

**SYDE 556/750**

## **Simulating Neurobiological Systems**

### **Lecture 11: The Semantic Pointer Architecture**

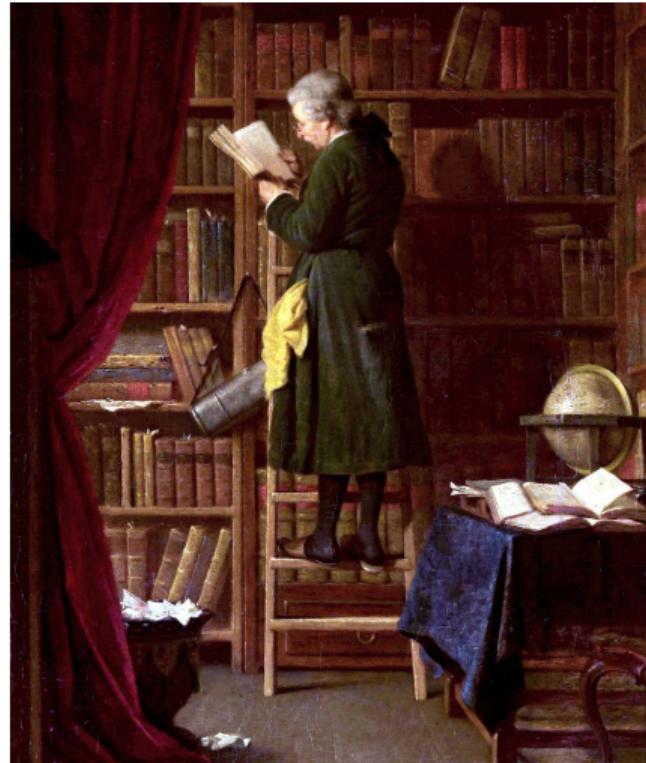
**Chris Eliasmith**

**November 13 & 18, 2024**

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



**FACULTY OF  
ENGINEERING**



## Administrative Notes – Remaining Deadlines

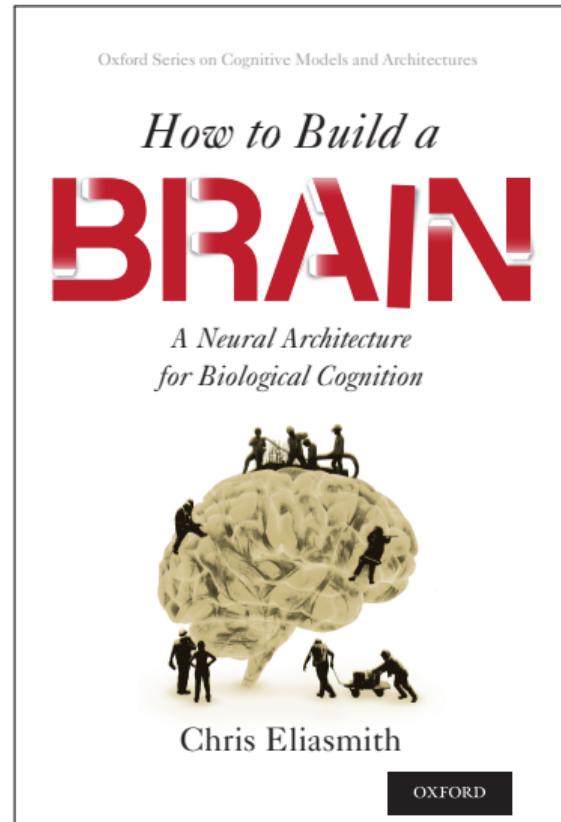
- ▶ **Assignment 4** – Due Nov. 18\*
- ▶ **Assignment 5** – Due Dec. 2\*
- ▶ **Project Presentations** – Nov. 27 & Dec. 2
  - ▶ 5-10 min. presentation (see the ‘project summary document’ on the website for instructions)
  - ▶ Worth 3 marks of the final project
- ▶ **Final Project** – Due Dec. 18\*
  - ▶ 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

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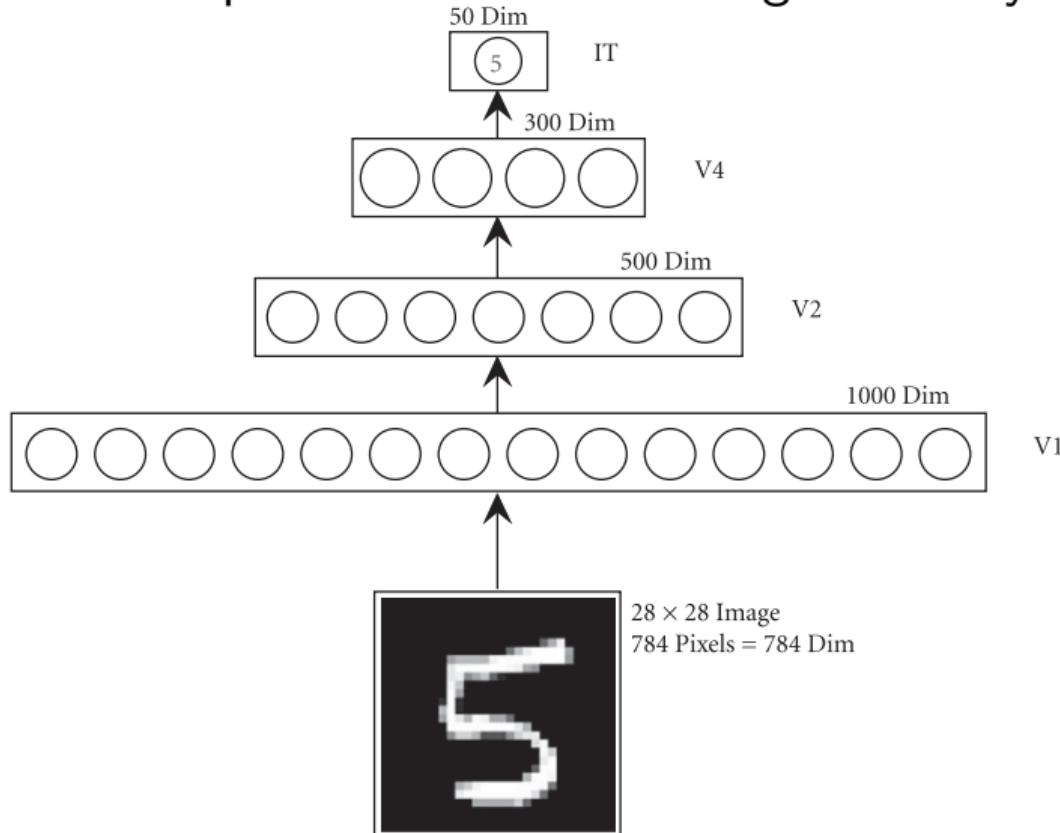
*Shallow semantics (relational)*

- $\forall x \text{is\_a}(x, \text{PINE}) \rightarrow \text{is\_a}(x, \text{TREE}) \wedge \text{has}(x, \text{NEEDLES}) \wedge \text{is}(x, \text{EVERGREEN}),$
  - $\forall x \text{is\_a}(x, \text{TREE}) \rightarrow \text{is\_a}(x, \text{PLANT}),$
  - $\forall x \text{is\_a}(x, \text{PLANT}) \rightarrow \text{is}(x, \text{ALIVE}).$
- 

*Deep semantics (“modal experience”)*



# Deep Semantic in Perception: Visual Processing Hierarchy

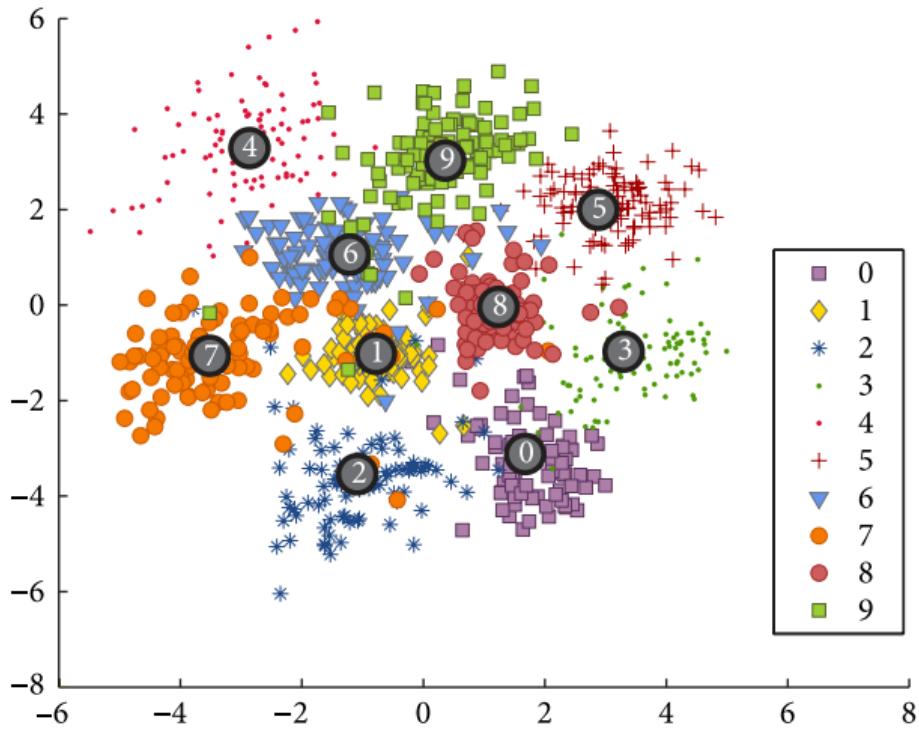


# Deep Semantic in Perception: Dereferencing

A.

7	8	3	/	7	6	3	6	6	8
5	2	0	4	5	3	6	8	4	9
4	1	1	7	5	0	3	8	7	6

D.



B.

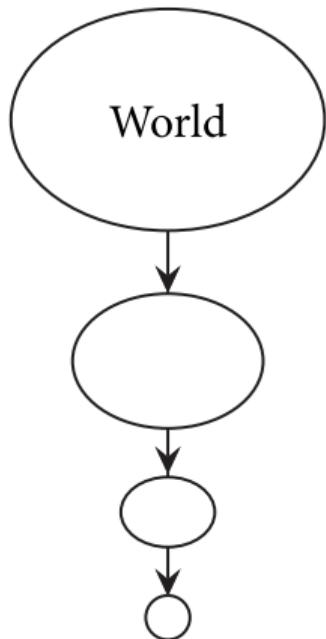
7	8	3	/	7	6	3	6	6	8
5	2	0	4	5	3	6	8	4	9
4	1	1	7	5	0	3	8	7	6

C.

0	1	2	3	4
5	6	7	8	9

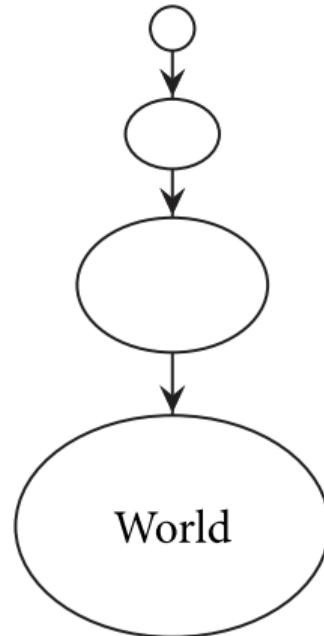
# Perception vs. Action

Perception



$\text{World} \rightarrow \text{Representation}$

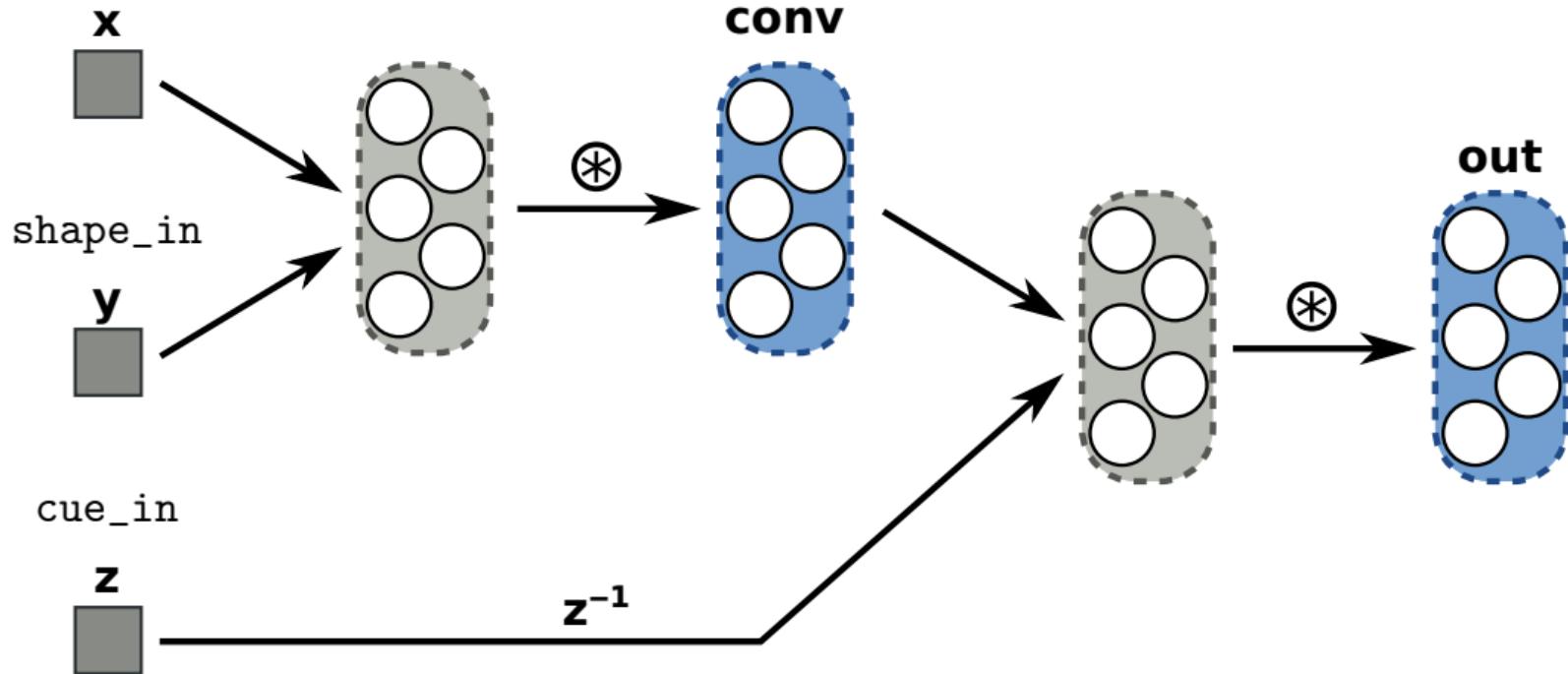
Motor Control



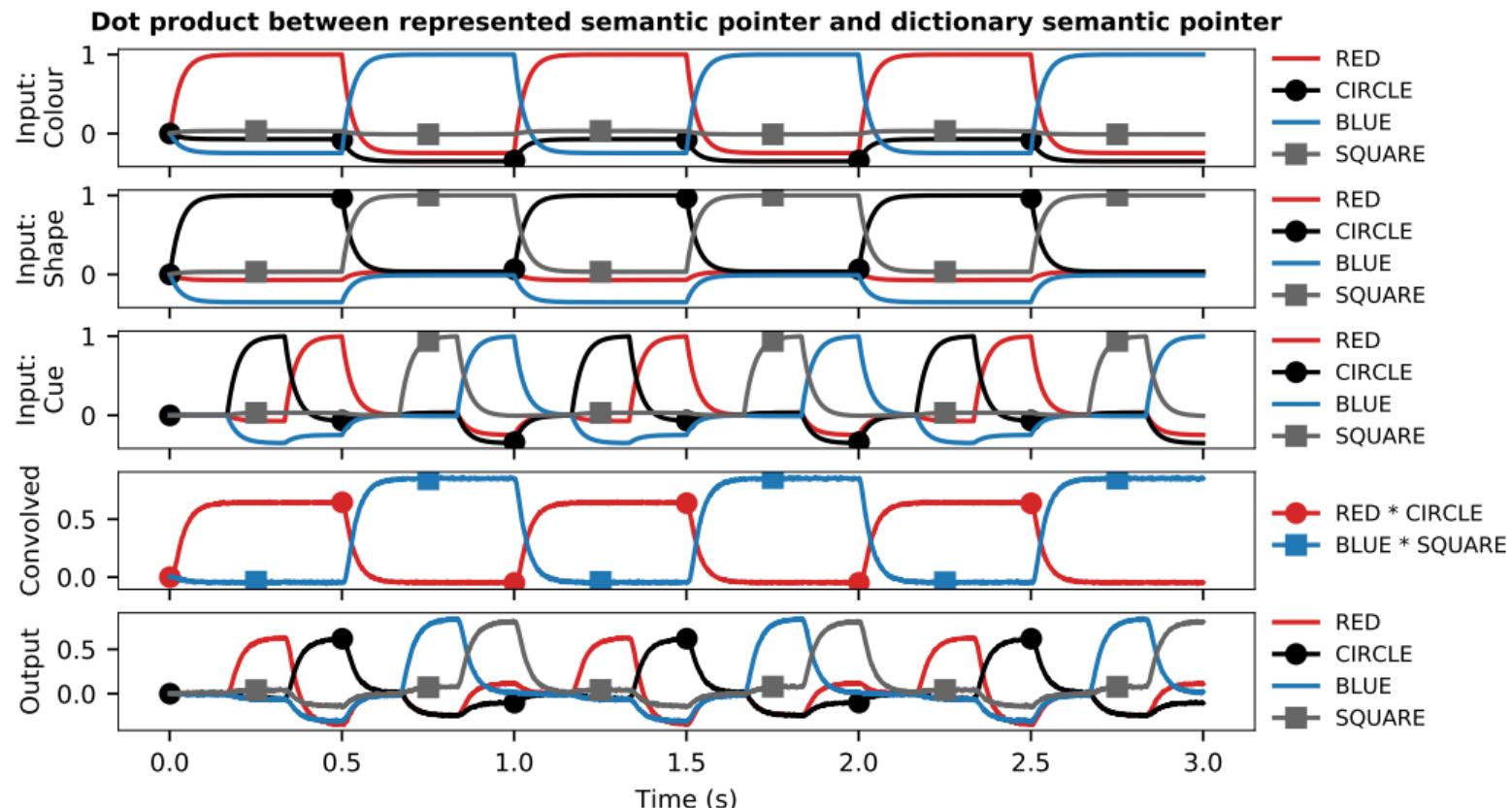
$\text{Representation} \rightarrow \text{World}$

# Nengo SPA Example (I)

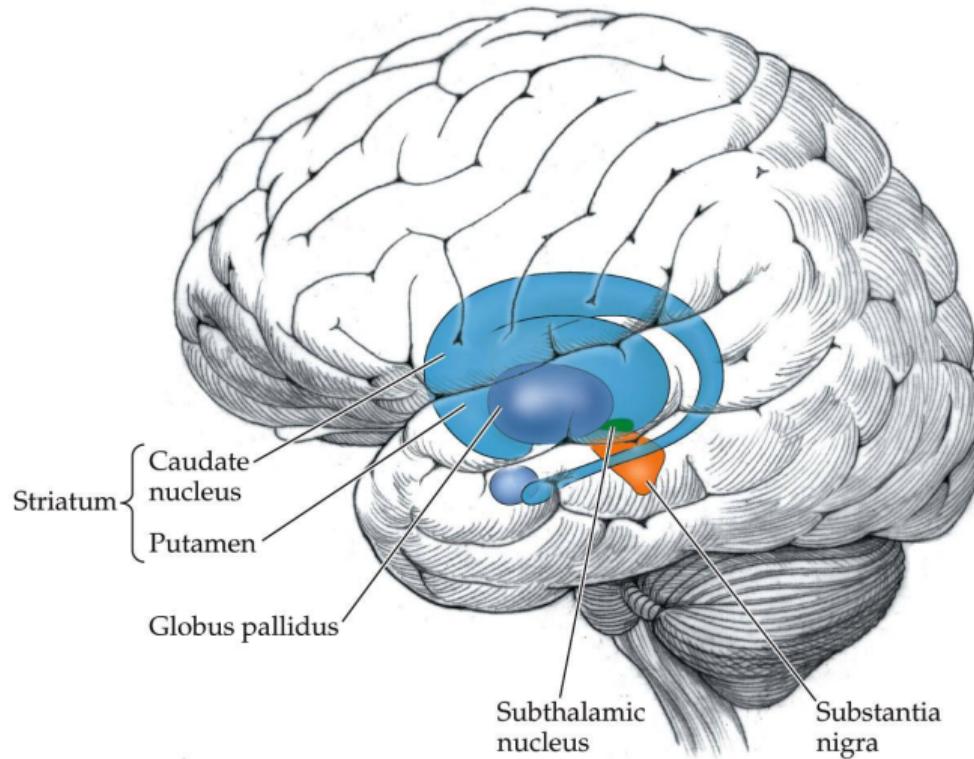
colour\_in



## Nengo SPA Example (II)



# Basal Ganglia (BG)



*Biological Psychology 6e, Figure 11.18*

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# Clinical Evidence for the Role of the BG in Action Selection

## Parkinson's disease

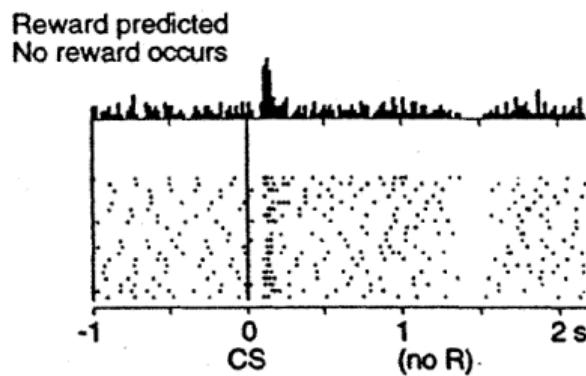
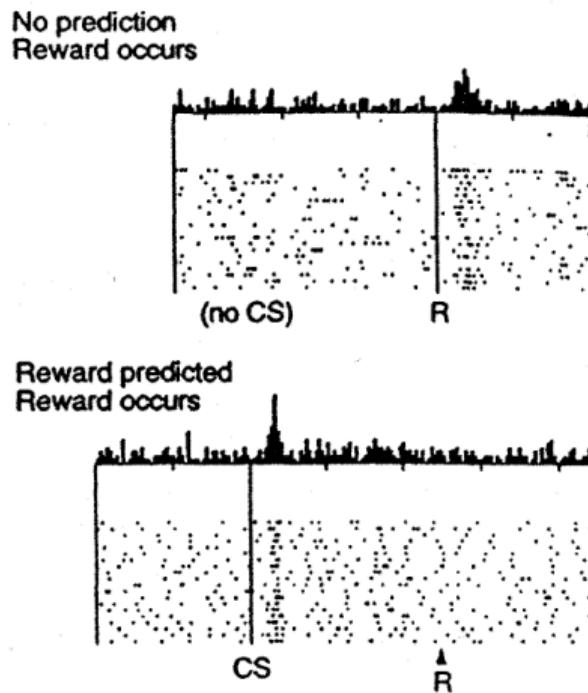
- ▶ Neurons in the substantia nigra die off
- ▶ Difficult to trigger actions to start
- ▶ Usually physical actions
- ▶ Cognitive effects in later stages

## Huntington's disease

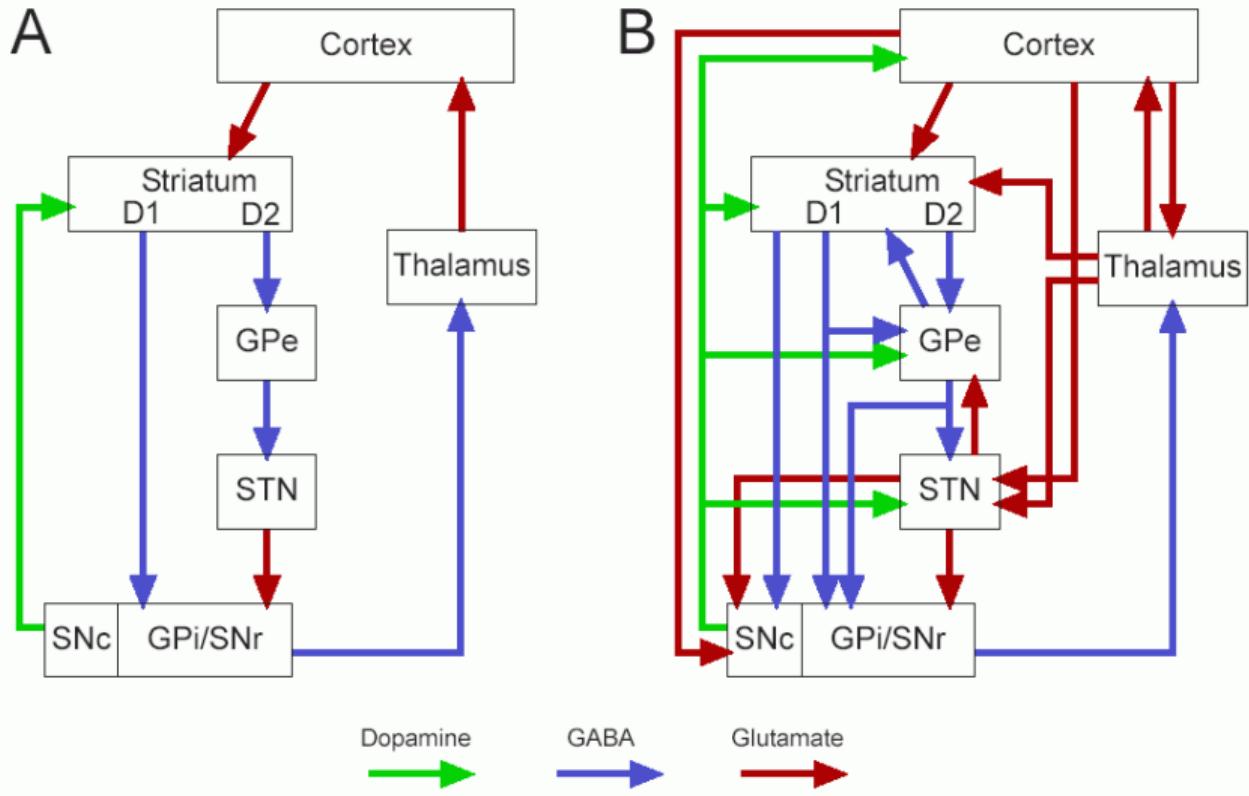
- ▶ Neurons in the striatum die off
- ▶ Actions triggered inappropriately
- ▶ Small uncontrollable movements
- ▶ Trouble sequencing cognitive actions

# Neurophysiological Evidence for the Role of the BG in Action Selection

- Role in reinforcement learning
- Dopamine levels map onto reward prediction error



# Microcircuitry of the Basal Ganglia



# Simplified Model

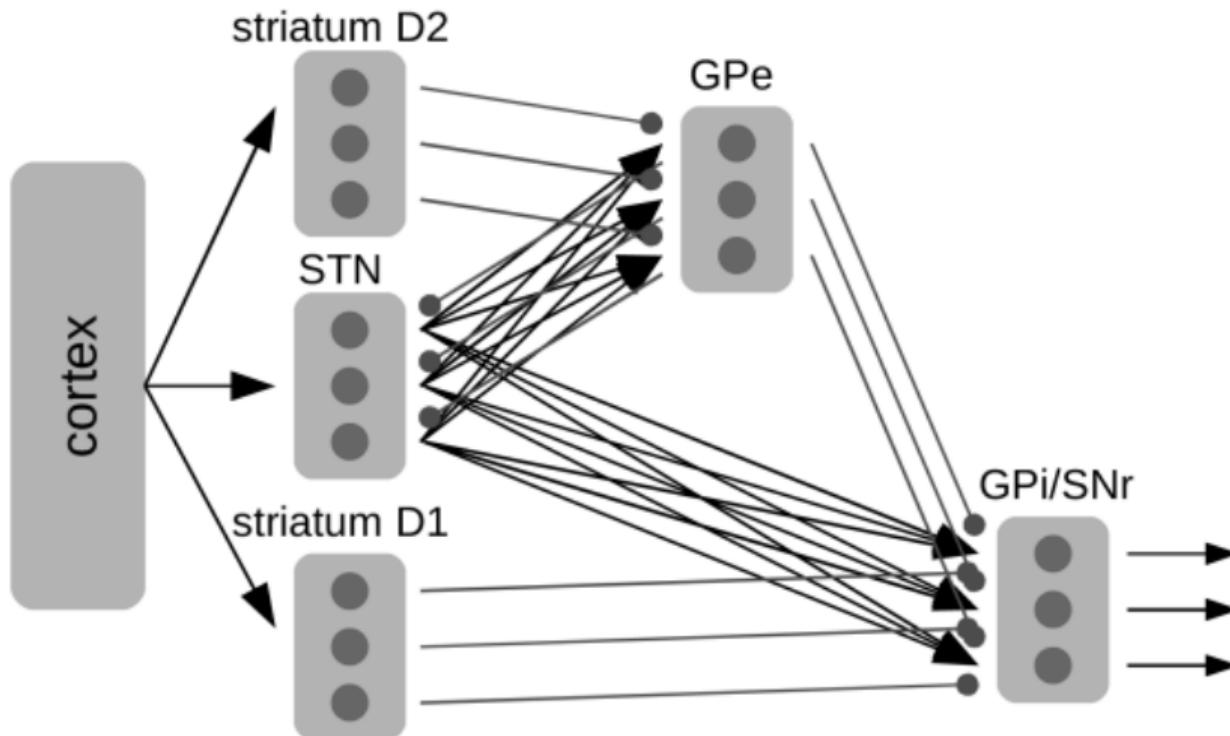
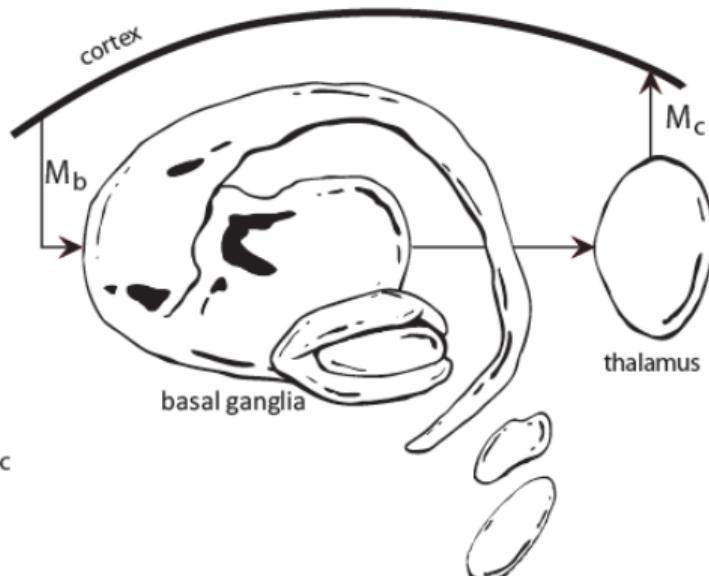
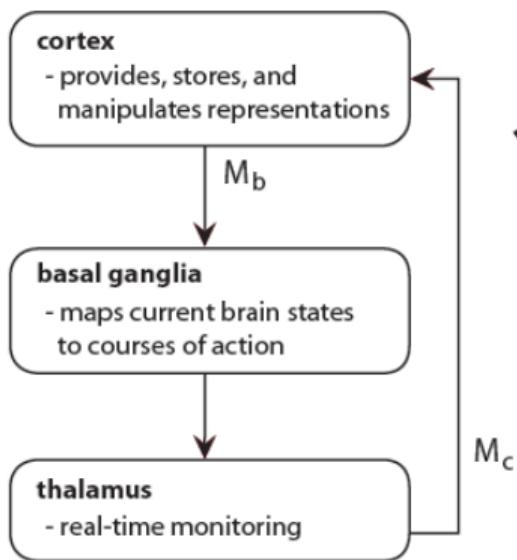
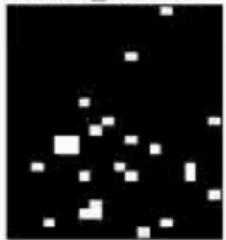


Image Sources. Gurney, Prescott, and Redgrave, *Model of Action Selection in the Basal Ganglia*, 2001

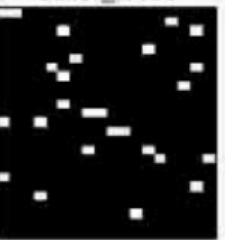
# The Cortex-Basal Ganglia-Thalamus loop



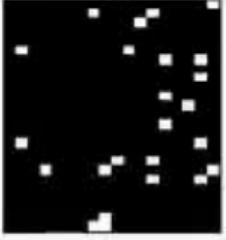
buffer\_setfocus



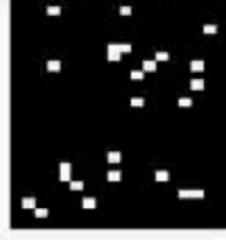
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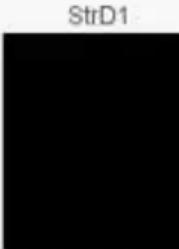
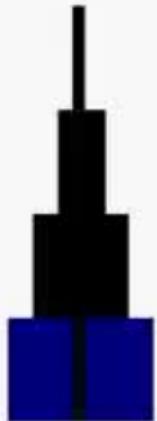
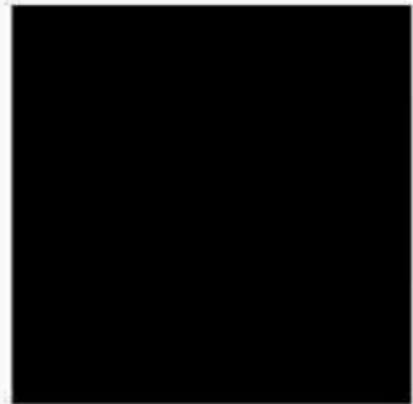
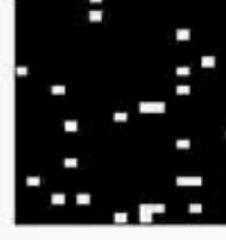
buffer\_goal



buffer\_goalpeg



buffer\_tocusppeg



GPI



GPe



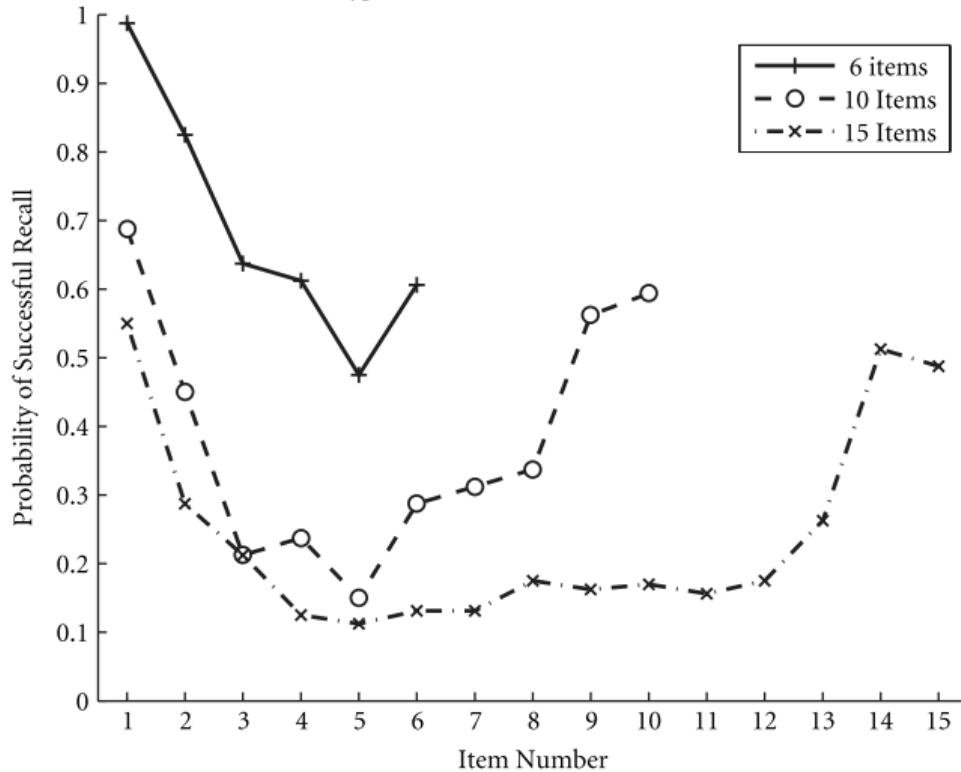
## Recency and Primacy Experiment

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

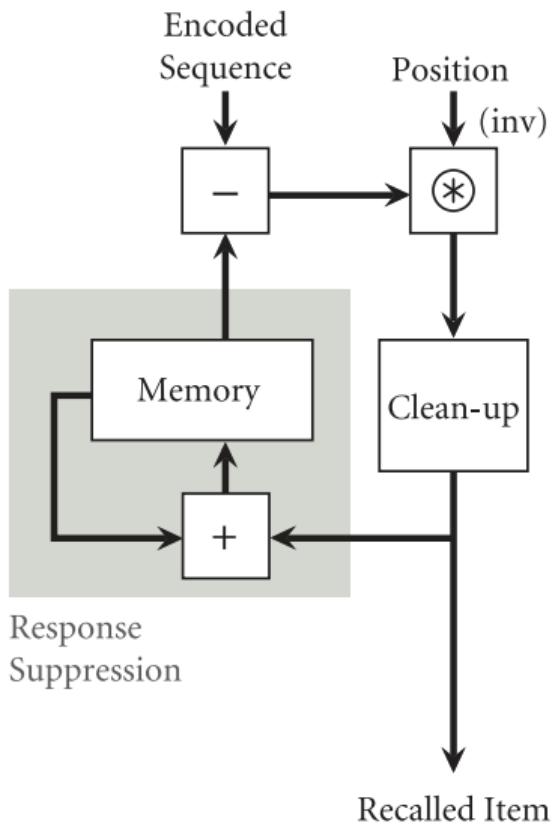
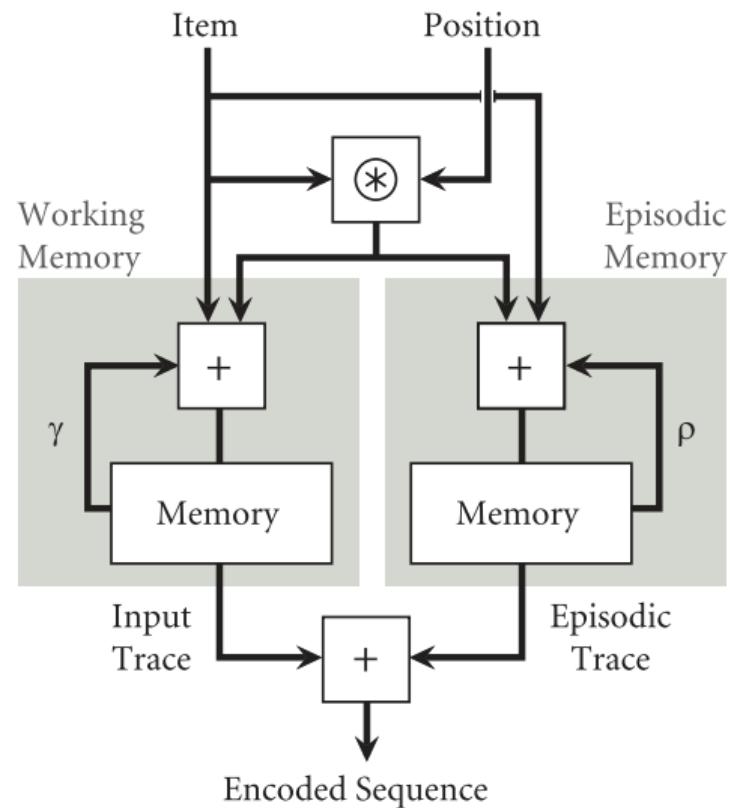
- |                   |                  |
|-------------------|------------------|
| 1. robot          | 6. conglomerates |
| 2. teflon         | 7. waxberries    |
| 3. kettlemaking   | 8. electrograph  |
| 4. big-league     | 9. overjoyous    |
| 5. troubleshooter | 10. unquailing   |

# Recency and Primacy Data

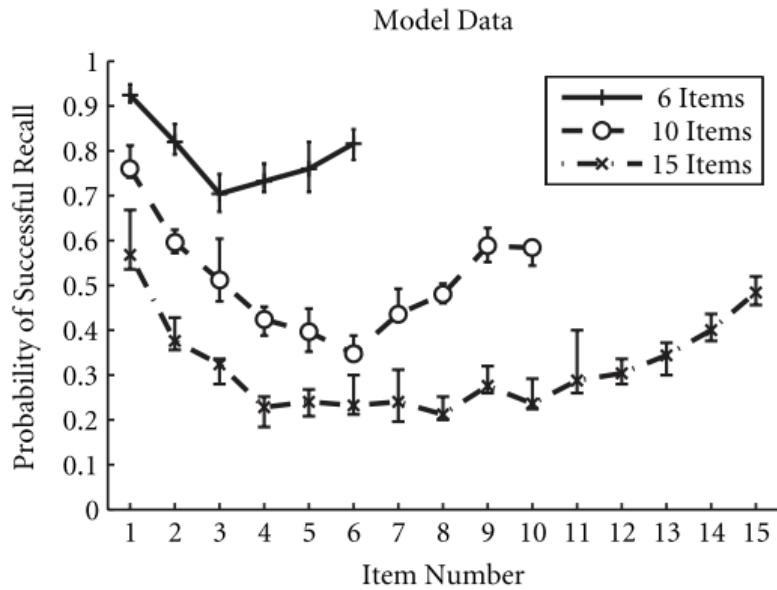
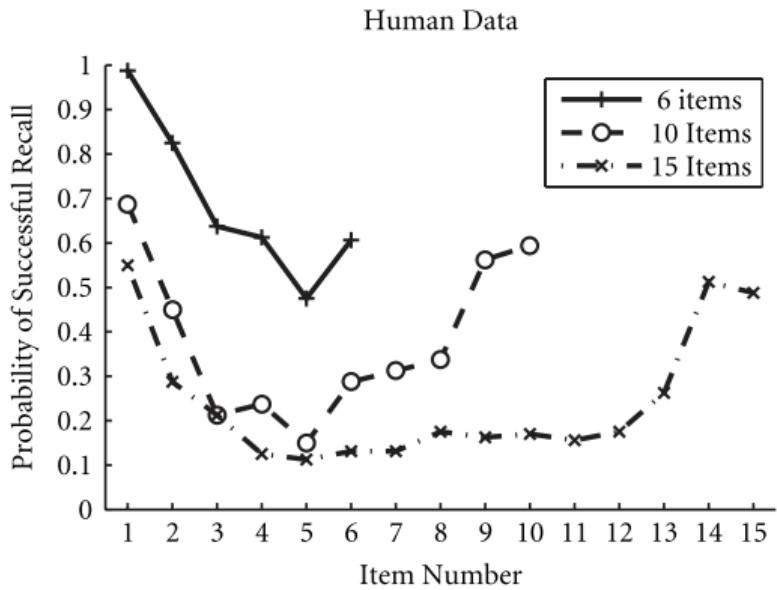
Typical Forward Serial Recall Curves



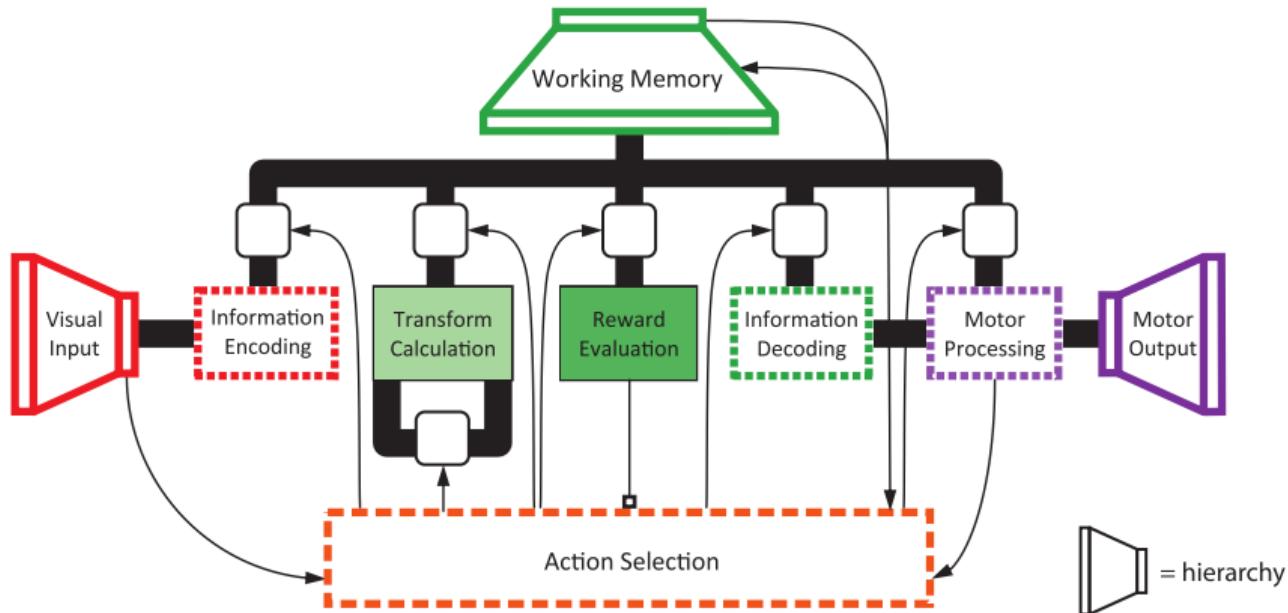
# Ordinal Serial Encoding (OSE) Model



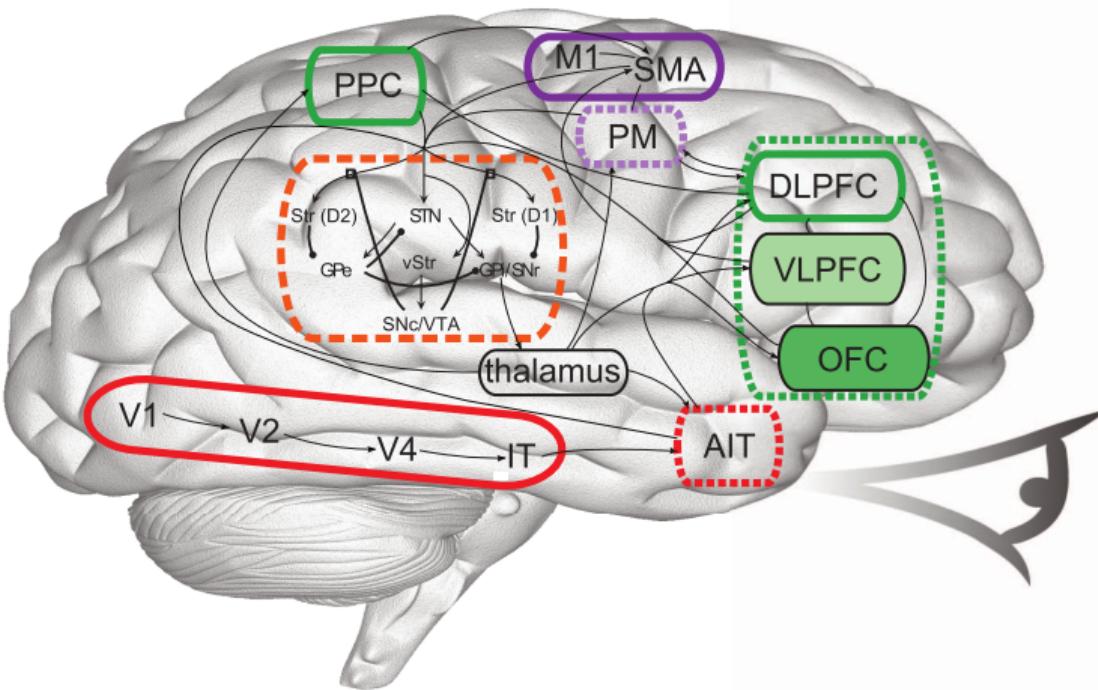
# Ordinal Serial Encoding (OSE) Model: Experiment



# 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.