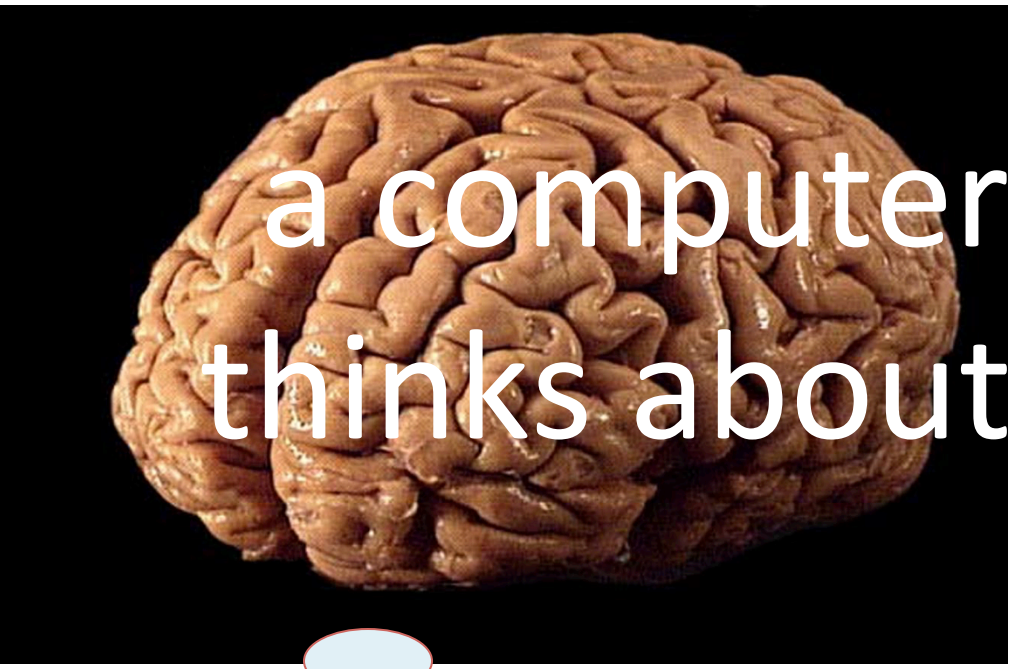
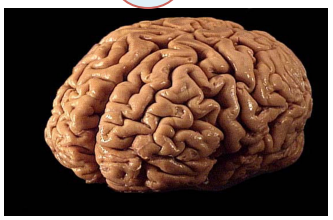
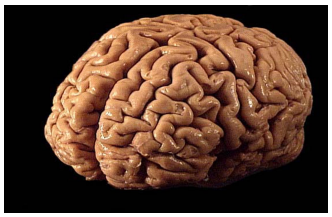


a computer scientist thinks about the Brain

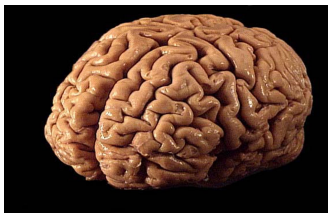


Christos H. Papadimitriou
Columbia U

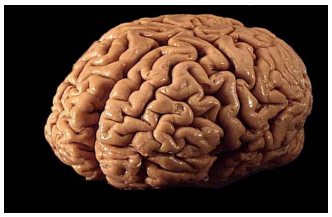
1936 – 1995: the Computer



1995 – :
the Internet



1995 – :
the Universe

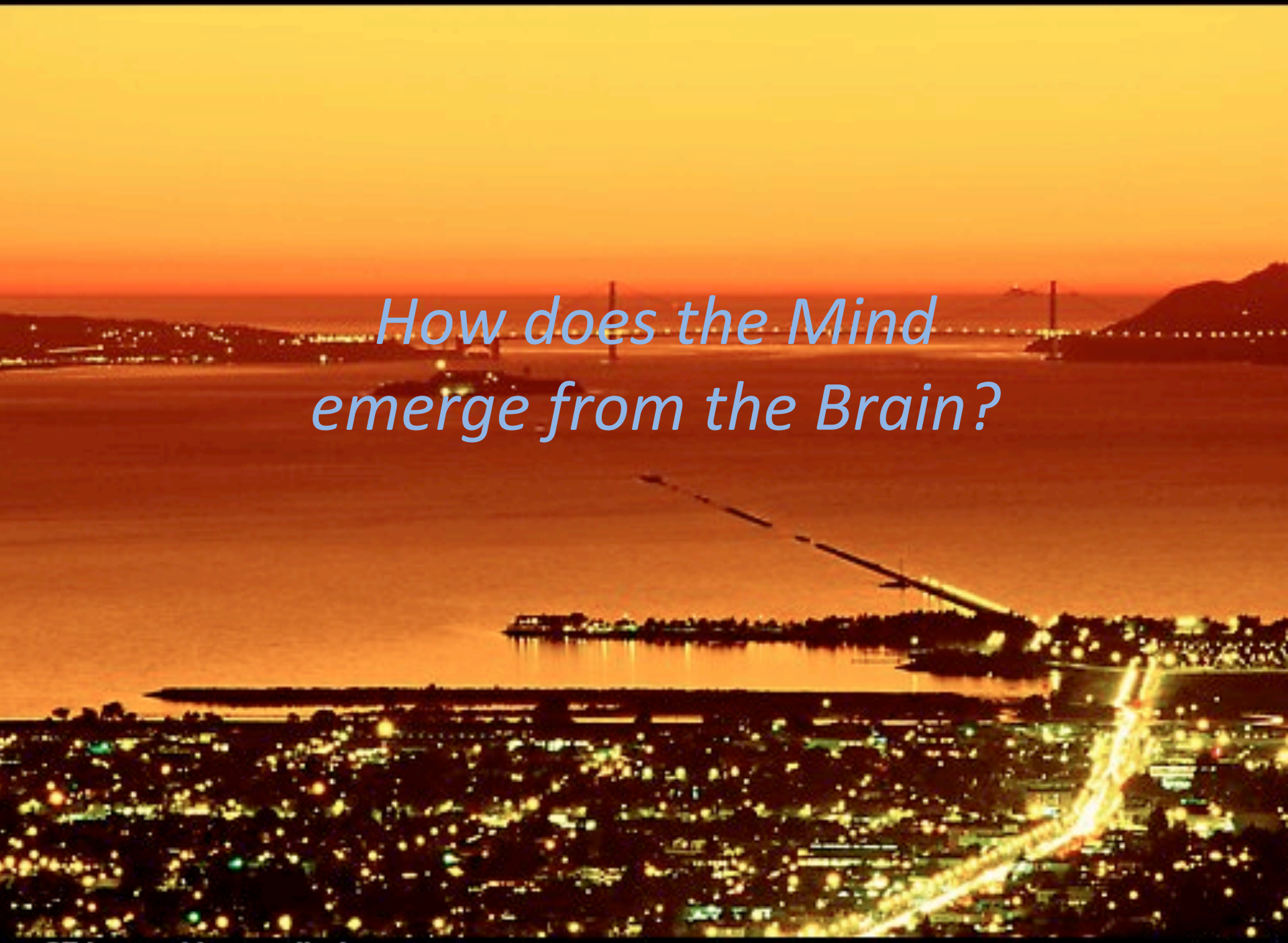


Brain and Computation:

The Great Disconnects

- Babies *vs* computers
- Deep nets vs the Brain
- Understanding Brain anatomy and function *vs* understanding the emergence of the Mind

How does the Mind emerge from the Brain?

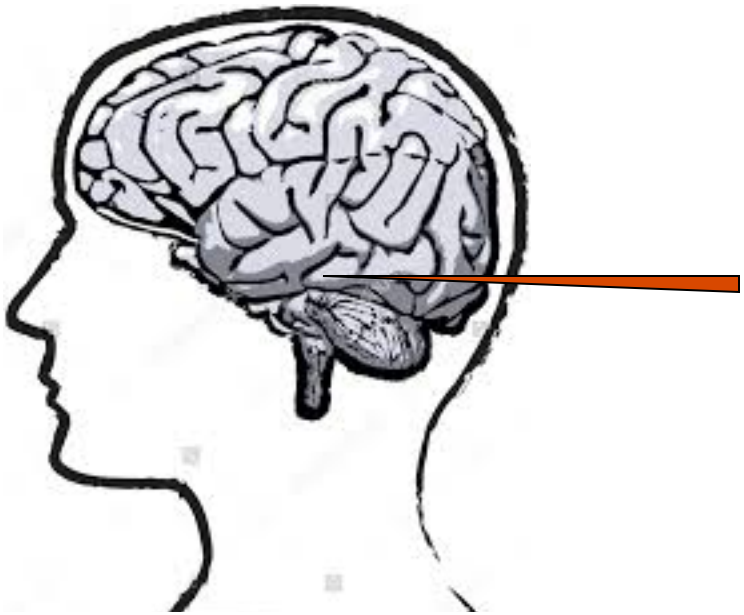

How does the Mind
emerge from the Brain?

David Marr (1945 – 1980)

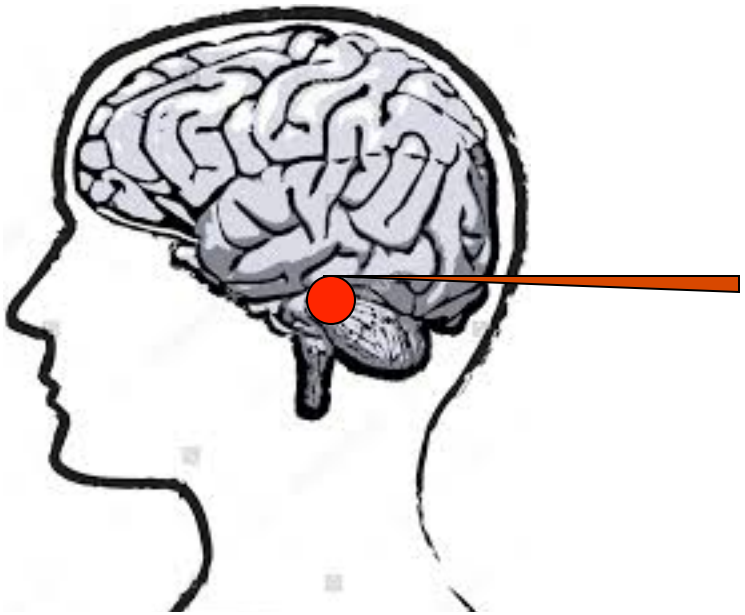
The three-step program:

- specs
- algorithm
- hardware

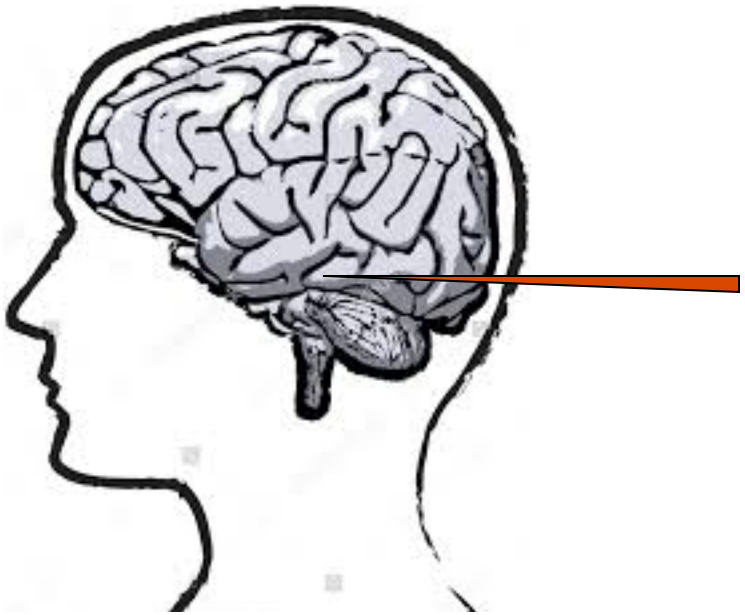
The experiment by [Ison et al. 2016]



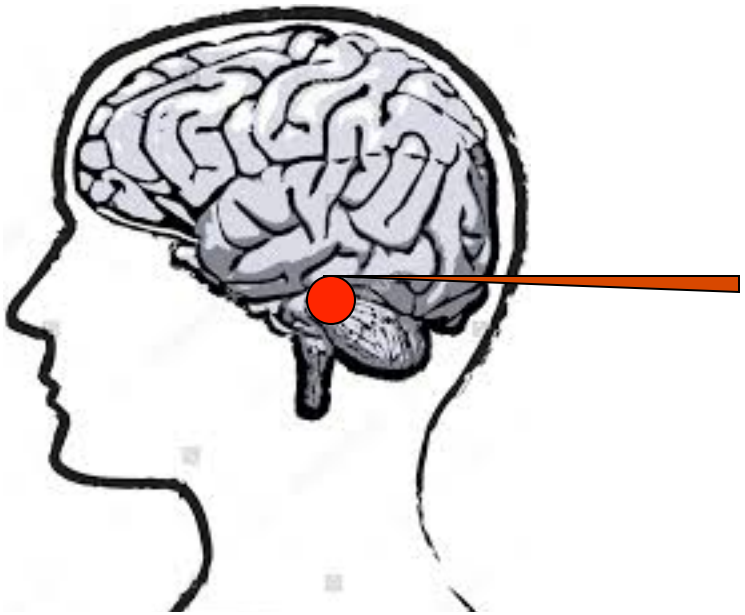
The experiment by [Ison et al. 2016]



The experiment by [Ison et al. 2016]



The experiment by [Ison et al. 2016]



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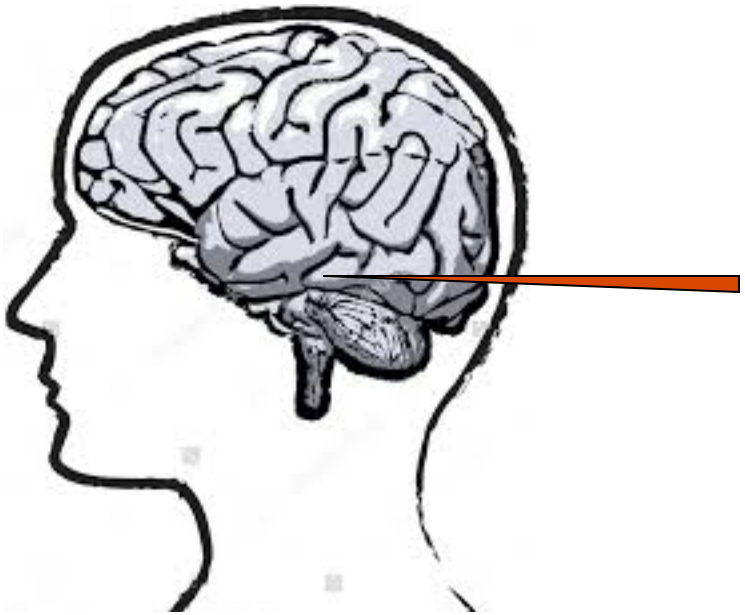

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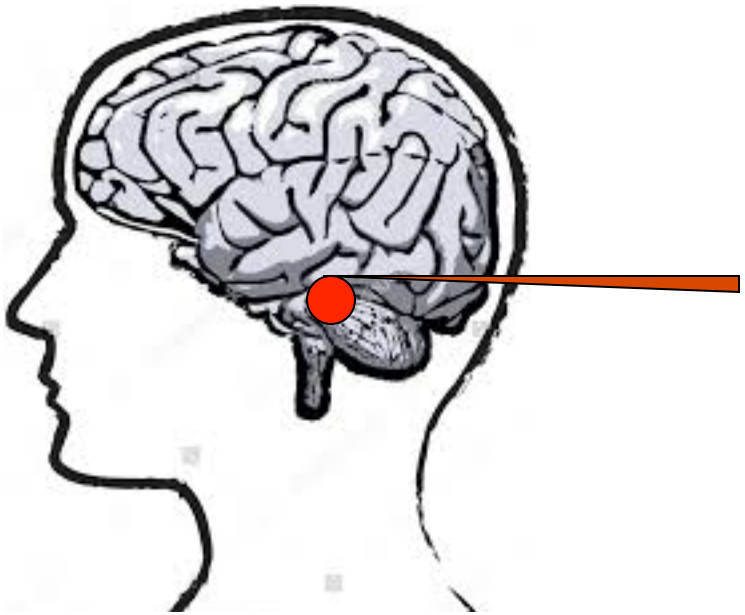
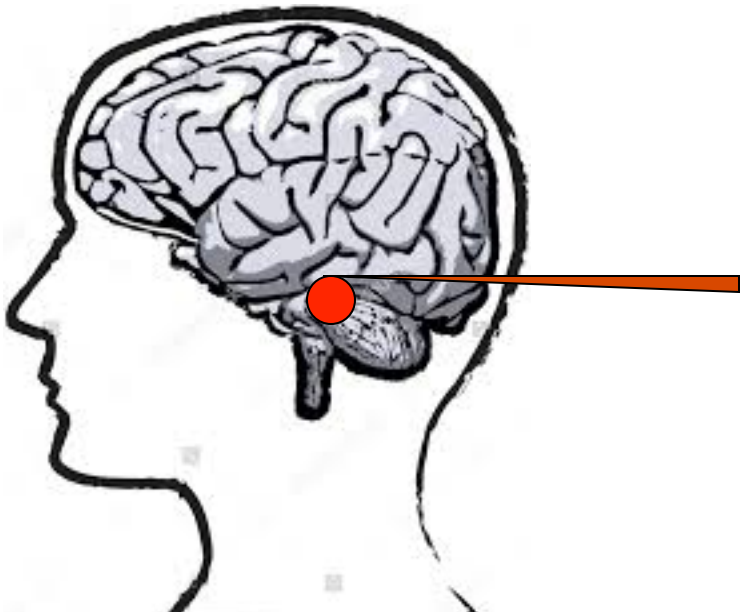
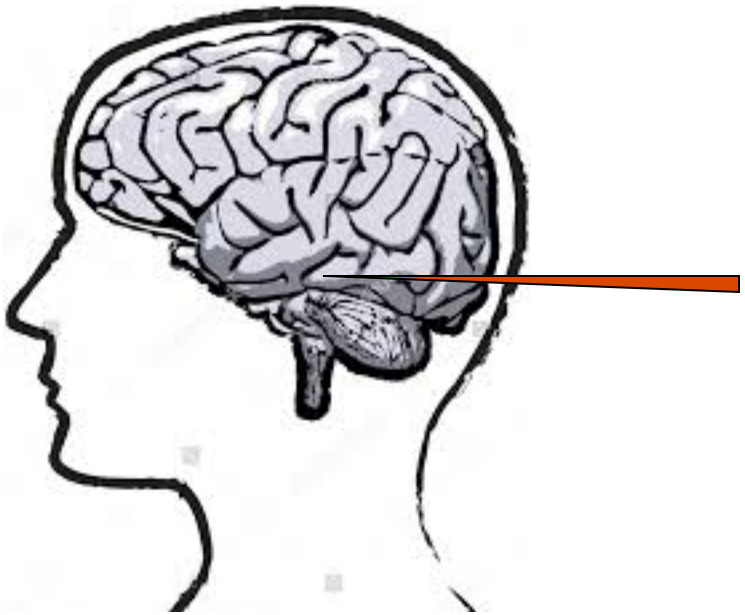


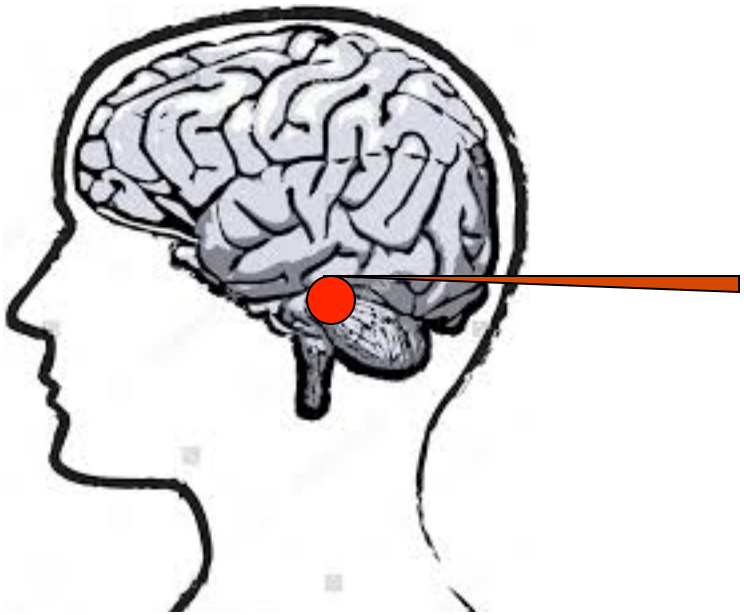
The experiment by [Ison et al. 2016]



The experiment by [Ison et al. 2016]



The experiment by [Ison et al. 2016]



The Challenge:

- These are the specs (Marr)
- What is the hardware?
- What is the algorithm?

cells (or concept cells)

Speculating on the Hardware

- A little analysis first
- They recorded from ~10^2 out of ~10^7 MTL neurons in every subject
- Showed ~10^2 pictures of familiar persons/ places, with repetitions
- each of ~10 neurons responded consistently to one image
- *Hmmmm…*

Speculating on Hardware (cont.)

- Each memory is represented by an *assembly* of ***many*** (perhaps ~ 10^4 - 10^5) neurons;

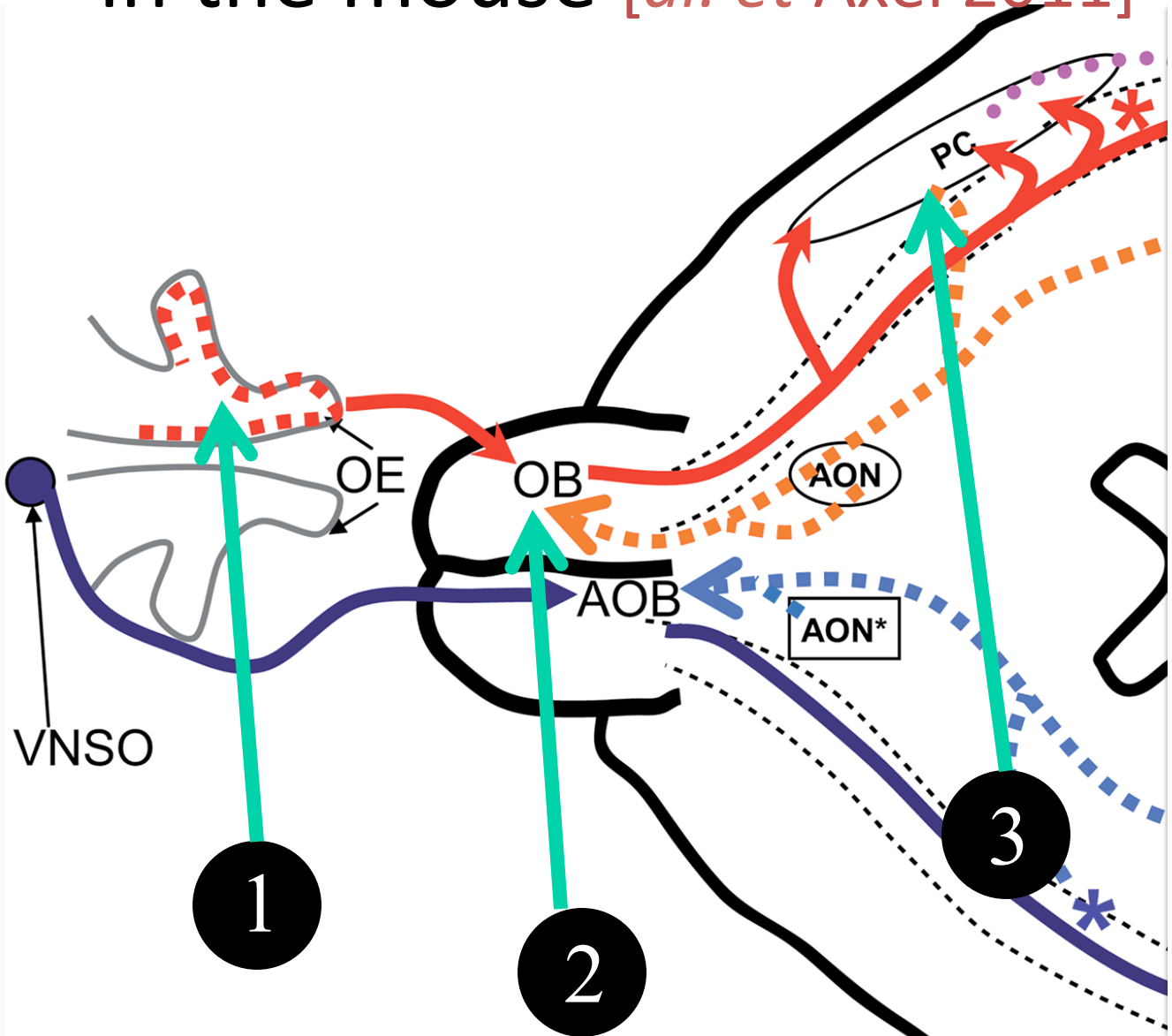
  cf [Hebb 1949], [Buzsaki 2003, 2010]
- ***Highly connected***, therefore stable
- It is somehow formed by sensory stimuli
- Every time we think of this memory,

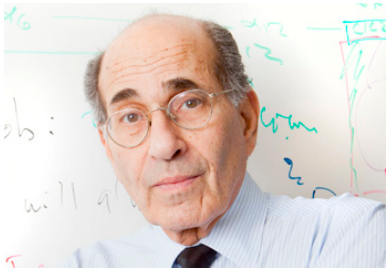
  ~ all these neurons fire
- Two memories can be associated by "creeping" into each other

Algorithm?

- How are assemblies formed?
- How are they recalled?
- How does association happen?

A distant metaphor: olfaction in the mouse [*al. et* Axel 2011]





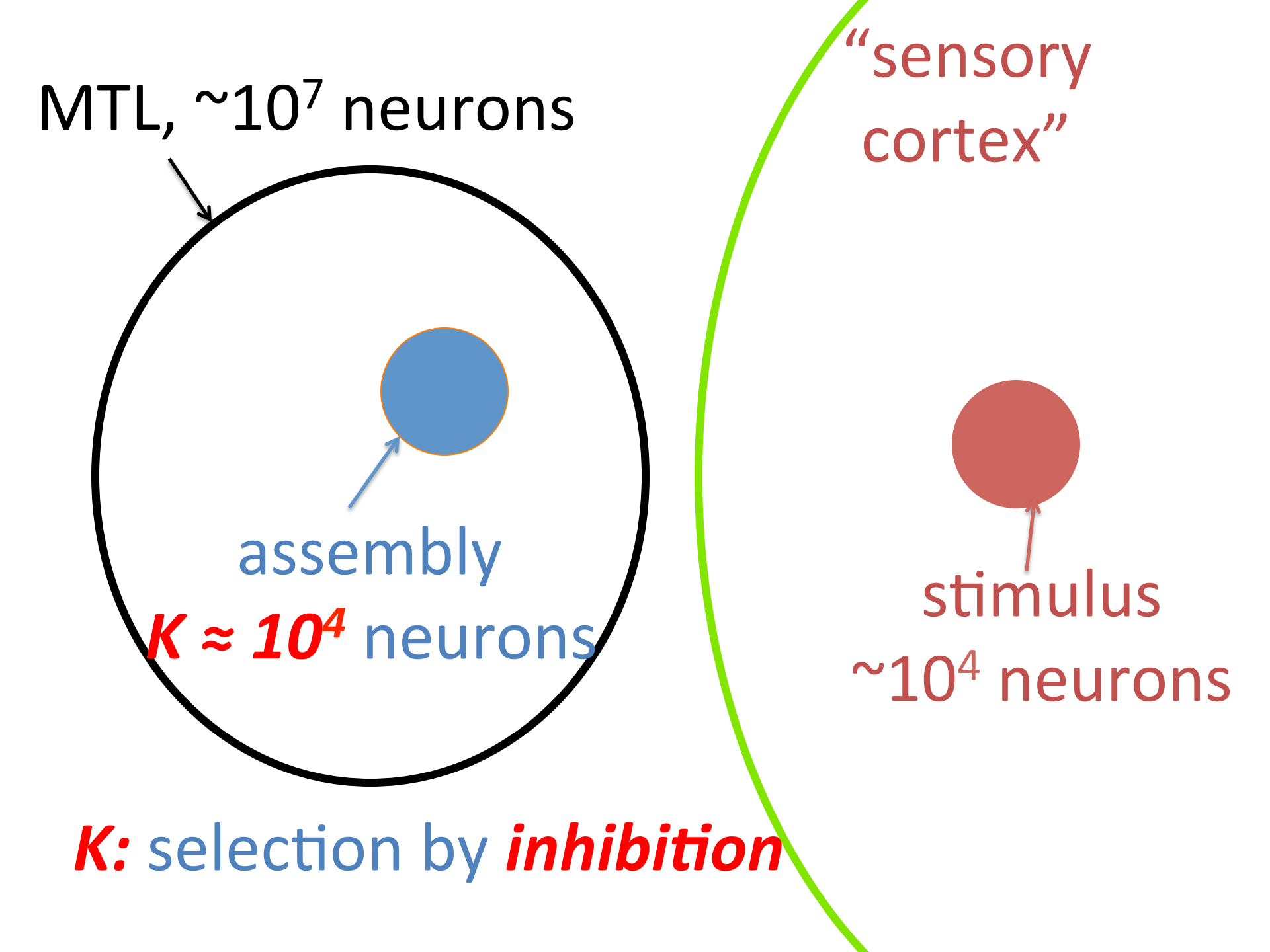
From the *Discussion* section of [*al. et* Axel]

An odorant may [cause] a small subset of … neurons [to fire].

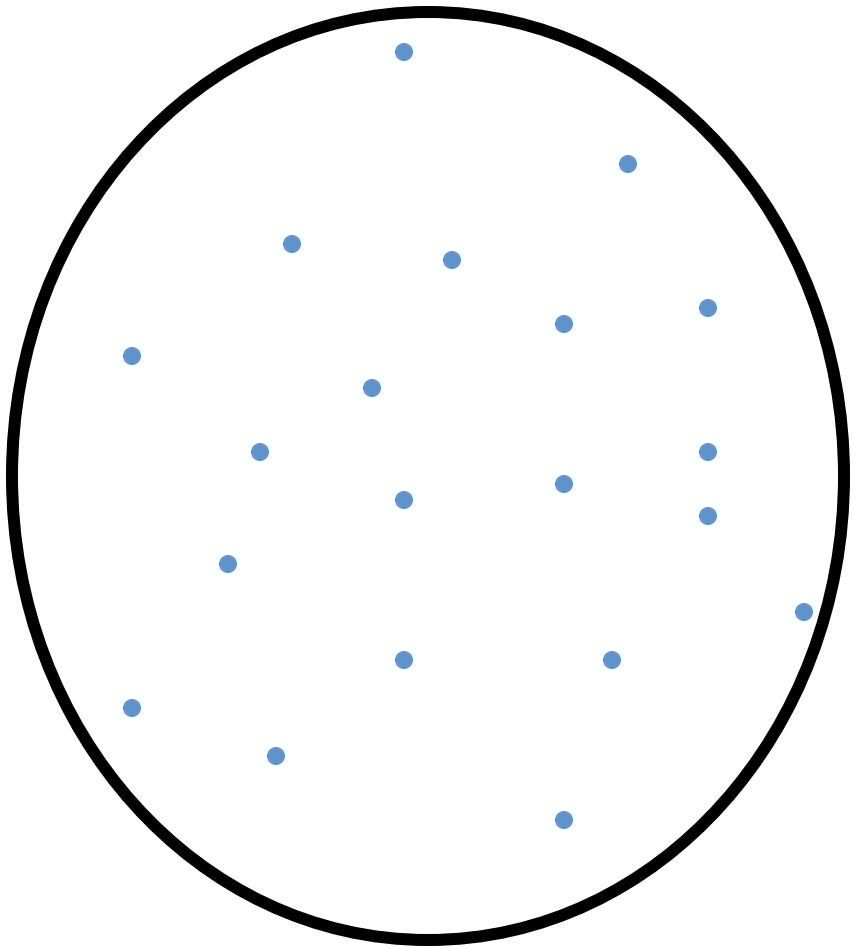
This small fraction of … cells would then generate sufficient recurrent excitation to recruit a larger population of neurons.

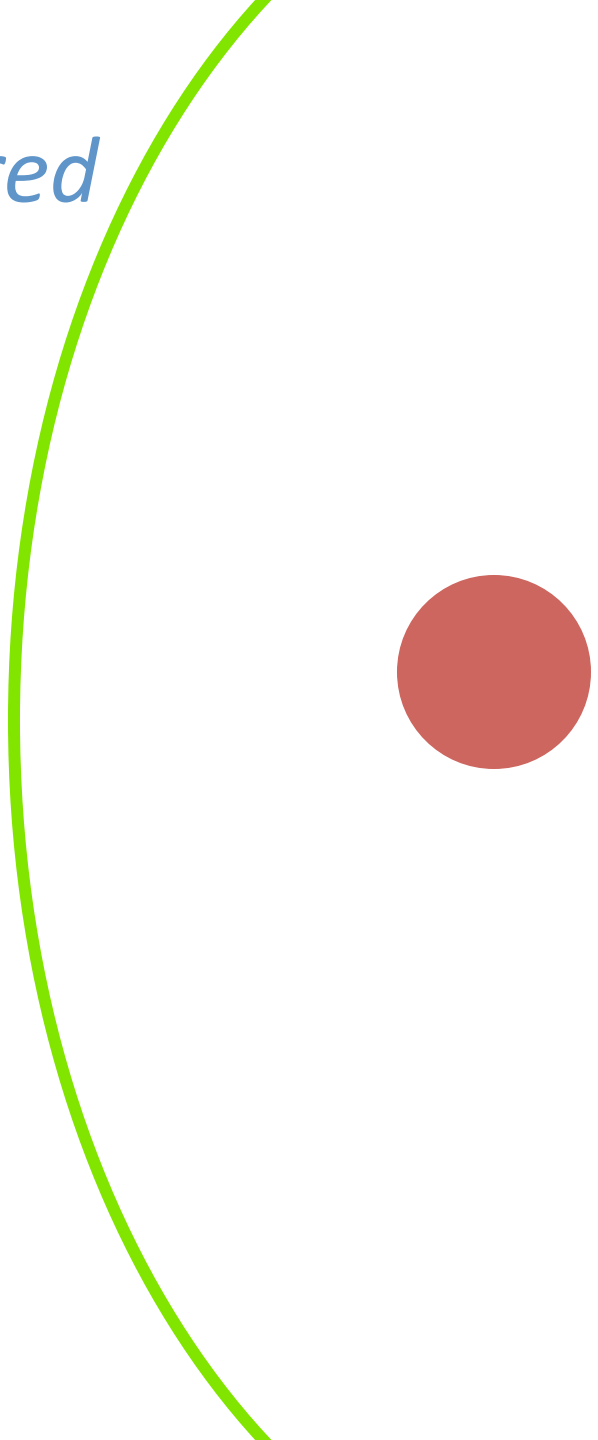
Inhibition triggered by this activity will prevent further firing

In the extreme, some cells could receive enough recurrent input to fire … without receiving [initial] input…

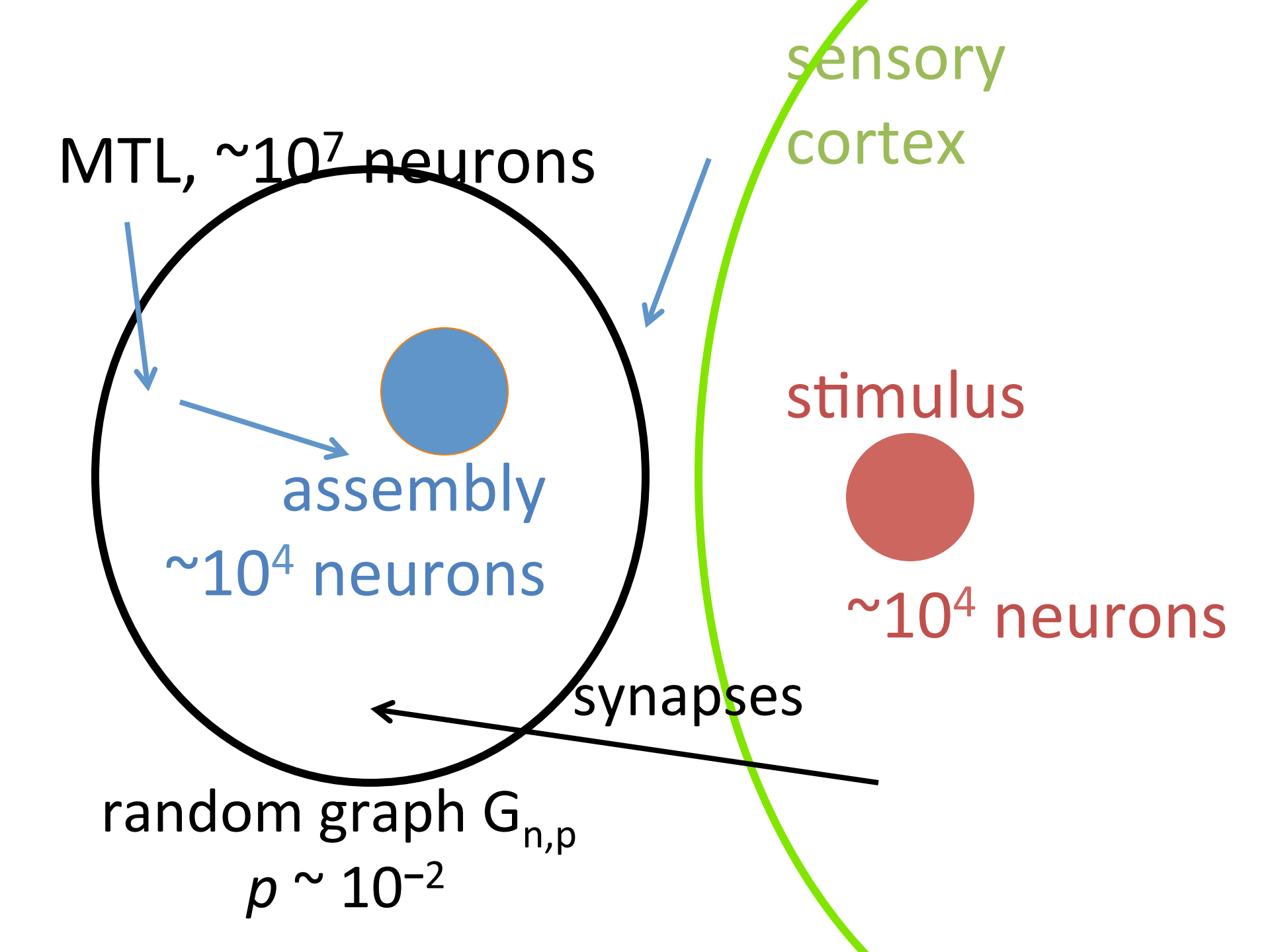

MTL, ~10^7 neurons
assembly
K ≈ 10^4 neurons
"sensory cortex"
stimulus
~10^4 neurons
K: selection by inhibition

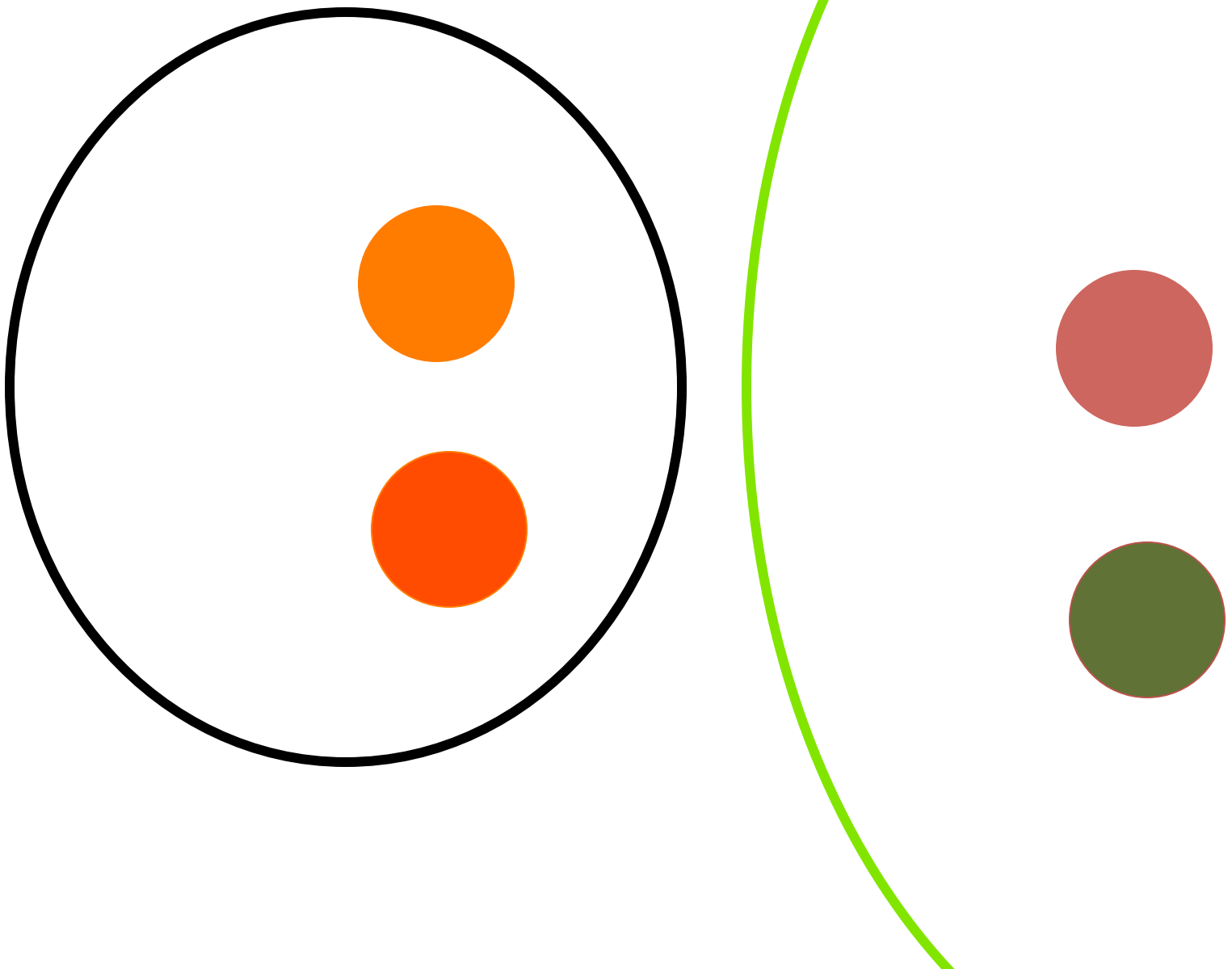
NB: these cells are *scattered*





~10^4 neurons


sensory
cortex
MTL, ~10^7 neurons
assembly
~10^4 neurons
stimulus
~10^4 neurons
synapses
random graph G_n,p
p ~ 10^-2



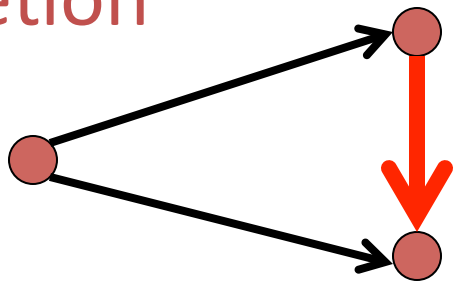
High connectivity? Associations?

- Random graph theory does not seem to suffice

- [Song et al 2005]: reciprocity and triangle completion

$G_{n,p}$

$p \sim 10^{-2}$

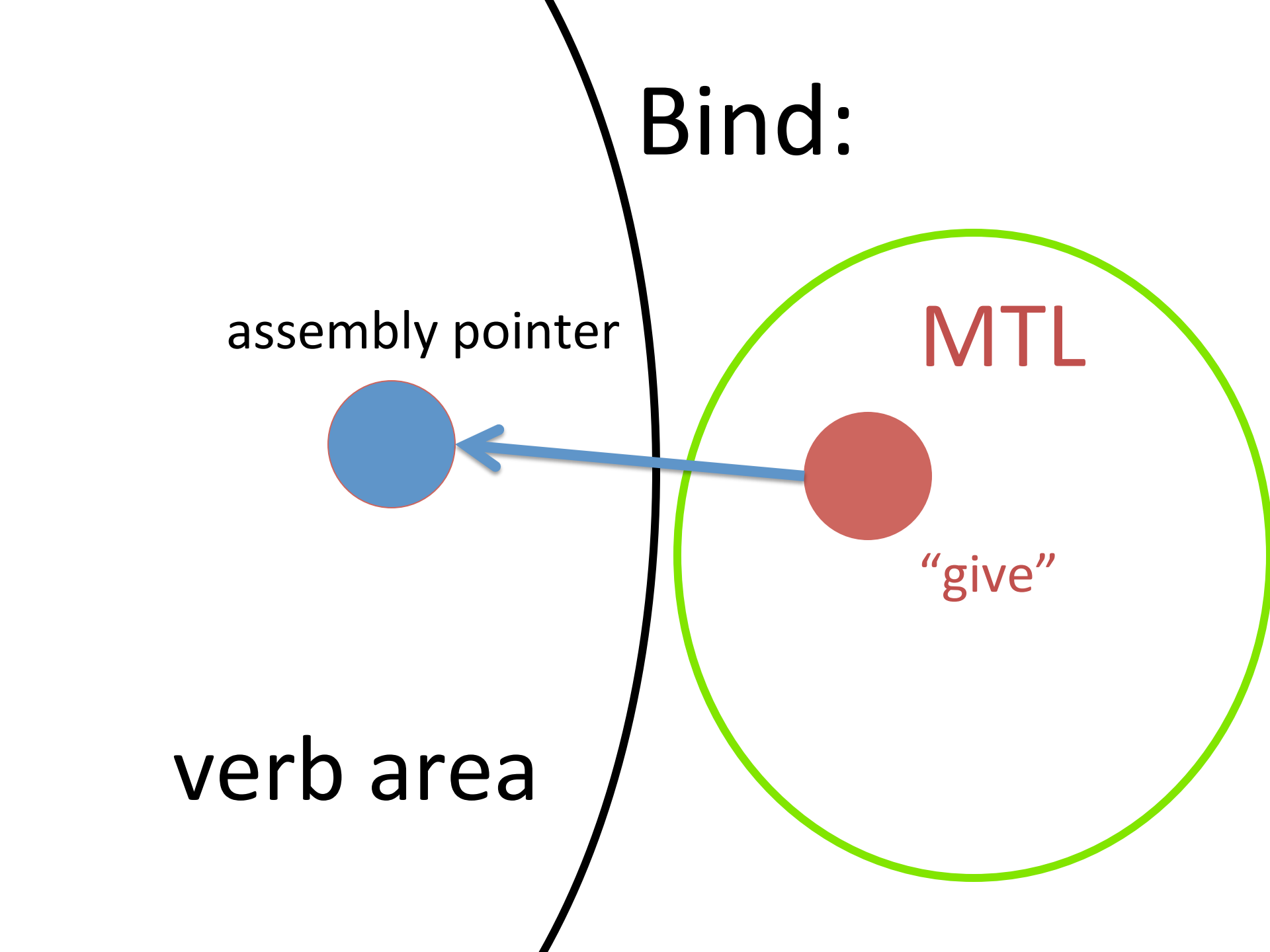


$G_{n,p}$++

$p \sim 10^{-1}$

Another operation: Bind

- e. g., “give” *isa* Verb
- Not between assemblies, but...
- ...between an assembly and a Brain area
- A ***pointer assembly***, a surrogate for “give,” is formed in the ***verb area***
- Same process (and math...)


Bind:
assembly pointer
MTL
"give"
verb area

Which brings us to: Language

- An environment created *by us* a few thousand generations ago
- A "last-minute adaptation"
- Hypothesis: it evolved so as to exploit the Brain's strengths
- Invaluable lens for studying the Brain

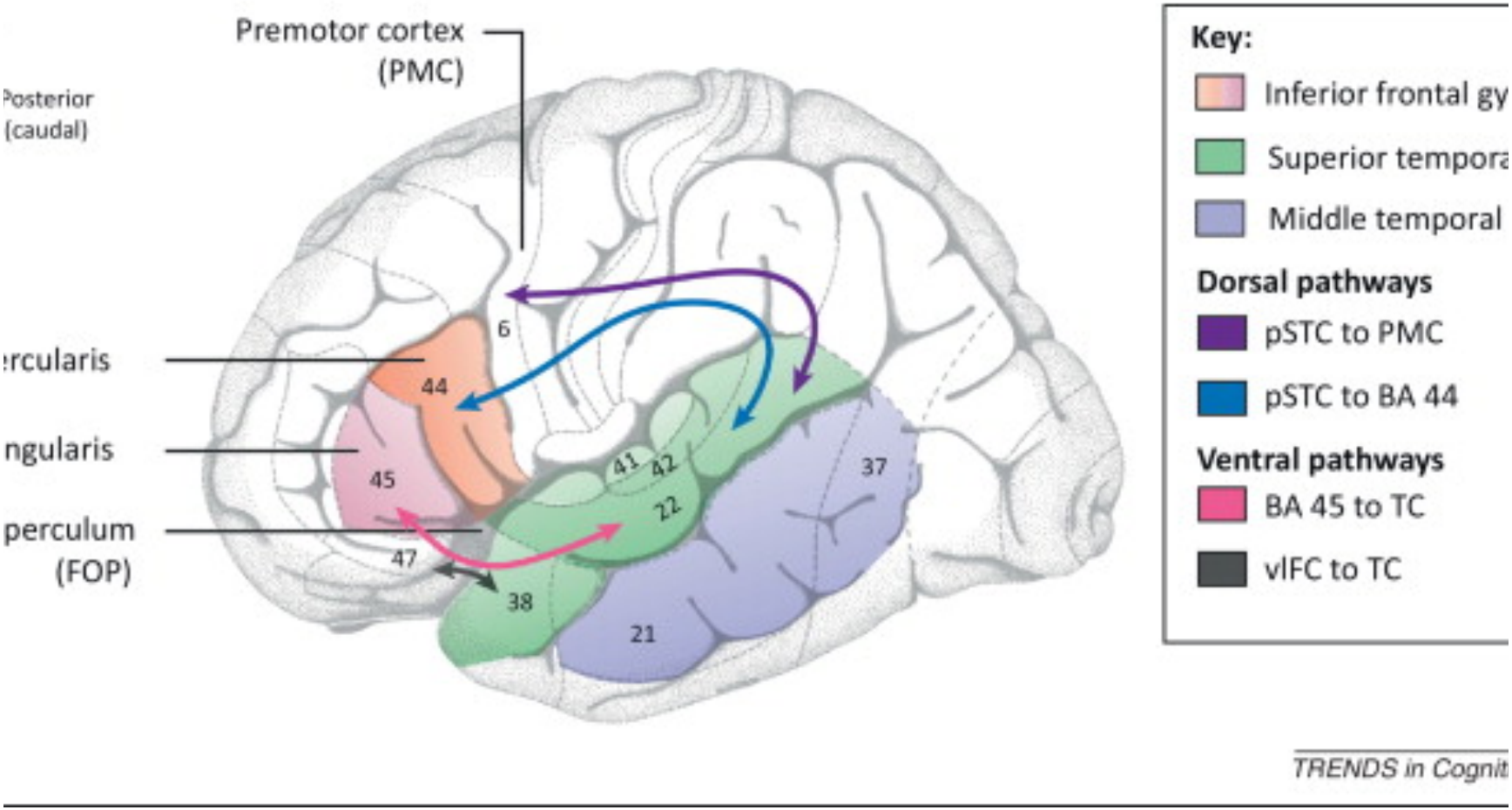
Language!

- Knowledge of language = grammar
- Some grammar may predate experience (is *innate*: [Chomsky 1956 … 2016])
- Grammatical minimalism (ca. 2010)

Merge: S → VP NP

- Assemblies, Association *and* Bind *seem ideally suited for implementing grammar and language in the Brain.*

Is S → NP VP Innate?



Soooooooo…

- *How does one think computationally about the Brain?*
- Assemblies of concept cells may be one starting point and path
- Experimental Neuroscience and Cognitive Science provide specs, hardware
- The algorithm [often, almost] vanishes
- Parameters, architecture, biology, plus extremely simple algorithms
- Ultimately, language