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Alternative approaches to modelling: Unified Theories of Cognition and Embodied Cognition

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Different modelling approaches

- Neural networks
- Evolutionary computation
- Complex systems
- Unified theories of cognition (part A)
- Symbolic models (part B)
- Embodied cognition (part C)
- …

Part A. Unified Theories of Cognition (UTCs)

- A UTC is a theory that aims to provide
  - a complete description of the functions and capabilities of a cognitive system. (Not just what a system can do, but also able to account for its potential)
  - Usually a UTC is defined as a small set of principles of operation, rather than an exhaustive list of behaviours (why is this an important aspect of a cognitive theory?)
  - A UTC is not a hypothesis to be empirically tested, but rather is a blue print for constructing models

Examples of UTCs

- Soar (State Operator and Result) (Alan Newell)
  - All behaviour is seen as a search through a problem space made up of goals, states and operators.
  - Soar is built on a production rule framework
- Act* (John Anderson)
  - The core of cognition is a spreading activation-based semantic memory and production rules for operators
- Copycat (Melanie Mitchell, Douglas Hofstadter, and FARG)
  - The essence of thinking is high-level perception (fluid analogies)
  - It uses heuristics to combines bottom up and top down pressures
  - Components include the slipnet, workspace, coderack and temperature

A small set of principles of operation

- All three examples of UTCs are based on some form of working memory and operators over that memory.
- Why is a small set of principles a critical part of the theory of cognition?

From finite instructions to infinite behaviours

- Context is unbounded
- Behaviour is unlimited
- But the cognitive architecture is a finite machine. How can it generate unlimited behaviours?

(Consider a grammar vs the set of sentences it can generate.)

Part B. Symbolic models

- Information is processes in the form of symbols, typically inspired by von Neumann machines (traditional computers)
  - The *physical symbol system hypothesis* says that thinking involves symbol systems that are physically instantiated.
- A symbolic level of description and processing can be a complete description of "thinking"

Typical basis of symbolic models

- Production systems: The mind consists of
  - A working memory
  - A large set of production rules
  - A set of precedence rules determining the order of firing of the production rules

Production Systems

- Were introduced as a flexible model of the control structure of human cognition by Newell and Simon in 1973.
- Unlike standard programs, there is no fixed program or procedure laid out in advance
- Instead, the system consists of a set of independent production rules (condition-action pairs) that may fire at any time their conditions are satisfied.
- The flow of control is determined at run time and is a function of the dynamically evolving components of the working memory that triggers the productions
- A cognitive model written is a production systems makes a theoretical commitment to the set of production rules and is complete at that level.

Production systems cont.

- All instructions take the form:
  IF <<condition>> THEN <<action>

  If <red block is on blue block> then <move red block to table>
  If <all blocks are blue> then <create memory element "all-same">

- The conditions are propositions that state properties of (or relations among) the current state of the components being modelled.
- The conditions are usually stored in working memory (short-term memory, current sensory memory, or an activated portion of semantic memory)
- Actions may be motor ones that act on the environment of actions to alter memories, including erasing and creating working memory elements

Metalevel architecture of Soar

- Soar comprises sets of states, operators and actions
- Given a particular state of working memory, rules with that state as a condition will fire
- To the basic production system architecture are added mechanisms for recursive application of operators to a hierarchy of goals and subgoals for learning productions and for making decisions
- Whenever Soar does not have an unambiguous rule telling it which problem-solving step to take next, it invokes universal subgoaling to set up a metalevel problem space that will resolve the issue

Typical features of symbolic models cont.

- Typically viewed as a sequence of processing stages
  - Input and encoding
  - Memory storage and retrieval
  - Output

Such theories typically assume a central executive to control the flow of information, one or more memories to retain information, sensory devices to input information and an output device

(How does Copycat differ from this view?)

Typical features of symbolic models cont.

- Schemata: information is mostly in the representational structure of human knowledge.
  - Frames and scripts each specialise in an aspect of the world (objects, events and action sequences) which represent default situations, use variables to represent items and relations, can be embedded in one another, are multilevel
  - Eg restaurant script; doctors visit; typical room

Eg. Parts of a restaurant script

- Objects: tables, chairs, waiters, customers, food, payment
- Events and action sequences: arrival at restaurant, ordering a meal, eating, paying for the meal
- Variables: type of food, cost
- Embedded descriptions: paying with a credit card can be a script in its own right
- Multilevel descriptions

Advantages of symbolic models

- Handle variables well
- Can use recursion
- Captures the essential intuitions about logical thinking

Weaknesses of symbolic models

- Has not been useful for modelling vision, hearing, motor control
  - Ie Input and output is often poorly modelled
- Usually doesn't deal well with contextual processing
- No connection to neuroscience (not guidance for implementation in the brain)

Part C. Embodied cognition

- At the other end of the philosophical spectrum of cognitive theories are ones based on embodiment
  - Intelligence is grounded in interactions between the body and the world
  - Explanations are in terms of interactions between brain, body and environment in roughly equal parts

(How does this approach differ from that of general artificial intelligence?)

EmCog cont.

- Bodies are survival mechanisms
- The brain takes 20% of the oxygen and other nutrients used by the body.
- It's not there as a luxury ornament, but rather as a coordinating function
- If information is available in the world, the brain won't duplicate the information.
  - Eg road maps and street signs

Evolutionary approaches

- Theories of embodied cognition are often theoretically close to evolutionary psychology.
- Evolutionary psychology researchers, Tooby and Cosmides have argued that general purpose intelligence could not have evolved, since the brain is only useful in solving specific tasks that individuals face in their lives, Thus the brain, like the body will turn out the be a series of computational modules, each one designed for a specific purpose (finding a mate, finding food, fighting predators or competitors, etc)

Epistemic actions

- Many animals build designer environments
  - They put information such as chemical trails that others of their species can use
  - This allows coordinated action with very simple cognitive capacities
  - Eg ant trails

Examples of models

- Synchronous flashes in fire flies
- Ant trails
- Walter grey's robots
- Braitenberg's vehicles using very simple rules show approach / avoid behaviours.
- Brooks subsumption architectures

Lessons

- Communication can be circumvented using epistemic actions
- Simple mechanisms, when interacting with the environment can give rise to seemingly complex behaviours.
- Simple mechanisms can even look like purposeful behaviour, s.a. grouping objects
- Cooperation is an emergent phenomenon
- Behaviours depend on how sensors are configured
  - Zebras have eyes facing outwards (prey)
  - Lions have eyes that face forwards (predator)

What EmCog does well

- Interaction with the environment
- Integrating sensors and motor control
  - Eg walking insects
  - Helicopters based on the brain of a bee

Weaknesses

- High level behaviours
- Reasoning, memory, high-level cognition

Summary

- Models in cognitive science vary from symbolic, through connectionist, to evolutionary and embodied.
- Some of these are mutually exclusive, but in many cases they provide alternative viewpoints to understand different aspects of cognitive architecture.