SYDE 556/750

Simulating Neurobiological Systems
Lecture 11: The Semantic Pointer Architecture

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November 17 & 18, 2022

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UNIVERSITY OF WATERLOO | FACULTY OF ENGINEERING

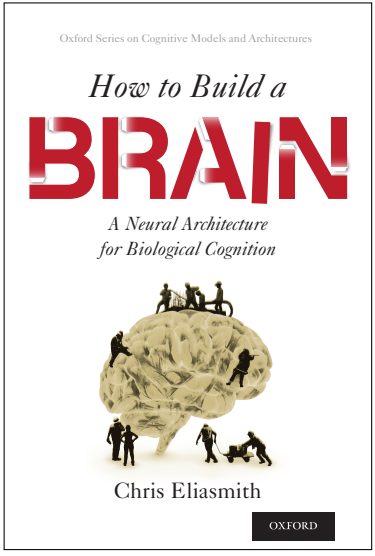
Administrative Notes – Remaining Deadlines

- **Assignment 4** – Due Nov. 18*
- **Assignment 5** – Due Dec. 2*
- **Project Presentations** – Dec. 1
  - 5-10 min. presentation (see the 'project summary document' on the website for instructions)
  - Worth 5 marks (25% of the final project) of the final project
- **Final Project** – Due Dec. 18*
  - Worth 20% of the final mark

* 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)

$$\forall x \, \mathbf{is\_a}(x, \texttt{PINE}) \rightarrow \mathbf{is\_a}(x, \texttt{TREE}) \wedge \mathbf{has}(x, \texttt{NEEDLES}) \wedge \mathbf{is}(x, \texttt{EVERGREEN}),$$

$$\forall x \, \mathbf{is\_a}(x, \texttt{TREE}) \rightarrow \mathbf{is\_a}(x, \texttt{PLANT}),$$

$$\forall x \, \mathbf{is\_a}(x, \texttt{PLANT}) \rightarrow \mathbf{is}(x, \texttt{ALIVE}).$$

Deep semantics (“subjective experience”)

Deep Semantic in Perception: Visual Processing Hierarchy

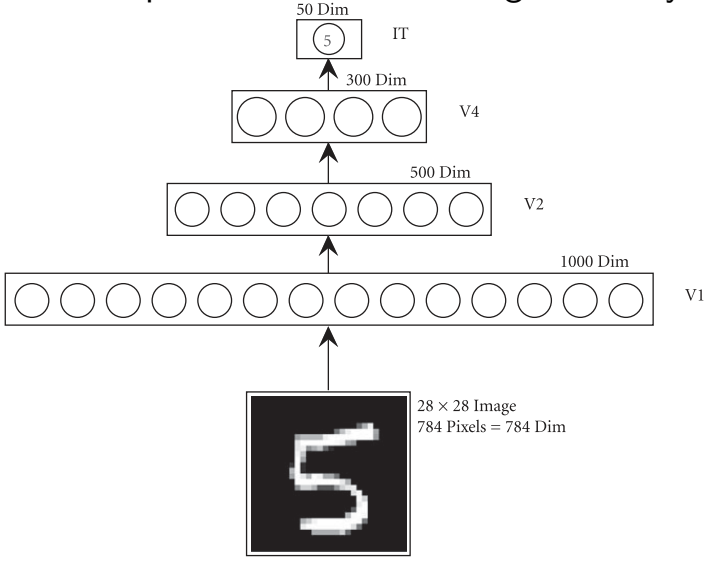


Image Sources. Eliasmith, "How to Build a Brain", 2013, Figure 3.4

Deep Semantic in Perception: Dereferencing

A.

B.

C.

D.

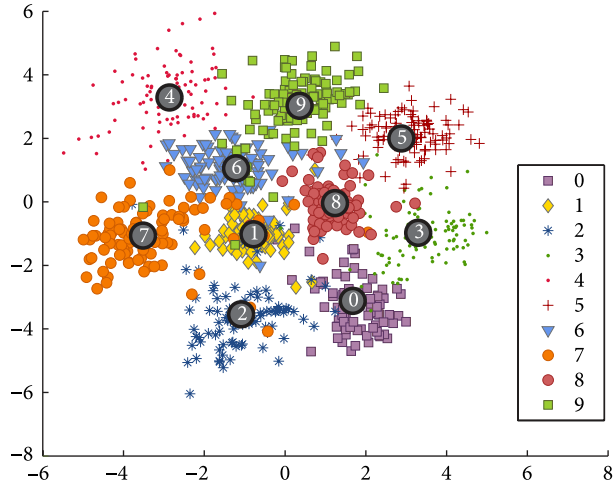
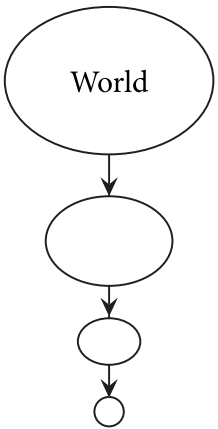


Image Sources. Eliasmith, "How to Build a Brain", 2013, Figure 3.7

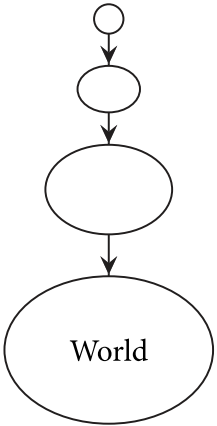
Perception vs. Action

Perception



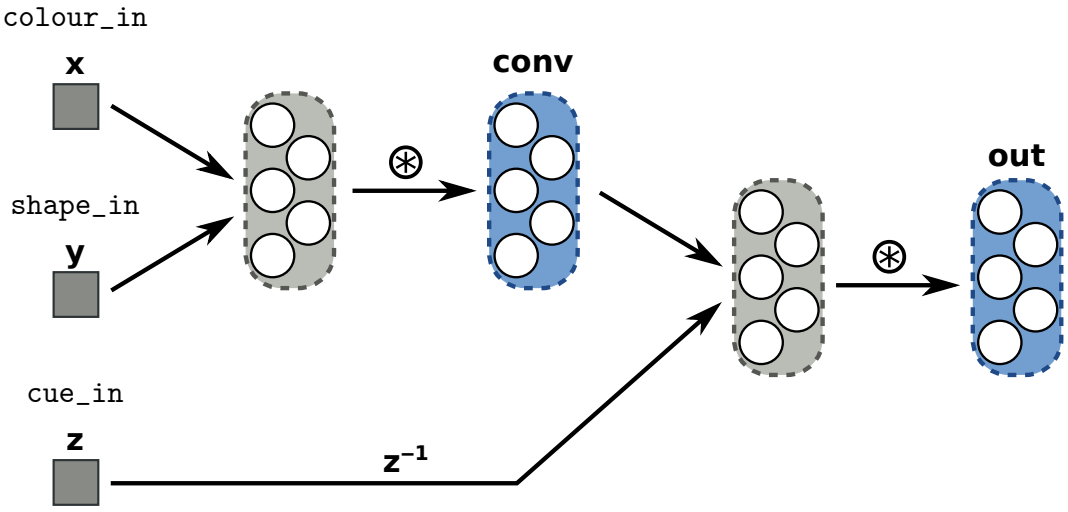
World → Representation

Motor Control

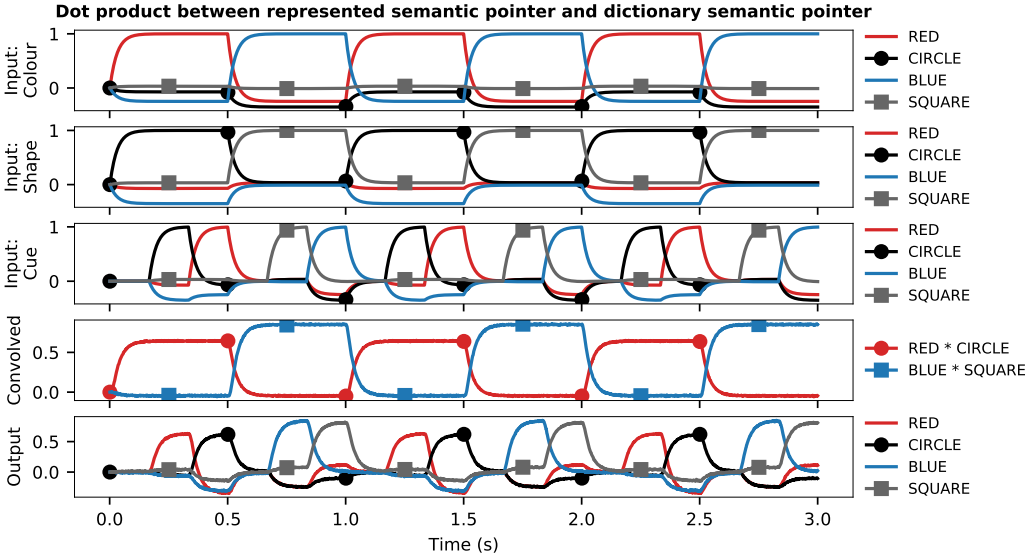


Representation → World

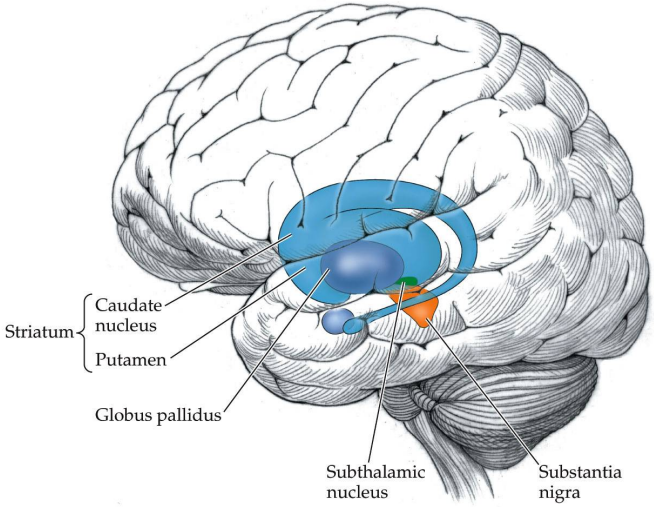
Nengo SPA Example (I)



Nengo SPA Example (II)



Basal Ganglia (BG)



***Biological Psychology 6e*, Figure 11.18**

Clinical Evidence for the Role of the BG in Action Selection

Parkinson's disease

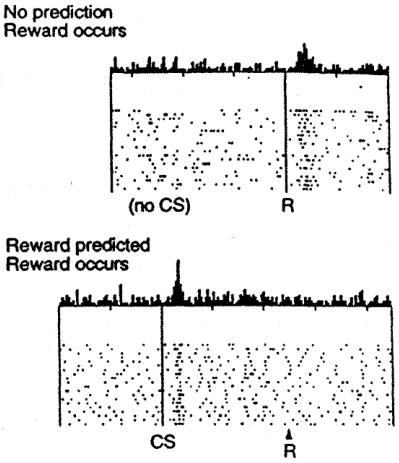
- Neurons in the substantia nigra die off
- Difficult to trigger actions to start
- Usually physical actions
- Cognitive effects in later stages

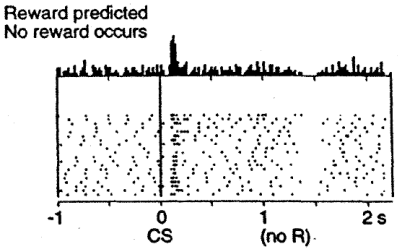
Huntingtons's disease

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

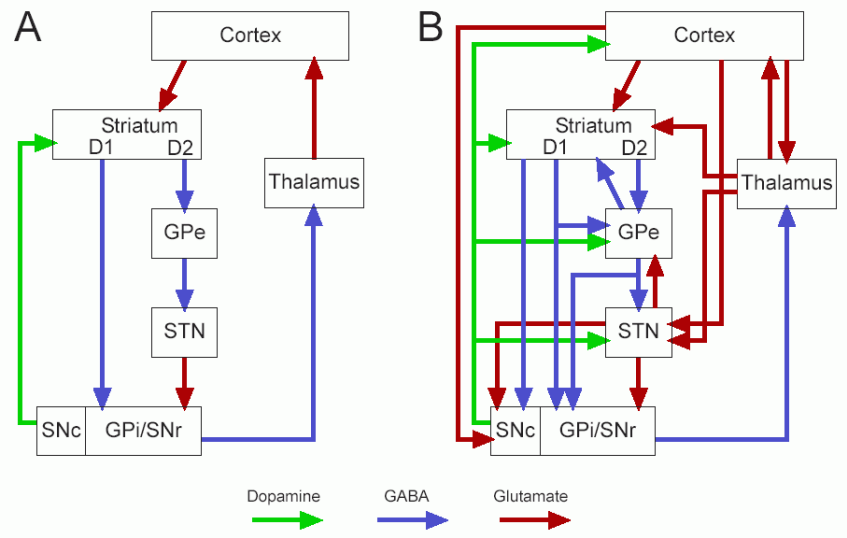
Neurophysiological Evidence for the Role of the BG in Action Selection

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





Microcircuitry of the Basal Ganglia



Simplified Model

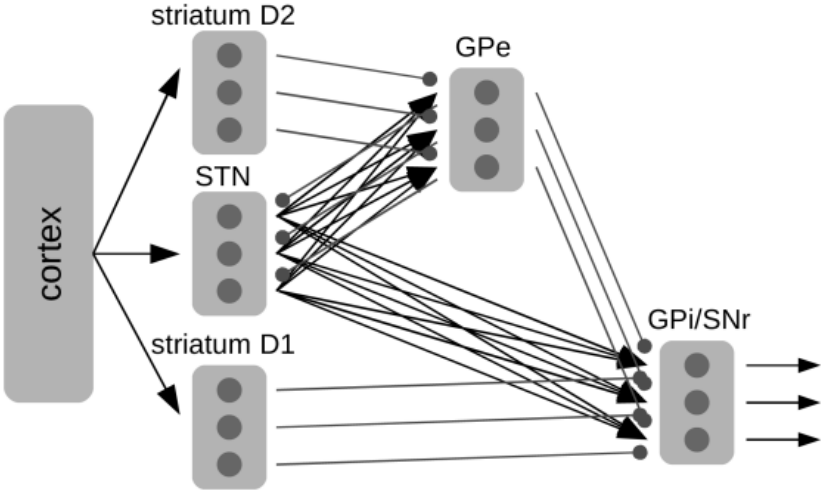
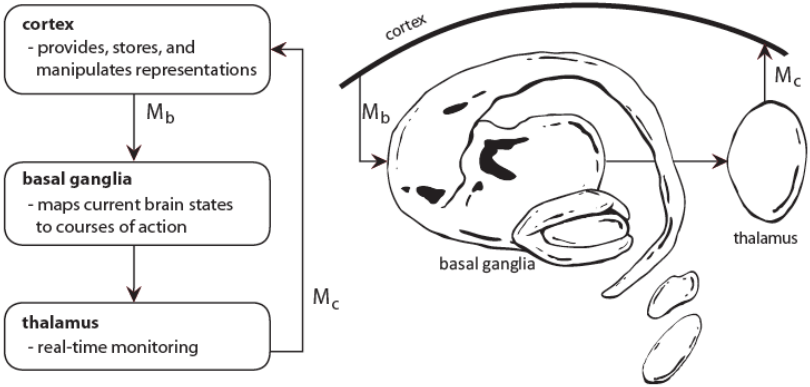
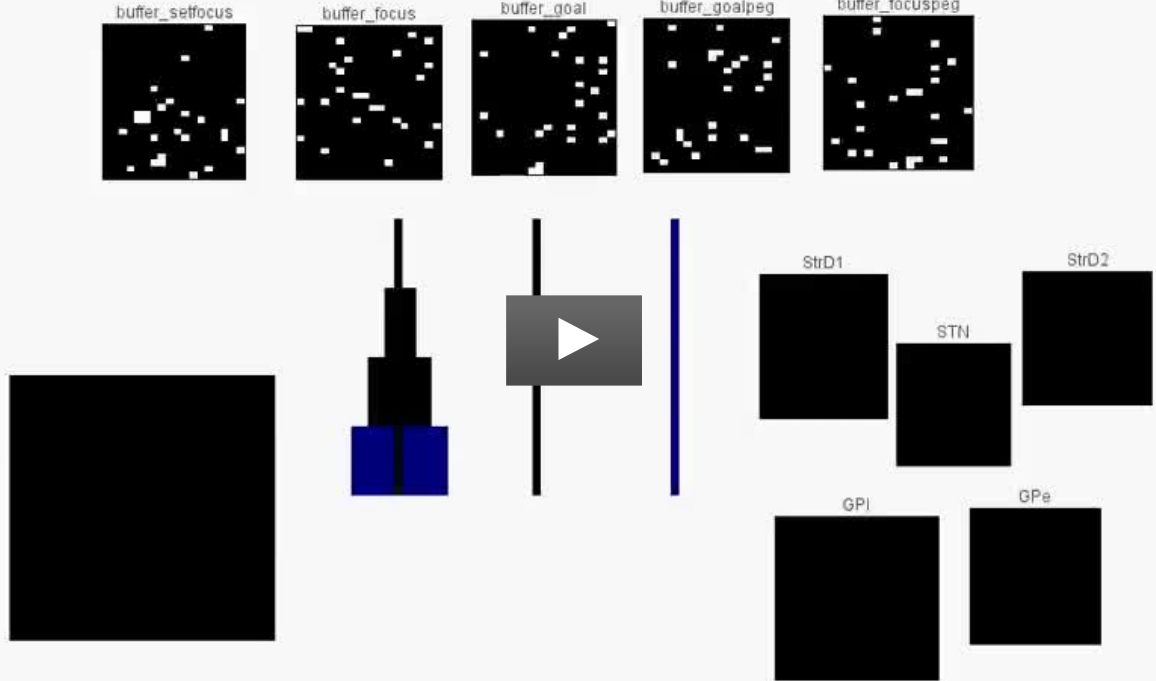


Image Sources. Gurney, Prescott, and Redgrave, *Model of Action Selection in the Basal Ganglia, 2001*

The Cortex-Basal Ganglia-Thalamus loop



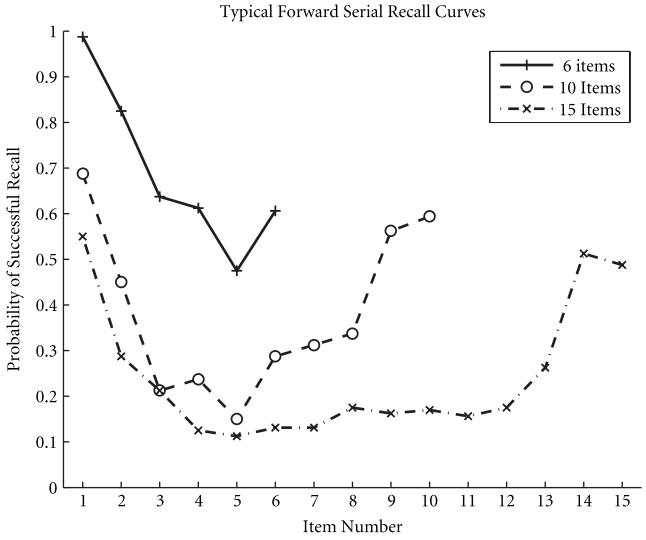

buffer_setfocus
buffer_focus
buffer_goal
buffer_goalpeg
buffer_focuspeg
StrD1
StrD2
STN
GPI
GPe

Recency and Primacy Experiment

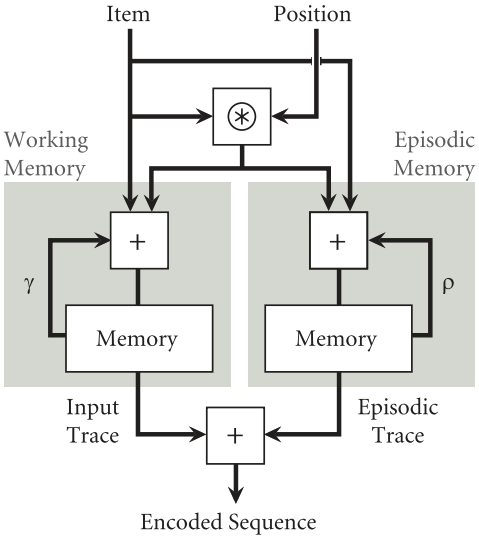
Experiment: Remember this list (presented one at a time)

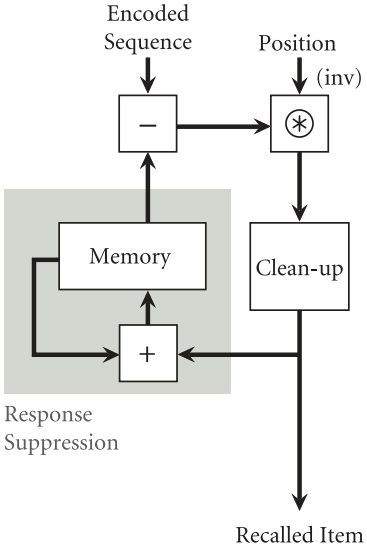
1. robot
2. teflon
3. kettlemaking
4. big-league
5. troubleshooter
6. conglomerates
7. waxberries
8. electrograph
9. overjoyous
10. unquailing

Recency and Primacy Data

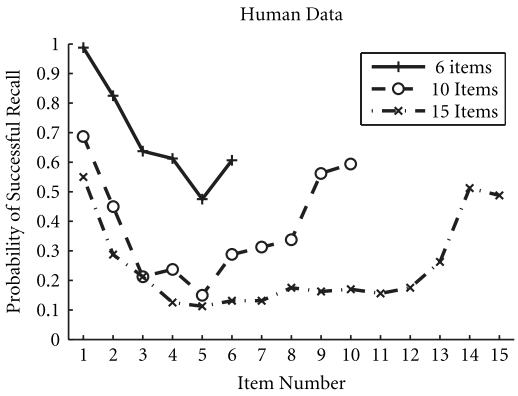


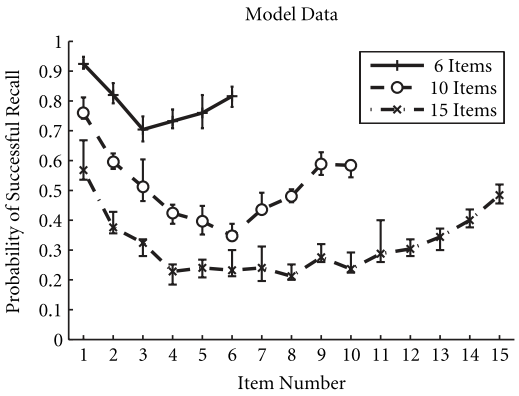
Ordinal Serial Encoding (OSE) Model



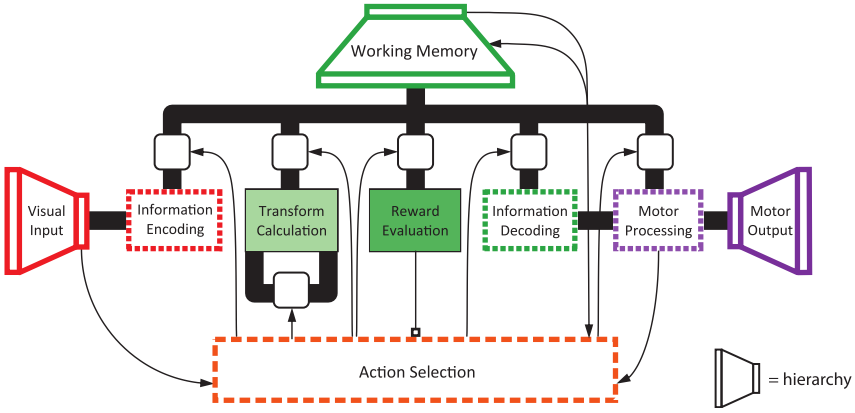


Ordinal Serial Encoding (OSE) Model: Experiment





Spaun – Semantic Pointer Architecture Unified Network (I)



Spaun – Semantic Pointer Architecture Unified Network (II)

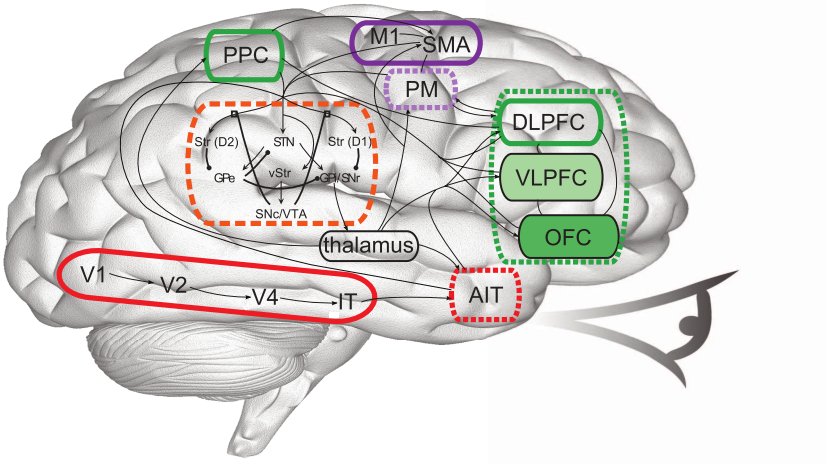


Image sources

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