BMD ENG 301
Quantitative Systems Physiology
(Nervous System)

Lecture 1: Introduction to the Nervous System

Professor Malcolm A MacIver

Class Attendance

- Let me know if you are unable to attend a class or exam
- Recording of lectures
- Masks are optional, but if you feel unwell best to wear one
- If not feeling well, be sure to COVID test and follow the NU guidelines, which are found by Googling “Northwestern Procedures for Positive Cases of COVID-19”

Grading

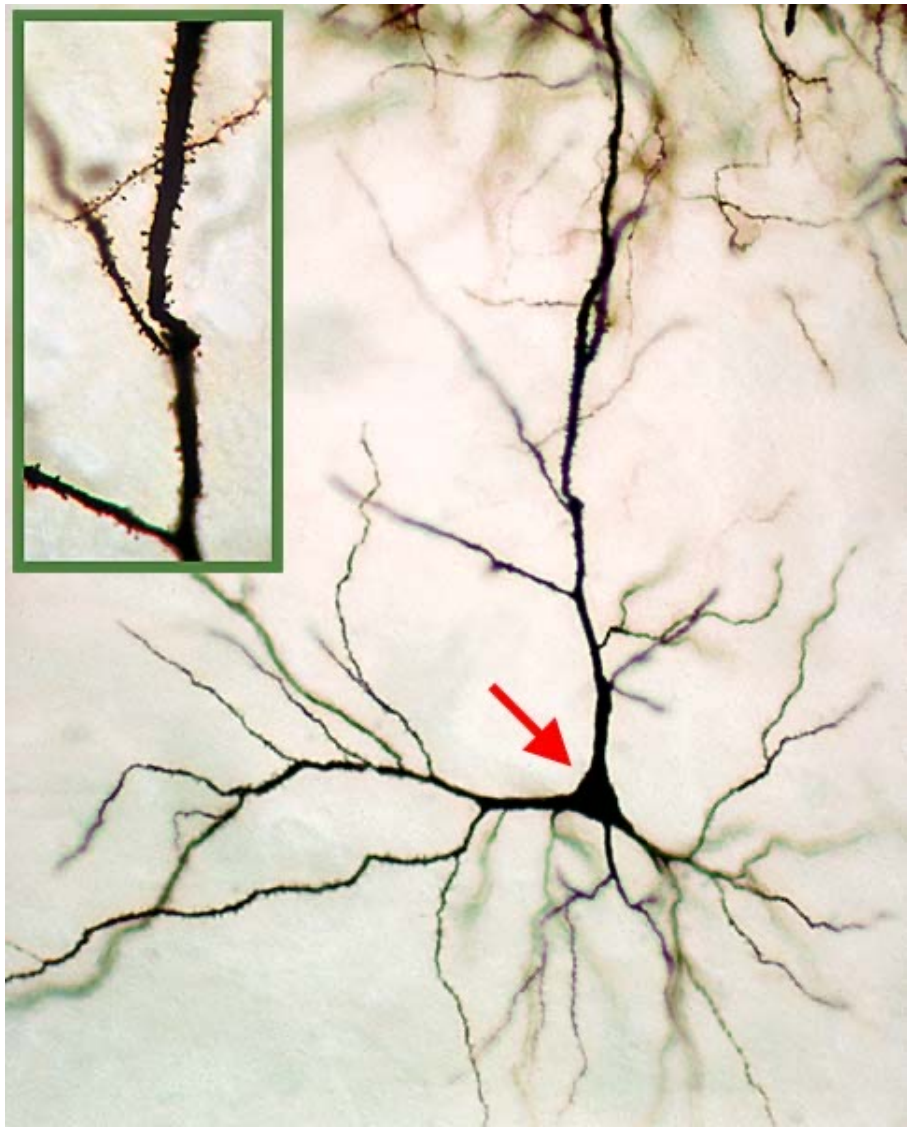
- Quizzes – keep up with Readings (see Files on Canvas)
- Homework Assignments
- Examinations
- Group Project (Graduate Students Only)

What are the components of the nervous system?

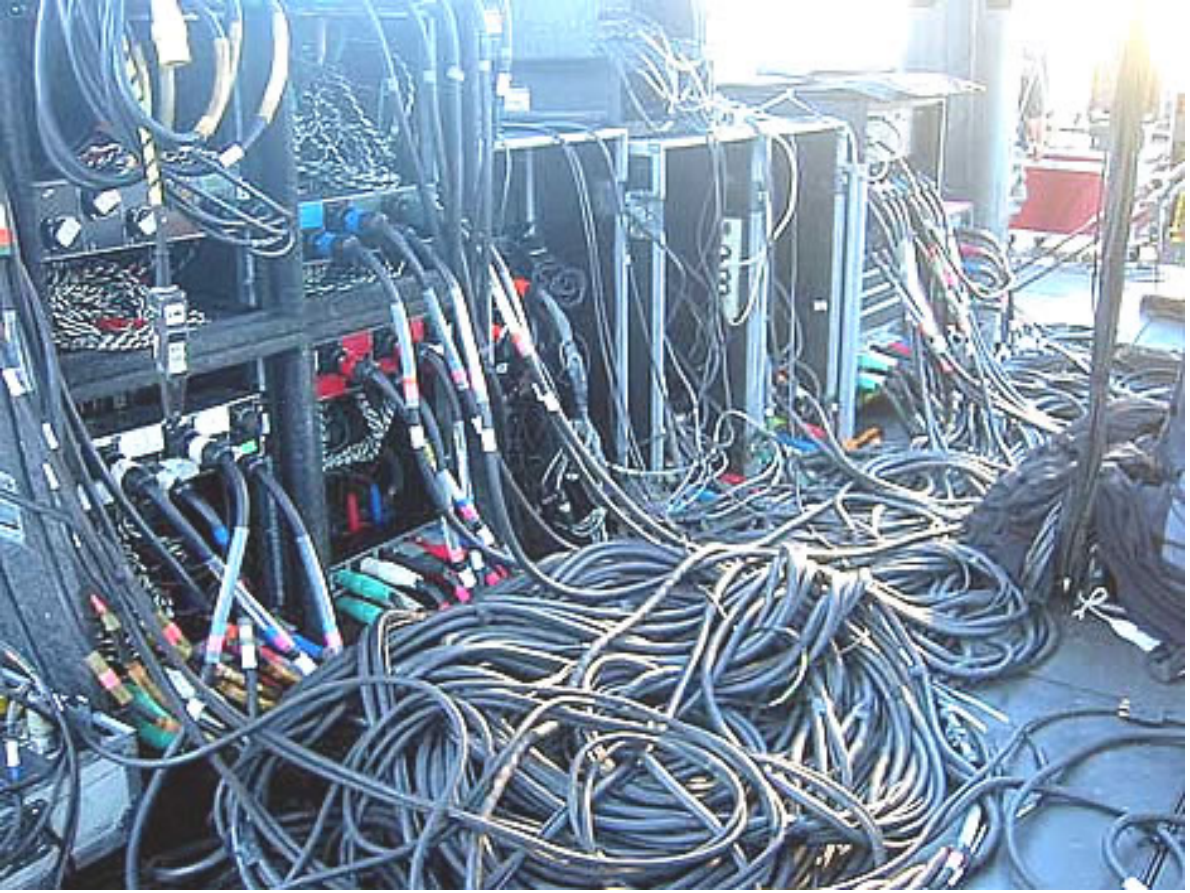
- Main cellular components: neurons and glial cells
- Vasculature
- Lymphatic system
- Ventricles: reservoirs of cerebrospinal fluid
- Blood-brain barrier
- Meninges

The Neuron and its functional components

1. Cell Body (Soma, Perikaryon)
    a. 10-30 µm diameter
2. Dendrites
    a. Dendritic spines
3. Axon
4. Axon terminal arborization



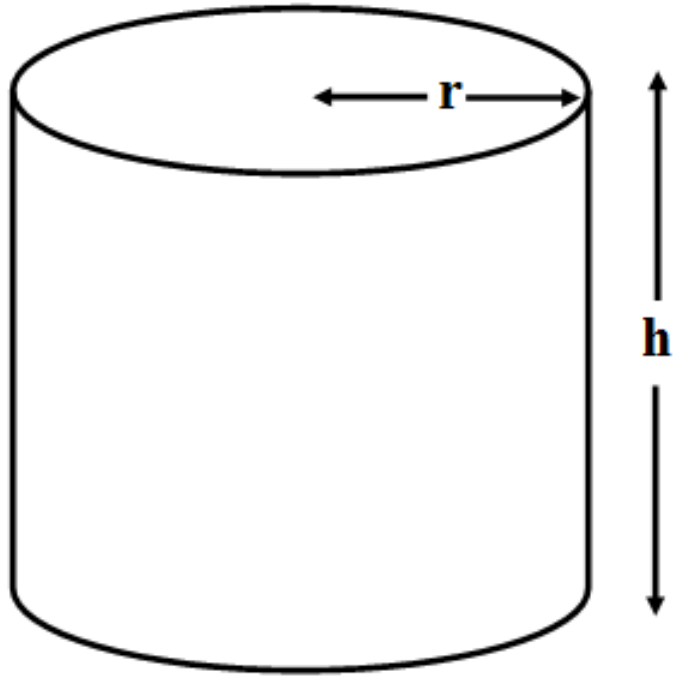
This neuron is only visible because it has been stained



It has been said that there are one million miles of neural cabling in the human brain

If we assume that the average diameter of an axon or dendrite is 1 µm, what is the volume occupied by one million miles of neural cable?

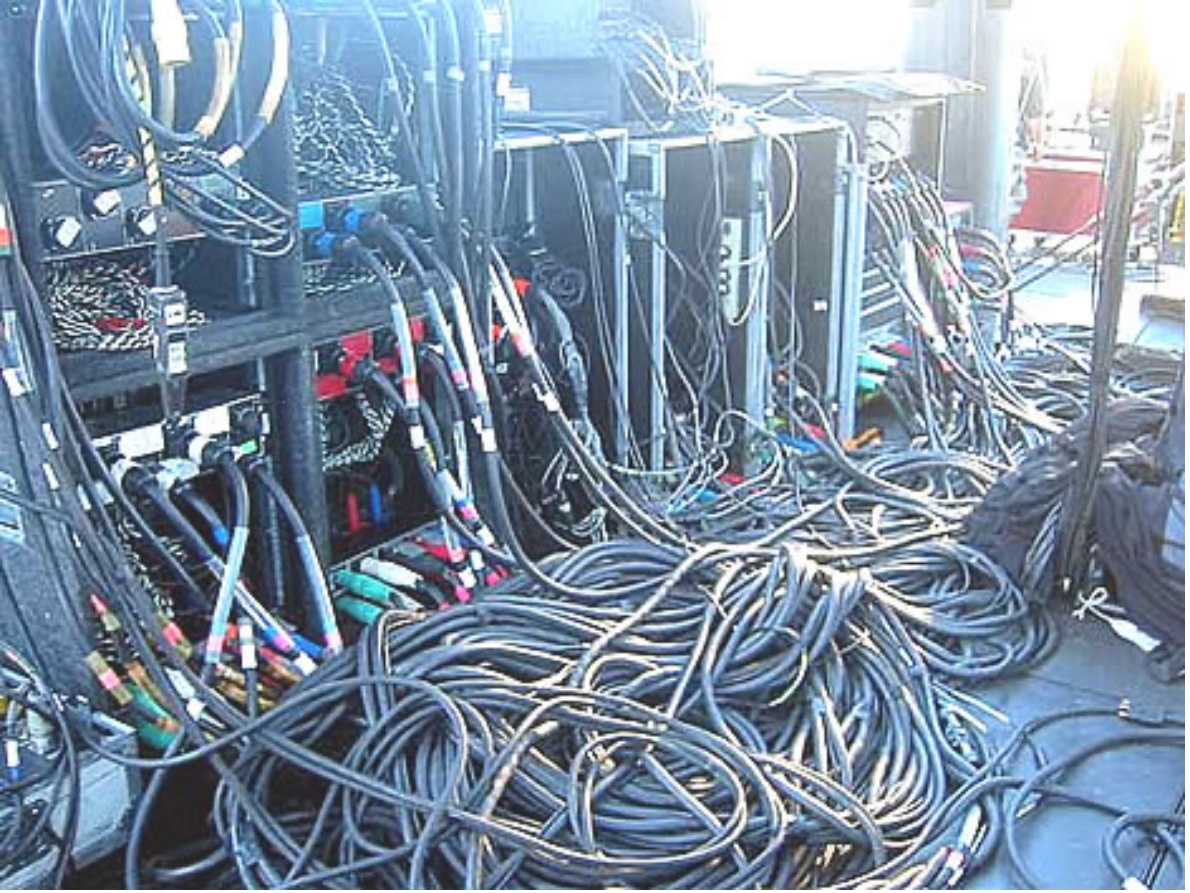
$$V = \pi r^2 h$$



h = 10^6 miles (1.61×10^9 meters)

r = 0.5×10^{-6} m

V = 1.26×10^{-3} m^3



All this wiring is accomplished by the neurons sending out growth cones to find targets

A wave of disassembly follows the growth cone providing it with material to use as its front end

It has been said that there are one million miles of neural cabling in the human brain

If we assume that the average diameter of an axon or dendrite is 1 µm, what is the volume occupied by one million miles of neural cable?

A cube of approximately 1 dm x 1 dm x 1 dm (or 4” x 4” x 4”)

That the human brain could have a million miles of neural cable seems plausible

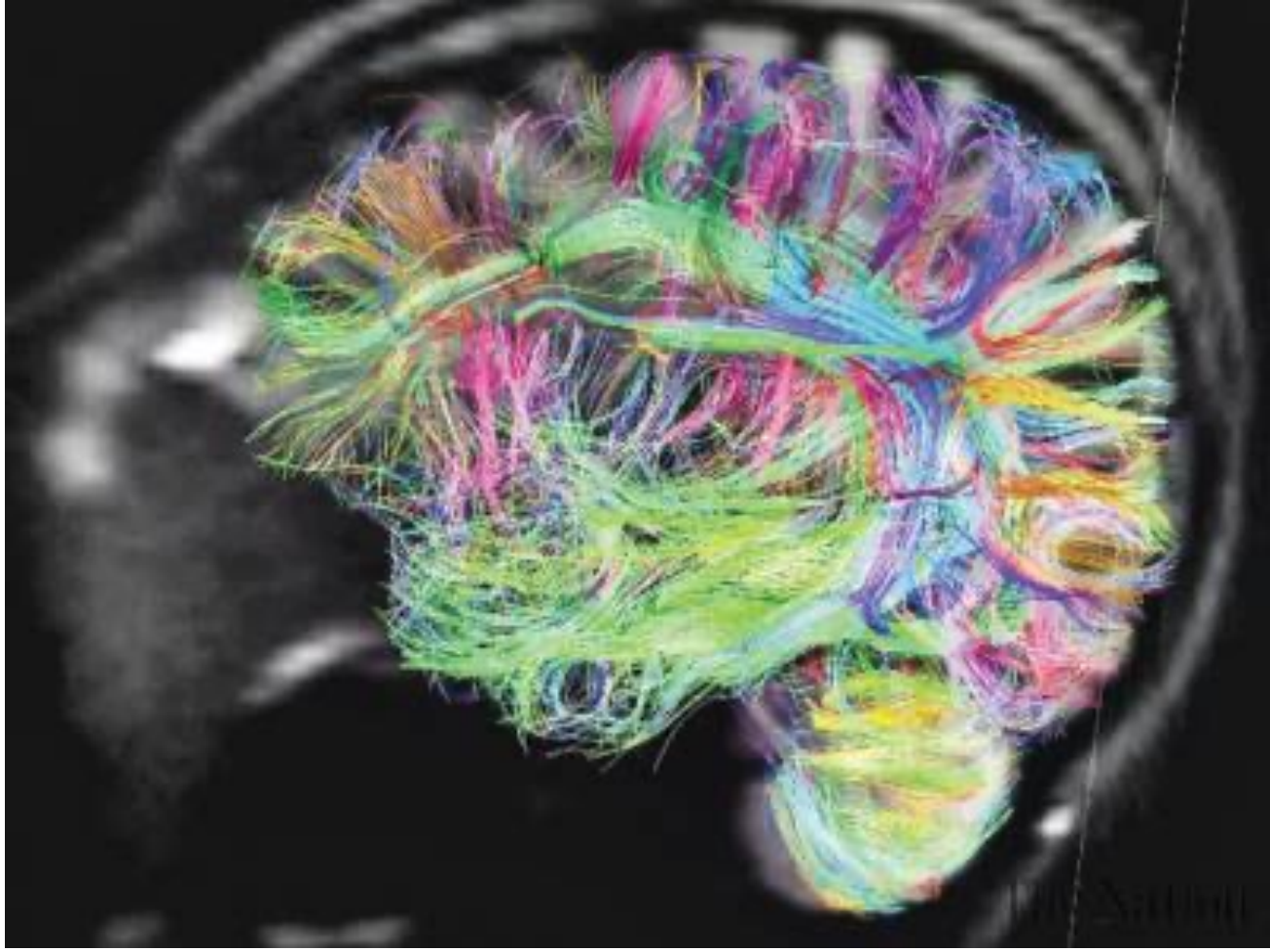
GROWTH CONE VIDEO

It should be possible to estimate what types of and how much material would be needed for one million miles of neural cable but that is for another day / course

The size of the human brain is about 1,400 cm^3

Most of this volume must be taken up by wiring

What this could mean



- Although more numerous than neurons, glial cells cannot occupy as much space
- The brain's vasculature also occupies little space
- As does the brain's lymphatic system
- Ventricular space is perhaps less than one might have imagined
- There must be more water inside neurons and glia than outside them

- A mechanism to carry neural signals over cm to dm distances seems essential
- As does a mechanism for neurons to "speak" to other neurons

- Assemblies of neurons (neural circuits) would seem to be fundamental to brain operation
- The same might also be said of grouping neural circuits (into neural systems) and the interplay of these neural systems

Course Outline

- Components of the Nervous System
  - Large scale view – Neuroanatomy
  - Small scale view – Cellular elements: Neurons and Glial Cells
- Neural Signals
  - Passive electrical signals – short-range signaling
  - Action potential – long-range signaling mechanism
- Neural Connections
  - Synapses
- Neural Circuits
  - Emergent properties from neural ensembles
- Neural Systems
  - Somatosensory System – capture information about one's environment
  - Motor System – influence that environment

These need not be considered apart

Quote of the day

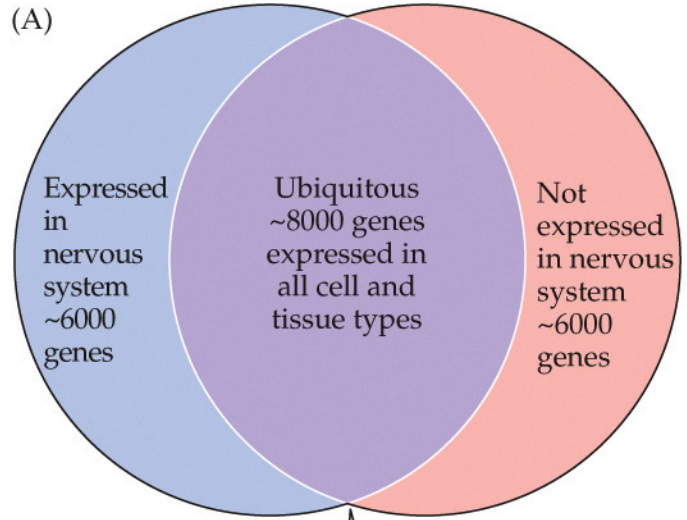
“If the human brain were so simple that we could understand it, we would be so simple that we couldn’t”

From “The Biological Origin of Human Values” by Emerson Pugh

If it is, what makes the human brain special?

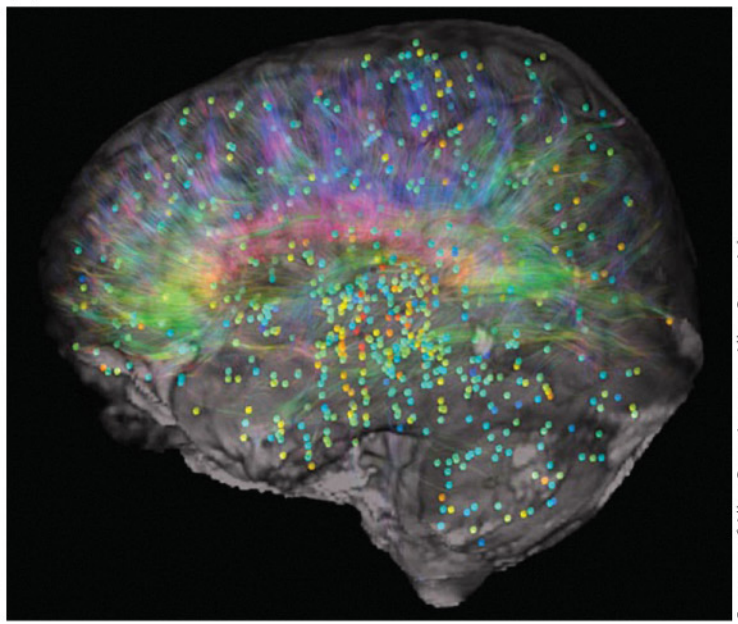
- Genes

(A)



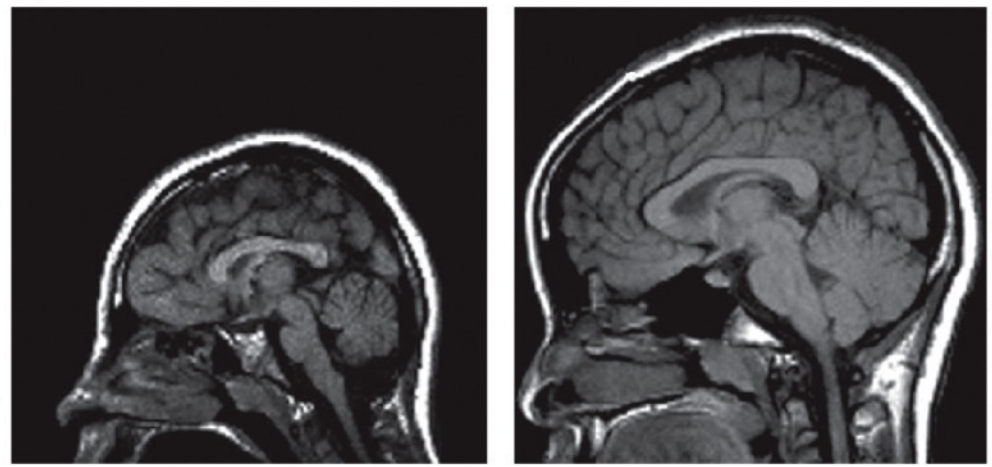
Data from Ramsköld et al. (2009) *PLoS* 5:12 e1000598.

(B)



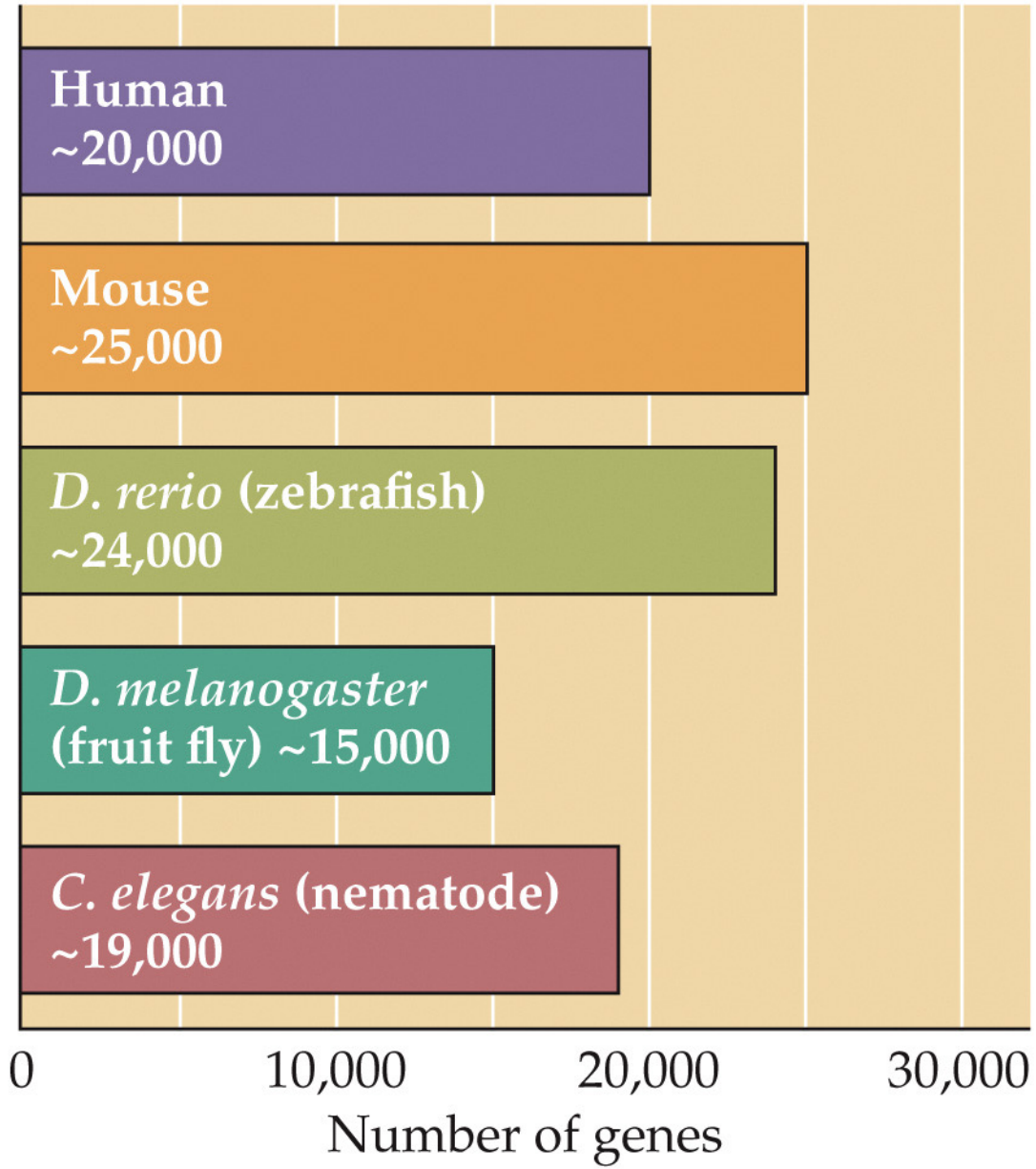
Courtesy of Allen Brain Institute, Allen Brain Atlas.

(C)



From Bond et al. (2002) *Nat. Genet.* 32: 316–320.

***NEUROSCIENCE 6e*, Figure 1.1**



NEUROSCIENCE 6e, Box 1A

If it is, what makes the human brain special?

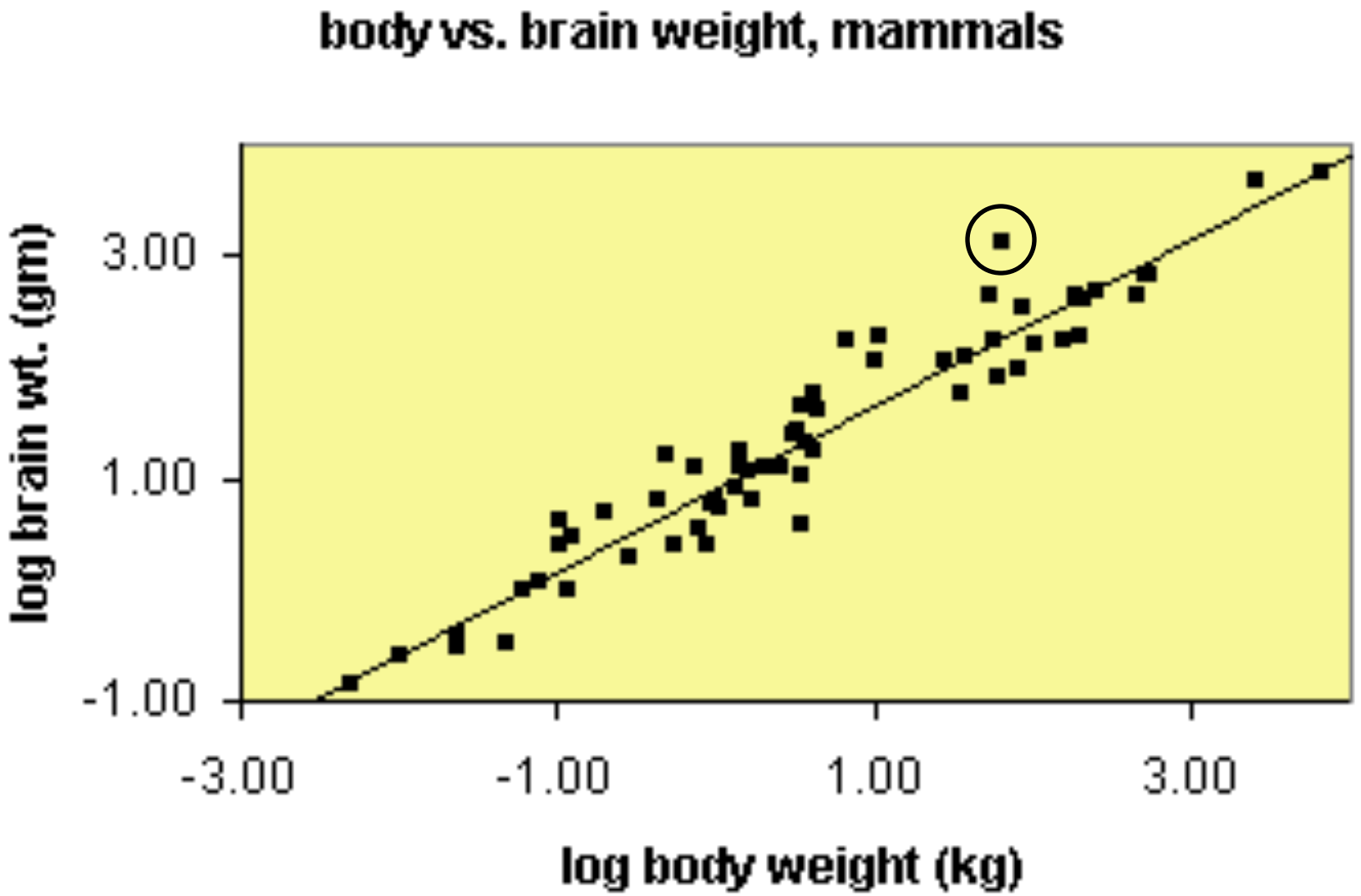
- ~~*Genes*~~
- Number of neurons

Number of neurons

Nematode:	**302**
Drosophila:	**~250,000**
Zebrafish:	**~10 million**
Mouse:	**71 million**
Human:	**8.6×10^{10}**
African elephant:	**2.6×10^{11}**

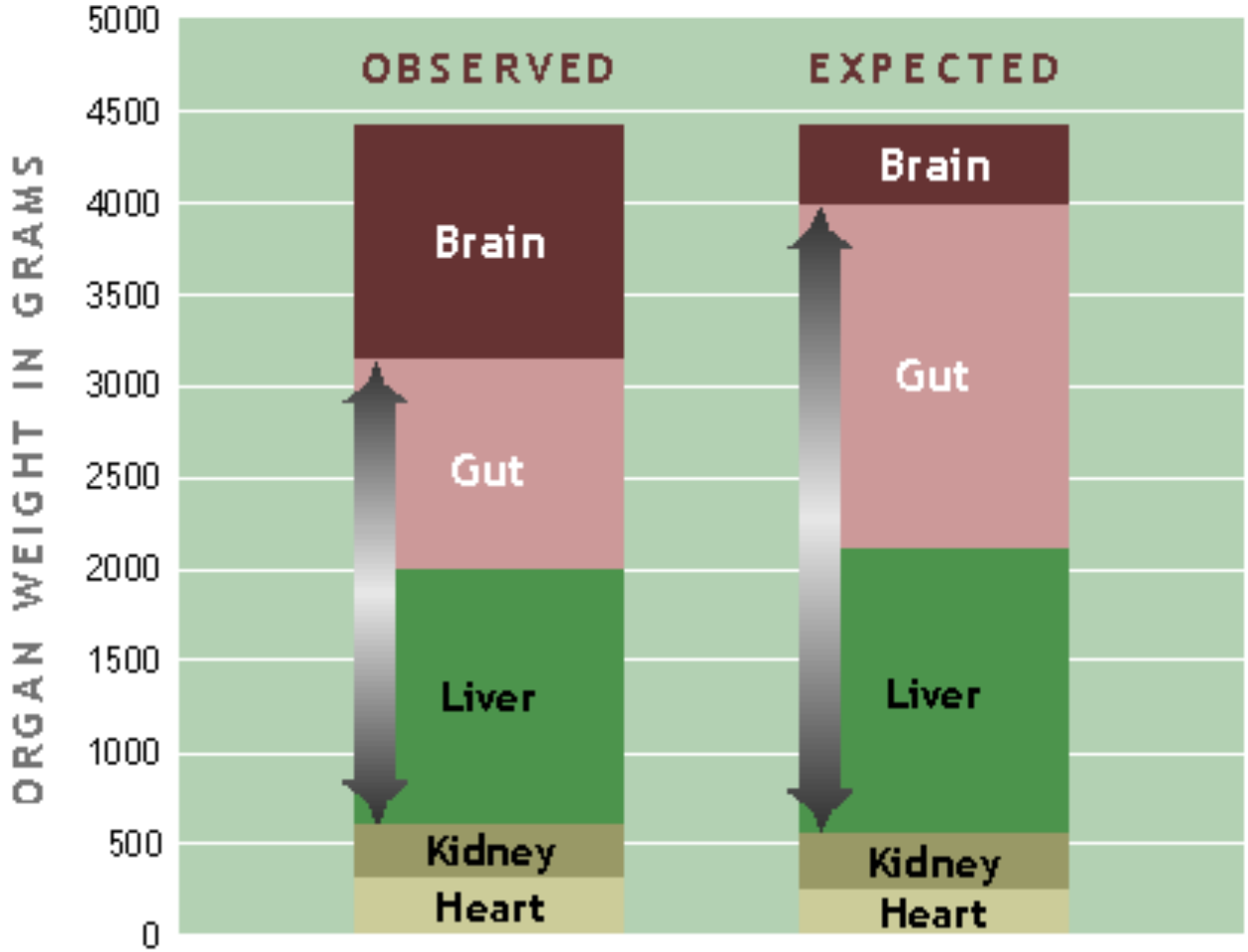
If it is, what makes the human brain special?

- ~~*Genes*~~
- ~~*Number of neurons*~~
- Brain size


body vs. brain weight, mammals
log brain wt. (gm)
3.00
1.00
-1.00
-3.00
-1.00
1.00
3.00
log body weight (kg)

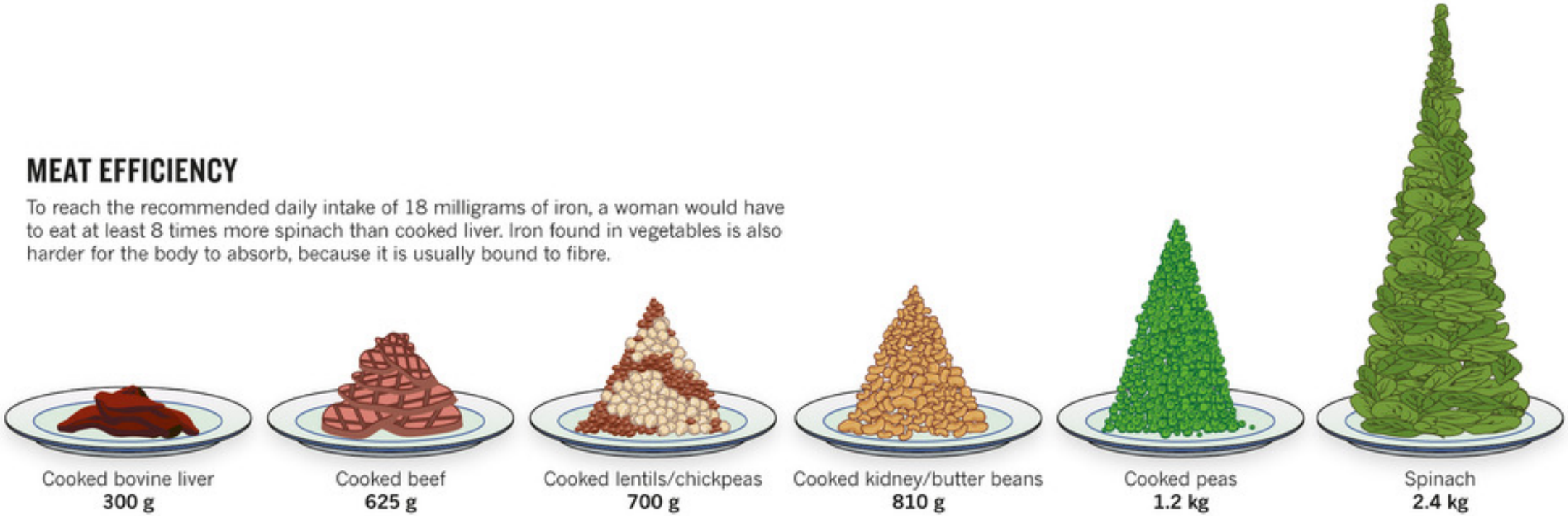
If it is, what makes the human brain special?

- ~~*Genes*~~
- ~~*Number of neurons*~~
- ~~*Brain size*~~
- Relative brain size



Observed and expected organ masses for a "standard" 65-kg human.

Meat eating is efficient



If it is, what makes the human brain special?

- ~~*Genes*~~
- ~~*Number of neurons*~~
- ~~*Brain size*~~
- Relative brain size
- Forebrain (neocortex)

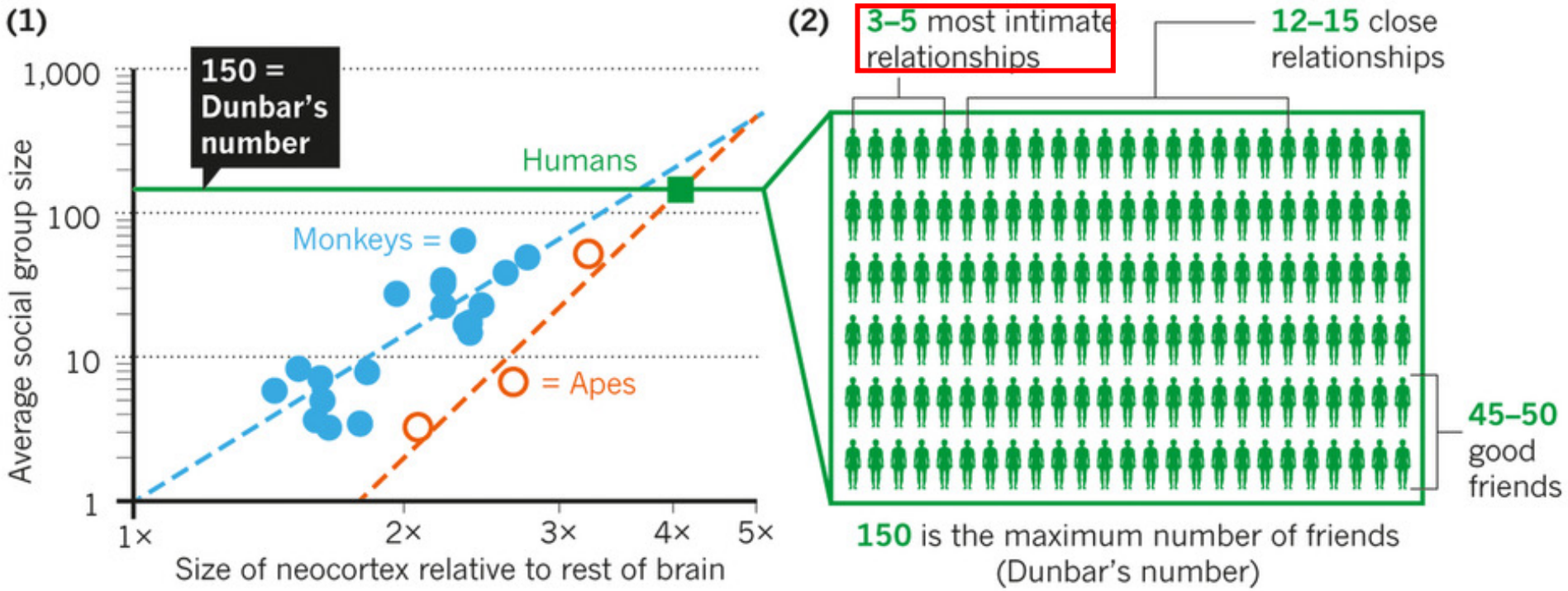
Theories of human brain expansion

- The social brain hypothesis (Robin Dunbar)

- Primates' disproportionately large brains evolved to handle the complex demands of social living

SOCIAL ANIMALS

In primates, the size of social circles correlates to the relative size of the neocortex compared with the rest of the brain (1). In humans, Dunbar's number is a suggestion of the amount of relationships a person can maintain. Human social networks seem to be split into hierarchies (2, 3), with group sizes varying by a factor of about three.



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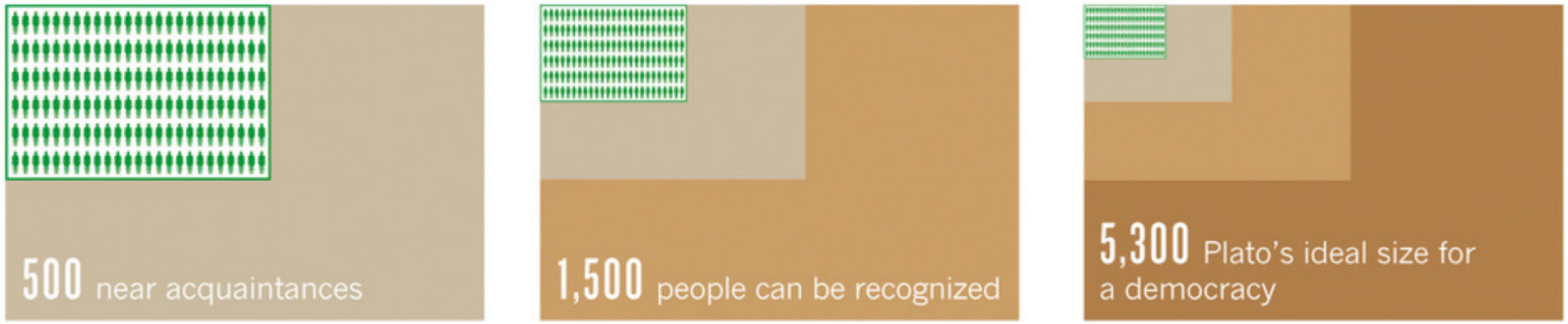

Forebrain Neurons

• Mouse:	14 million
• Opossum:	22 million
• Grey Squirrel:	77 million
• Starling:	226 million
• Brown Bear:	251 million
• Raccoon:	453 million
• Lion:	545 million
• Rook:	820 million
• Raven:	1.2×10^9
• Beluga:	2.7×10^9
• Mandrill:	3.1×10^9
• African Elephant:	5.6×10^9
• Human:	16.3×10^9
• Killer Whale:	43.1×10^9

Forebrain Neurons Relative to Body Weight

- Human: 16.3×10^9
- Killer Whale: 0.6×10^9

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