

Computational models of creative problem solving

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A brain-based approach to AI

- To develop a brain model, as faithful as possible to human data
- The model allows abstraction and scaling into AI systems
- We need a natural science description language for information-processing in the brain
- Computer science concerns information-processing description languages and uses multiple levels of description
- We use a logic programming descriptive approach where data are logical expressions and computation is logical inference

Describing the brain at the system level

- First, study neuroanatomy, finding brain areas and connections
- The system level concerns information, with operations for data construction, storage, and transmission
- The neural circuit level concerns neurons and synapses

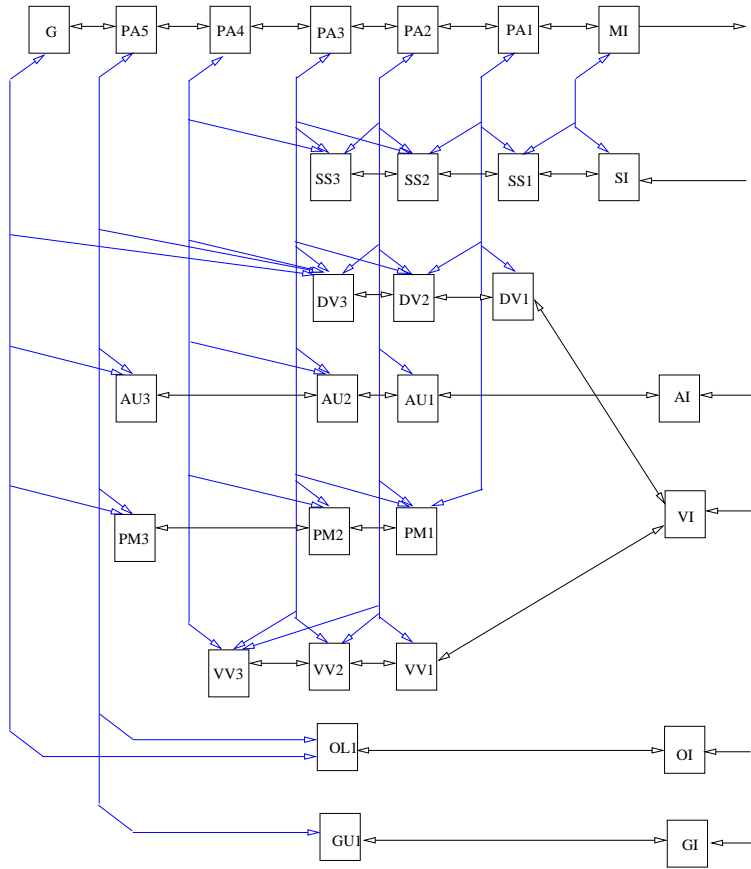


Figure 1: Neocortical perception-action hierarchy

This diagram summarises my survey of the areas and connectivity of the neocortex. It consists of several ascending perceptual hierarchies and one descending planning and action hierarchy, with lateral connections between them.

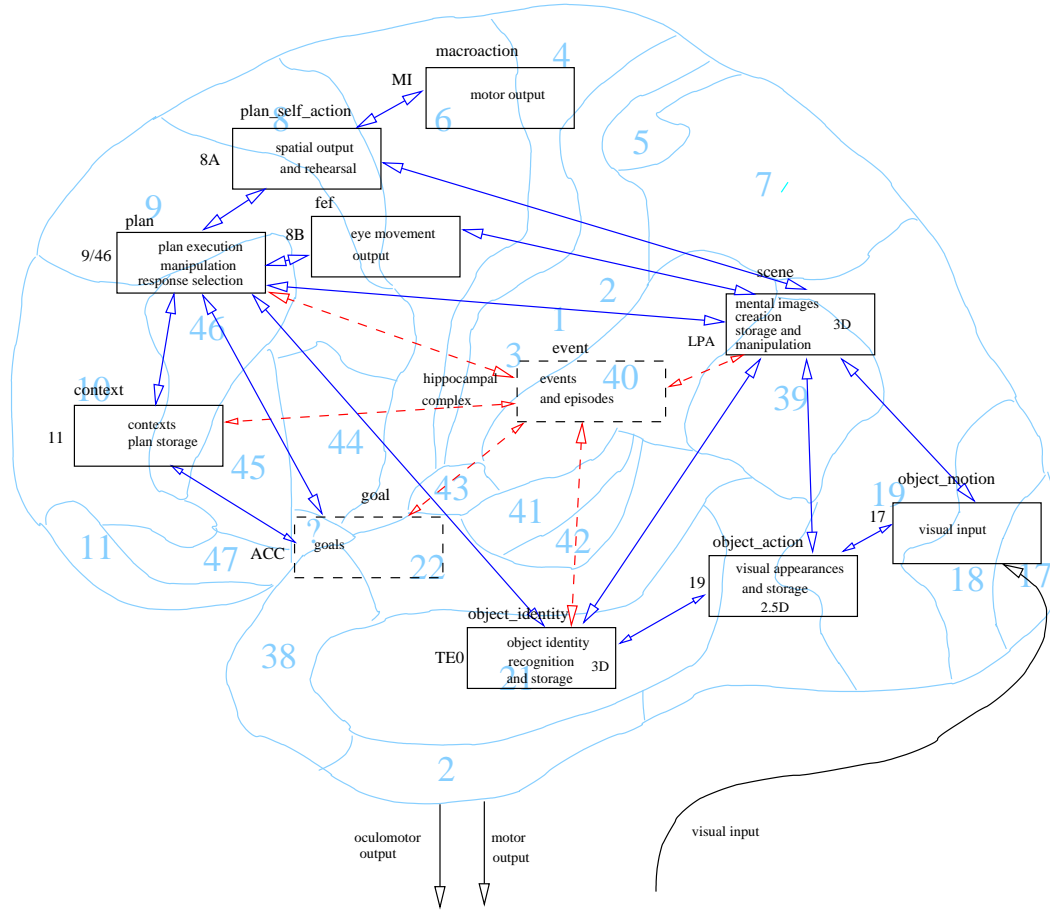


Figure 2: Brain architecture at the system level

This diagram is of a model I recently implemented to demonstrate spatial working memory. It shows how each processing module of the model corresponds to a different brain area, and each brain area constructs data of types characteristic of that particular area.

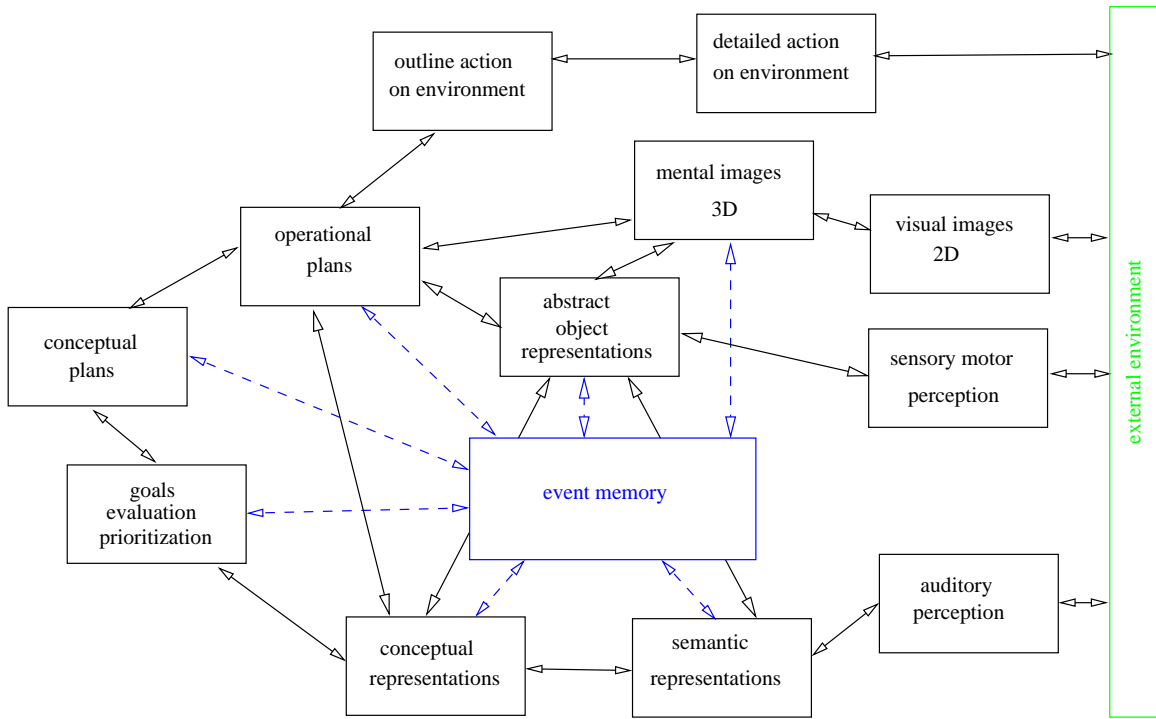


Figure 3: Abstraction to brain-inspired system architecture

This diagram indicates how, from a brain model, we can derive an abstract computational model, with different data types not found in the brain and with different connectivities of processing modules.

Our implemented model of the primate brain: perception-action and social behavior

- It has perception-action dynamics
- A number of memory mechanisms were developed to ensure well-formed action of memory modules
- We developed confirmatory feedback between modules to ensure stability of action of the distributed system
- We used perception of intention for better accommodation to change
- The system tends to form relatively stable **viable states**
- Systems show natural social interaction

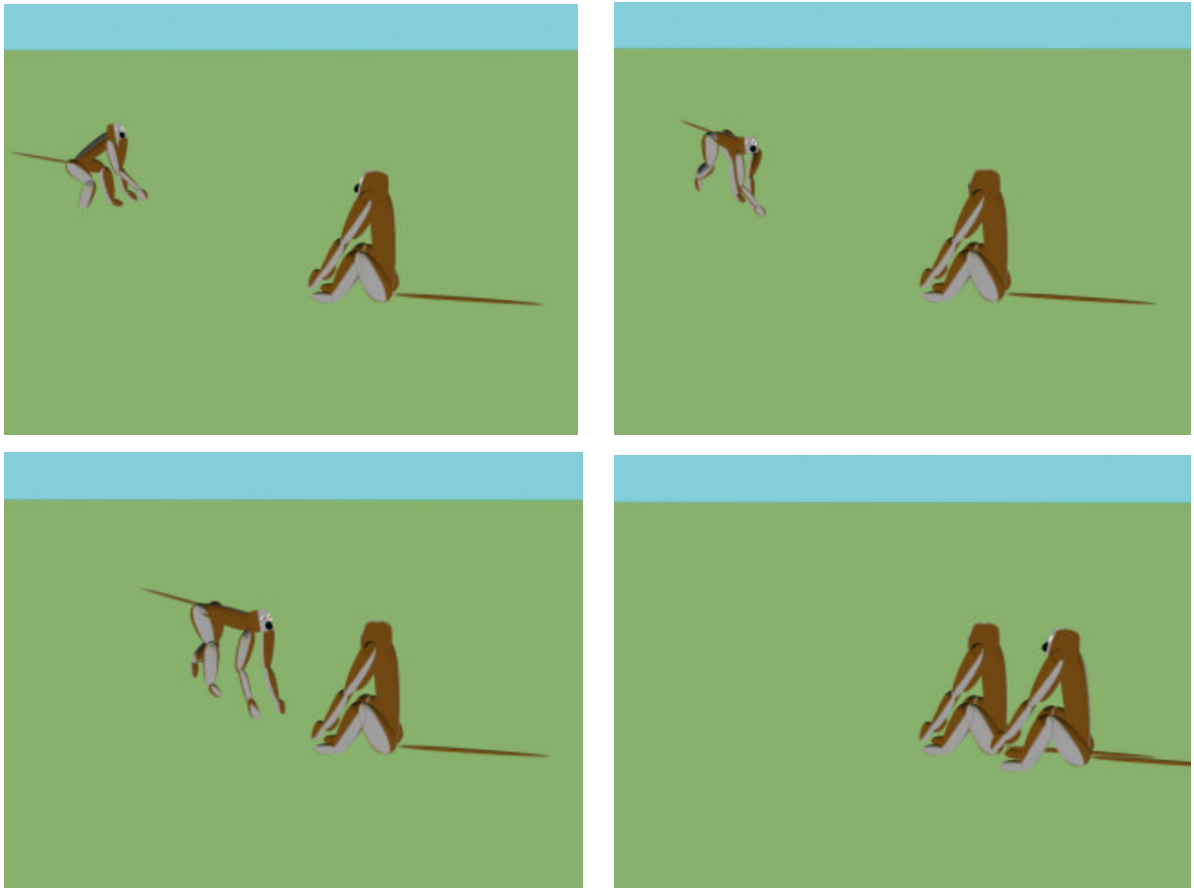


Figure 4: Grooming sequence

This shows snapshots of a simple social behavior obtained with our model. Each primate is driven by a brain model and they perceive each other and act towards each other in a 3D space.

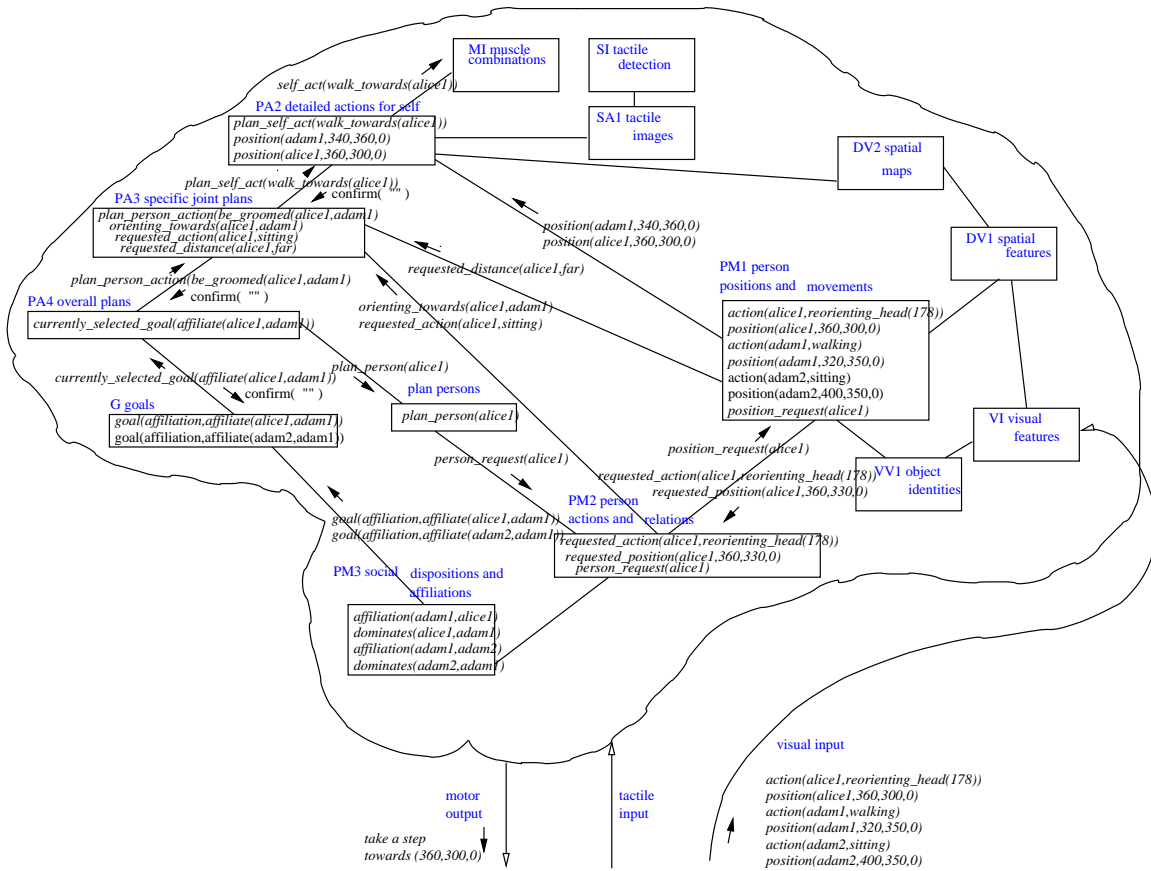


Figure 5: Visualization of a typical instantaneous state of the model

This diagram shows a mental state of the model.

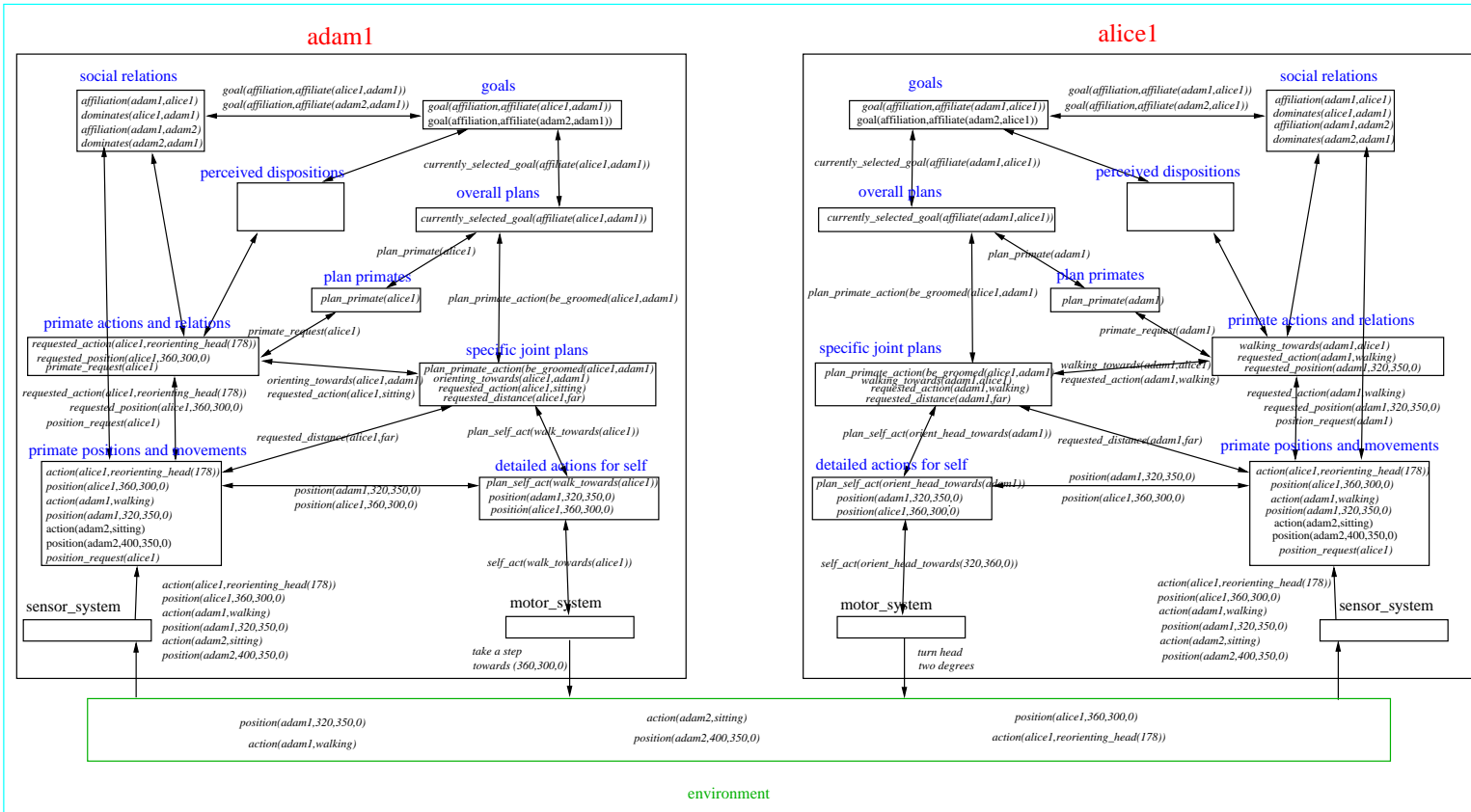


Figure 6: Social relationship and action

This diagram attempts to show the complementary mental states of two interacting persons, so each is predicting the other and acting towards the other, and has a goal that it important to it, and is executing a plan that is relevant to its goal, leading to action which is in perceived agreement with the other person's goals.

Towards human cognition

We are extending this model to include additional memory systems, episodic, long term memory and routine memory, implemented by the hippocampus the and basal ganglia.

- We studied simple problem-solving strategies, i.e., the Tower of Hanoi
- We developed processes for mental imagery, as part of our model of spatial working memory
- We developed an approach to episodic memory formation

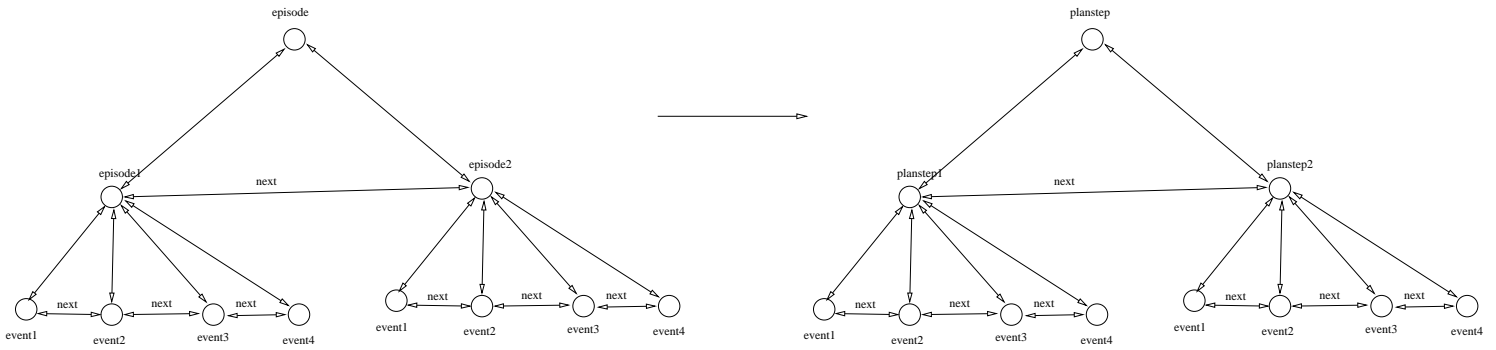


Figure 7: An episode as a sequence of episodes, and its correspondence to a plan created from it

Our idea of episodic memory is to use a limited branching structure of events and episodes combining to form higher level episodes. This has temporal and spatial relationship information. From a set of remembered episodes, plans can be formed and executed

Issues in problem-solving

We hit a number of difficult problems in extending our model to have episodic memory and problem solving.

- We found parallel plan execution to be very useful but needed a biologically plausible, simple and stable execution mechanism
- We need some new simple types of goals in perceptual modules
- We need a uniform method for parameter passing and for returning results
- We would like to have constraints as components of plans
- We would like a natural correspondence of the system level model to cortical circuitry, and ideally we would like matching at the system level to correspond to iterative parallel matching at the circuit level.

Creativity

- Creativity as combining disparate knowledge
- Creativity and construction, memory retrieval as construction, from Schacter et al.

An approach to creative construction

- Extend episodic memory to be more explicit with relations and constraints explicitly represented in episodic memory
- One source of constraint expressions is the perception-action hierarchy
- Relations include control and sequencing relations
- Plan execution now is construction of plan steps and sequences

richer and more
comprehensive
event representation

explicit representation
of relations among data items



broader matching
and creative construction
in each module

components of more than
one event records matching
together
produces novel new
event representation



(slower)
matching between
modules

new module events
reconcile across
different modules
producing viable
new event

Figure 8: Creative construction process

Control of the creative constructive process

- We suggest creative construction as a central process in cognition, described at the information and the neural circuit levels
- This central process is controlled and modified by different mechanisms:
 - Queries
 - Focus on one module or representation
 - Seeding with expression which should be satisfied if possible, e.g. use of parity in Tower of Hanoi → parity strategy

Creative construction should solve several problems

- Flexible and correct plan execution
- Use of constraints as components of plans/contexts
- Use of simpler iterative matching, corresponding neural net description
- Flexible reconstruction of remembered events
- Creation of novel events