Parsing sequentially presented commands in a large-scale biologically realistic brain model

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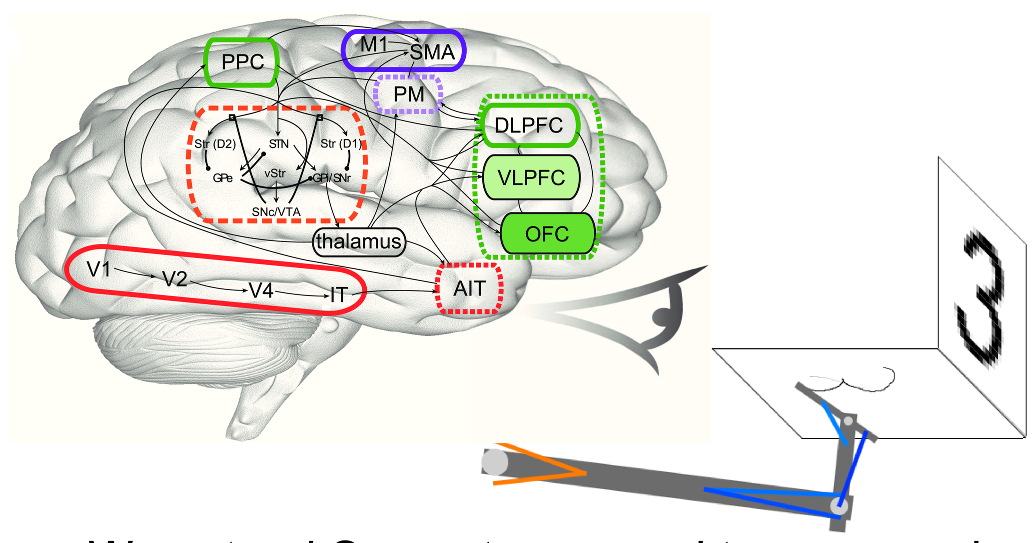
Overview

- Spaun: first large-scale functional simulation of the human brain (Eliasmith et al., 2012)



- We extend Spaun to respond to commands

W 3	(write three)
R 4 W #	(remember four, write number)
S 2 W 9	(see two, write nine)

- Input is 28 x 28 pixel image
- Output is written numbers
- 2.5 million spiking LIF neurons

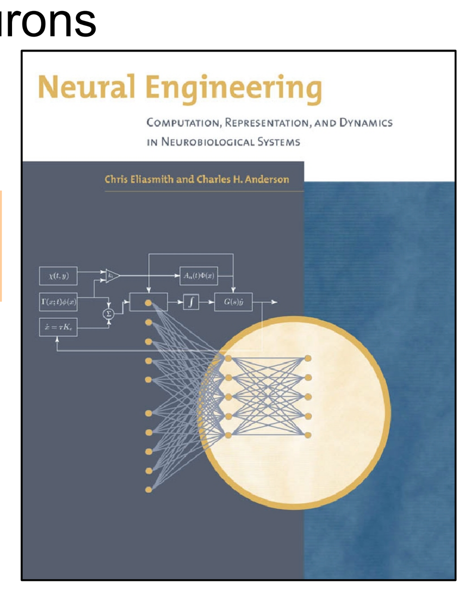
The Neural Engineering Framework

- General method for converting algorithms into neural models (Eliasmith & Anderson, 2003)
- Groups of neurons encode vectors

each neuron has random preferred vector (distributed representation)

- Connections between neurons compute functions on those vectors

find connection weights to best approximate given function



- Open-source neural compiler solves for connection weights: **http://nengo.ca**

Symbol-Like Processing with Neurons

- Basic concepts are random 64-D vectors

ONE TWO THREE WRITE SEE NUMBER

- Resolve binding problem: circular convolution

SEE⊛NINE + WRITE⊛EIGHT ≠ SEE⊛EIGHT + WRITE⊛NINE

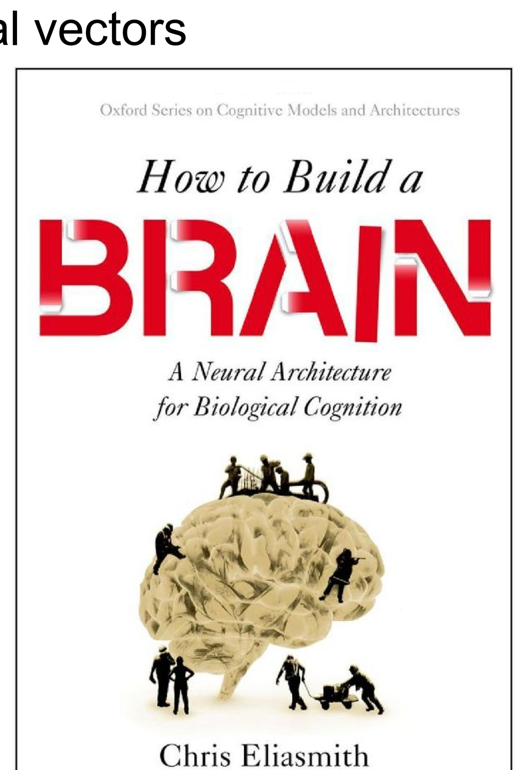
- Can do nested representations

S = CONDITION⊛(SEE⊛NINE) + VERB⊛WRITE + NOUN⊛EIGHT

- Can extract the original vectors

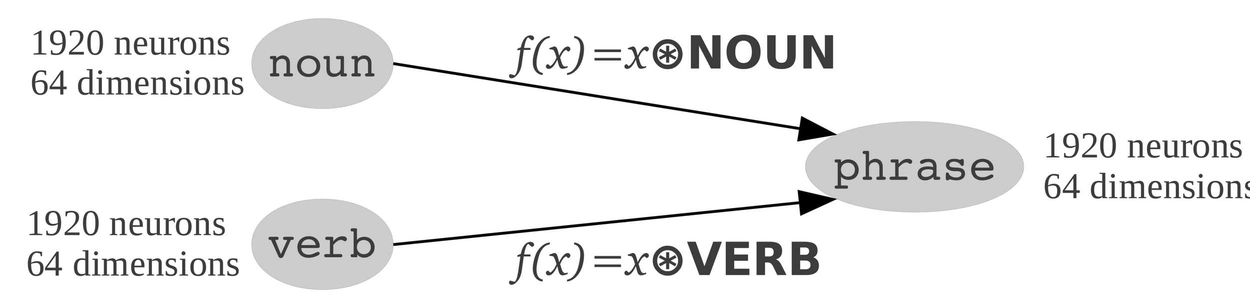
S⊛inv(VERB) ≈ WRITE

- A type of Vector Symbolic Architecture (HRR; Plate, 2003)
- Easy to implement in spiking neurons using the NEF
- Basis of the Semantic Pointer Architecture used for Spaun (Eliasmith, 2013)

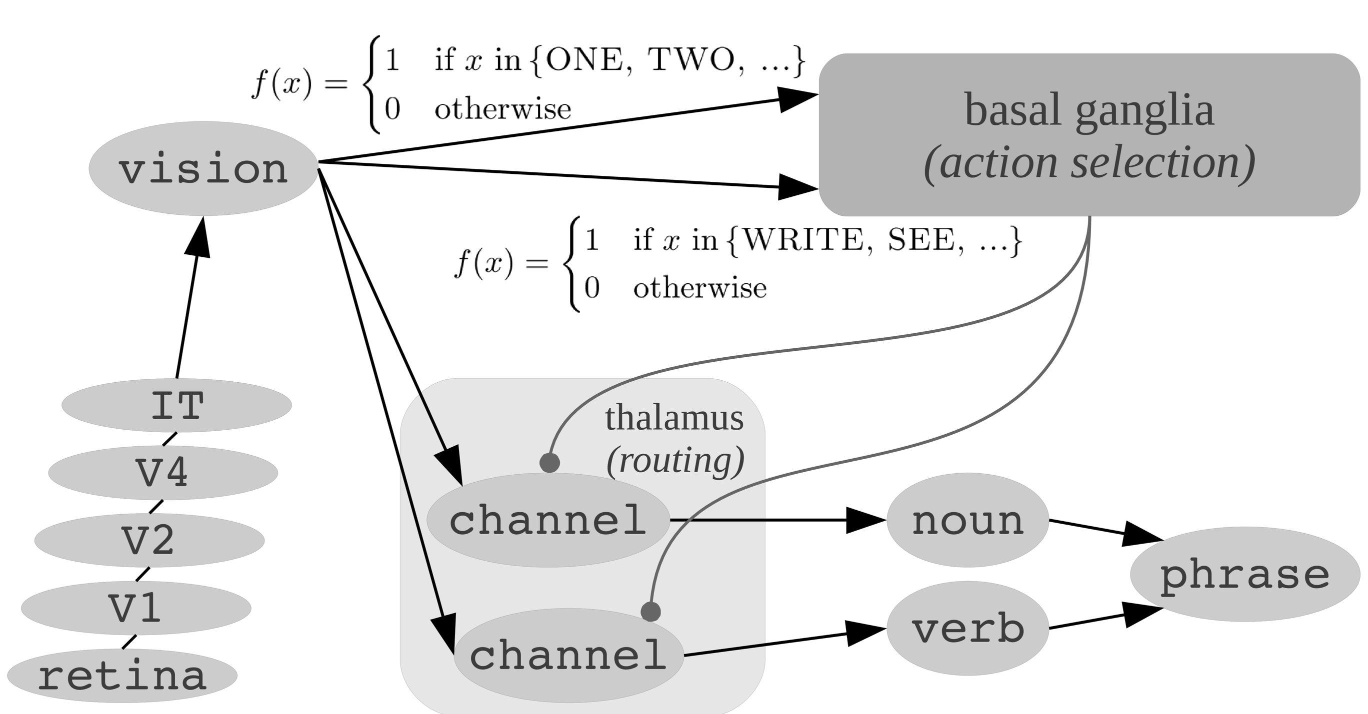


Simple Parsing

- **Vision:** Deep Belief Network (Hinton, 2010) in LIF neurons
- **Phrase representation:** Combine noun/verb pairs

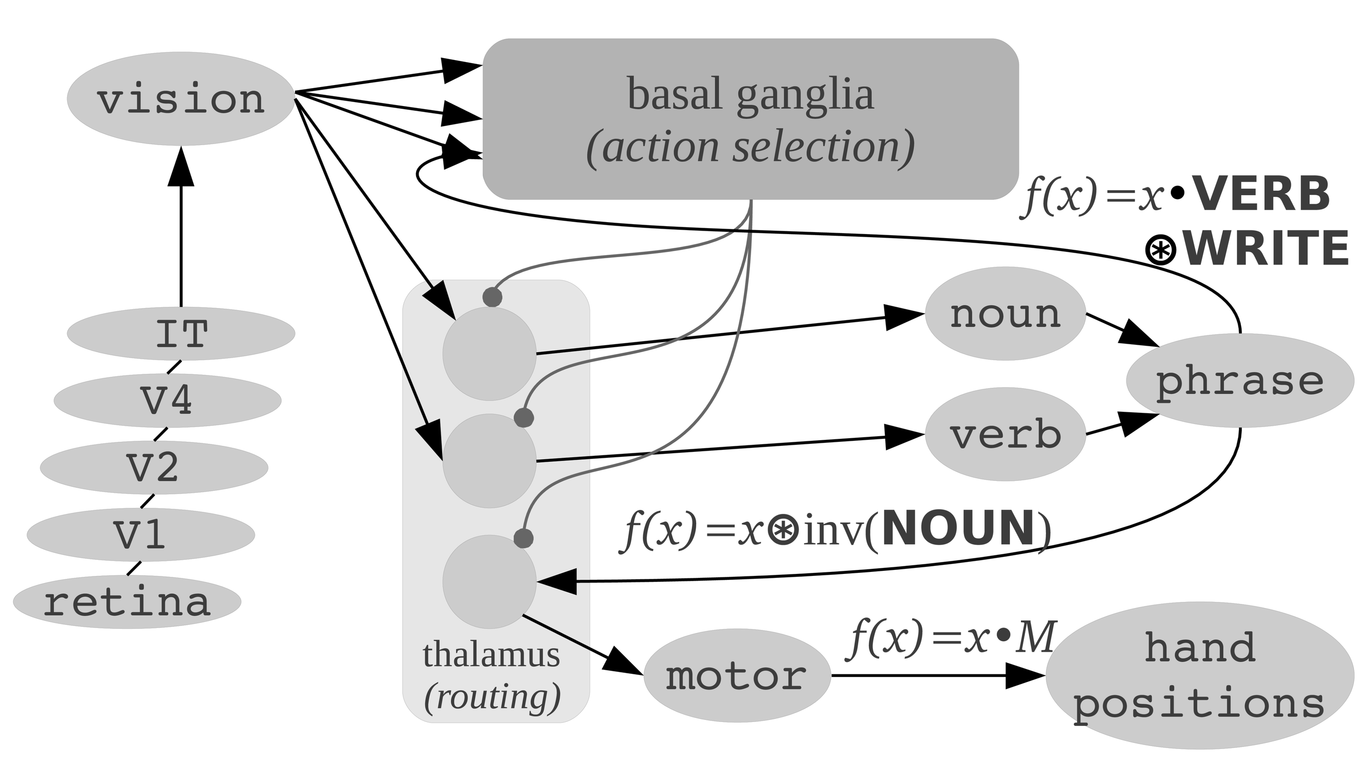


- **Control:** Route information appropriately as command appears sequentially
- Use existing basal ganglia model of action selection (Stewart et al., 2010)
- Inputs to basal ganglia are utilities of different actions, based on current state
- Output is which actions to inhibit (the action with highest utility is not inhibited)

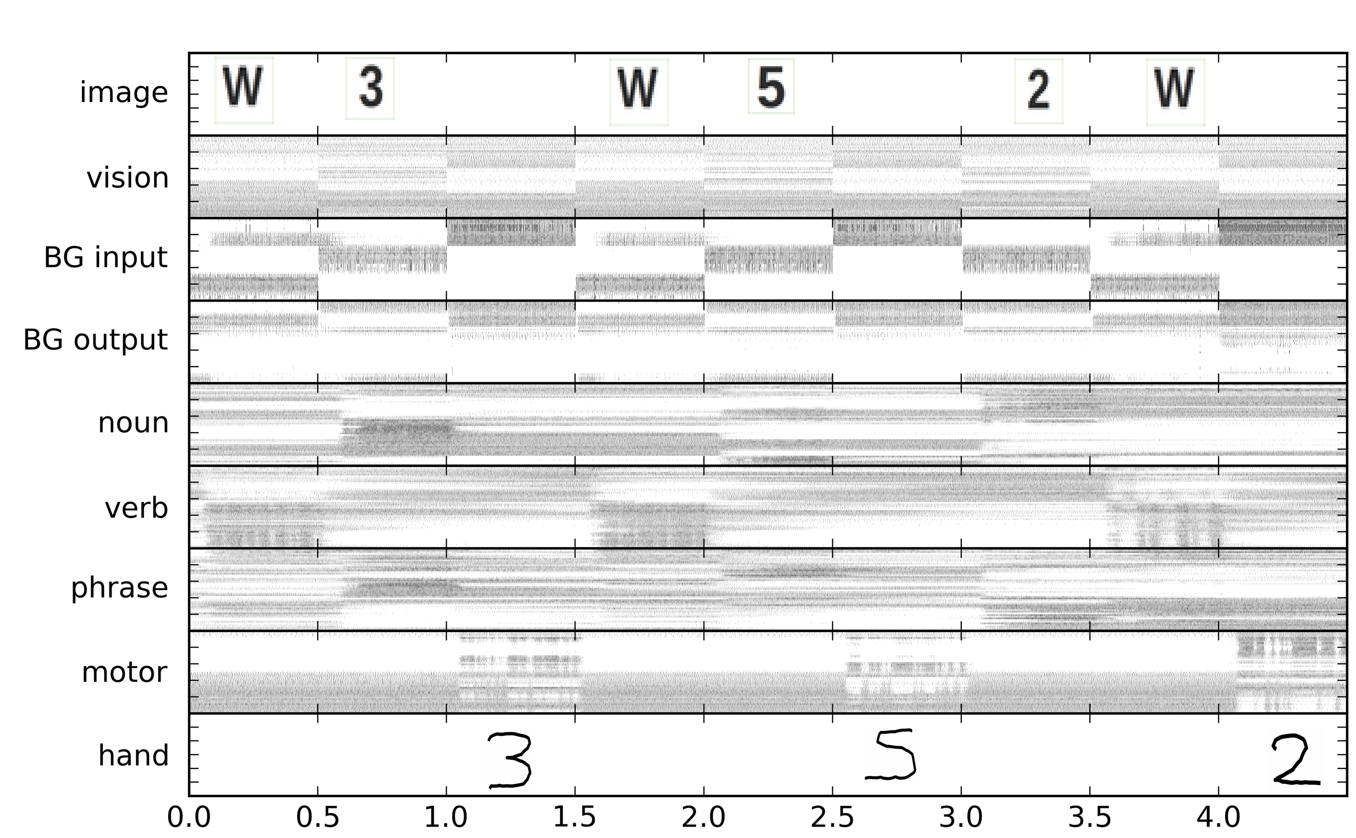


If **vision** is ONE or TWO or THREE...:
send **vision** to **noun**
If **vision** is WRITE or SEE or REMEMBER:
send **vision** to **verb**

- **Executing Actions:** Use action selection system again

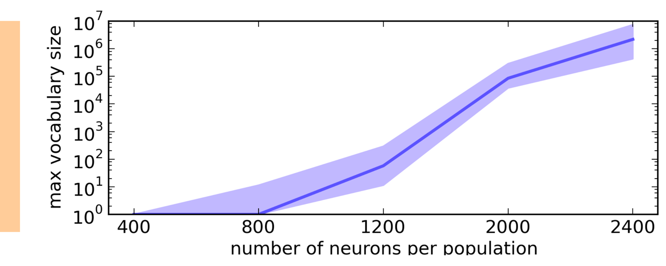


If **phrase** is VERB*WRITE:
send **phrase***inv(NOUN) to **motor**

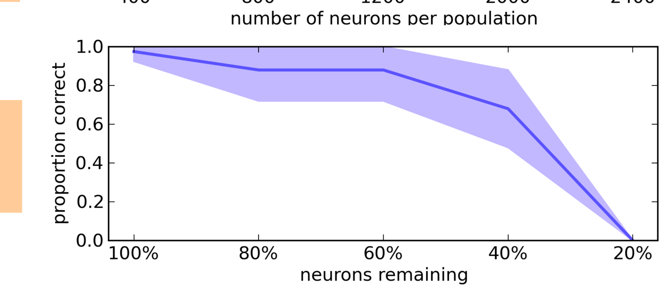


Results

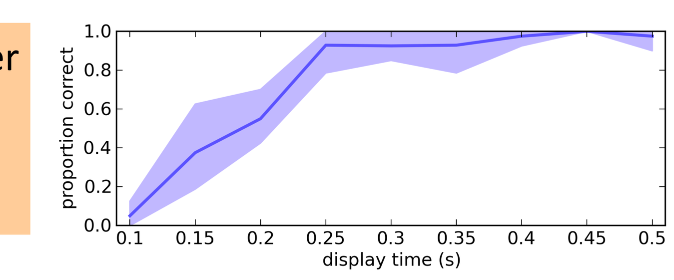
exponential growth in vocabulary size as number of neurons increases



robust to neural destruction

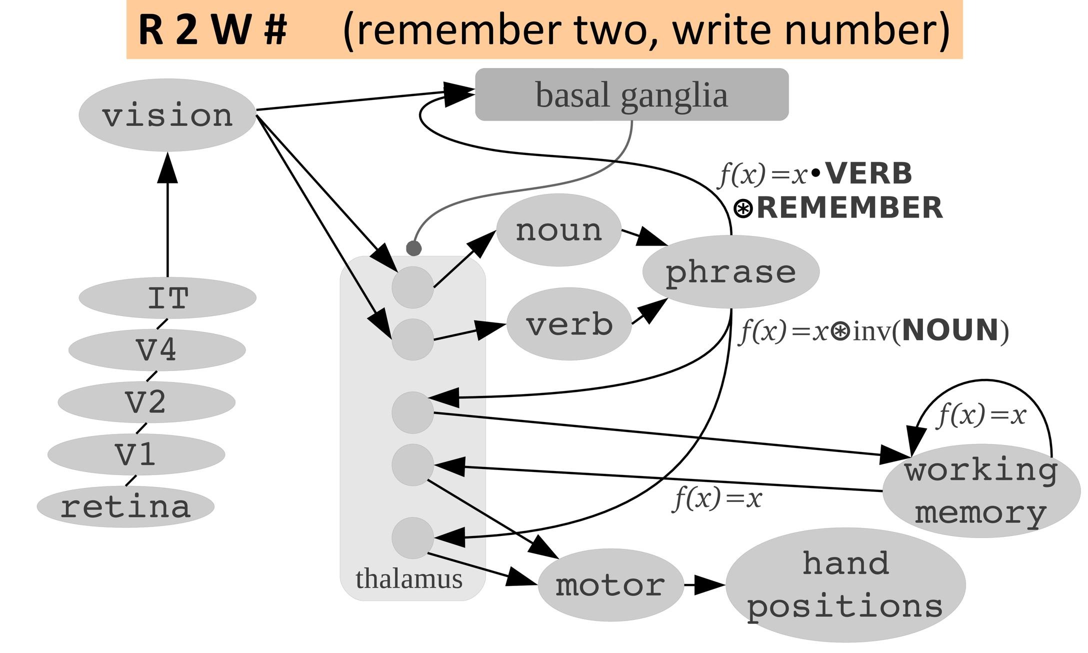


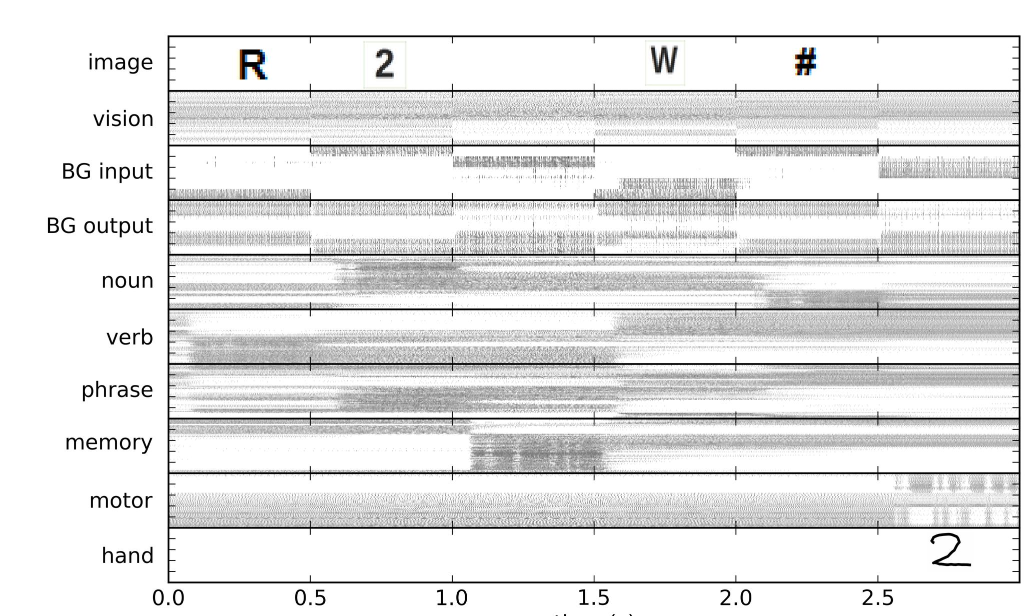
Requires ~250ms per visual stimulus for 95% response accuracy



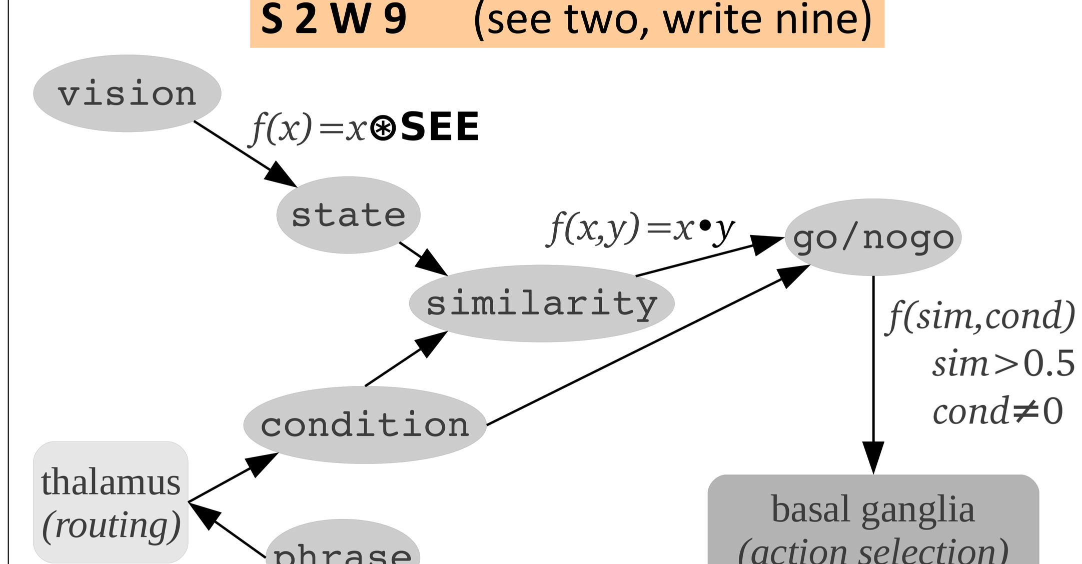
More Complex Commands

R 2 W # (remember two, write number)





S 2 W 9 (see two, write nine)



Conclusions

- Biologically realistic brain model can be extended to follow commands
- Neural model of building up complex symbol structures in a realistic manner
- Robust to damage, scales up to human-sized vocabularies
- Timing is dependent on neural properties
- Basic grammatical capabilities (no center-embedding)
- Extensible to more complex grammars
- No token separation, no ambiguity
- No development/learning process