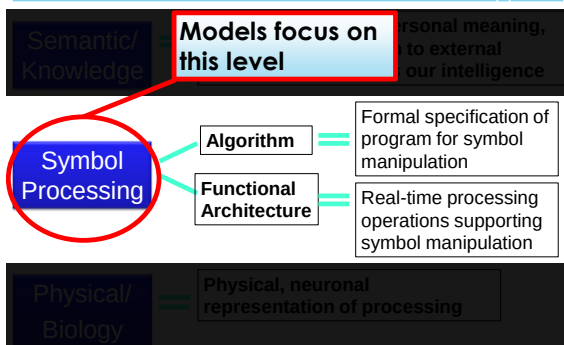
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- A model is a very explicit theory regarding our mind's processing.
- Is described in formal, mathematical, & computer languages.
- Differs from conceptual models, as they use verbal descriptions of theoretical assumptions.

Cognition: Levels of description



Cognition: Levels of description



Cognitive Modelling

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- **Symbol-processing level:**
 - Here we find differences between individuals.
 - Not at algorithm level but at functional architecture level.

- **Example:**



- Both run same algorithm for word processing programme
- But architecture is different meaning one may be quicker

Cognitive Modelling

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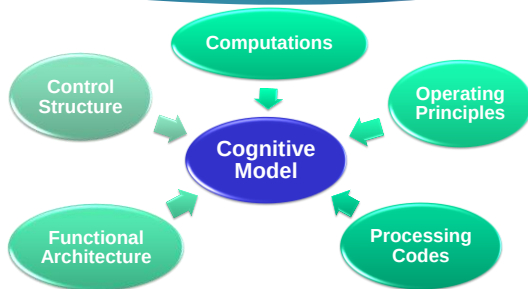
- The same applies to human cognition



- Rules to work something out are the same for all but our functional architecture may differ
- E.g., someone with less working memory capacity may be unable to comprehend a sentence as quickly as someone else.

Building Models

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Processing codes

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Code	Description
Visual	Properties from stimuli such as their colour, shape, and brightness that are seen through visual perception.
Spatial	Stimulus properties relating to spatial relationships or configuration.
Acoustic	Properties derived from auditory perception: e.g., pitch, intensity, direction of sound.
Phonological	Speech sounds
Lexical	Enters words into out internal dictionary
Semantic	Meaning assigned to the stimulus
Graphemes	Used for spelling and writing
Motor	Instructions sent to muscles to make us move
Articulatory	Instructions sent to larynx to produce speech

Processing codes

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- Codes can be further broken down.
- Ps required to indicate whether 2 letters were the same.



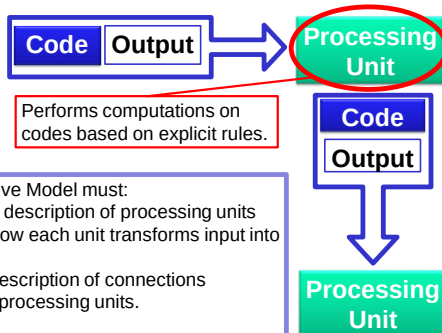
- When letters were the same, the response was faster if they were both in the same case than in different cases.
- Same semantic code but different physical form.

Posner (1978)

Computations

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- Once internal processing codes are defined, what happens with the codes is defined.
- Computations on the codes are achieved by processing units or component processes.
- Processing unit = anything that processes or performs various operations on codes according to predetermined rules.
 - Unit then sends a different output code, which is sent to another processing unit and so on.



- Any Cognitive Model must:
- Include a description of processing units
 - Specify how each unit transforms input into output.
 - Include description of connections between processing units.
 - Description of this whole information-processing circuitry is called:
The Cognitive Architecture.

Cognitive Models

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- There are a vast number of models
 - Some focus on specific aspects of human cognition (e.g., reading)
 - Others focus on the **Cognitive Architecture**
- They differ in many ways - E.g., in assumptions about:
 - Representation (symbolic or distributed).
 - Domain-specificity and modularity.
 - Need for & nature of built-in (innate) constraints

Spreading Activation Models

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FISH + **CHIPS**

Concerned with structure of LTM & the way information is retrieved from it to make decisions about concepts.

3 Principles of Association:

- **Contiguity** (association through occurrence in time).
- **Similarity** (associated because they are alike).
- **Contrast** (associated because they are opposite).

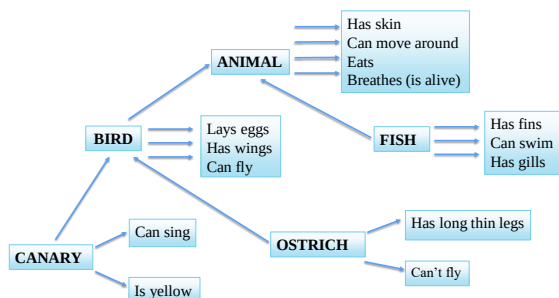
Can you think of real-life examples that fit these principles?

Spreading Activation Models

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- Make two types of statements:
 1. Describe hierarchical structure of association between concepts.
 2. Describe the spreading activation.
- Each concept has an activation value (normally low or zero).
- Experience activates corresponding concepts.
- Activation spreads to associated concepts (& decays).
- Rate of spread reflects strength of associated link (determined by factors such as similarity of concepts).

Collins & Quillian (1969): Spreading Activation Model



Connectionist Models

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- Try to explain range of cognitive phenomenon
 - Not just associative memory as is the case with spreading activation models.
- Concerned with learning responses by applying algorithms.
- Reject idea of a controlling executive system.

Connectionist Models

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- Use representations consistent with physiology
 - Networks resemble interconnected neurons.
 - Each unit has activation level (an associated level of energy that can be transmitted to other units).
 - Nature of the transmission depends on type of connection between the units.
 - Connections have weights: **facilitatory** or **inhibitory**
 - Weights vary in size and direction

Connectionist Models

- Number of rules in the system:
 1. Activation rule: determines how unit deals with input
 2. Output rule: determines unit output to other units.
 3. Learning rule: determines the way associated weights with connections between units are changed
- All rules thought to be hardwired - contained within the physical properties of the system.

CONNECTIONIST MODEL: EXAMPLE

Interactive Activation Model (IAM): McClelland & Rumelhart (1981)

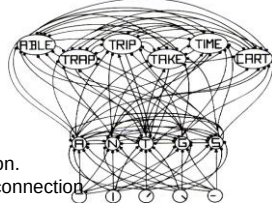
- Attempts to simulate word recognition with units arranged in 3 levels:
- Each level codes for a different type of property:
 1. Activating features: line segments of a letter
 2. Letter representations (bottom-up parallel process).
 3. Word unit (top-down processing also occurs).
- The feature units can inhibit letter units that do not contain a particular feature.

Nodes:

1. Word detector
2. Letter (Position)
3. Feature (Visual)

Arrows show excitatory connection.

Rounded heads show inhibitory connection.



Connectionist Model: Evaluation

- Step-up from spreading activation models.
- Criticised for not representing formal structure of inter-relationships between mental states.
- Lack explanatory power associated with the symbolic approaches to cognition.
- Only useful for explaining certain things
 - E.g., language acquisition.
- Intention to copy neural functioning has limited application + is not direct model of processing

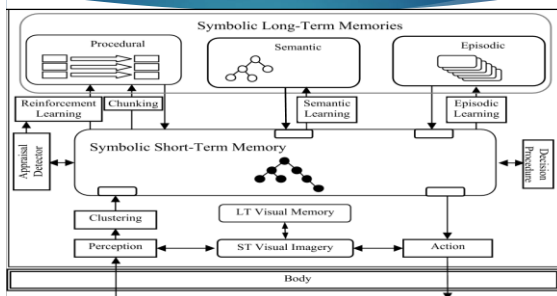
General Cognitive Architecture Model

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- Laird, Newell, & Rosenbloom's **SOAR** model
 - Intends to work on full range of tasks expected of an intelligent agent, from highly routine to extremely difficult, open-ended problems.
 - All decisions are made through combination of relevant knowledge at run-time.
 - Every decision is based on current interpretation of sensory data, contents of working memory created by prior problem solving, and relevant knowledge retrieved from long-term memory.

SOAR Website: <http://soar.eecs.umich.edu/>

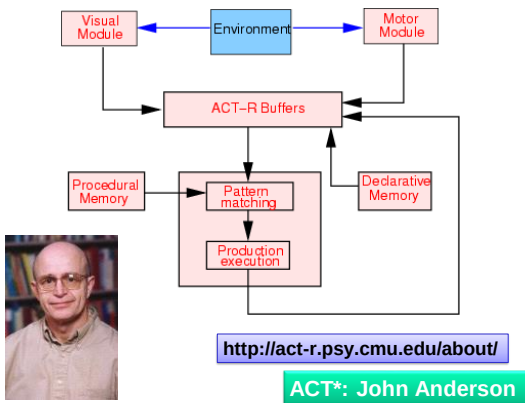
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John Anderson's Adaptive Control of Thought (ACT*)

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- Assumes cognitive systems have several modules.
- Four modules important to human cognition:
 1. Retrieval: cues are required to access stored info
 2. Imaginal: transforms representations for problem solving
 3. Goal: keeps track of intentions & controls processing
 4. Procedural: uses production (IF → then) rules to determine action
- Each module has a buffer with info from buffers integrated by a central production system



Strengths

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- ▶ Is explicit in terms of theory explanation
- ▶ Can help provide an overarching framework to understanding the cognitive system.
- ▶ Can link with other cognitive approaches.
- ▶ Requires depth, clarity, & specificity in theorising.
- ▶ Models can be developed to account for new conflicting data.
 - ▶ Underlying principles of model may be correct but fails due to minor problem in programming.

Limitations

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- Bonini's paradox: "As a model of a complex system becomes complete, it becomes less understandable"
- Difficult to falsify models as models can account for numerous findings
- Overfitting: generalising to certain datasets when others have failed (Ziegler et al., 2010)
- Most models ignore fact that cognition is influenced by conflicting motivational and emotional factors
- Programmers do not always make code available

Limitations

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- Dreyfus: we do not find ourselves in situations where we are incidental to cognition.
- We are involved in open-ended task with infinite ways to perform.
 - Behaviour is not driven by knowledge encoded explicitly from rules, but from practical knowledge.
- Machines are disembodied and only interact with the world through humans.

Limitations

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- For skilled actions, such as riding a bike, the role of the situation is critical.

EMBODIED COGNITION



- Clark (1997): Brain, body, and world interact causally and computationally.

Lecture Summary

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- ▶ Computational Cognitive Science involves developing computational models to explain cognitive functioning.
- ▶ Relies heavily on the computer metaphor, which suggests the manner in which our cognitive processes compute information is akin to that of the software of computers.
- ▶ General architectural and module specific models have been developed.
- ▶ However, the approach is criticised for not taking account of situational and individual human factors
