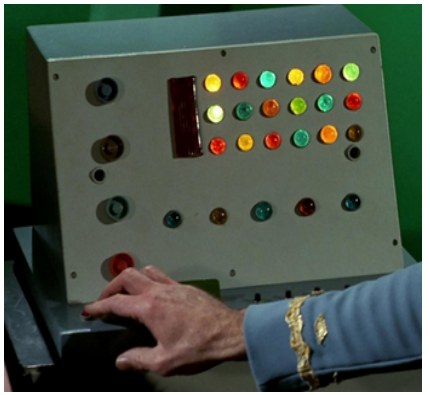
Neuromorphic Computing

Who will develop Artificial Intelligence?

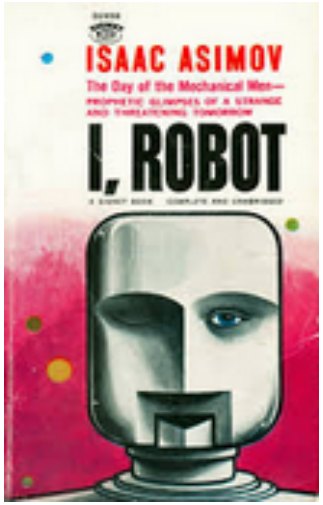
Michael Moore
Principle Engineer
Harris Inc
April, 2017

AI Story Telling
Fantasy & Science Fiction==> Reality

Fritz Lang
1927



Boston Dynamics



K.I.T.T.

Boston Dynamics

Various Approaches to "AI"

Philosophers: intelligence as Logic & Reason.

sixteenth-century alchemy: Homunculus

Symbologists/rules: 1950s …Lisp and Prolog.

Bayesians/ Belief systems: Probabilistic graphs

Numeric classifiers: Support Vector Machines (delightful mathematical elegance)

Connectionists: lots of neurons ==> intelligence

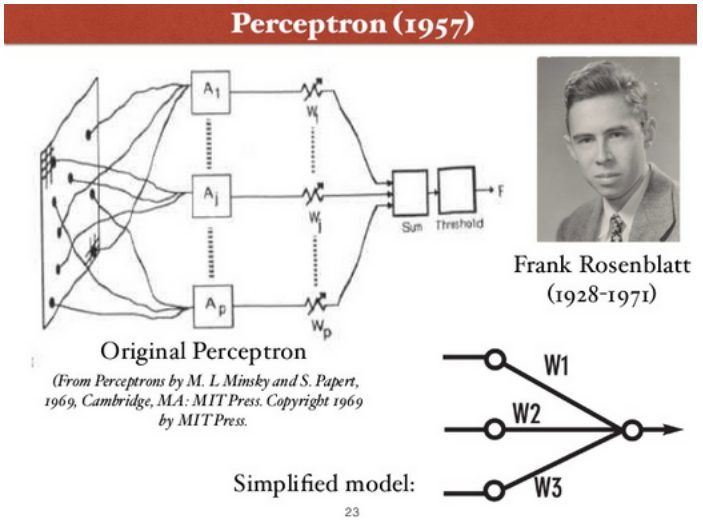
Deep Learning: layers of artificial neurons, back-propagation.

Who is doing this stuff? (Tinkerers,Intelligentsia)

ANSWER

Not the farmers: they are too busy; nor the smiths.

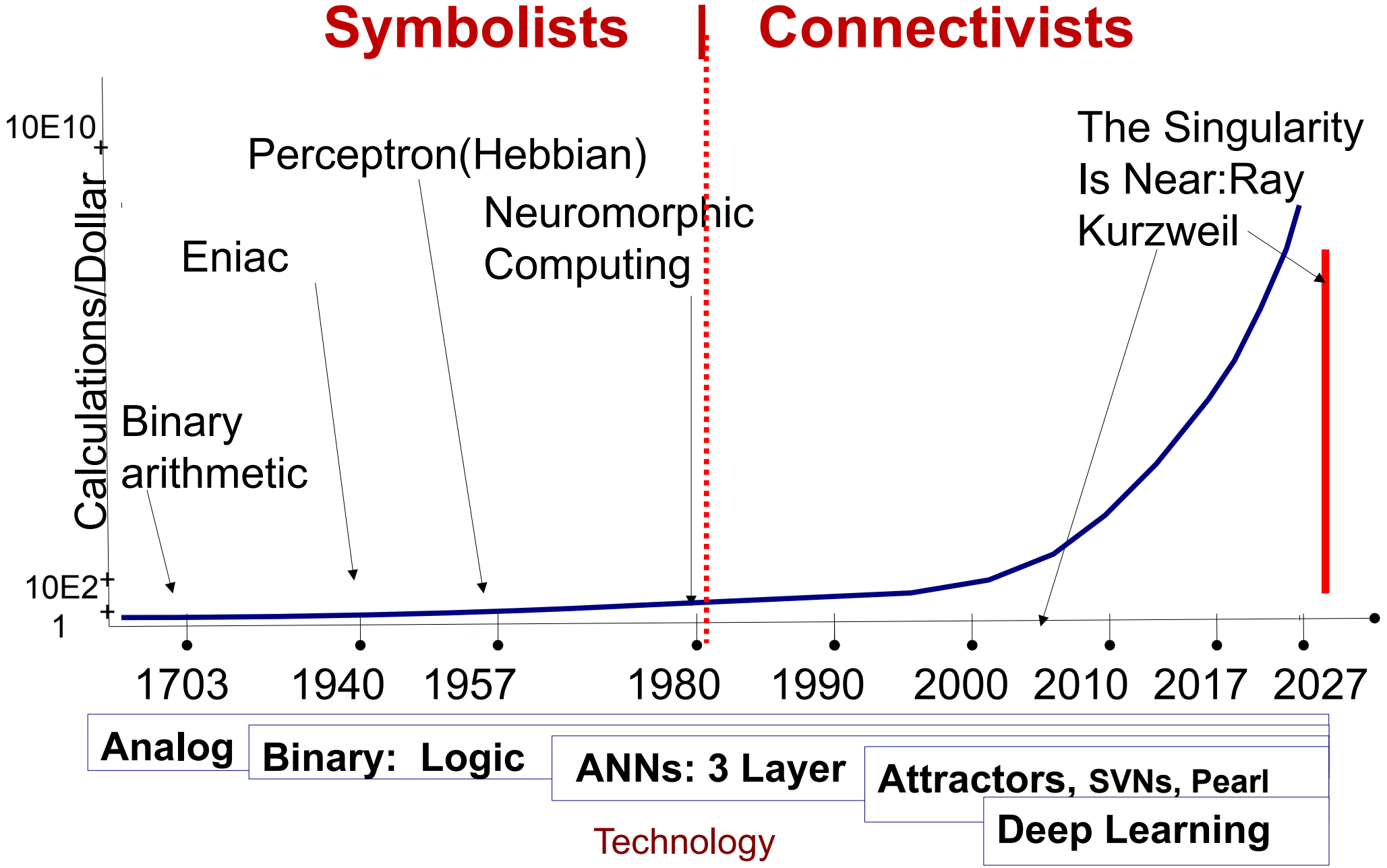
People with leisure time: the curious tinkerers



Chomsky in 2015

1950: Alan Turing introduces the **Turing test** in his paper "Computing Machinery and Intelligence."(Credit: National Portrait Gallery, London)

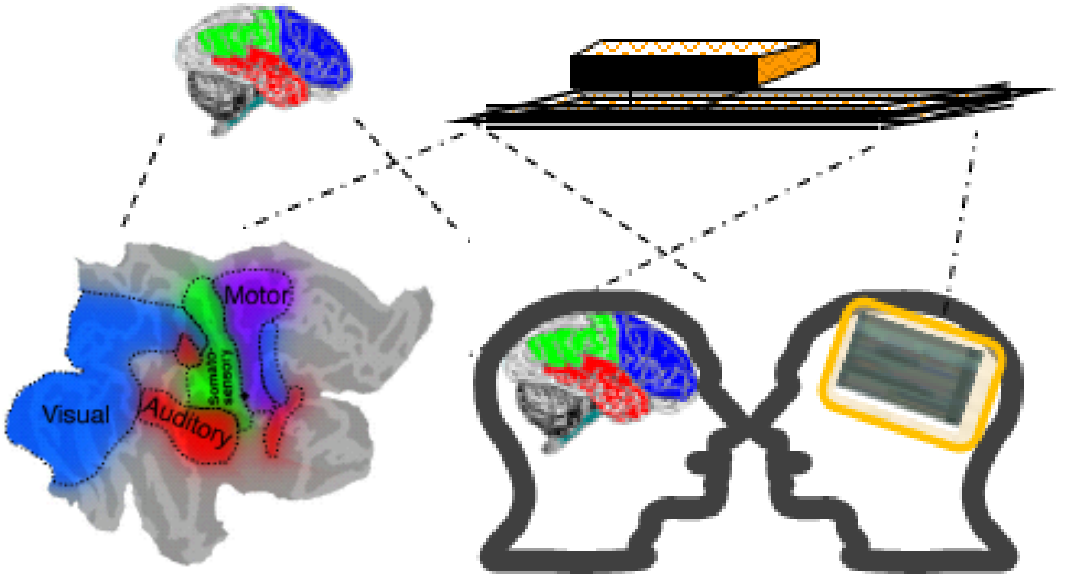
AI Development: Historic Perspective



Kurzweil's Singularity

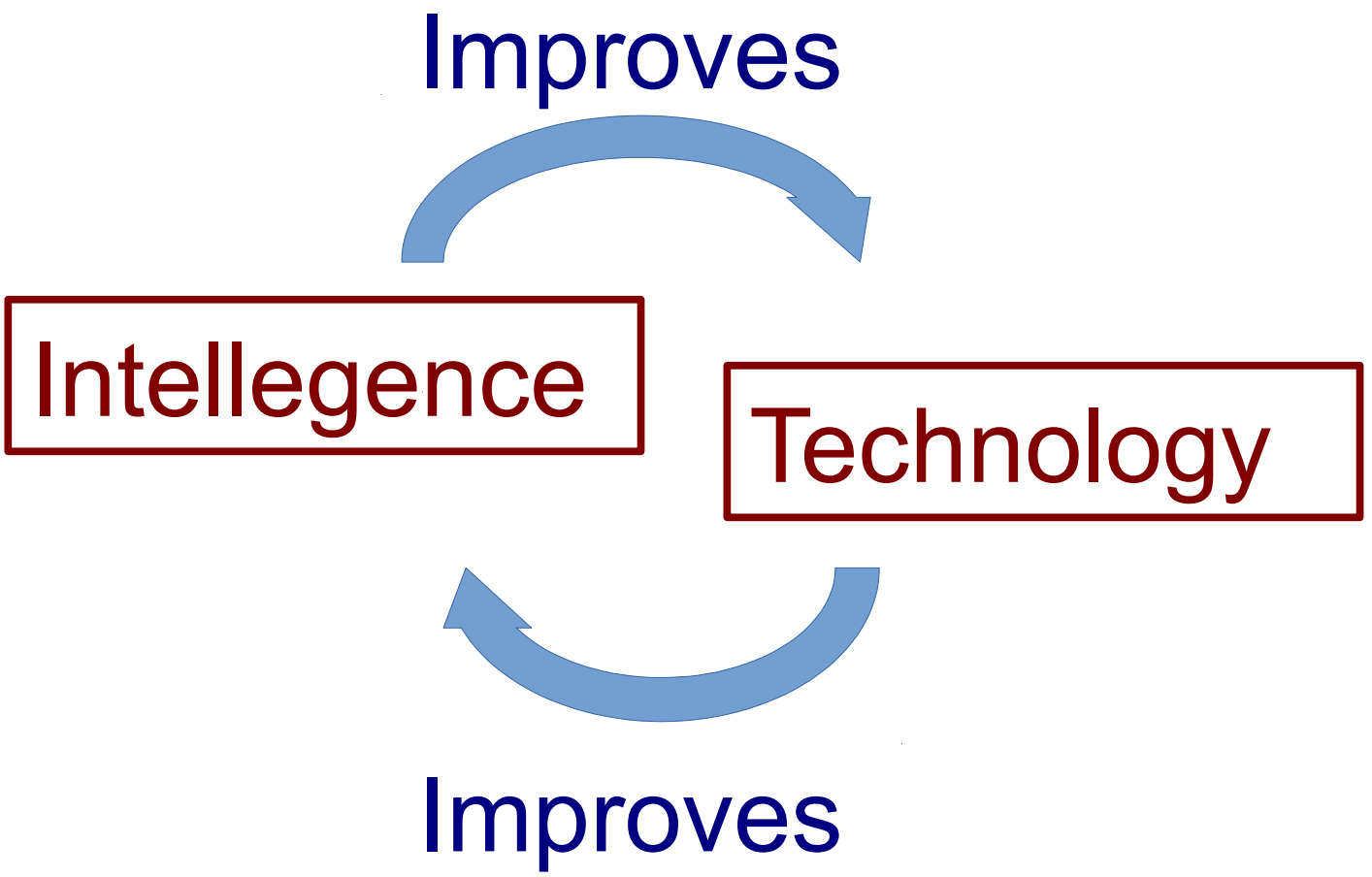
When it is economical to match the brain's computing power (in about the same space and power constraints)

- 10E15 operations/sec, inexpensive machines.
- CHIP TECHNOLOGY based on brain mechanisms and architecture, instead of Von Neumann architecture.
- Low power



This will likely happen in a few decades, but robots?

Kurzweil's Singularity



Why No “I Robots” Yet?

Hundreds of millions of dollars spent on AI over last 65 years. Multiple “Winters” (dead-ends)

Always seems like :10 years away”.

As late as year 2000, the “chant” was “**we just need to scale it up with more computing power.**”

Answer: we have the computing power now, but we don’t understand what “cognition” is, and how it comes about (emergence).

Growth of Computing Power
(motivated by market incentives)

Gordon Moore's law is still true:

gates get smaller by ½, every 18 months.

Corollary **no longer true**:

things get faster X2 every 18 months:

Only way to go faster, is to make things parallel:

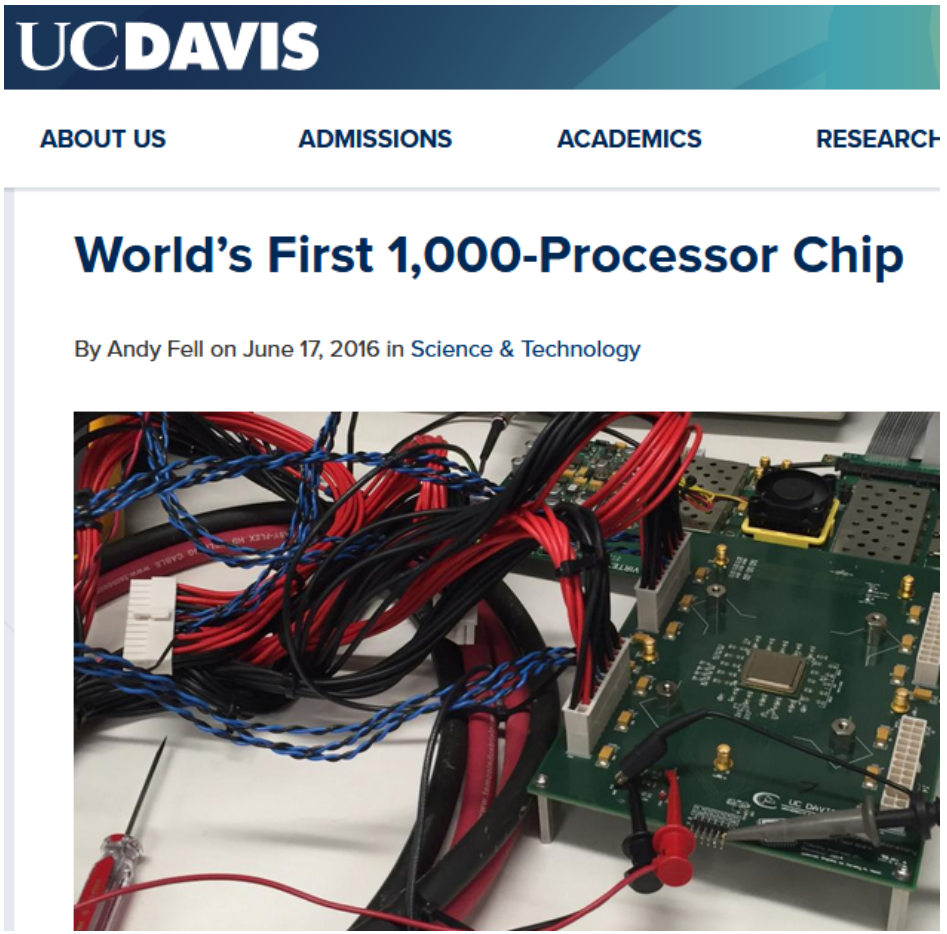
Multicore machines: 7 micron technology ~ 128 cores/chip?

What is the basic motivator? Why go faster?

Growth of Computing Power

(motivated by market incentives)

Software Developer's Nightmare: General Purpose Large scale parallel processing.



Just exactly how does one program this kind of thing ?

Do we have any examples of successful, large scale general purpose parallel processing systems?

A Brain!

The ‘brain’ is a parallel computing system using less than 45 watts, doing impressive computation: perception, cognition, motor control.

It is very general purpose.

AND: it programs itself!

- We call this: “learning”

Part of Kurzweil’s Singularity is that we will know how to make a brain! (True Intelligence)

Why No "Robot Brains" Yet?

We have pretty good "drones" that prove good control systems can be built.

"youtube: Boston Dynamics"

None of these examples have "Minds" that work like human minds.

But now: Economic Incentive!

Automation Intelligence
Driven By Industry

History

- Cotton Gin
- Conveyor Belt
- Assembly Line
- Programmable Machines
- Data Systems
- Office Automation
- Ubiquitous Networks

Trends

- Reduce Labor
- Increase Productivity
- Increase Quality
- Innovate

Reverse Engineering the Brain

What does it do?

- Perception
- Cognition (?) what does this mean?
- Motor control

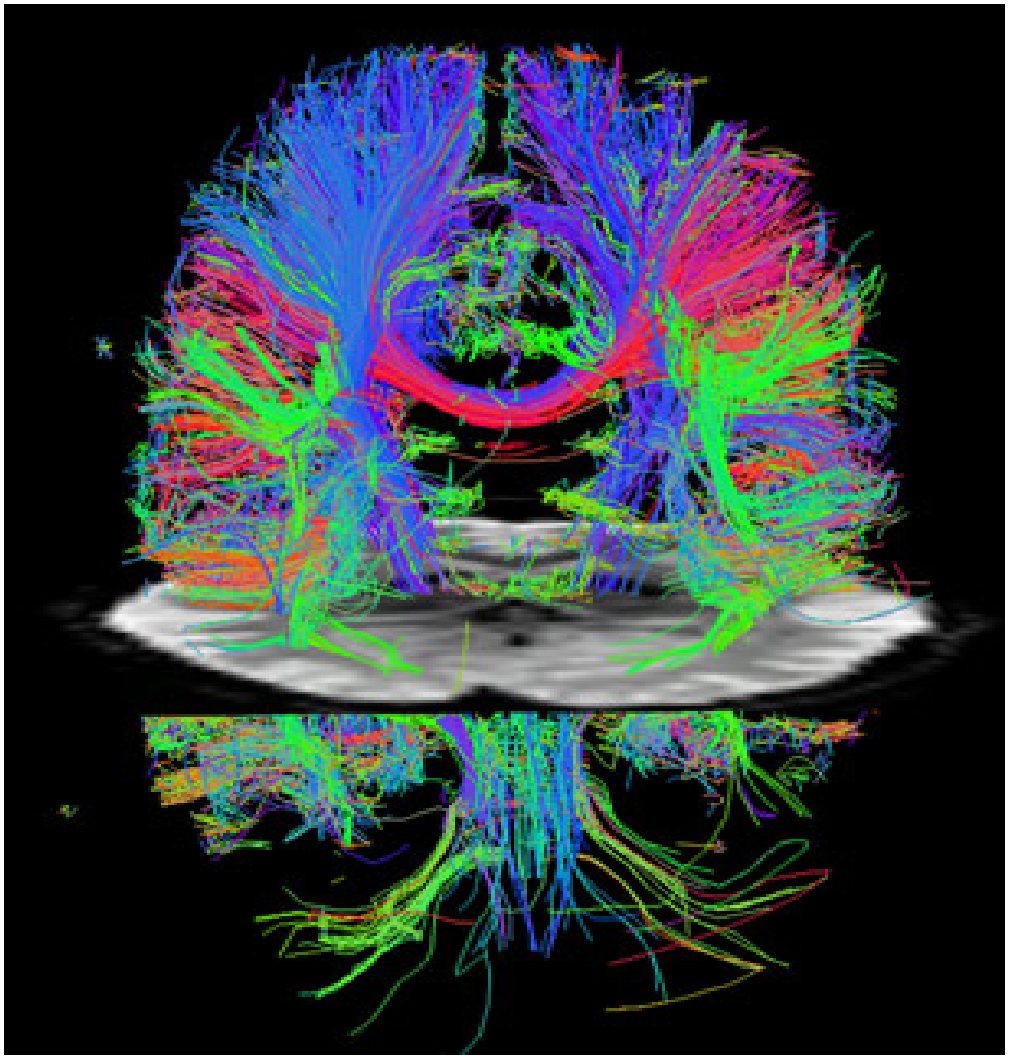
Architecture: How are the parts arranged?

- 10E9 neurons to explain;
- 10E13 connections to map out, at submicron level;
- 10E10 glial cells to explain

How do the parts make the mind?

A Brain is more than a jumble of ‘parts’

The brain is “built out of neurons” (well, sort of)
10E9 Neurons, each neuron: 10E4 connections.
10E10 Glial cells: keeping the connections “fed”.



berkeley.edu/2011/01/05/functionalmri/

If the Brain is not digital, what are those neurons doing?

Definitely NOT Boolean gates and flip-flops.

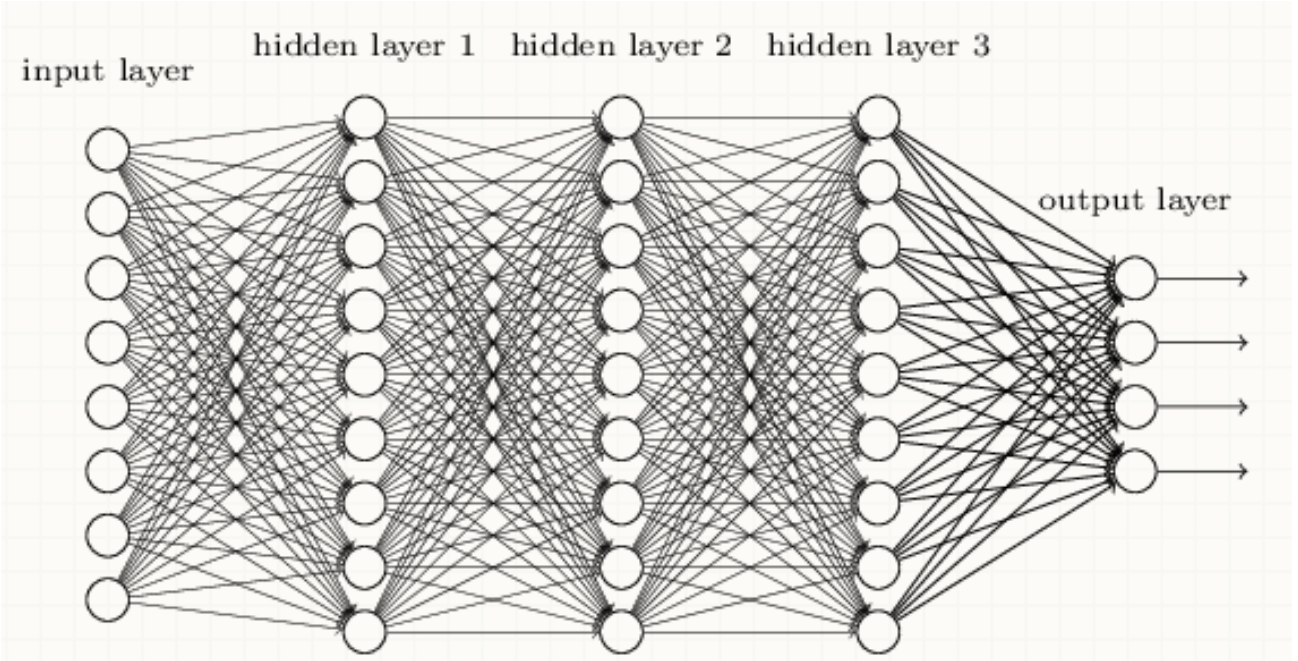
Some mechanisms that can be built of both 'neurons‘ and bits:

- Deep, recursive neural nets: Deep Learning;
- Attractors: a form of memory, possibly a basis of Belief, and Thin Slicing;
- Dynamical systems; networks of attractors;
- Belief Networks;
- Polychronic neural nets (multipurpose neurons)
- “Confabulation networks” (a speculation by Hecht-Nelson)

Are these the mechanisms of cognition?

Deep Learning: Deep Neural Nets

Multiple ‘hidden layers’, can also be recurrent.

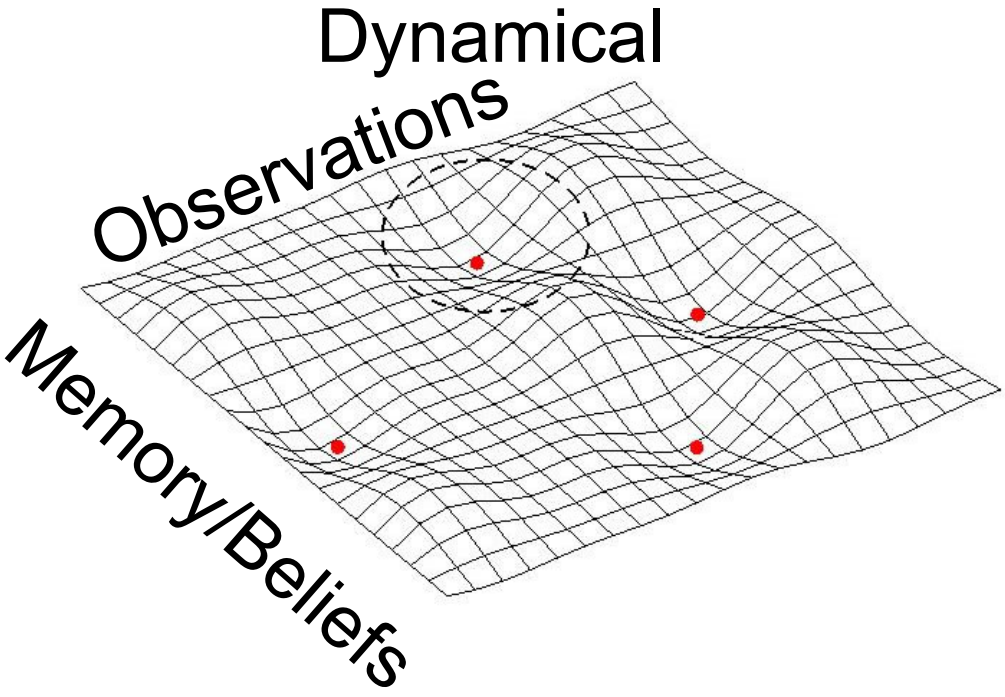


StackExchange.com

Attractors: forming conclusions

Metaphorically like gravity. They have basins of stability which ‘attract’.

These are practical to make with neurons, and easy to model algebraically.



Common example: N’ = 0.5 X (P/N + N) RECURSIVE

Pick any P > 0; then any N. Keep recursing, and this converges at sqr(p).

This formula is an attractor whose basin is SQR(P)

Reverse Engineering the Brain

We need to figure out what the brain is:

- The architecture affects function.
- Seemingly impossible compute speeds from slow parts.
- Extreme complexity: 10E9 parts, each of these with 10E4 connections.
- Really small and compact: we can't see details!
  - Sub-micron dentrites: 1/100th of human hair diameter.

Then, figure out what it does!

Reverse Engineering the Brain

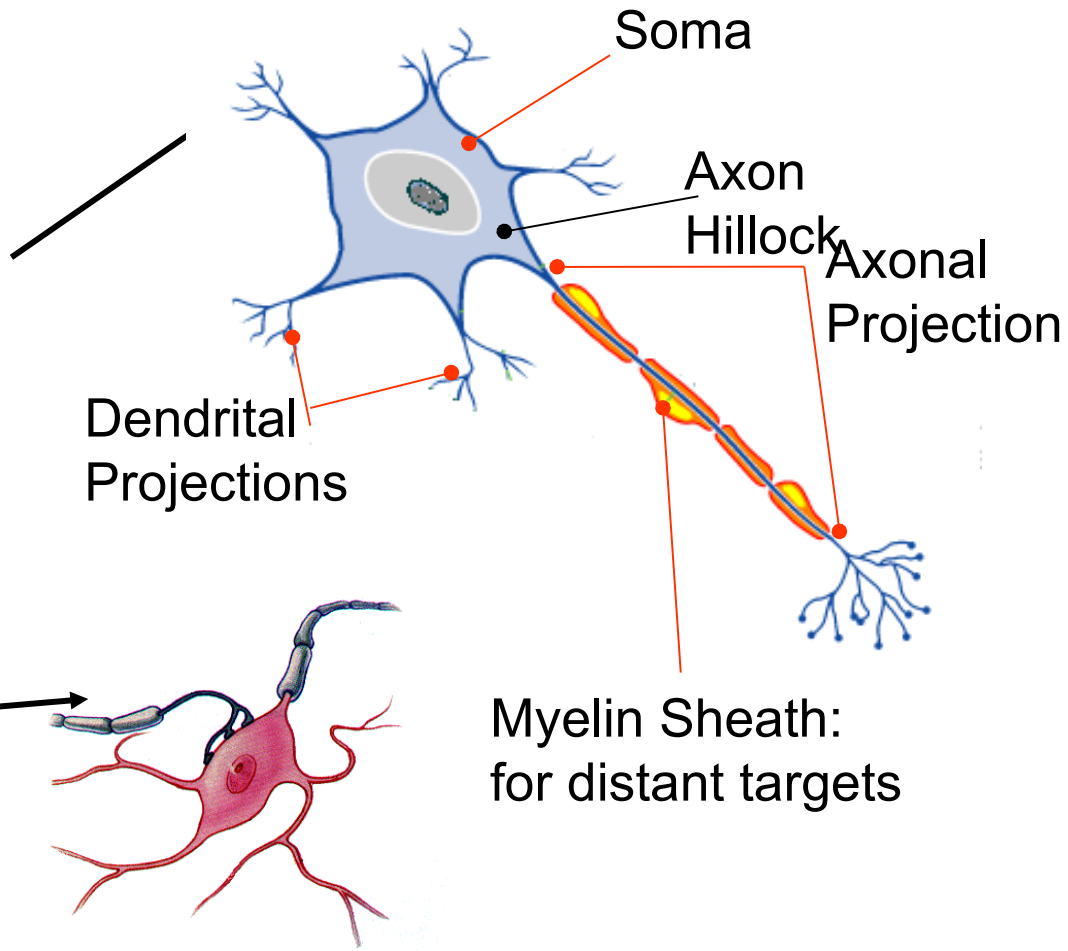
Tools of the trade

- **Neuroscience**: Bottom up: stains, fMRIs, slicing, compartmental modeling (neurons), animal studies, electrophysiology
- **Behavioral Science**: illusions, reaction times, behaviors, mental illness, mental abilities (vs animals)
- **Trauma**: observations of effects of brain damage (Phineas Gage)
- **Computational Neuroscience**: Modeling & emulation for behavior comparisons

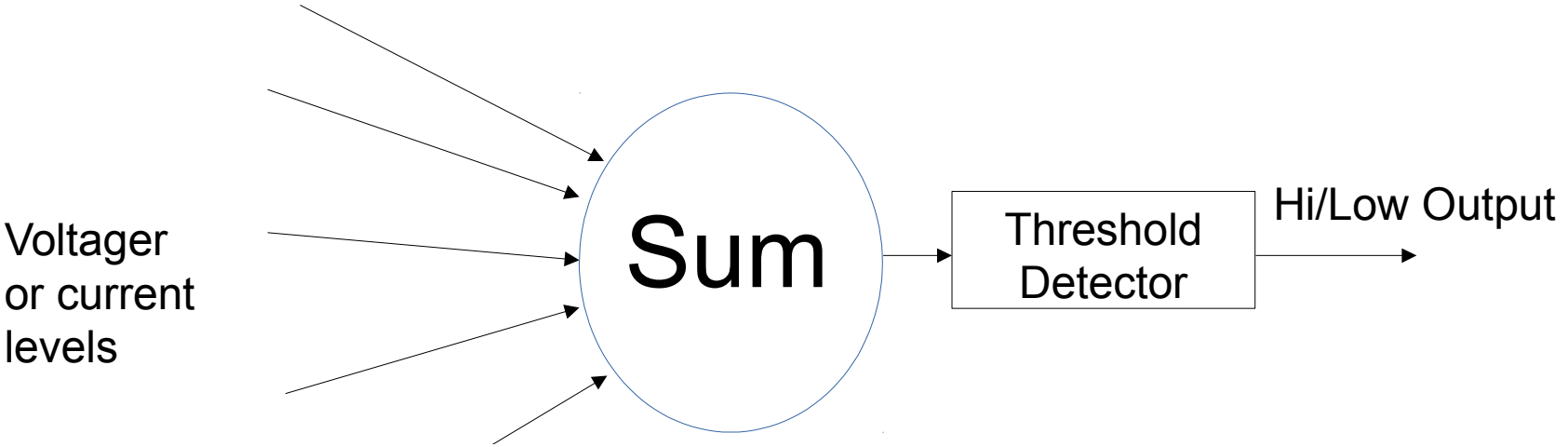
Neuron Structure: the biological objects

Neurons can have Excitatory or inhibitory connections.
Excitatory connections tend to happen far from the Axon Hilloc.

Inhibitory connections tend to be close to or on the Axon Hilloc.

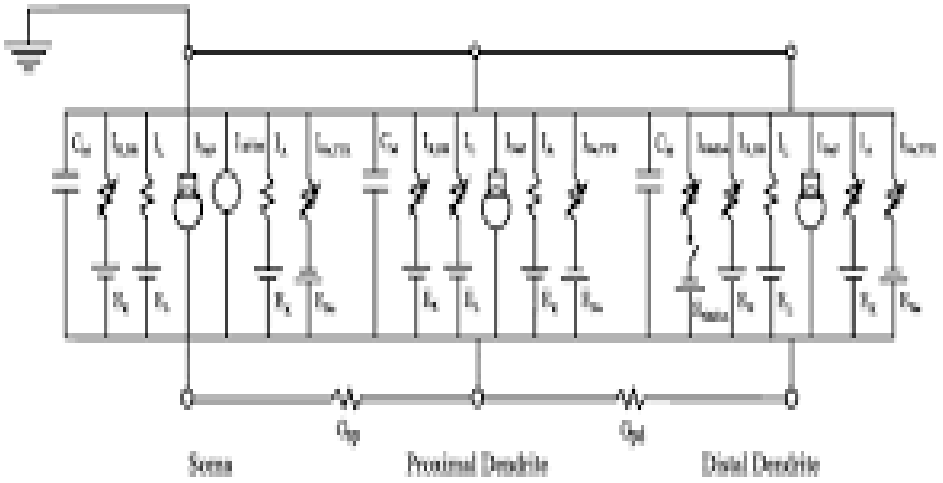


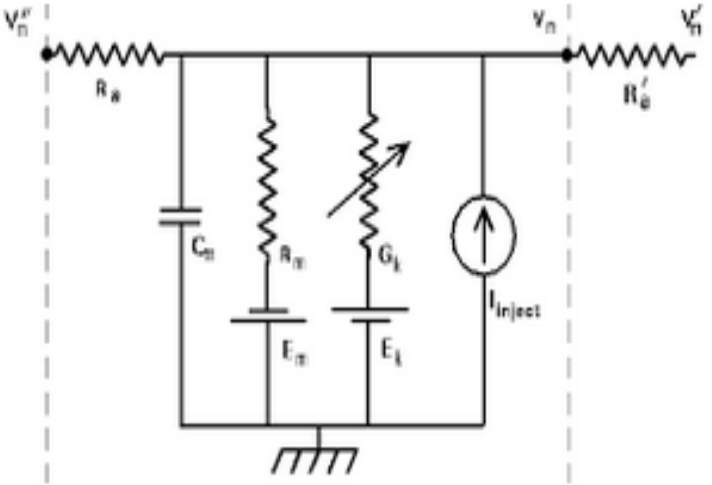
An “AI” community Artificial Neuron: A Convenient Equation



$$y_k = \varphi\left(\sum_{j=0}^{m} w_{kj} x_j\right)$$

Pharma: A Cable Neuron Model
An Inconvenient Equation

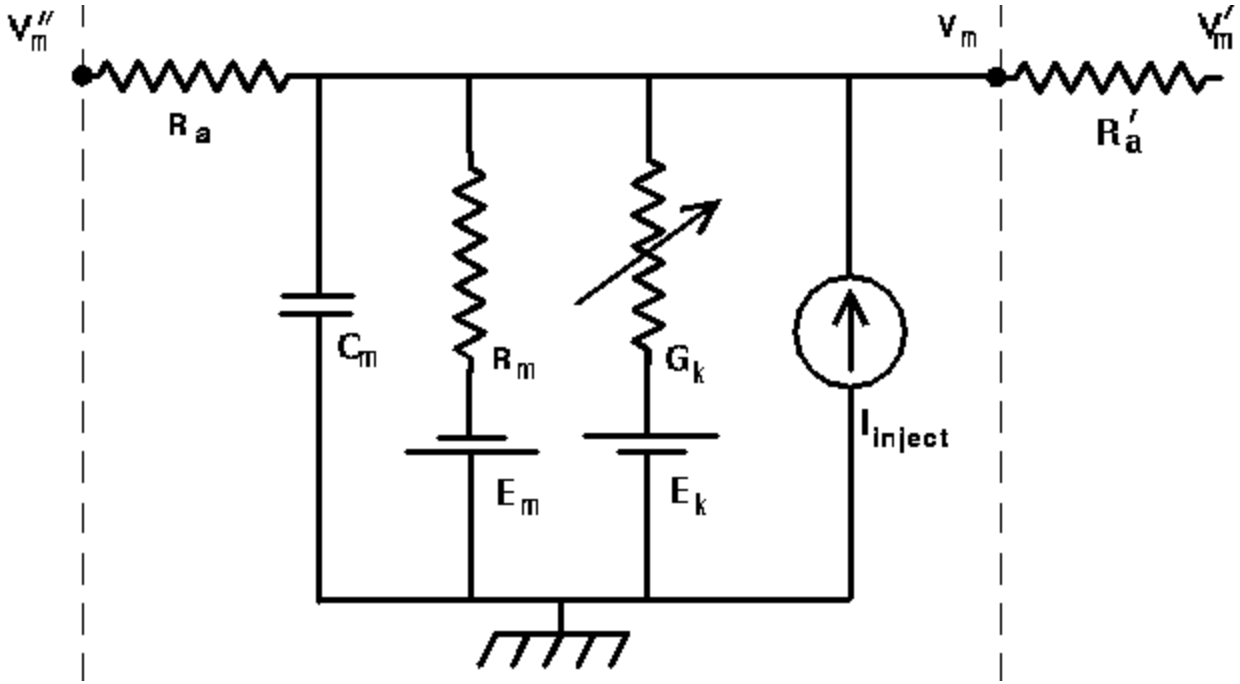




Electro-physiologists test individual neurons for electro-dynamic characteristics.
Very computationally intense models using time-dependent differential equations that are affected by the neuro-transmitter environments (Glia cells).

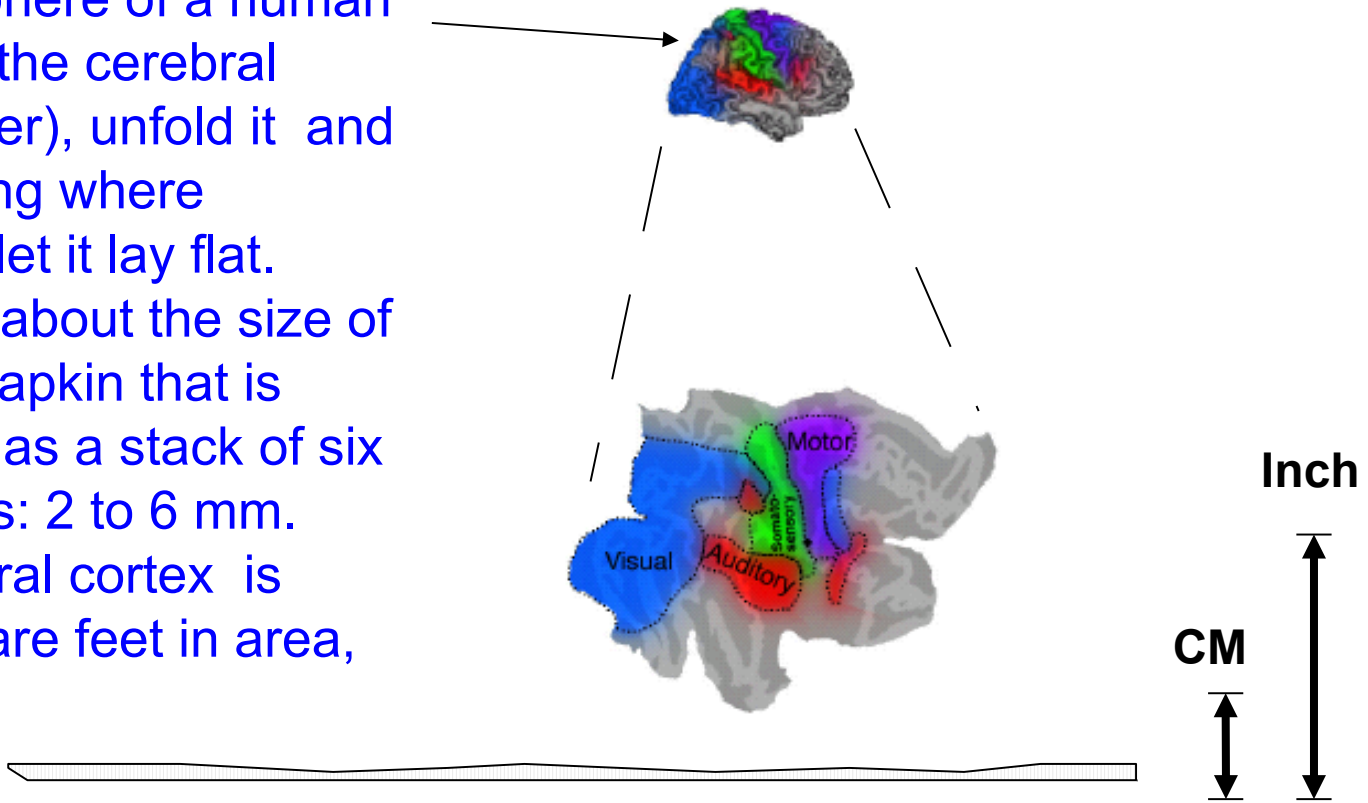
Neuron Modeling: Electrophysiology objects

"The Book of GENESIS: Exploring Realistic Neural Models with the GEneral NEural SImulation System" (Bower and Beeman, 1998)



Gross Anatomy:The neocortex (top of the brain) is amazingly flat and thin

Take a hemisphere of a human brain, strip off the cerebral cortex (top layer), unfold it and lay it flat (cutting where necessary) to let it lay flat.
It has an area about the size of half a dinner napkin that is about as thick as a stack of six business cards: 2 to 6 mm.
A whole cerebral cortex is about 2.5 square feet in area, and this thick:

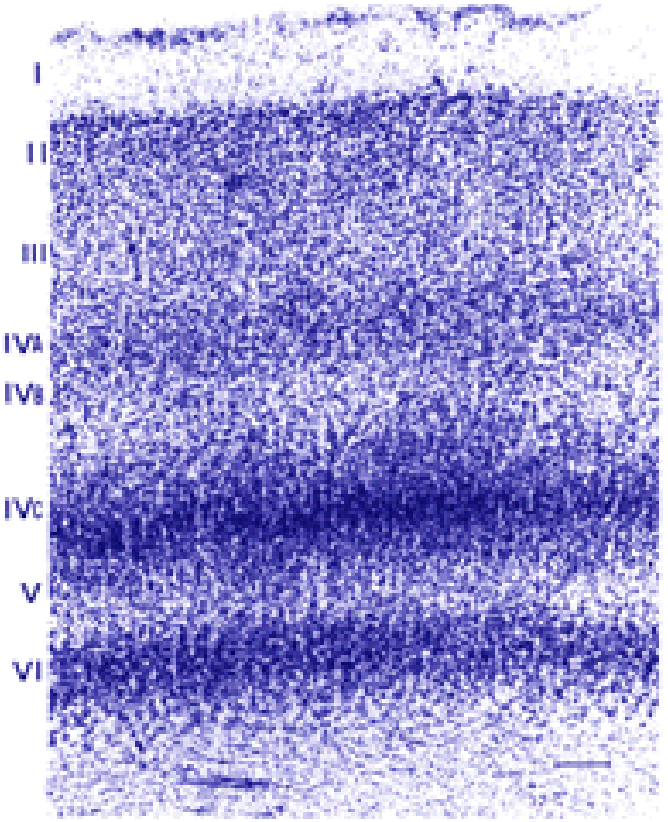


It has a structure

There are six distinct layers. These are labeled (using Roman Numerals) I through VI.

The layering is revealed by cytochrome oxidase (CO) staining. An ATP catalyst, CO uptake is an activity indicator.

Many different kinds of neurons, exhibiting various characteristics of inhibitory, excitatory, and branching characteristics.

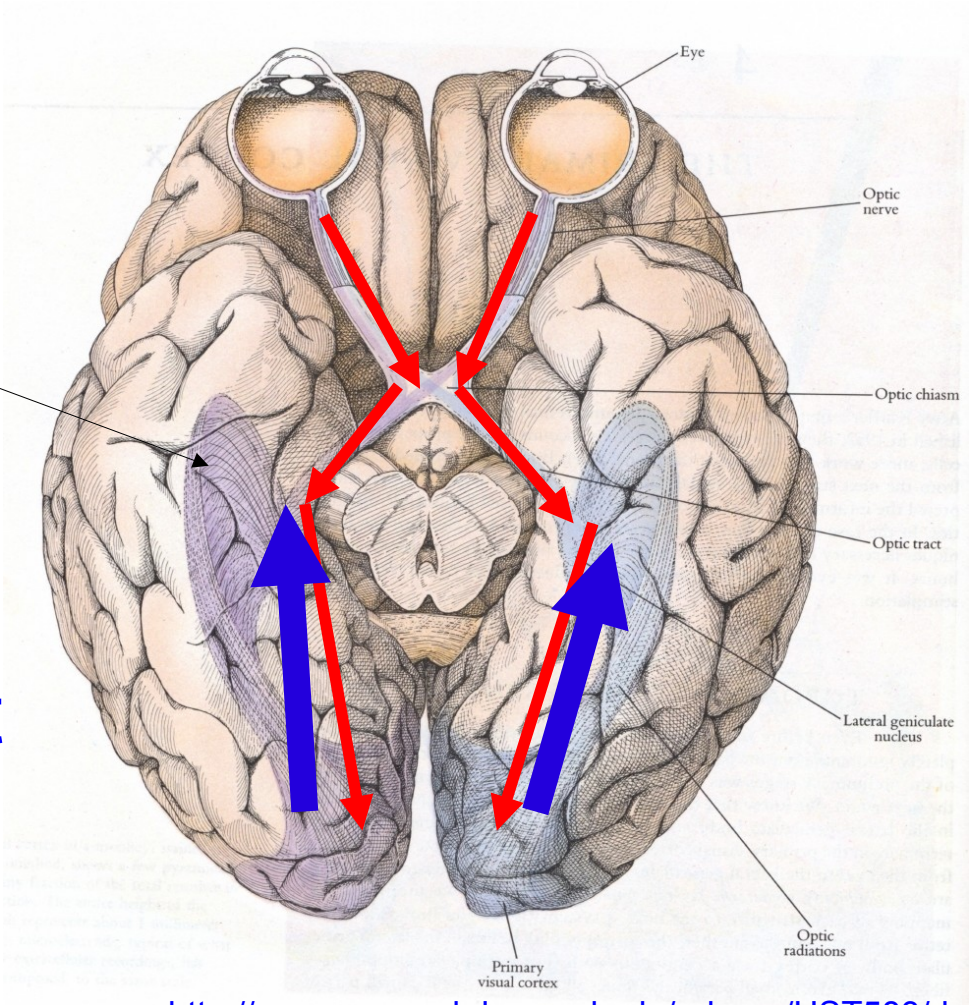


http://webvision.med.utah.edu/VisualCortex.html

Many Surprises: Strong Feedback

Note the ‘fatter’ fibers in the back of the visual track.

Visual **feedback** is 4X the bandwidth of feed forward!
(We see what we want to see)



http://www.nmr.mgh.harvard.edu/~rhoge/HST583/doc/VisualCortex.jpg

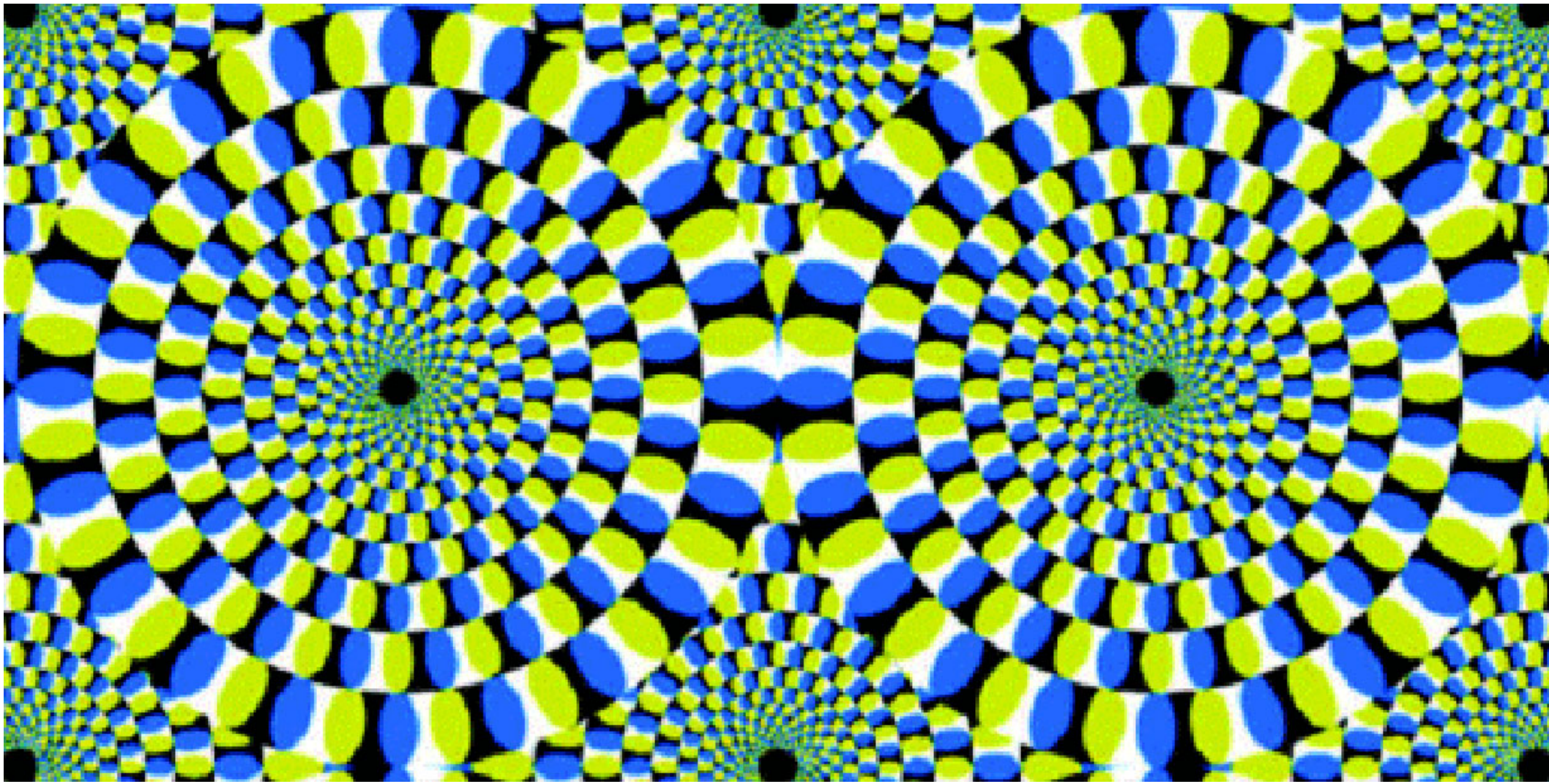
Our Minds Are What Our Brains Do

We can compare any 'brain models' we create to actual brains by comparing behaviors.

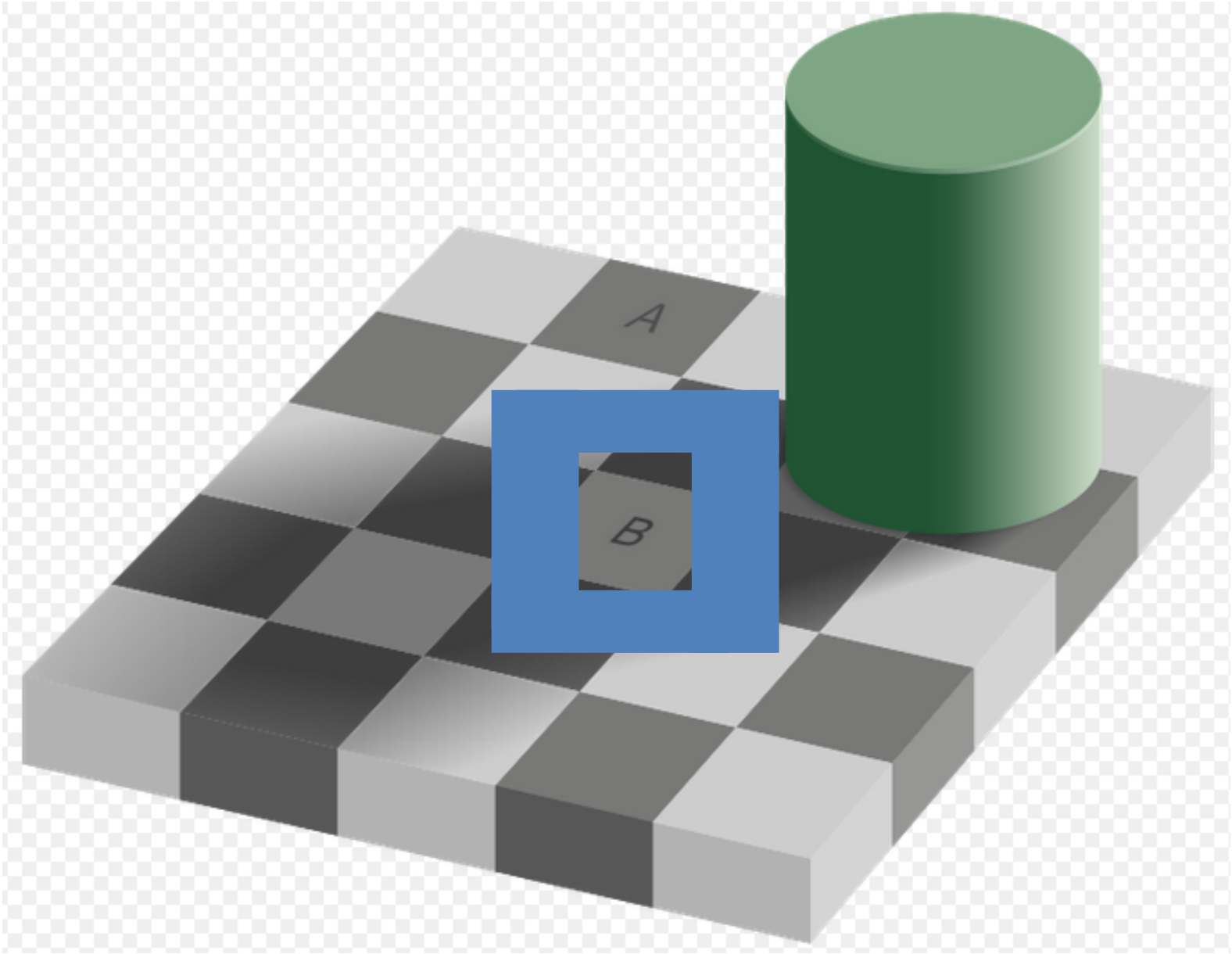
Let's look at a few aspects of this, just for fun:

- Some illusions
- Stories
- How memory & expectation might interact with perception
- Ignorance and certitude

Our minds are what our brains do: Perception Illusion



Our minds are what our brains do: Perception Illusion



Our Brains Hate Confusion: when we 'make sense' out of some observation, we get an 'award' (rush) to reinforce our 'conclusion'.

A basis of "story"?

Where have all the flowers gone? (Pete Seeger)

Where have all the flowers gone?
Young girls picked them, every one.

Where have all the young girls gone?
=> Young men

Where young men? gone? => Solders

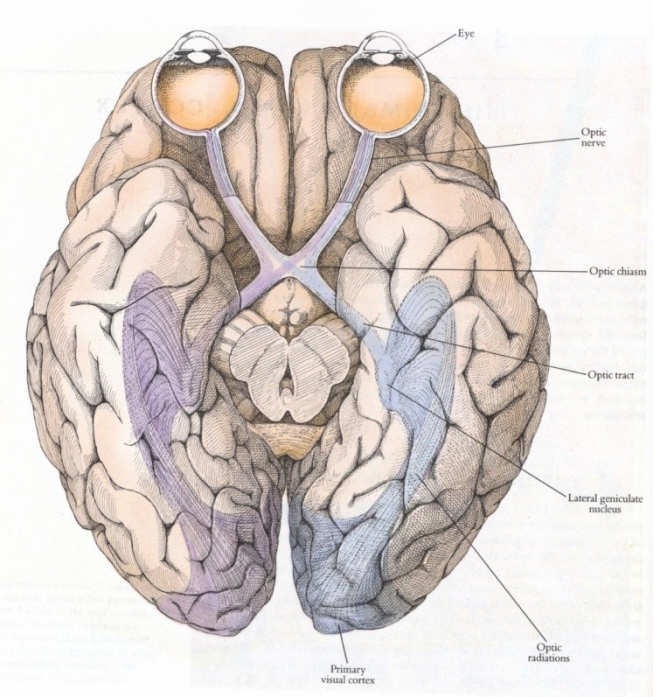
Where Solders gone? => grave yards

Where grave yards? => Flowers

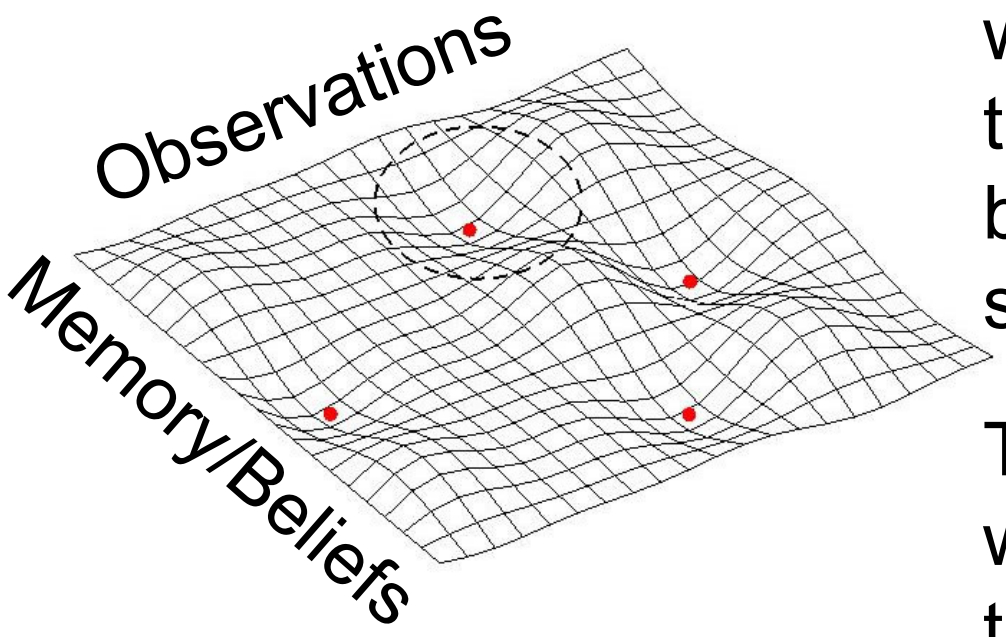
Pete Seeger

Our Brains Hate Confusion: Remember that our eyes supply only ¼ of our visual perception.

Our expectations can fill in a lot! That's why we see ghosts in scary dark rooms.



Remember Attractors? And forming conclusions? Models consistent with behaviors?



When the observations are weak (lights are out?) the memory and belief influence is stronger.

That's consistent with why we see ghosts in the dark, and why psychotics may hear voices.

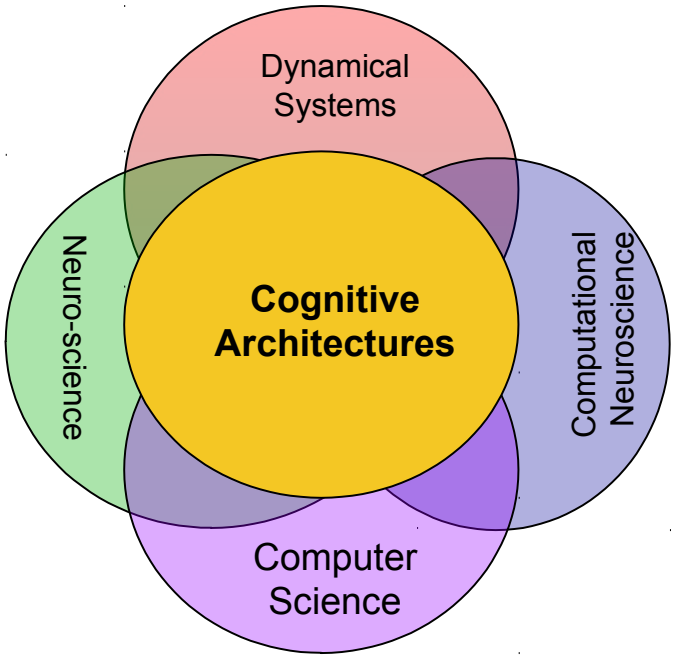
Our Brains Hate Confusion: when we get contrary evidence, we got to deal with it to settle the *anxiety*.

- **Binary thinking**: can't handle nuance. Result of needing to resolve confusion?
- **Certitude**: a practice for avoiding the anxiety of contrary evidence.
- **Dunning-Kruger effect**: a cognitive bias in which low-ability individuals suffer from illusory superiority, mistakenly assessing their ability as much higher than it really is.

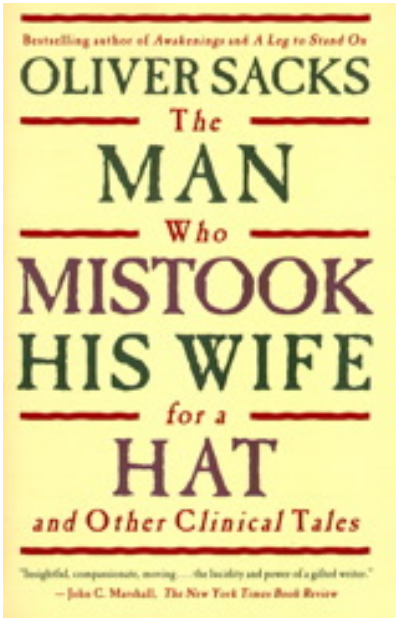
How can Neuromorphic Computing Succeed?

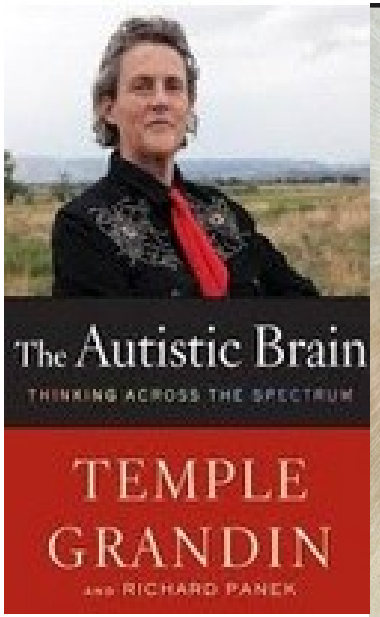
Multi-discipline Effort: This is much more than a computer engineering problem.

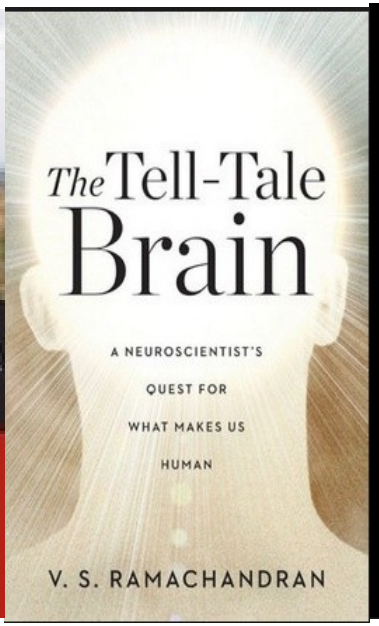
- Nano technology: computations, and instrumentation;
- Computer Science: building emulations
- Mathematics: dynamical systems, computational neural science;
- Cognitive Psychology: understanding of mind; sensing & perception
- Neuroscience
- Developmental Psych;
- Behavioral Psych;
- Social Psych;
- Biochem: understanding of Glial roles
- Engineering: technology for mapping all those neurons, and discovering architectural structure.

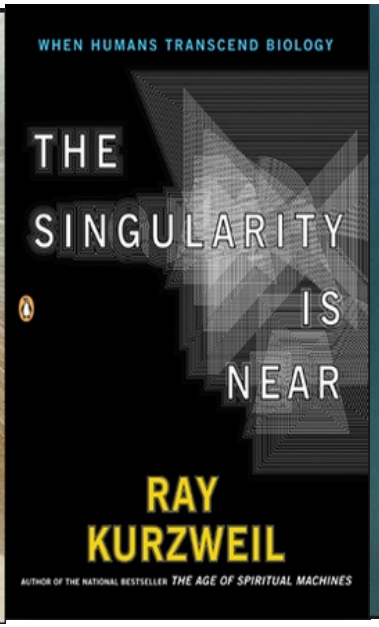


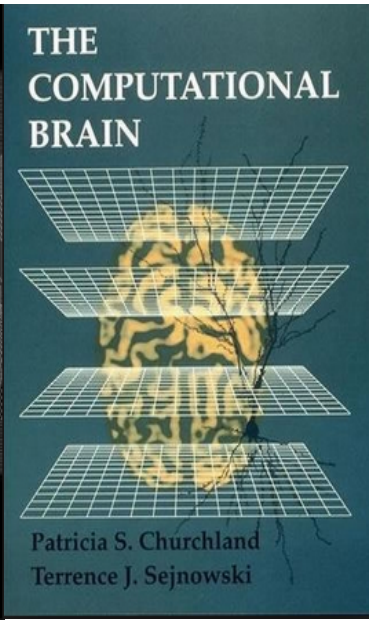
Suggestions for Fun Reads





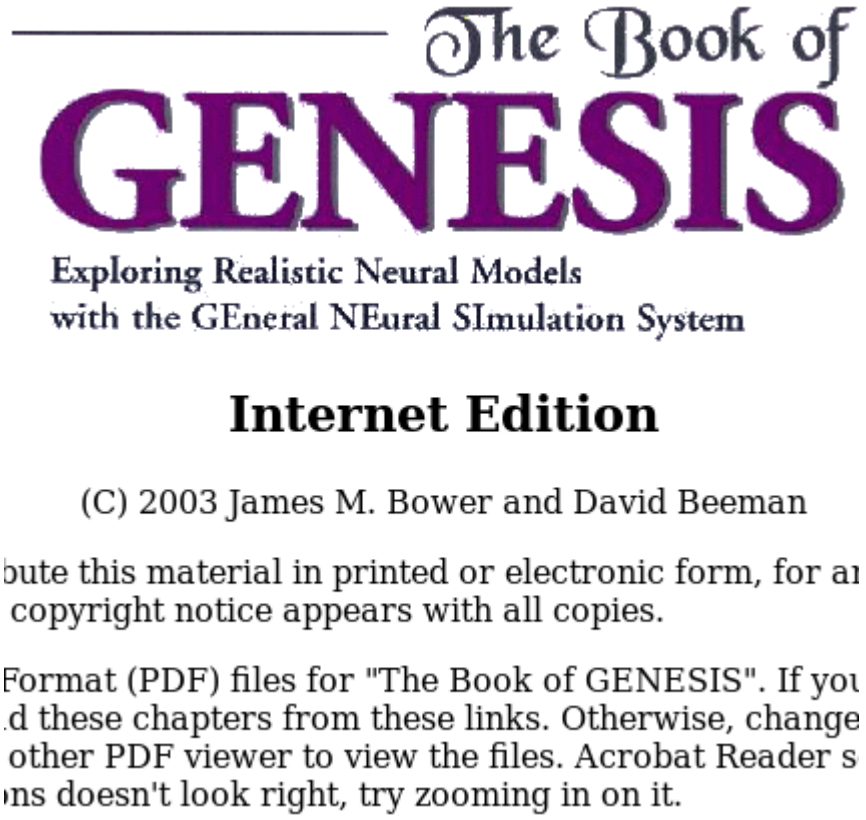






Suggestions for Vocational Reads

Compartmental Neuron Models


The Book of
GENESIS
Exploring Realistic Neural Models
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Suggestions for Vocational Reads

Compartmental Neuron Models

https://www.neuron.yale.edu/neuron/

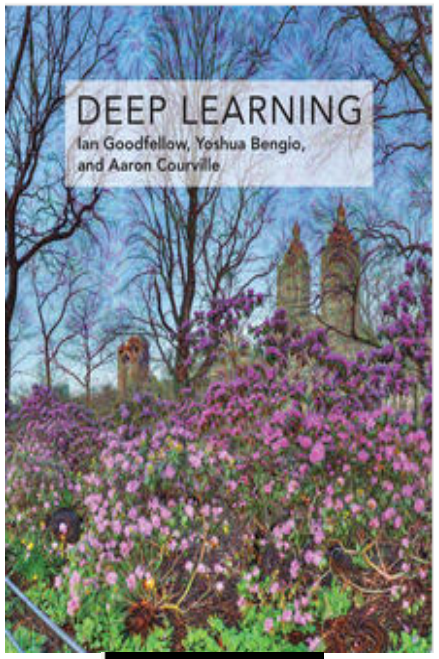
Suggestions for Vocational Reads

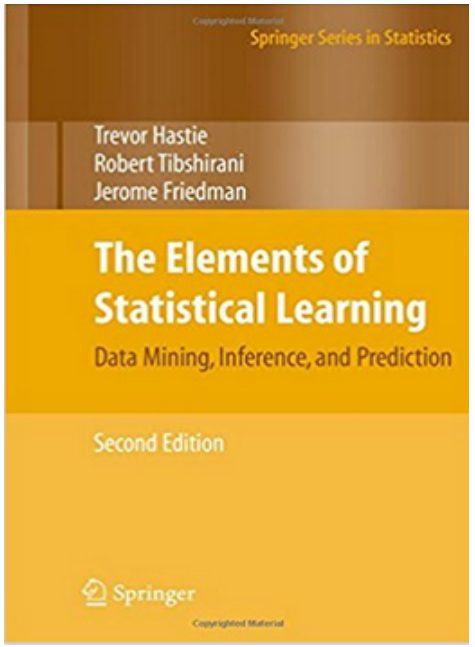
Computer Vision

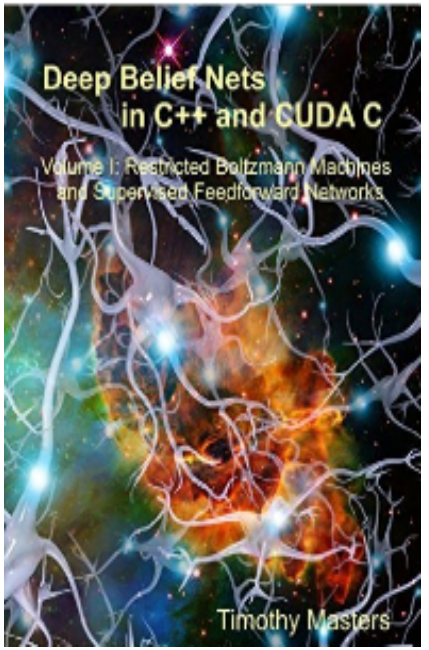
https://sourceforge.net/projects/opencvlibrary/

Suggestions for Vocational Reads

Machine Learning







Questions?

Where does the magic number 10E15 operations/sec come from?

- Assume each synapse 'firing' is 5 numeric operations:
- 10E9 X10E4 neuron connections = 10E13 synapses.
- Synapse firing rate: 100 Hz average?

- 10E13 X 5 X 100 => 5X10E15

BTW: Non-neuromorphic machines need to do a lot of indexing to do that math, so multiply **10E15** by about 10.

This is achievable now with a small GPU cluster.