University of Waterloo

How to Build a Brain

From single cells to cognitive systems

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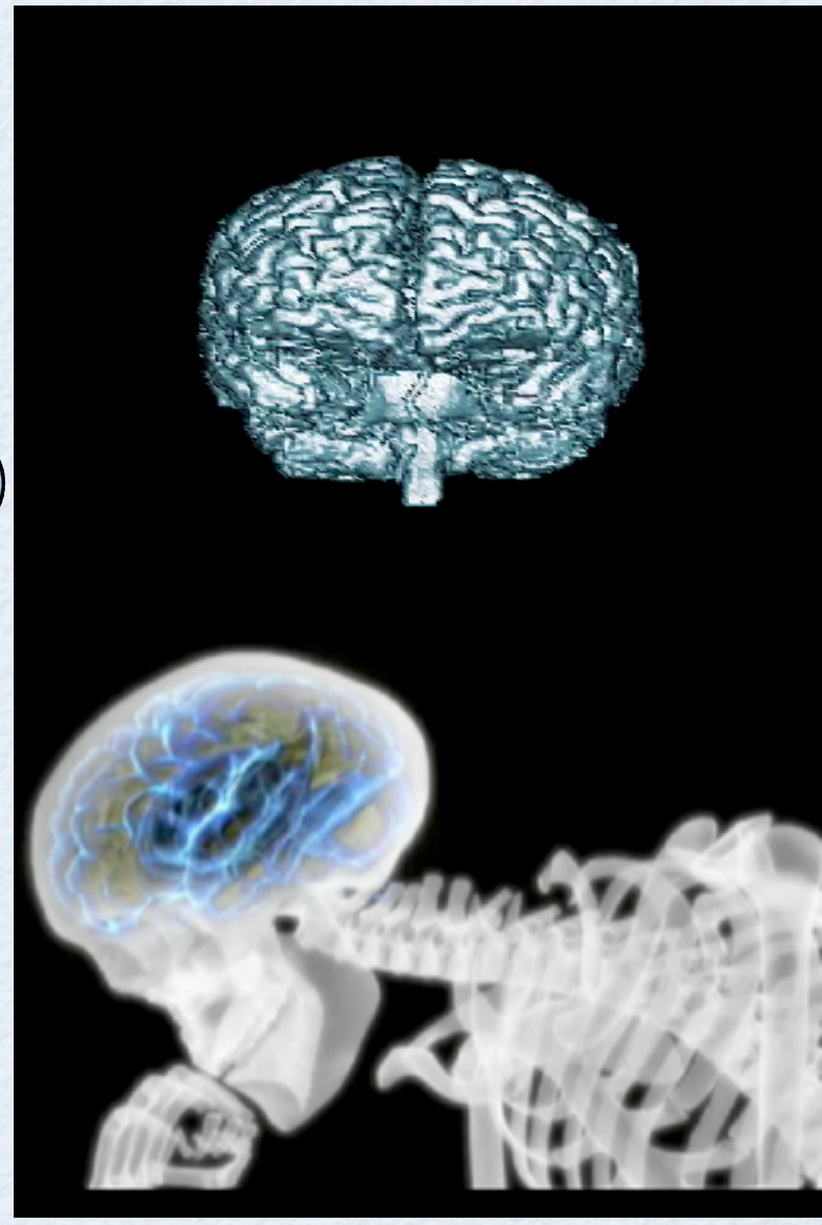
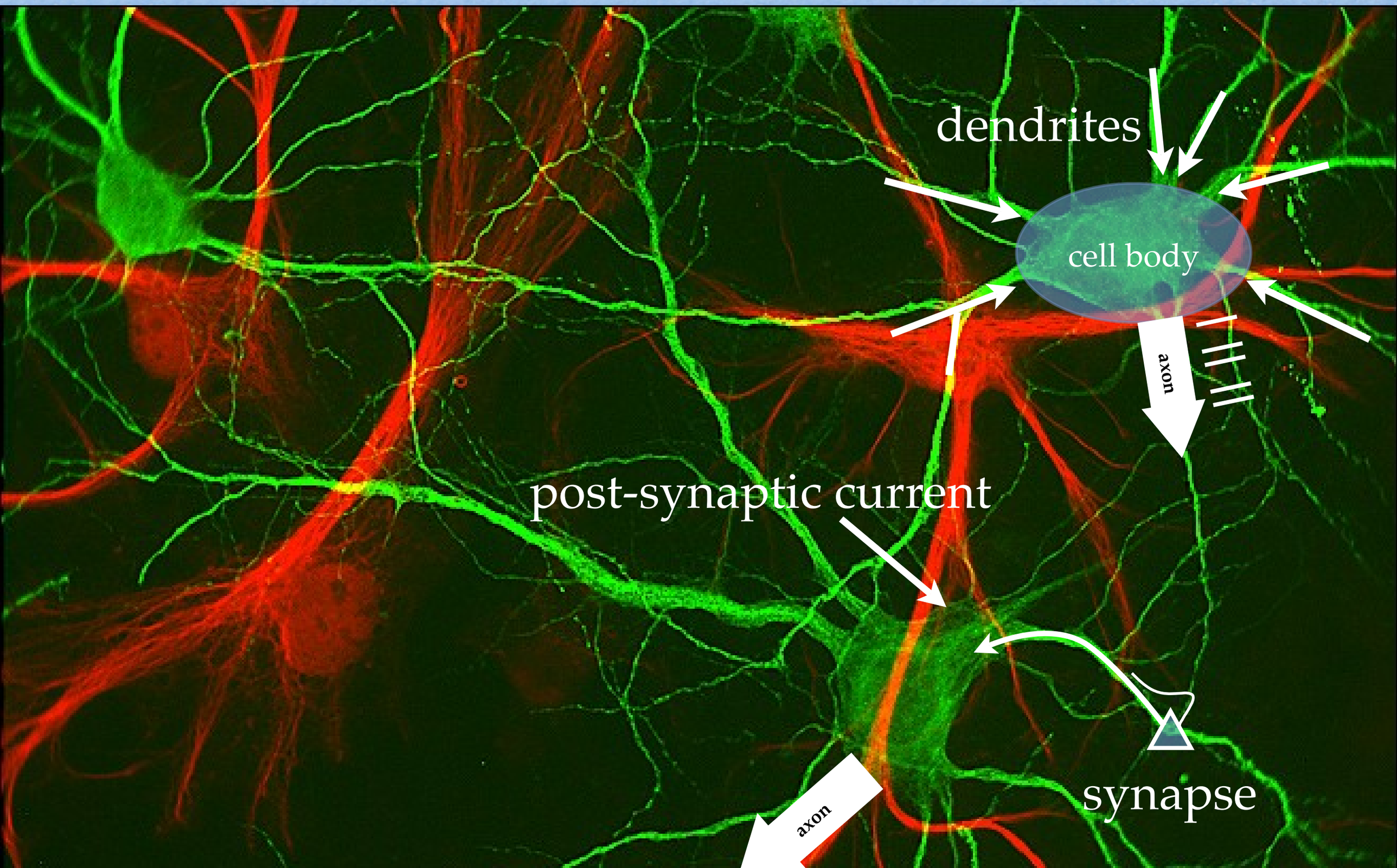
Brains

- Mass: 1-2 kg (2% body weight)
- 25% energy (glucose)

- Power: ~20 Watts
- Area: 4 sheets of paper
- Neurons: 100 billion
  - 150,000/mm^2



Single neurons



Cognition

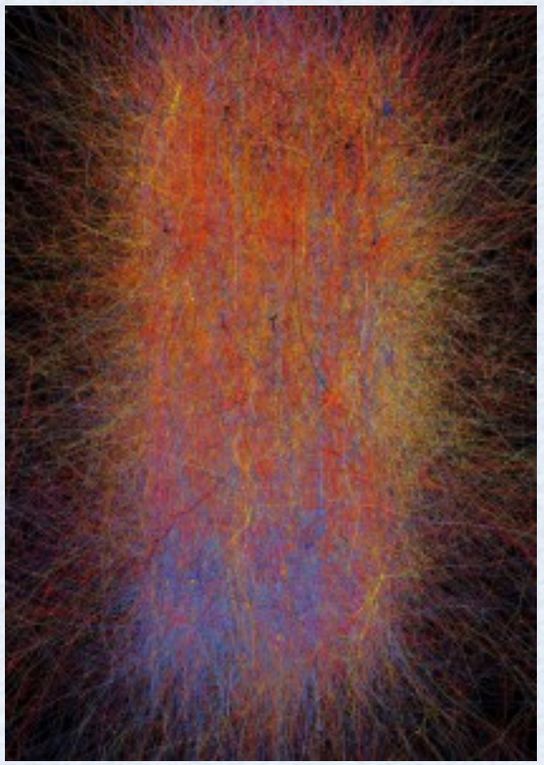
- A deep split between statistical (connectionist) and symbolic (classical) approaches
- Different kinds of representations:
  - PERCEPTION (recognition, pattern completion, inductive inference) - Statistical functions
  - COGNITION (grammar, planning, rules) - Symbols
  - ACTION (control, planning, dynamics) - ?

But it's the same *brain*!

State-of-the-art

- Blue Brain project - Henry Markram (EPFL)
- 10^6 ‘realistic’ neurons
- Concern: “It takes the established principles in neuroscience combined with mountains of data, shoving it all together to see what emerges” - nerd-alert.net

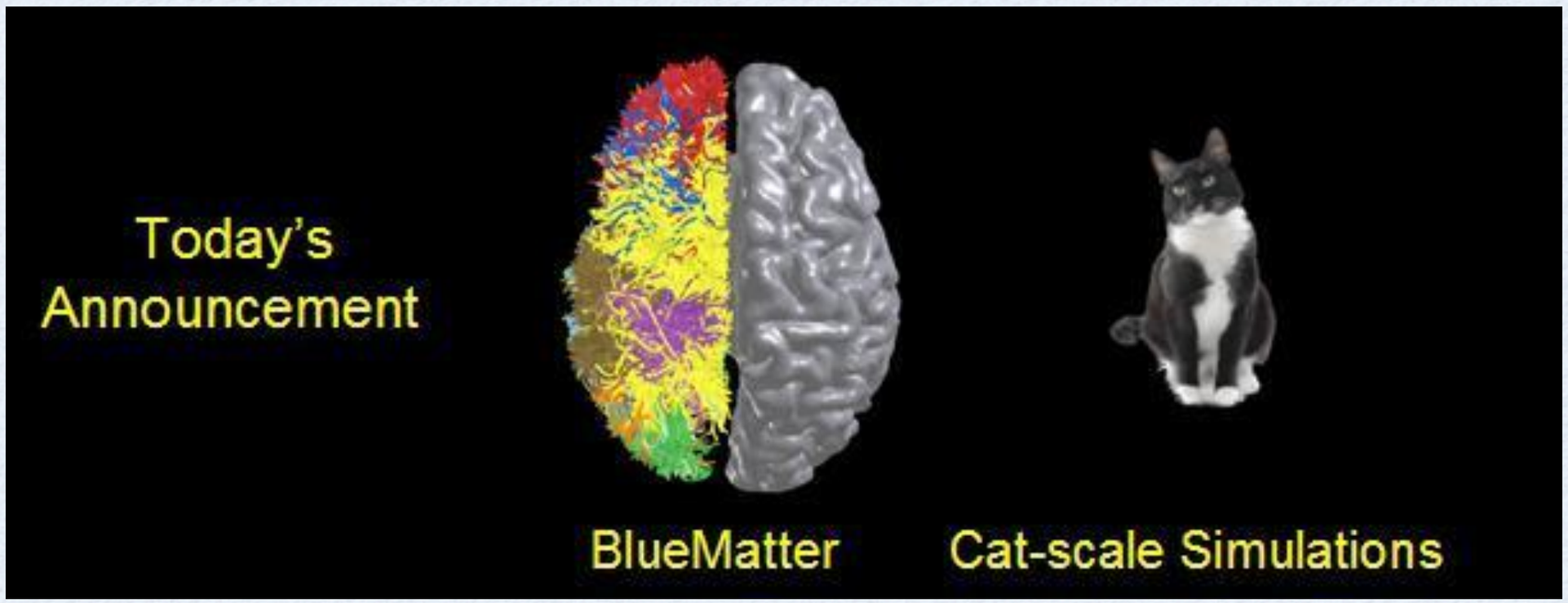
IBM Blue Gene



Cortical column activity

Cat brain

- IBM Cognitive Computing - Dharmendra Mohda
- 10^9 less realistic neurons



Mohda's slide

Some friction

- "...tremendous historic milestone" Modha
- "...a hoax and a PR stunt" - Markram
- "It is highly unethical of Mohda to mislead the public in making people believe they have actually simulated a cat's brain. Absolutely shocking." - Markram

Human-scale brain

Large-scale model
(Izhikevich)

100 billion simulated neurons

e took 50
ercomputer

No Function

Randomly connected

Bigger issue

- Simulations have no recognizable *function*.
- Therefore, neither is dealing with critical issues for complex *functional* system modelling:
  - Long range, fast coordination
  - Control of information flow
  - Appropriate function decomposition

Spaun

- Semantic Pointer Architecture Unified Network ('How to build a brain' Oxford, summer)
- Semantic pointers - a symbol-like, statistical, neural representation
- 2.5 million neurons
- 8 tasks, no changes to Spaun between tasks

Some Tasks

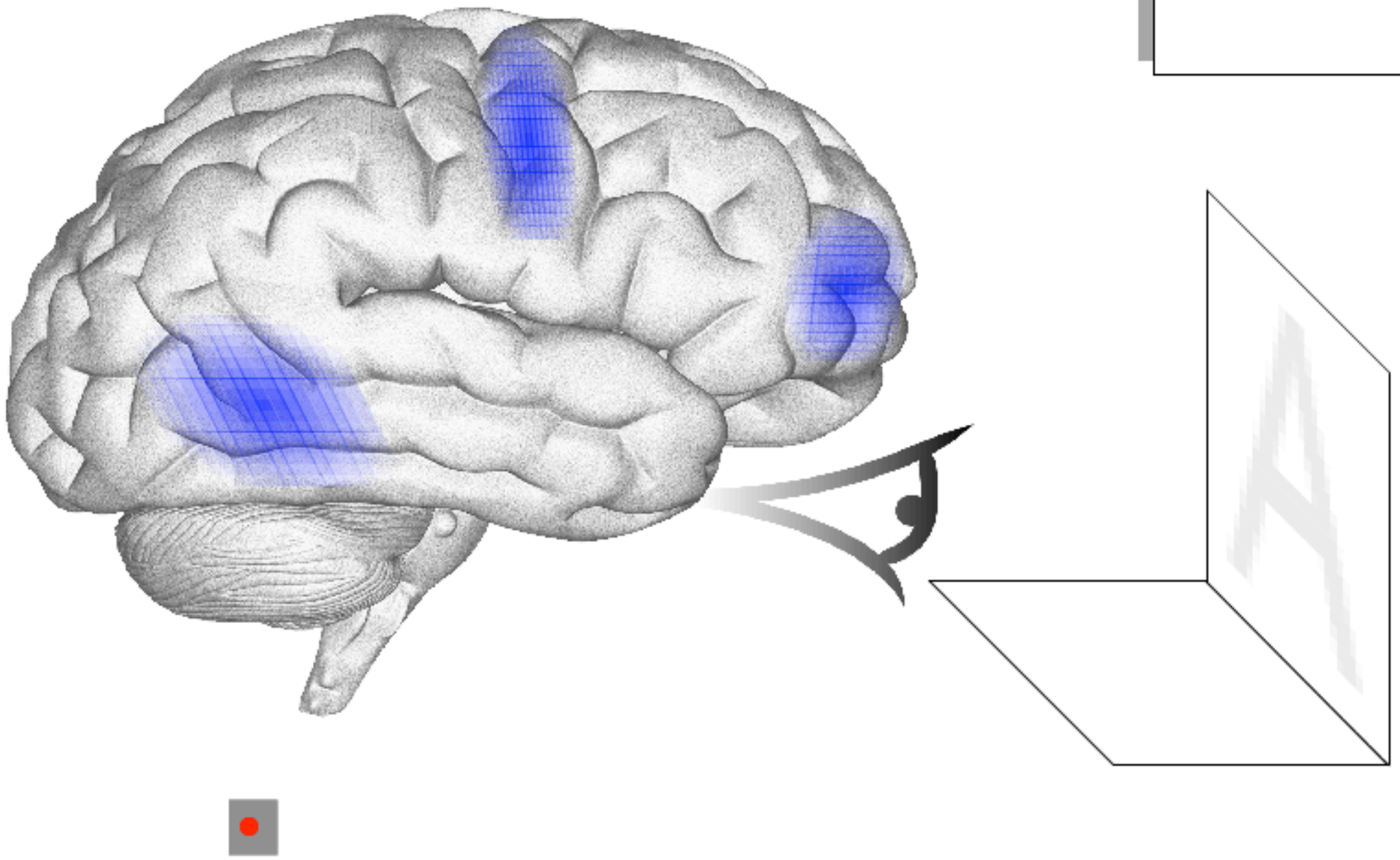
- A1 - Recognition
- A0 - Copy drawing
- A6 - Induction over structure
- Others: Reinforcement learning, silent counting, fluid intelligence, serial working memory, question answering
- Let's try some (notice you use the same brain)

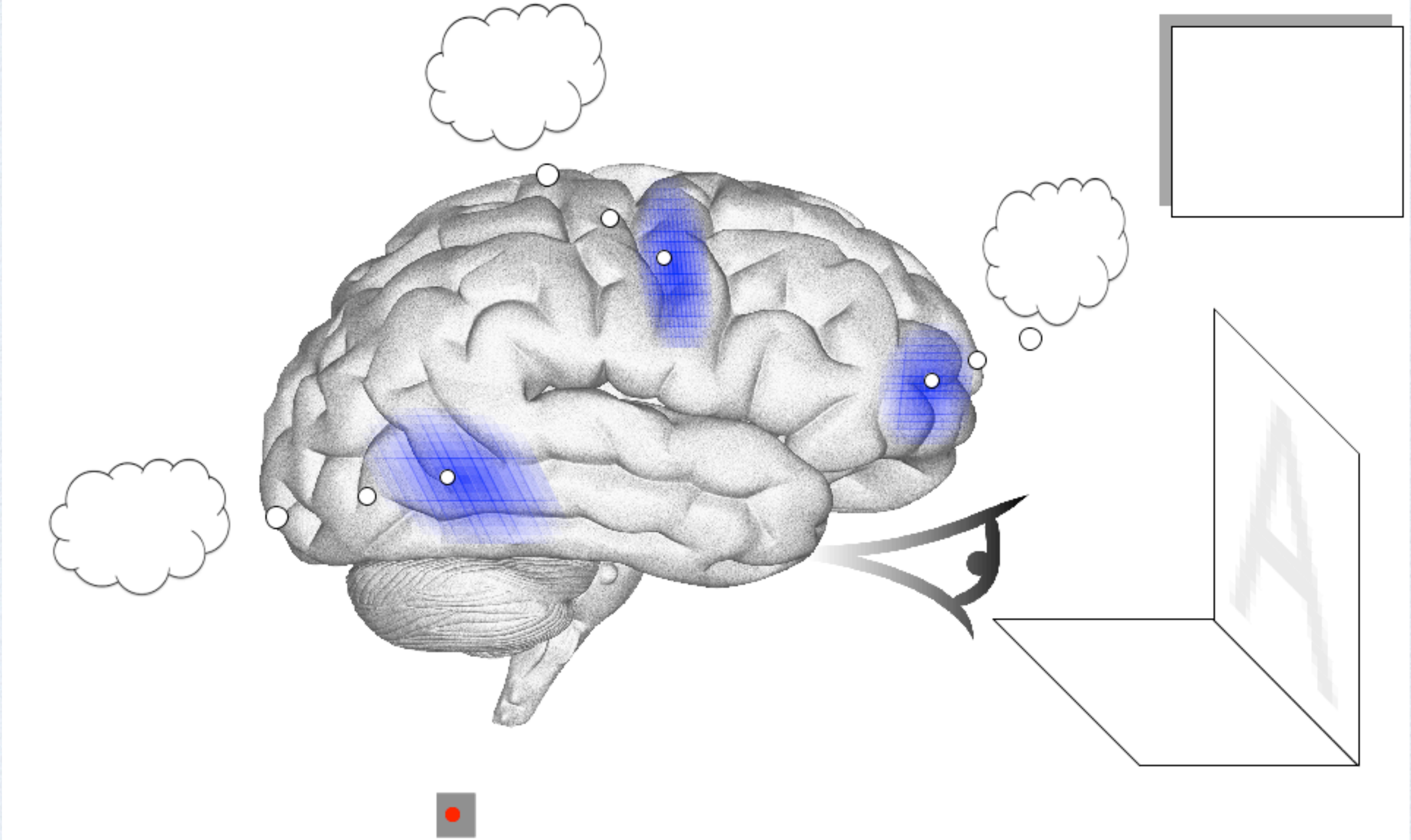
A

1

?

http://nengo.ca/build-a-brain/spaunvideos





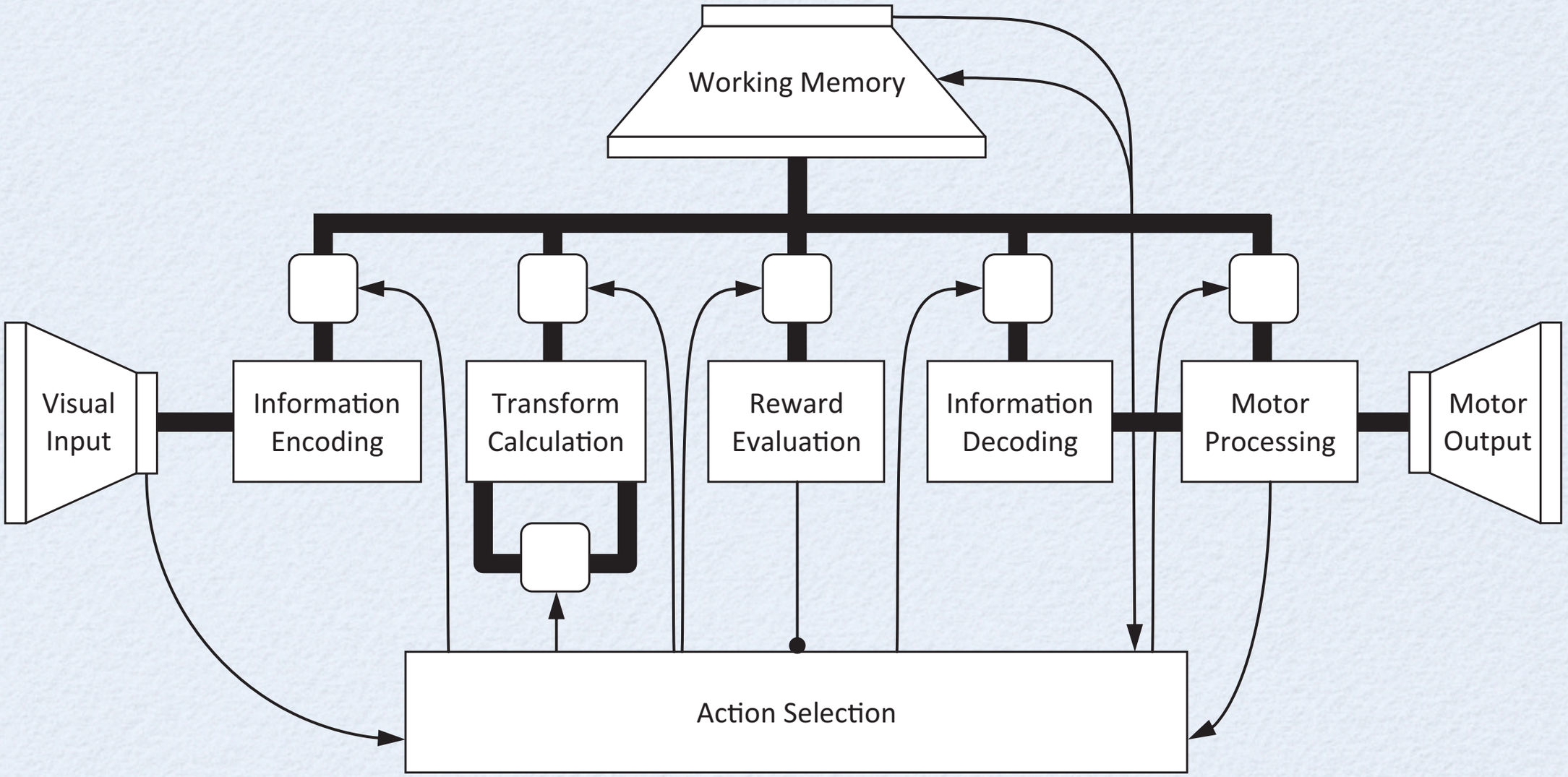
Spaun

- Performs statistical and symbolic reasoning
- Fully neural mechanisms (spikes, currents, weights, neurotransmitters)
- Captures: neuroanatomy, neurophysiology, reaction times, error profiles
- Perception, cognition, & action

Semantic Pointer Architecture

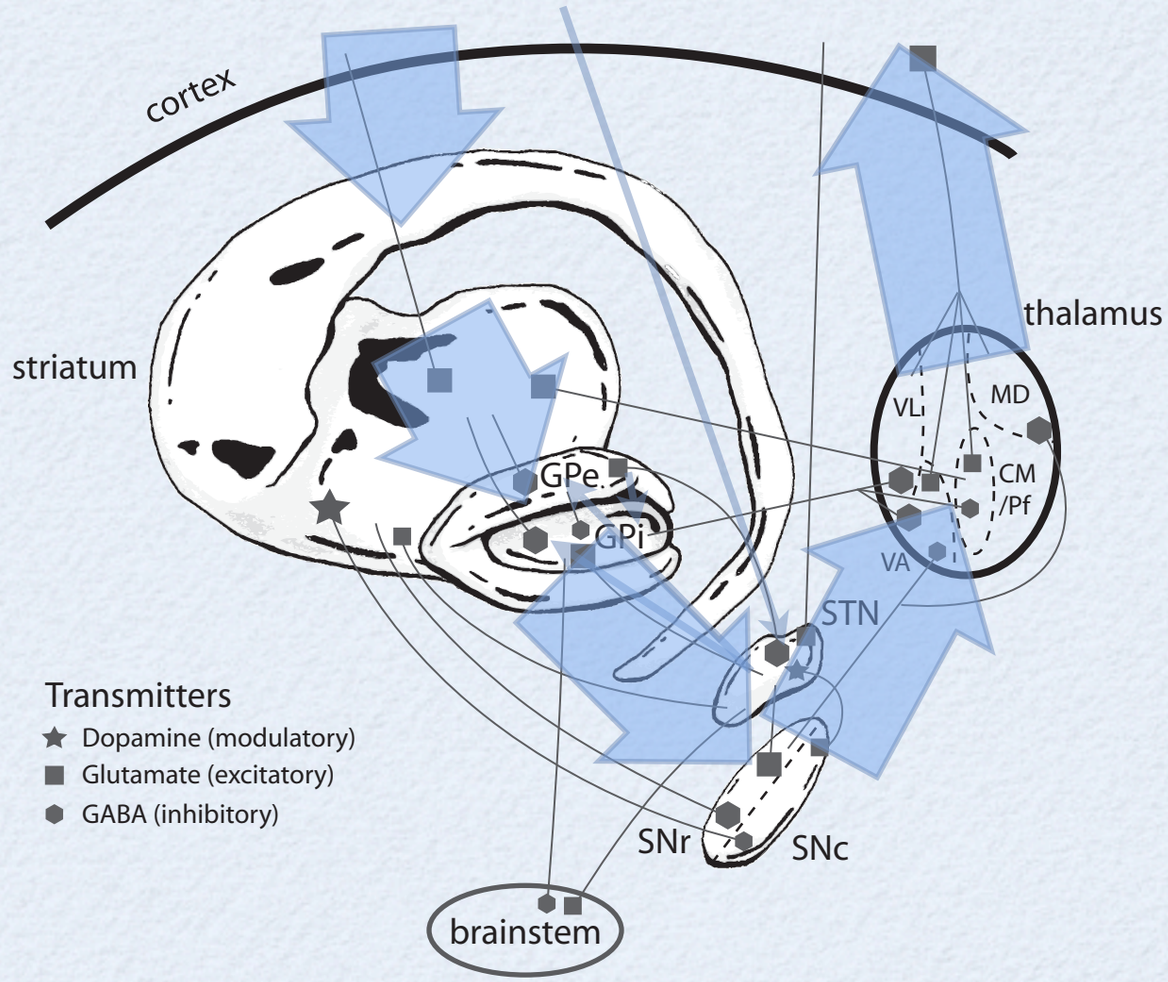
- The semantic pointer architecture (SPA; Oxford 2012):
- Four things to characterize:
  - Semantics
  - Syntax
  - Control
  - Learning & memory (adaptation)

Spaun Architecture



SPA: Action selection

- The basal ganglia has been implicated in action selection



Lessons in network synthesis

- Generic info processing decompositon
  - not task based (contra evol. psych)
- Compression/decompression to low-D space
  - lower bandwidth, higher order structure
- Control the action, don't compute the answer
  - monitor and reconfigure (exploit gating)
  - need fast decision mechanism

What's ahead?

- Speeding things up
  - Now: 1s = 2.5h on SharcNet HPC
  - Soon: Dedicated hardware
    - NeuroGrid (Stanford) - 10^6 real time
    - SpiNNaker (Manchester) - 10^9 real time (1.5 yrs)
- Expanding Spaun
  - Audition
  - Attention, eye control
  - Human sized vocabulary

A few footholds...

We are this person

... on the way to a functional brain

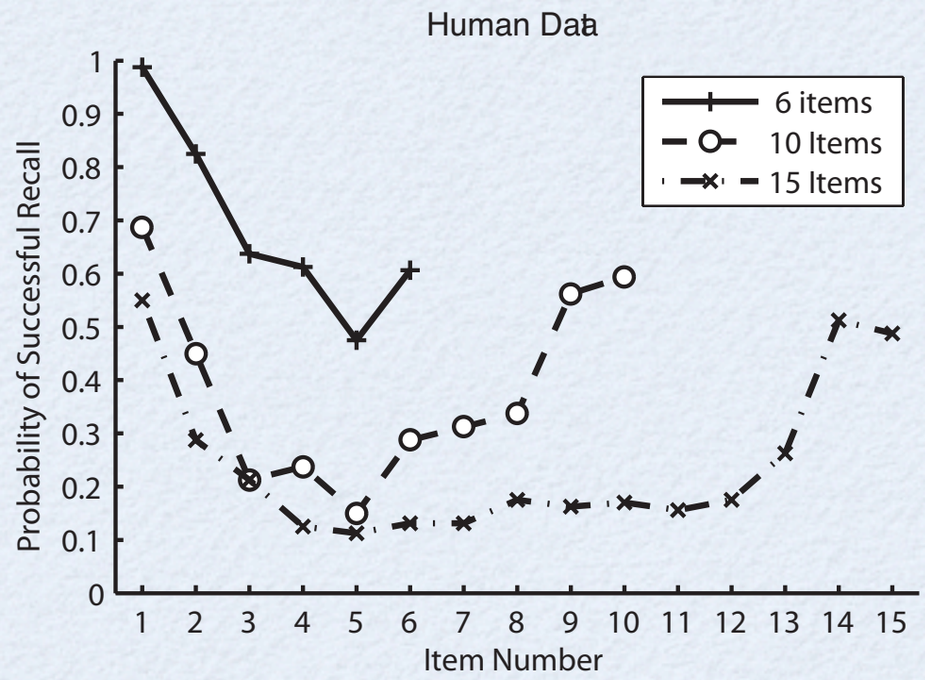
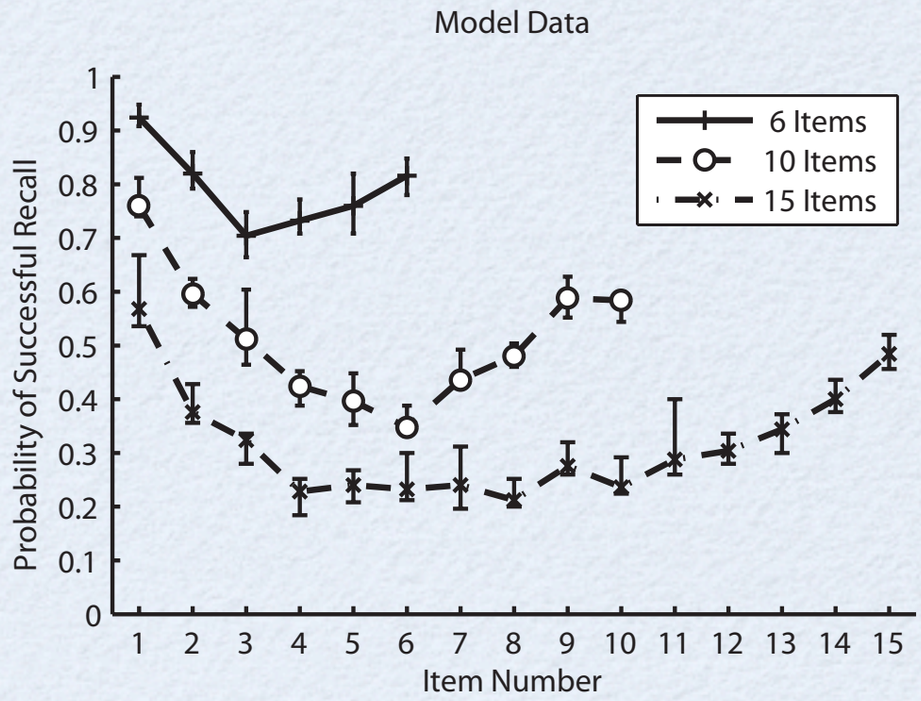
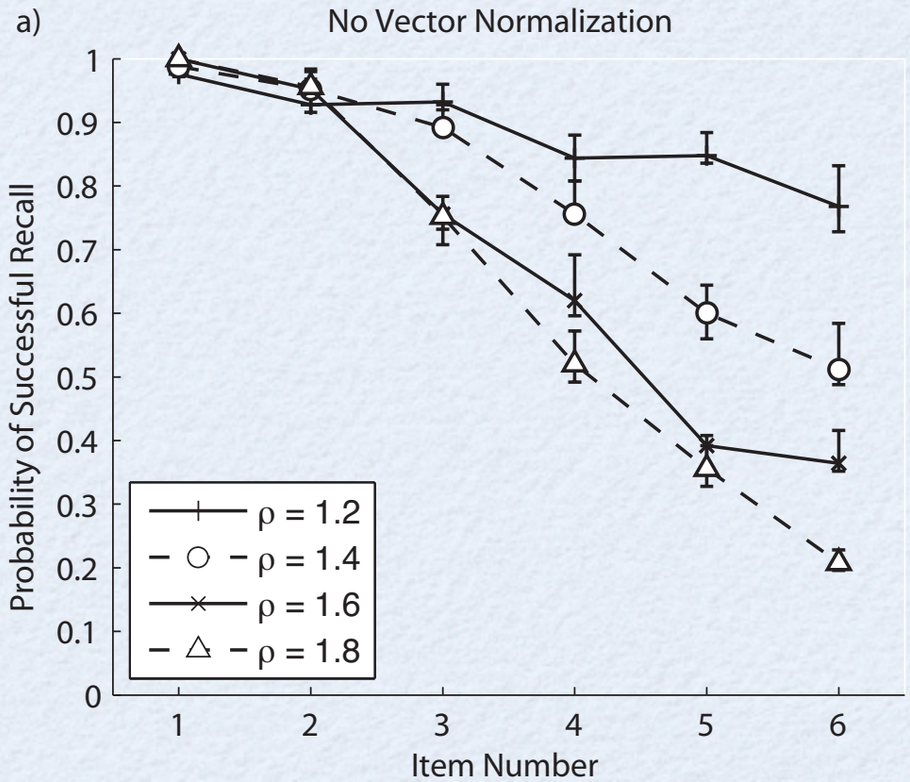
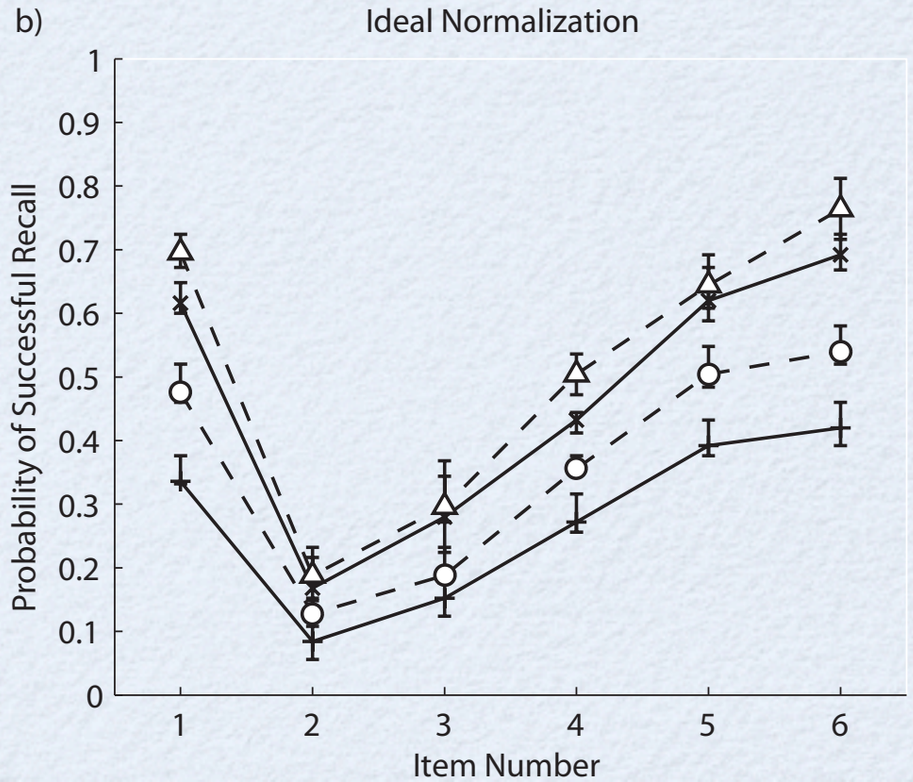
More about Spaun...

- http://nengo.ca/build-a-brain/spaunvideos

- Brain day April 4th, 2012

How to build a brain:

A neural architecture for biological cognition

Eliasmith, C. (in press), Oxford University Press.

Importance of neurons