

SYDE 556/750

Simulating Neurobiological Systems
Lecture 11: The Semantic Pointer Architecture

Chris Eliasmith

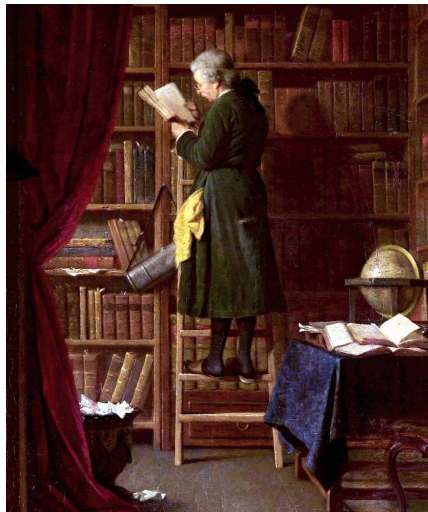
November 13 & 18, 2024

- ▶ Slide design: Andreas Stöckel
- ▶ Content: Terry Stewart, Andreas Stöckel, Chris Eliasmith



UNIVERSITY OF
WATERLOO

FACULTY OF
ENGINEERING



Administrative Notes – Remaining Deadlines

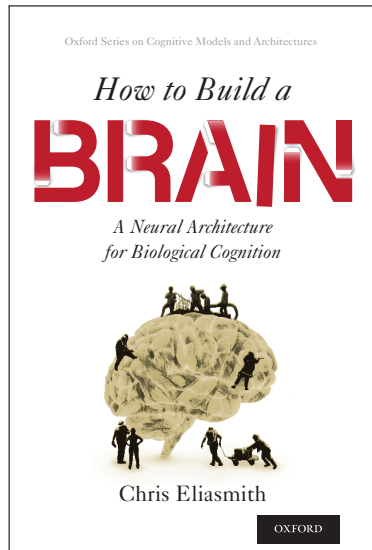
- ▶ **Assignment 4** – Due Nov. 18*
- ▶ **Assignment 5** – Due Dec. 2*
- ▶ **Project Presentations** – Nov. 27 & Dec. 2
 - ▶ 5-10 min. presentation (see the 'project summary document' on the website for instructions)
 - ▶ Worth 3 marks of the final project
- ▶ **Final Project** – Due Dec. 18*
 - ▶ Worth 30% of the final mark for 556
 - ▶ Worth 20% of the final mark for 750

* All deadlines are 11:59pm EDT

The Semantic Pointer Architecture (SPA)

- ▶ **SPA**

- ▶ Semantics
- ▶ Syntax
- ▶ Control
- ▶ Learning and memory



The Semantic Pointer Hypothesis

The Semantic Pointer Hypothesis states:

Higher-level cognitive functions in biological systems are made possible by semantic pointers. Semantic pointers are neural representations that carry partial semantic content and are composable into the representational structures necessary to support complex cognition.

Shallow Versus Deep Semantics

TREE

0x54 0x52 0x45 0x45

Shallow semantics (relational)

$\forall x \text{is_a}(x, \text{PINE}) \rightarrow \text{is_a}(x, \text{TREE}) \wedge \text{has}(x, \text{NEEDLES}) \wedge \text{is}(x, \text{EVERGREEN}),$

$\forall x \text{is_a}(x, \text{TREE}) \rightarrow \text{is_a}(x, \text{PLANT}),$

$\forall x \text{is_a}(x, \text{PLANT}) \rightarrow \text{is}(x, \text{ALIVE}).$

Deep semantics (“modal experience”)



Deep Semantic in Perception: Dereferencing

A.



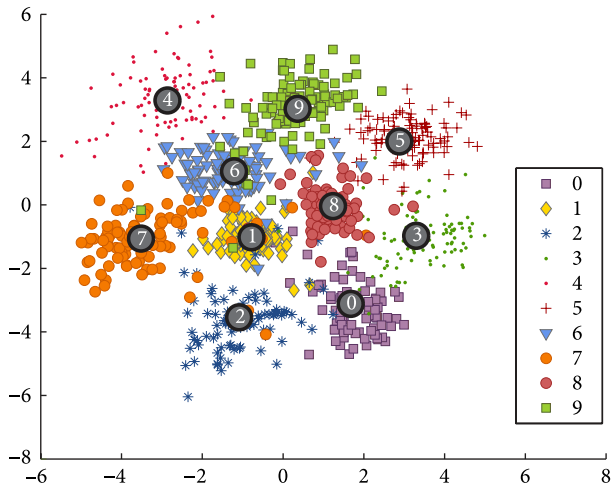
B.



C.

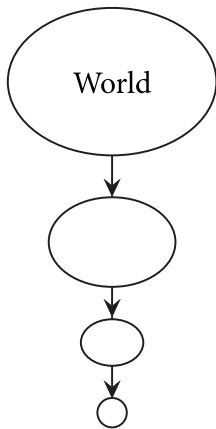


D.



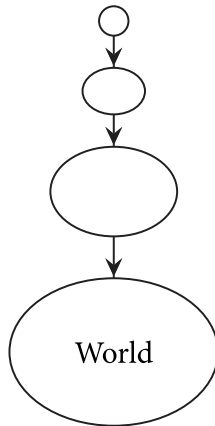
Perception vs. Action

Perception



World \rightarrow Representation

Motor Control



Representation \rightarrow World

Nengo SPA Example (I)

colour_in

x



shape_in

y



cue_in

z



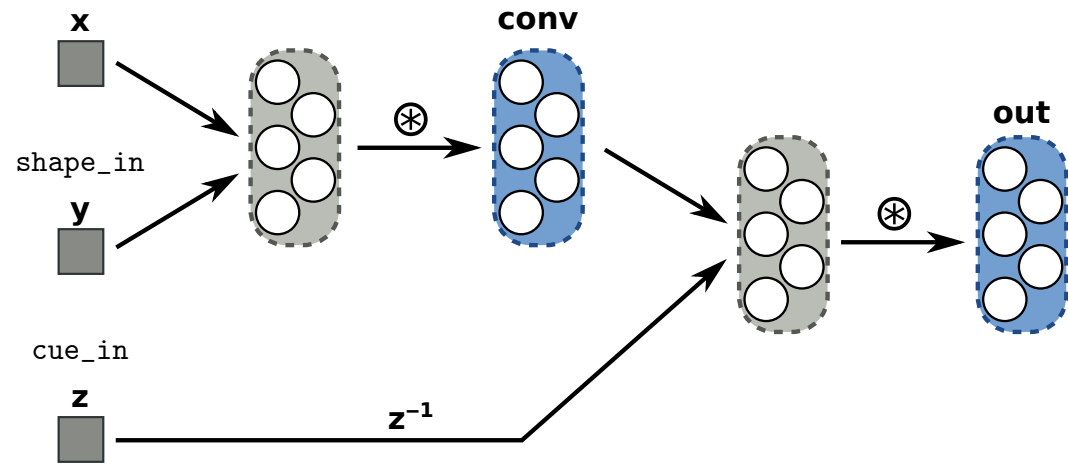
conv



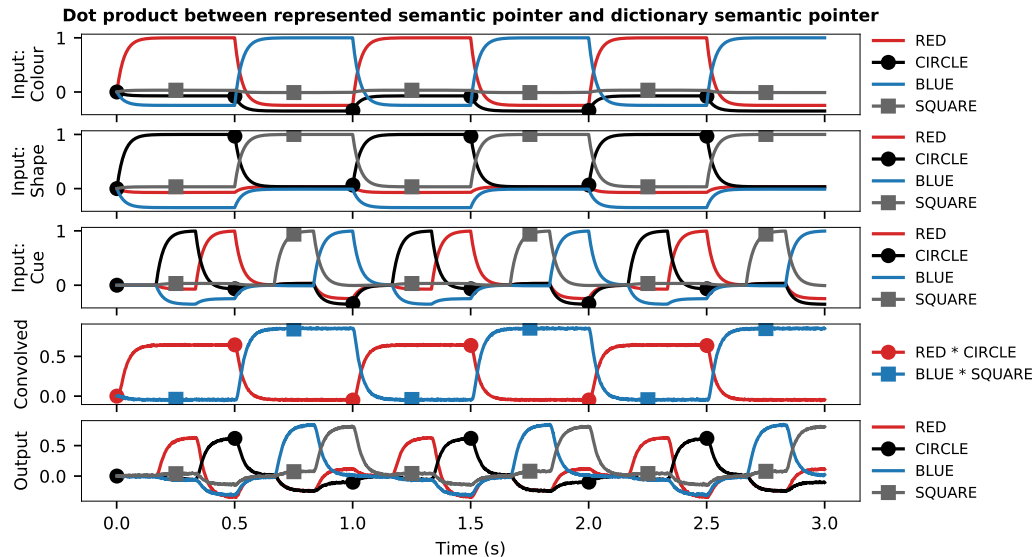
out



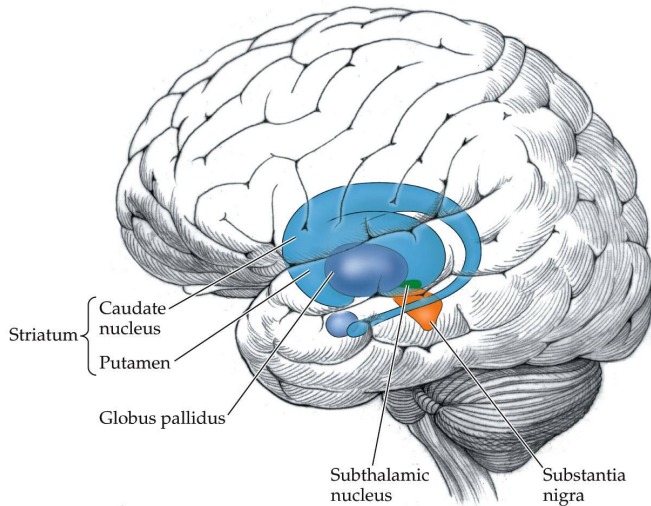
z^{-1}



Nengo SPA Example (II)



Basal Ganglia (BG)



Clinical Evidence for the Role of the BG in Action Selection

Parkinson's disease

- ▶ Neurons in the substantia nigra die off
- ▶ Difficult to trigger actions to start
- ▶ Usually physical actions
- ▶ Cognitive effects in later stages

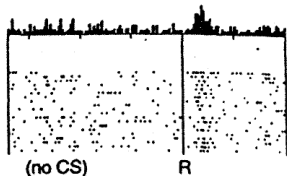
Huntington's disease

- ▶ Neurons in the striatum die off
- ▶ Actions triggered inappropriately
- ▶ Small uncontrollable movements
- ▶ Trouble sequencing cognitive actions

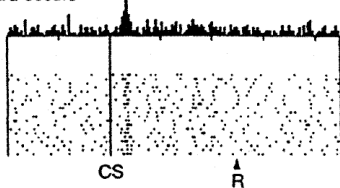
Neurophysiological Evidence for the Role of the BG in Action Selection

- Role in reinforcement learning

No prediction
Reward occurs

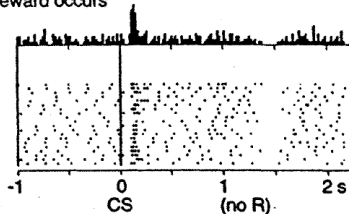


Reward predicted
Reward occurs

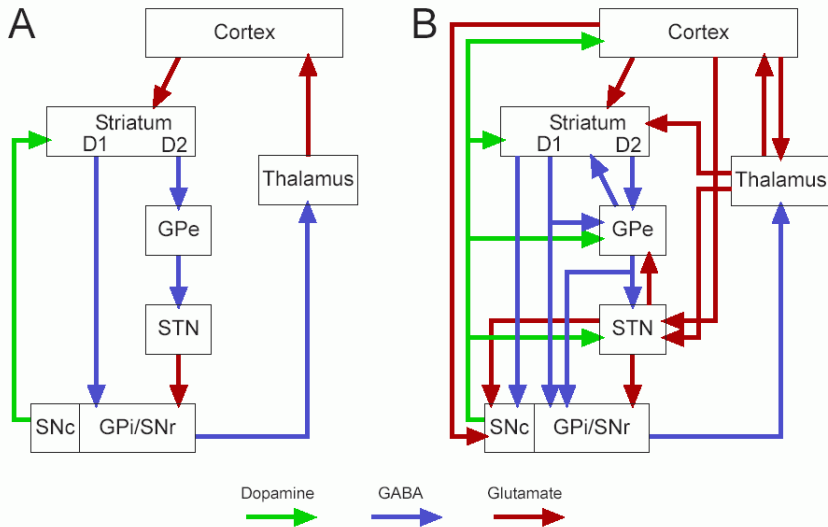


- Dopamine levels map onto reward prediction error

Reward predicted
No reward occurs



Microcircuitry of the Basal Ganglia



Simplified Model

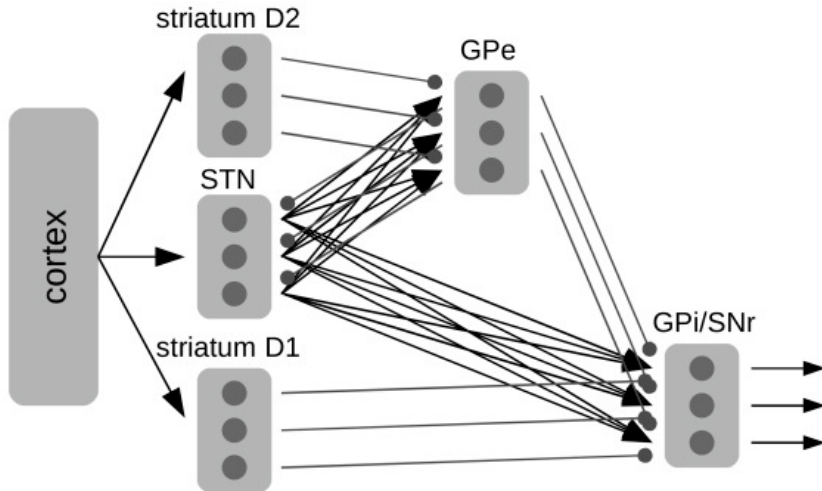
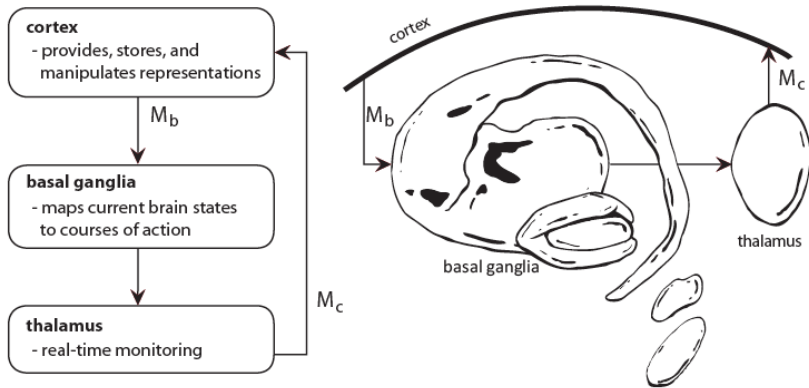
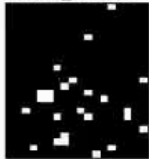


Image Sources. Gurney, Prescott, and Redgrave, *Model of Action Selection in the Basal Ganglia*, 2001

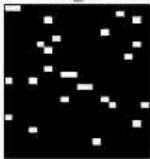
The Cortex-Basal Ganglia-Thalamus loop



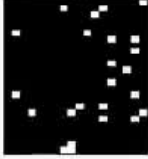
buffer_setfocus



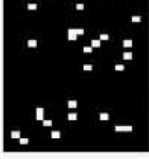
buffer_focus



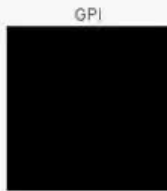
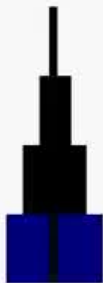
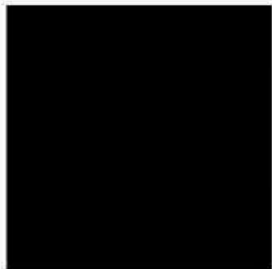
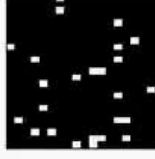
buffer_goal



buffer_goalpeg



buffer_focuspeg

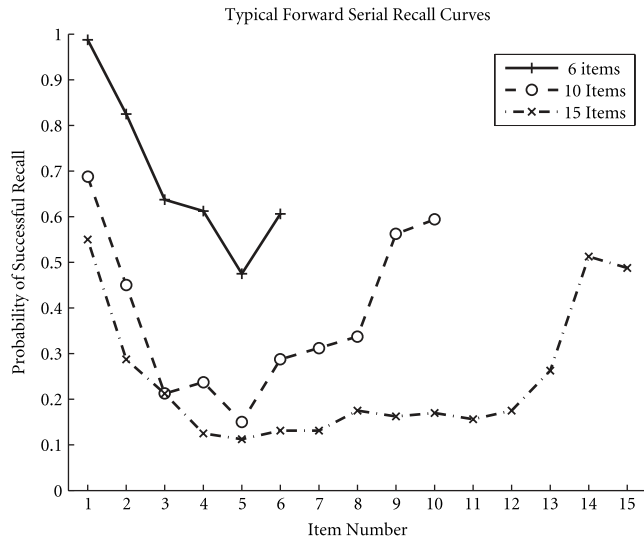


Recency and Primacy Experiment

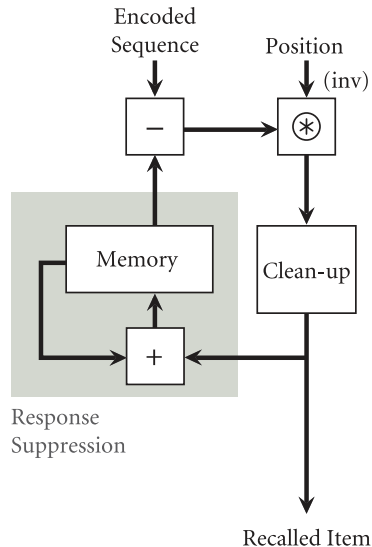
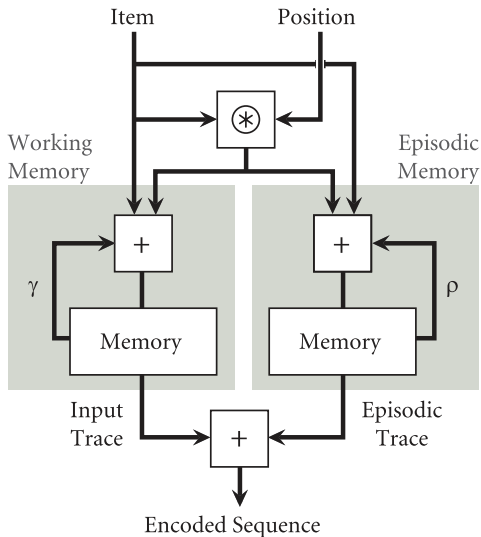
Experiment: Remember this list (presented one at a time)

- | | |
|-------------------|------------------|
| 1. robot | 6. conglomerates |
| 2. teflon | 7. waxberries |
| 3. kettlemaking | 8. electrograph |
| 4. big-league | 9. overjoyous |
| 5. troubleshooter | 10. unquailing |

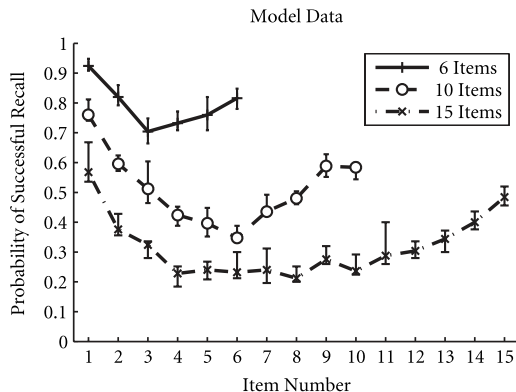
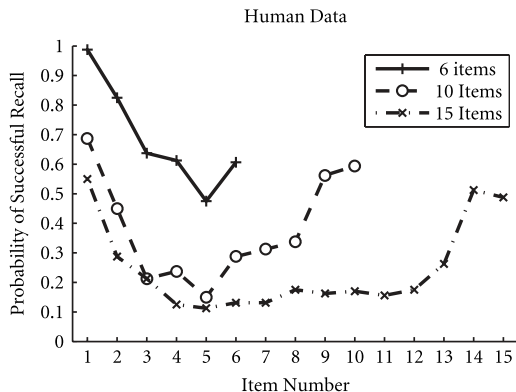
Recency and Primacy Data



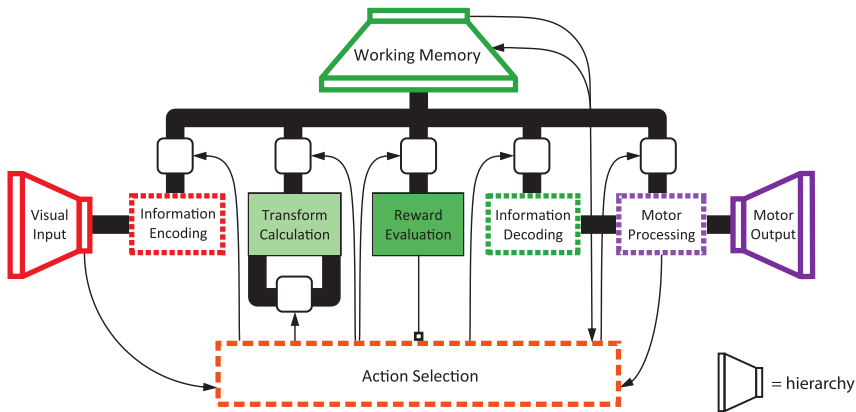
Ordinal Serial Encoding (OSE) Model



Ordinal Serial Encoding (OSE) Model: Experiment



Spaun – Semantic Pointer Architecture Unified Network (I)



Spaun – Semantic Pointer Architecture Unified Network (II)

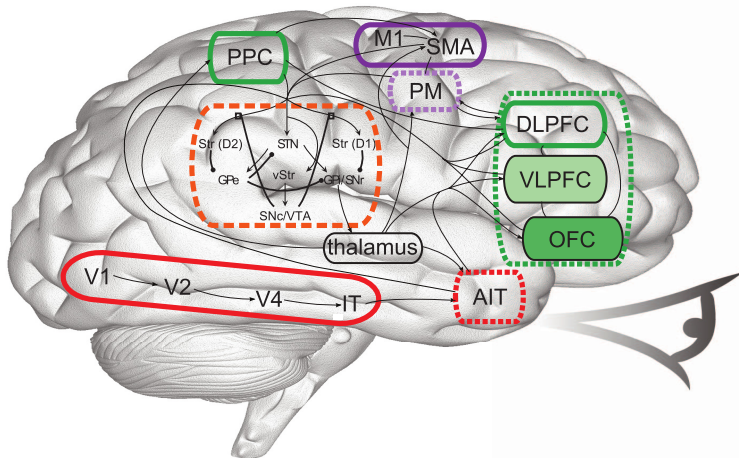


Image sources

Title slide

Librarian (In a library), between 1850 and 1866, Georg Reimer
Wikimedia.