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From Physical Neurons to Cognitive Programs: How to build a Cognitive Computer Architecture?

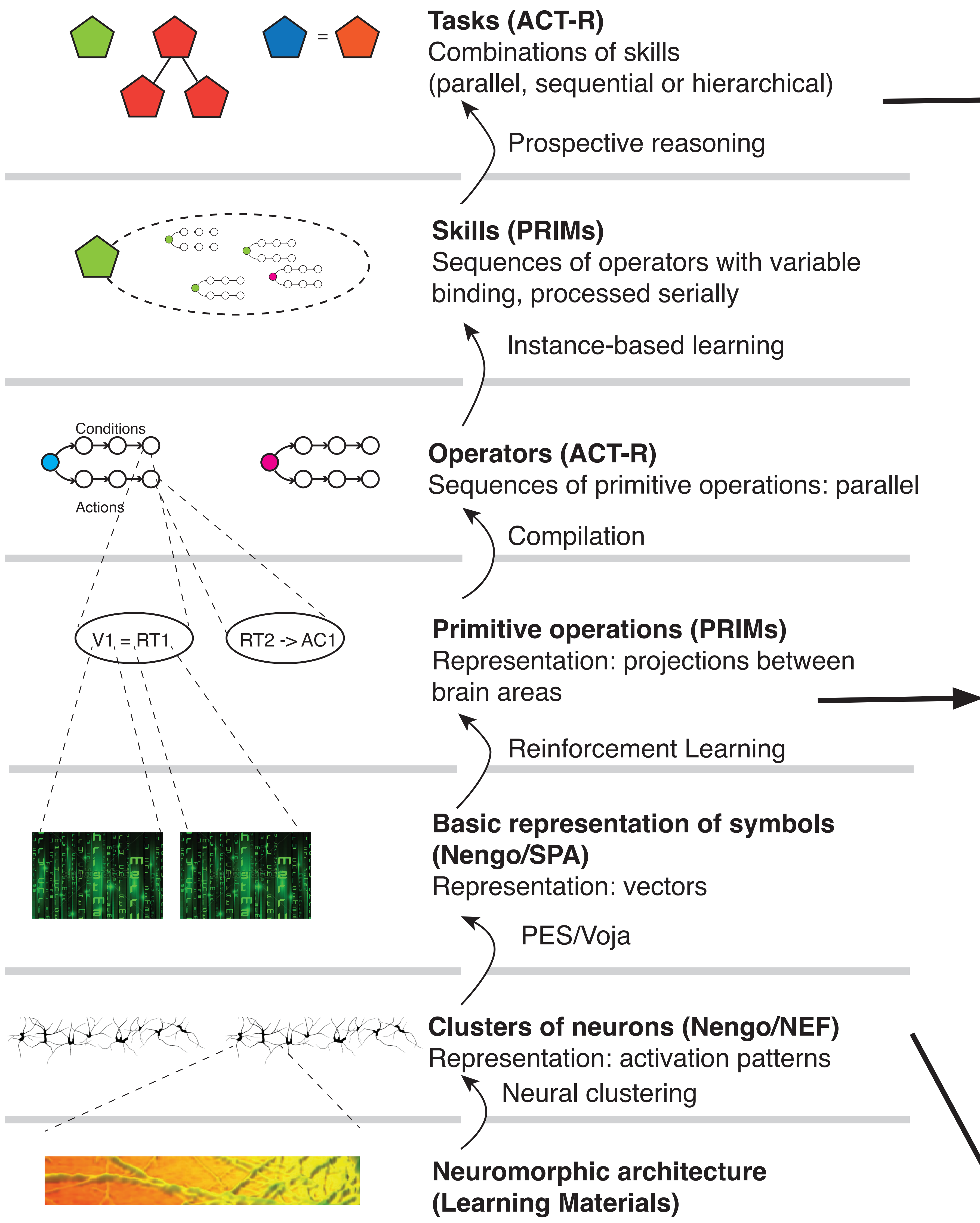
Niels Taatgen (n.a.taatgen@rug.nl)
Bernoulli Institute for Mathematics, Computer Science and Artificial Intelligence
Groningen Cognitive Systems and Materials Center

Overview

A Cognitive Computer based on neuromorphic hardware requires more than building neural networks out of silicon or other materials. Just like conventional computer architectures, multiple levels of abstraction are needed to support flexible computation, each with its own representation that can be reduced to the underlying level.

A critical difference between computer and cognitive architectures is that the latter is based on learning. This poster presents a possible framework that is based on what we know about human intelligence and learning.

Many of the components of the framework are based on existing theories: ACT-R, PRIMs, Nengo. The challenge is to combine them productively.



Tasks (ACT-R)
Combinations of skills
(parallel, sequential or hierarchical)

Prospective reasoning

Skills (PRIMs)
Sequences of operators with variable binding, processed serially

Instance-based learning

Operators (ACT-R)
Sequences of primitive operations: parallel

Compilation

Primitive operations (PRIMs)
Representation: projections between brain areas

Reinforcement Learning

Basic representation of symbols (Nengo/SPA)
Representation: vectors

PES/Voja

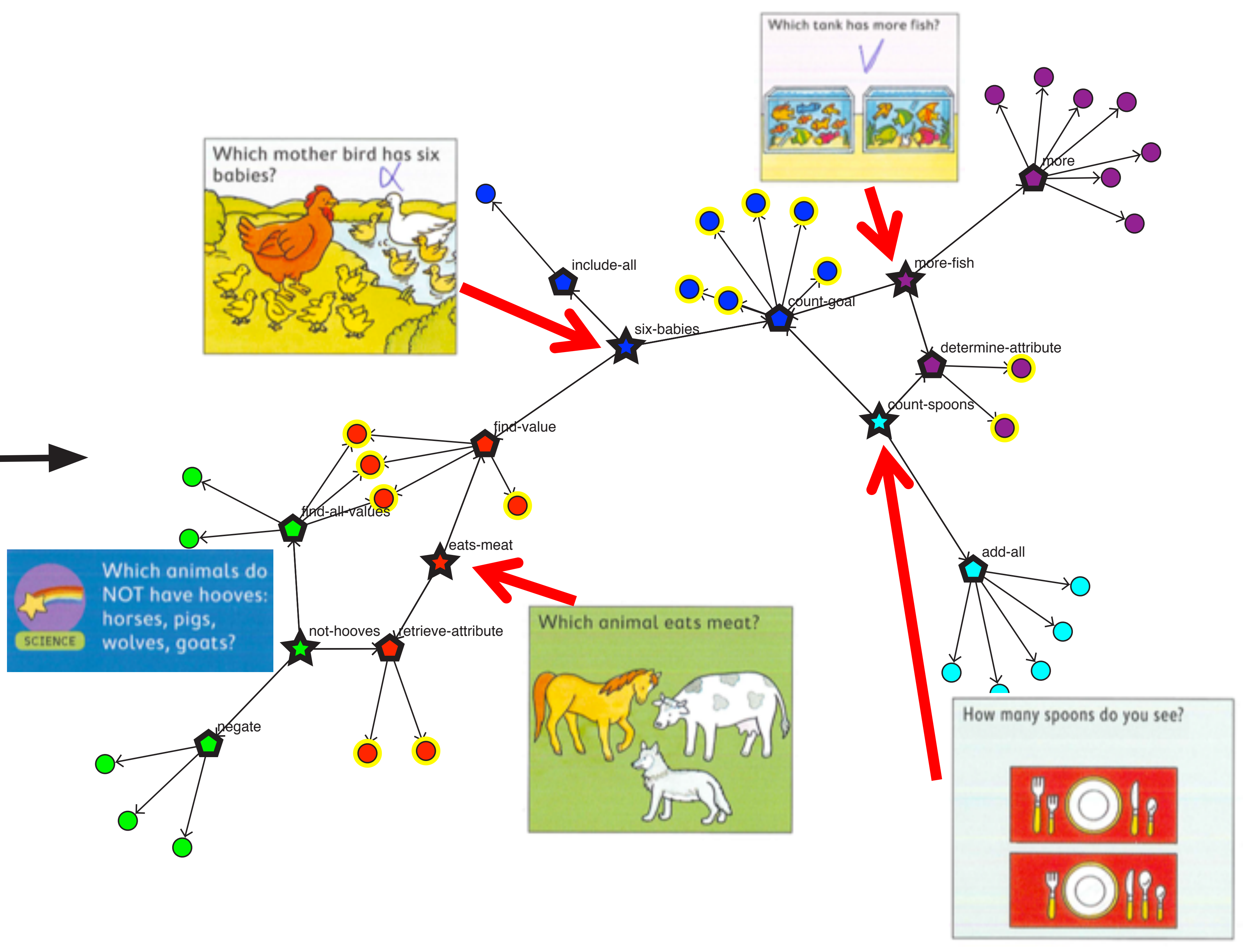
Clusters of neurons (Nengo/NEF)
Representation: activation patterns

Neural clustering

Neuromorphic architecture (Learning Materials)

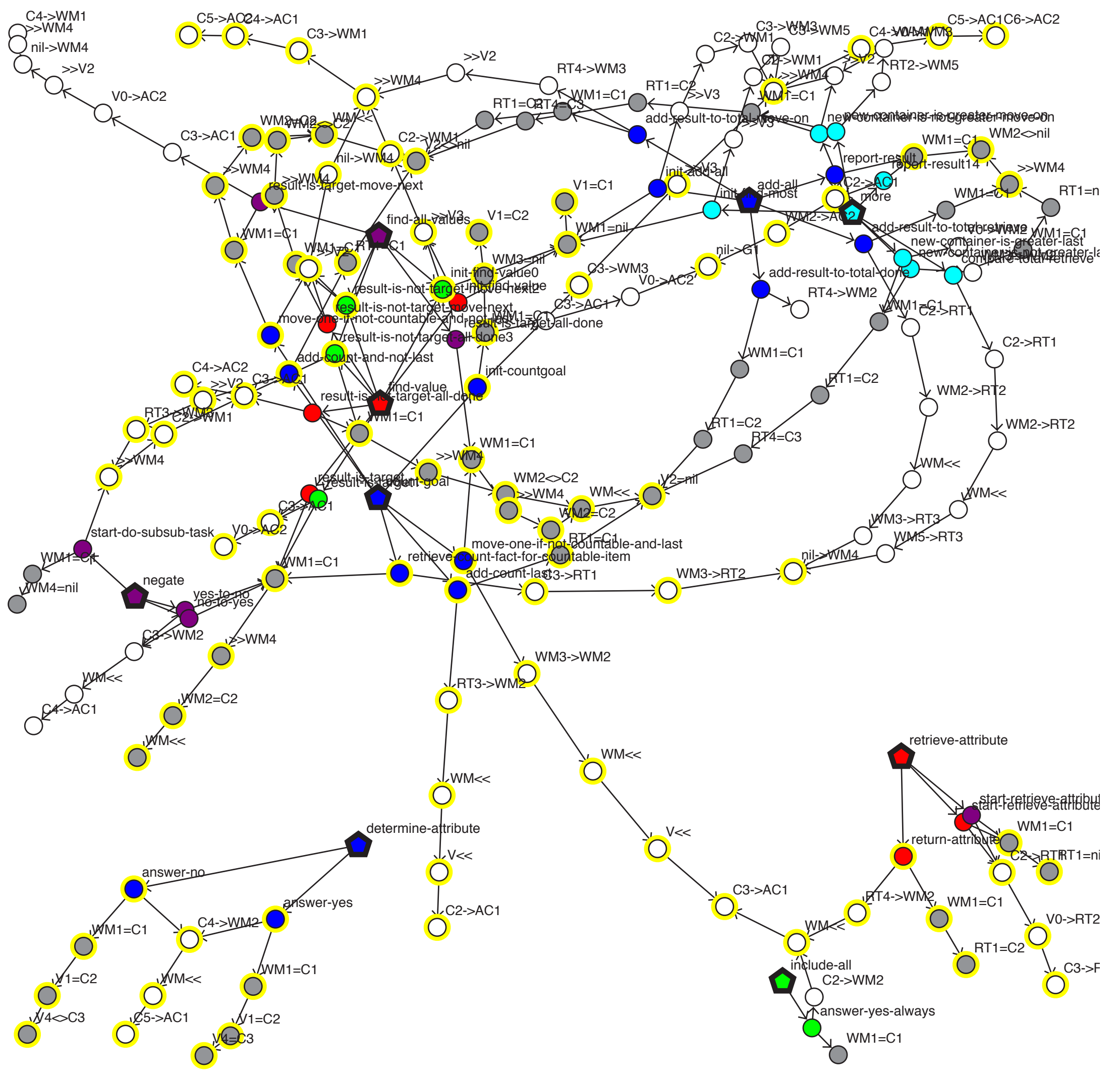
High level cognitive computing

At the top layer of the architecture we want to capture the human ability to carry out arbitrary tasks without prior training, as long as they have the required skills. Knowledge for a task, represented by stars in the diagram below, is constructed by instantiating the relevant skills (pentagons), which in turn require several mental



Medium level cognitive computing

Each operator consists of a number of primitive operations that can be carried out in parallel. There is substantial overlap between the condition and action sequences of operators, creating transfer phenomena.



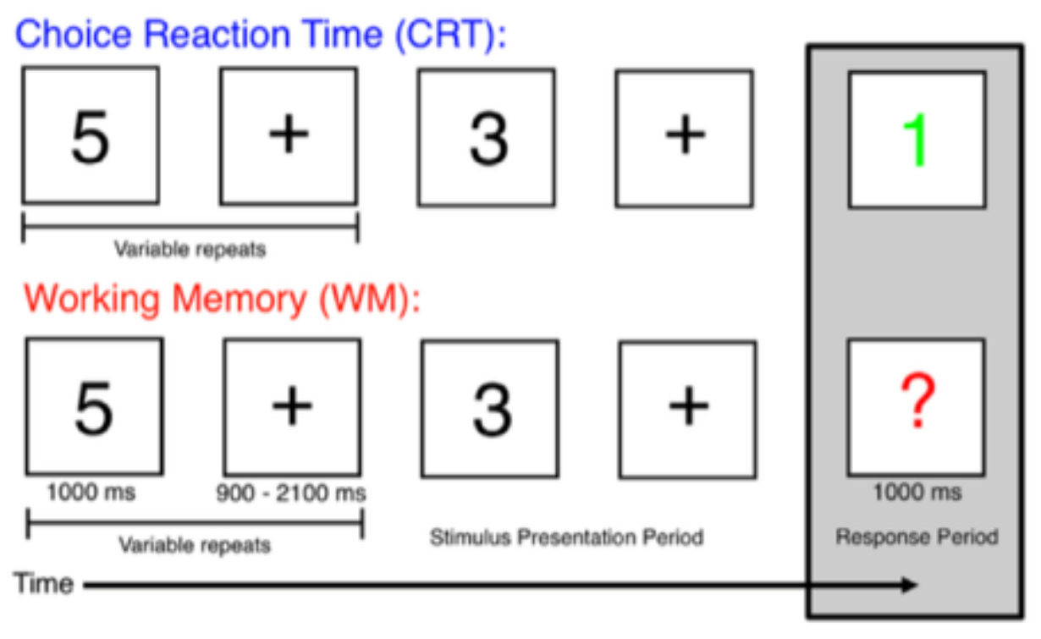
Low level cognitive computing

We have built an architecture based on spiking neurons that is capable of learning and carrying out primitive operations.

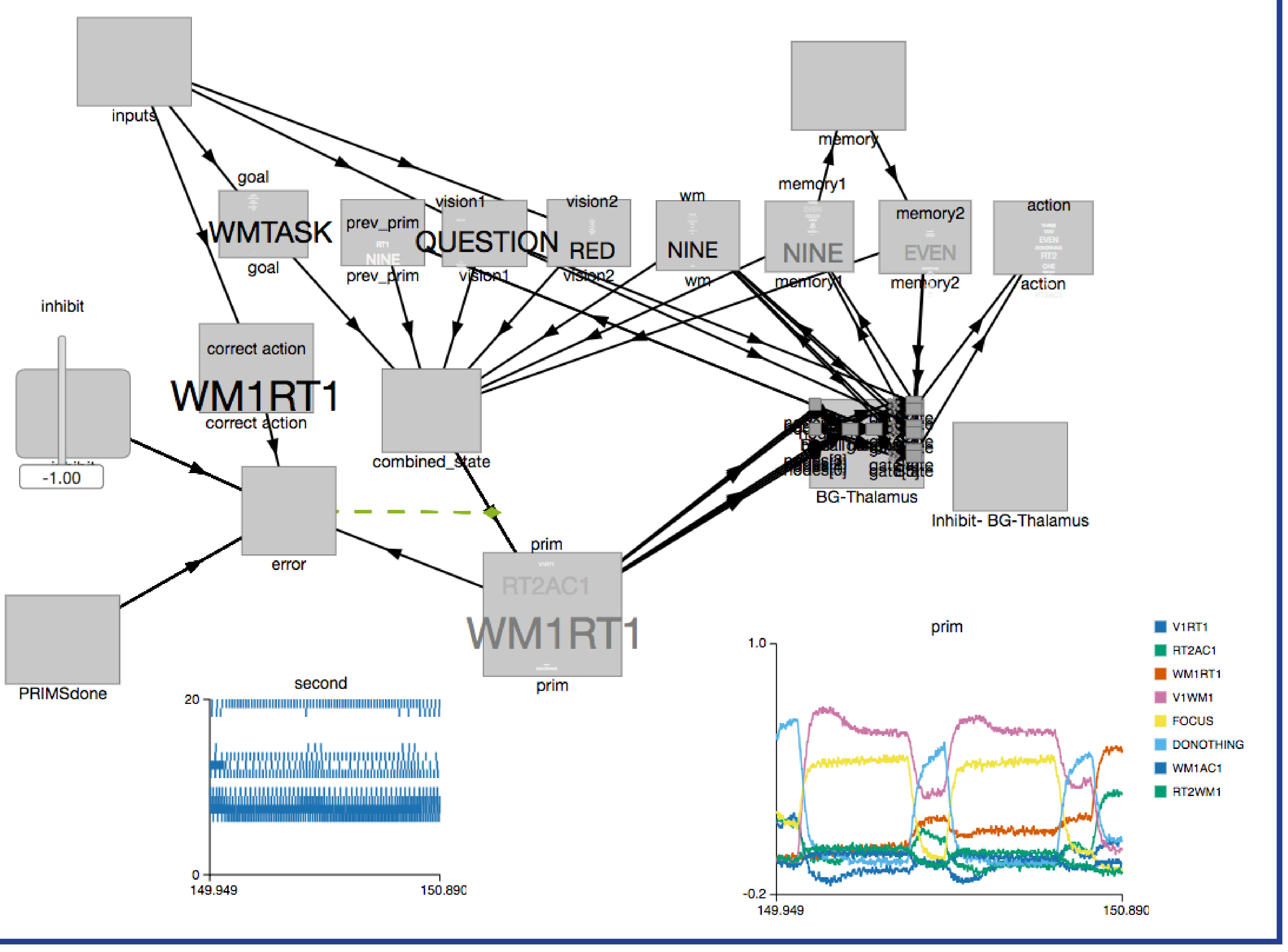
Primitive operations transfer information between specialized cortical areas. For our working memory task this means:

- Whenever you see a black digit (i.e., vision1 is a number and vision2 is black), copy that number to working memory (wm). --> V1WM1
- Whenever you see a red question mark, copy the contents of working memory (wm) to a memory query (memory1). --> WM1RT1
- Whenever you have retrieved something from memory, copy it to action -> RT2AC1

The current model learns the mapping between the current state of the system to the correct action through supervised learning. It is then capable of performing both the working memory task and the choice reaction task.



CRT: whenever you see a colored number, say whether it is odd or even
WM: whenever you see a colored question mark, say whether the last digit you saw was odd or even



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