

# Neuroinformatics 2024

February 21, 2024

Introduction

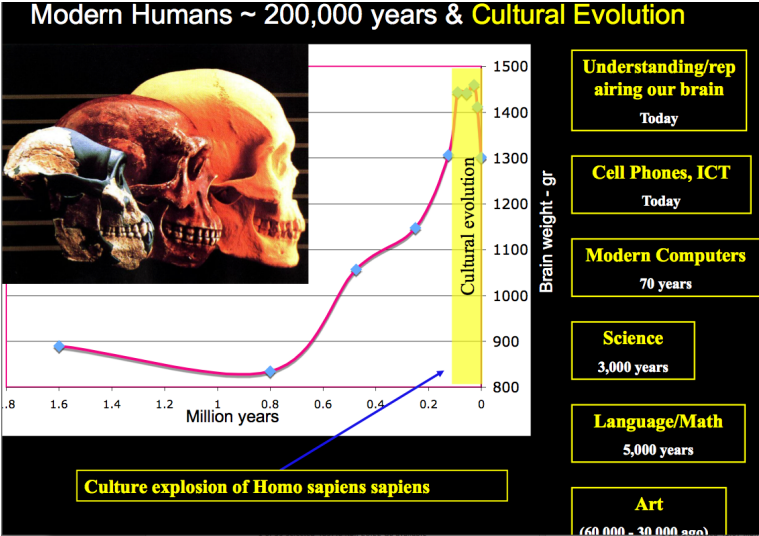
# What is Computational Neuroscience?

**Computational Neuroscience is the theoretical study of the brain to uncover the principles and mechanisms that guide the development, organization, information processing and mental abilities of the nervous system.**

# What is Neuroscience?

- ▶ How does the brain work?
- ▶ What are the biological mechanism involved?
- ▶ How is organised?
- ▶ How did evolve?
- ▶ How does it change during lifetime?
- ▶ What are the origins of the degenerative diseases and the possible rehabilitation?

# Brain r-evolution

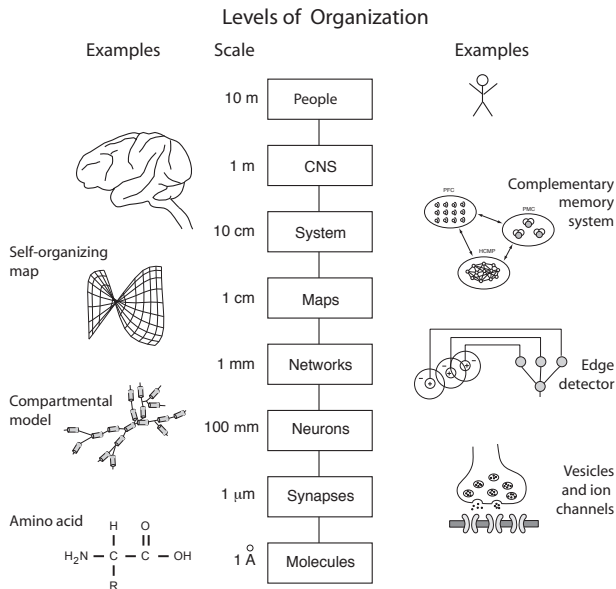




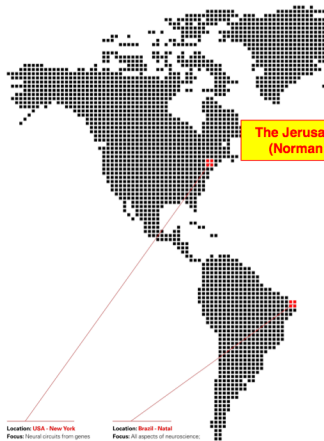
# Tools in Neuroscience?

- ▶ Genetic manipulations
- ▶ Brain slices
- ▶ Optical imaging
- ▶ Functional brain imaging
- ▶ Psychophysiological measurement
- ▶ Computational simulations (analytic solutions & Numeric simulations !!! )

# Levels of organizations in the nervous system



# Brain blossom



**The Jerusalem Brain  
(Norman Foster)**

**Location:** USA - New York  
**Focus:** Neural circuits from genes to behavior  
**Size:** 70 labs, 32,000 sq. m  
**Funding source:** Columbia University and additional sources

**Location:** Brazil - Natal  
**Focus:** All aspects of neuroscience; Science as an agent of social transformation  
**Size:** 25 labs, planned; 100 hectare Campus  
**Funding source:** Private and public funding. Above € 32.5 M. Total planned investment - € 100 M

## WORLDWIDE BRAIN BLOSSOM

**Location:** Great Britain - London  
**Focus:** Molecular, cellular, behavioral  
**Size:** ~30 labs  
**Funding source:** The Gatsby Charitable Foundation and The Wellcome Trust

**Location:** Germany - Frankfurt  
**Focus:** Cognitive functions  
**Size:** 100 researchers  
**Funding source:** € 200 M; Andreas and Thomas Strangmann

**Location:** Germany - 20 locations  
**Focus:** Computational neuroscience & neuroinformatics  
**Size:** ~60 labs, partly supported by German Federal Ministry of Education and Research (BMBWF)  
**Funding source:** € 100 M; BMBWF

**Location:** China - Shanghai  
**Focus:** Molecular, cellular, circuit function, plasticity  
**Size:** 30 labs, 700 researchers, 25,000 sq. m  
**Funding source:** Chinese Academy of Science

**Location:** Portugal - Lisbon  
**Focus:** Evolution, social behavior, social interactions, circuit development  
**Size:** 10-15 labs, 100-150 researchers, 8,000 sq. m  
**Funding source:** Champalimaud Foundation

**Location:** France - Paris  
**Focus:** Aging, neurodegeneration, movement and cognitive disorders  
**Size:** 60 labs, 500-800 researchers, 10,000 sq. m  
**Funding source:** 70% public, 30% private

**Location:** Japan - Okinawa  
**Focus:** Cellular, computational, cognitive  
**Size:** 10 labs, 20,000 sq. m  
**Funding source:** Japanese government

**Location:** Australia, Melbourne  
**Focus:** Neurosciences and mental health, bench to bedside  
**Size:** 43 labs, 600 staff, 40,000 sq. m  
**Funding source:** Australian Federal and State Government, University of Melbourne and the Pfizer and Merck Foundations

# Jerusalem Brain



## Jerusalem Brain - view from inside



## Perspective: Some new dramatic (\$ billions) projects for the brain

1. **Allen Institute** – Seattle, USA (Mouse/Human brain atlas – recently new focus on mouse vision)
2. **Janelia farm** – DC, USA (Industrial scale Inst. for connecting network level anatomy and physiology to a specific behavior)
3. **EU Human Brain Project** - EPFL, Lausanne Switzerland (ICT-based brain research platform, integrating data and knowledge from different disciplines, and catalyzing world-wide effort to achieve understanding of the brain, propose new treatments for brain diseases and new brain-like computing technologies) - **Lesson #7.**
4. **President Obama's "Brain Activity Map" initiative** (Creating revolutionary tools to measure/stimulate millions or even billions of neurons simultaneously)

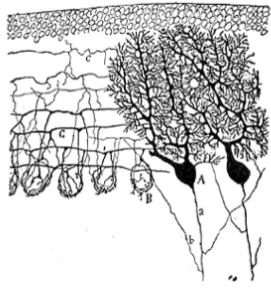
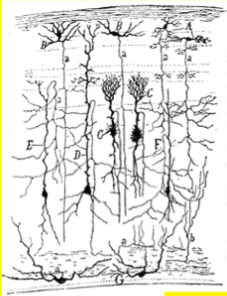
### ***Recent Brain-Excitements***

- 1. Connectomics – Complete 3D road-map for the brain**
- 2. Brainbow – Colorful, genetically-designed, brains**
- 3. Brain-machine/computer interface (BMI)**
- 4. Optogenetics – Light-activated brain circuits**
- 5. Computer simulation of the brain - “Blue Brain Project”**

# Beginning

## Beginning of Modern Neuroscience – Cellular Anatomy

The two giants: Camillo Golgi (Italy) & S. Ramon Y Cajal (Spain) – Nobel Prize 1906



Camillo Golgi

Using Golgi staining method  
Very small % of cells stained  
Connections (synapses) - not seen

The neuron doctrine (Cajal)  
Our brain is built from individual cells  
(neurons)

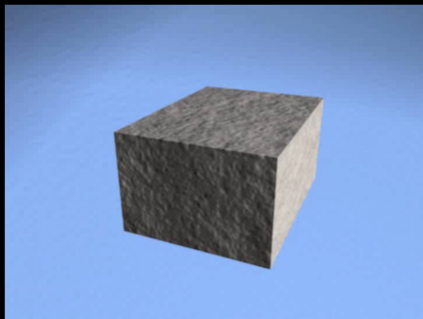
S. Ramon Y Cajal





## Frontiers 1: Connectomics - modern brain anatomy

Electron microscope (EM) reconstruction of a whole piece of brain (nanometers resolution). **All neurons (and other cell types) and all connections (synapses)**

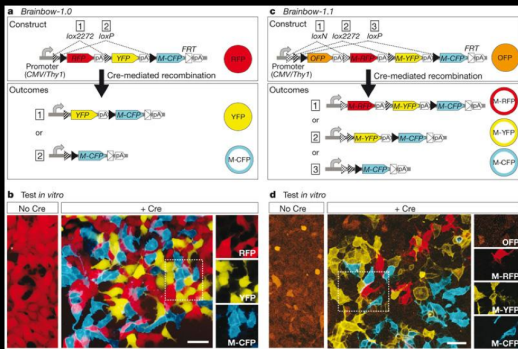


Courtesy of Mitya Chklovskii (Janelia Farm)  
Based on hippocampus data from Kristen Harris (U. Texas, Austin)

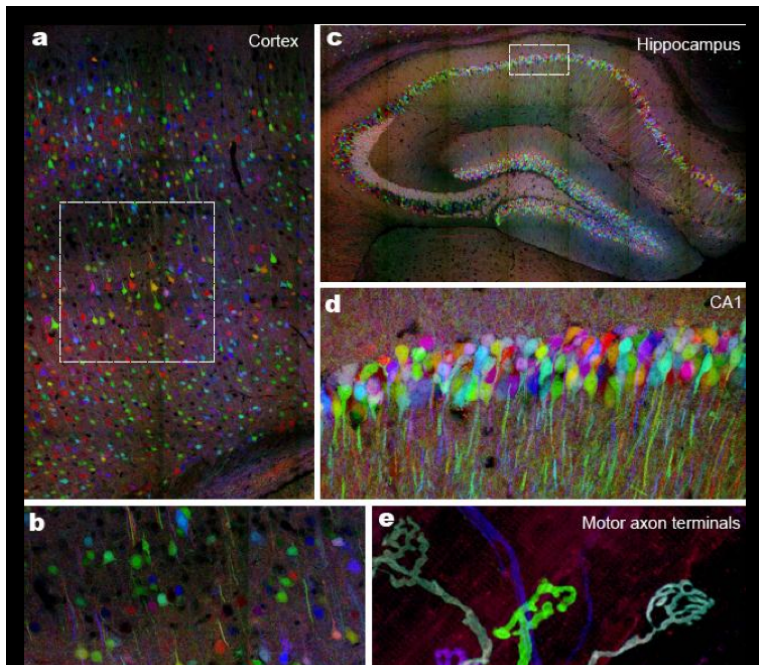
## Frontiers 2. "Brainbow" technology

Genetic staining of neurons *in vivo* (light microscope – micrometer resolution)

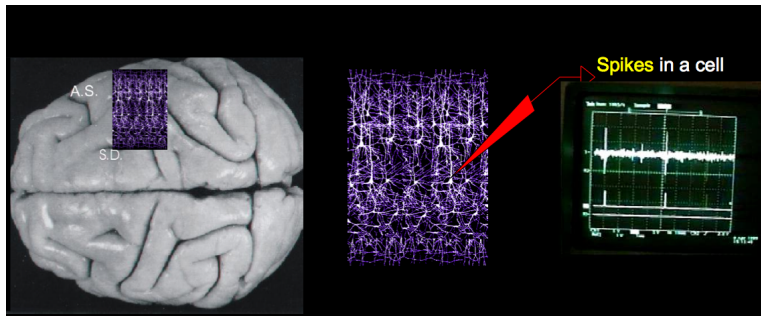
Courtesy of Jeff Lichtman, Jean Livet and Joshua R. Sanes



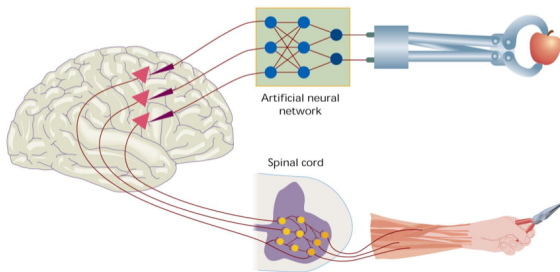
# Brainbow



# Brain Computer interface

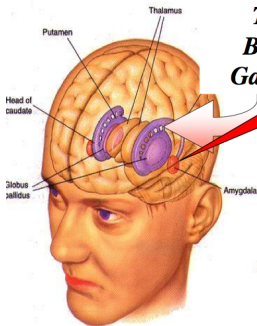


## Brain-activated robot arm



*Courtesy of Miguel Nicolelis (Duke University)*

**From machine (pulses generated by a battery) to brain  
(the amazing success of BMI for ameliorating Parkinson's)**



*The  
Basal  
Ganglia*

**Normal**



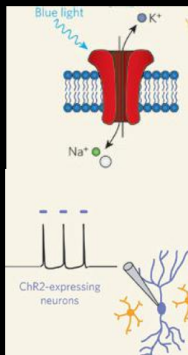
**Parkinson**



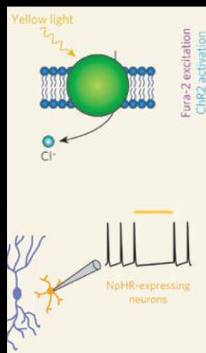
# Optogenetics

Optical stimulation (and recording) from single neurons in the **living brain**

*Channel Rhodopsin opens with blue light*  
*Causes spikes*



*Natronomonas pharaonis activated with yellow light*  
*Prevents spikes*



Hausser and Smith, Nature 2007

# Blue Brain Project

## The Blue Brain Project

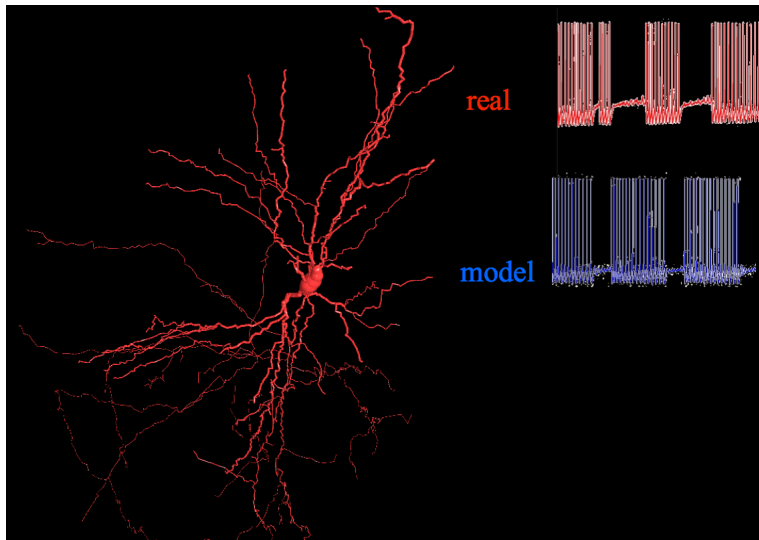
Using the powerful “Blue-Gene” IBM Computer for realistic simulation of the cortical circuits



*Courtesy of Henry Markram and the Blue Brain team (EPFL, Switzerland)*



# Modelling



## Further Readings

Patricia S. Churchland and Terrence J. Sejnowski, 1992, **The computational Brain**, MIT Press

Peter Dayan and Laurence F. Abbott 2001, **Theoretical Neuroscience**, MIT Press

Jeff Hawkins with Sandra Blakeslee 2004, **On Intelligence**, Henry Holt and Company

Norman Doidge 2007, **The Brain That Changes Itself: Stories of Personal Triumph from the Frontiers of Brain Science**, James H. Silberman Books

Paul W. Glimcher 2003, **Decisions, Uncertainty, and the Brain: The Science of Neuroeconomics**, Bradford Books

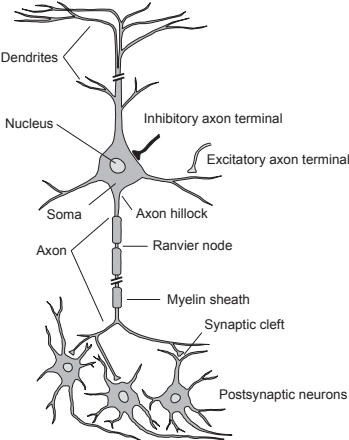
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Basic physiology and conductance-based model

# Biological background

A. Schematic neuron



B. Pyramidal cell



C. Granule cell



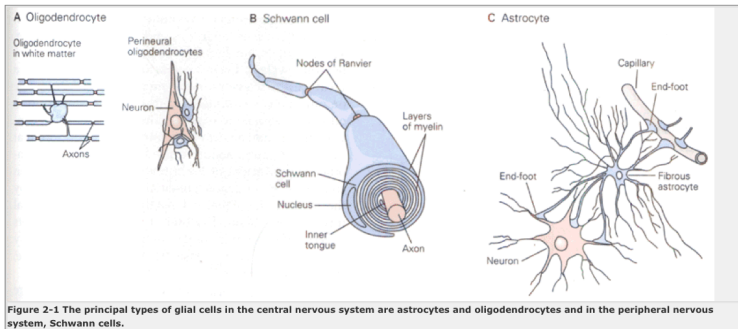
E. Purkinje cell



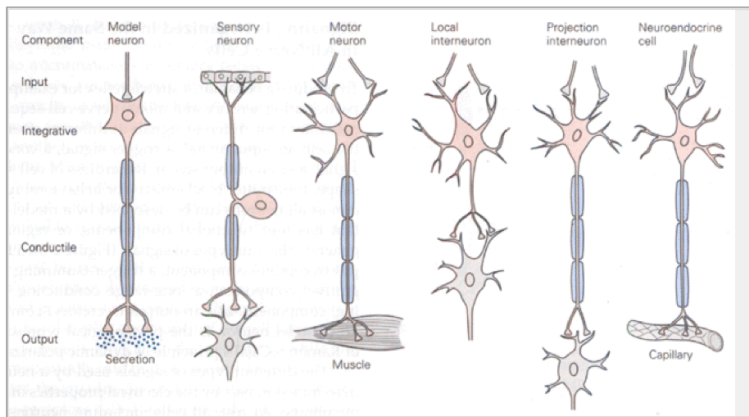
D. Spiny cell



# Glial cells

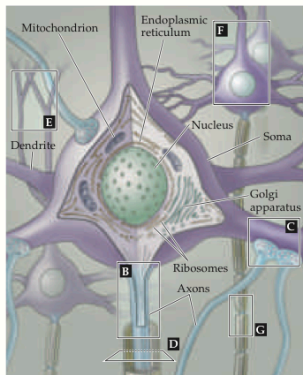


# Four components of neurons

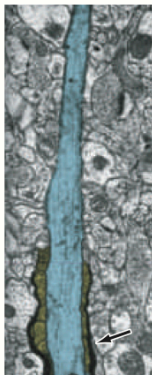


# Microscopical features of neurons

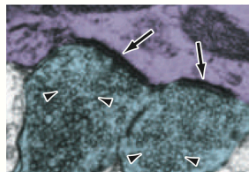
(A)



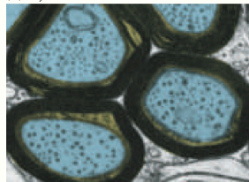
(B) Axon



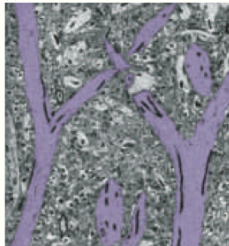
(C) Synaptic endings (terminal boutons)



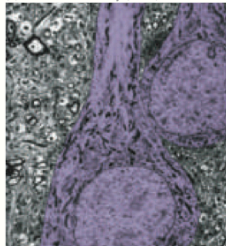
(D) Myelinated axons



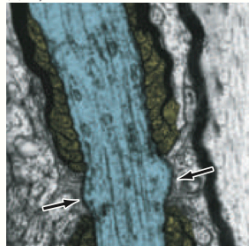
(E) Dendrites



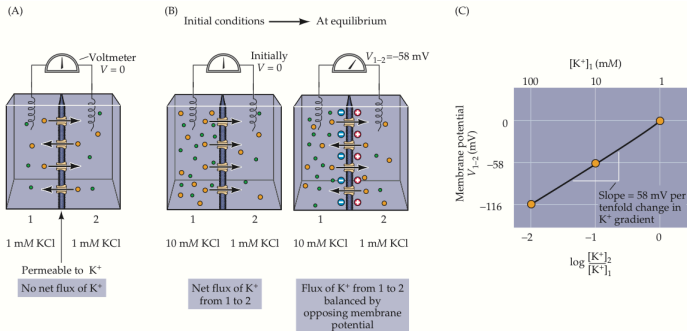
(F) Neuronal cell body (soma)



(G) Myelinated axon and node of Ranvier



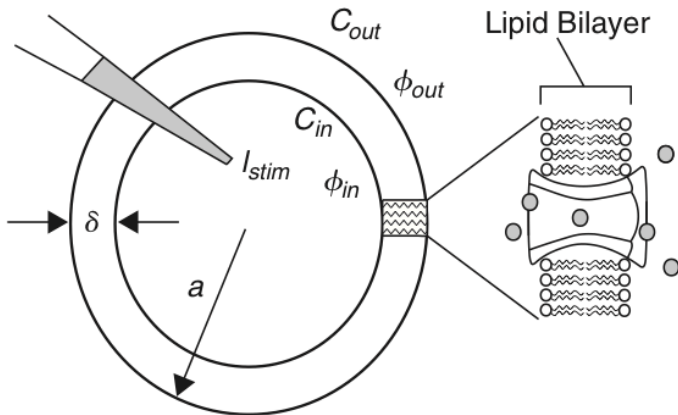
# Nerst potential





## Calculation of Nerst potential

- ▶ Nerst calculation for Cl ion!,  $V = \frac{kT}{ze} \log \frac{C_{out}}{C_{in}}$



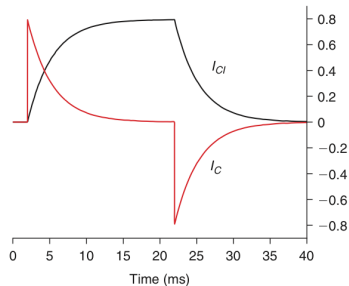
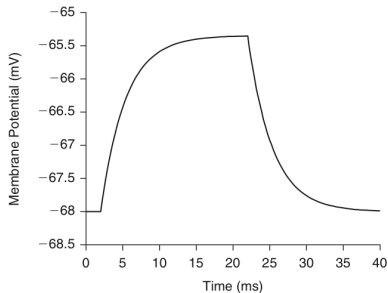
# Membrane simulation

- ▶ Simulation of membrane

$$I_C(t) = C_m \frac{dV}{dt}(t)$$

$$\tau \frac{dV}{dt} = V_{Cl} - V(t) + \frac{I_{stim}(t)}{Ag_{Cl}}$$

$$\tau = \frac{C_m}{g_{Cl}}$$



## Further Readings

- Mark F. Bear, Barry W. Connors, and Michael A. Paradiso (2006), **Neuroscience: exploring the brain**, Lippincott Williams & Wilkins , 3rd edition.
- Eric R. Kandel, James H. Schwartz, and Thomas M. Jessell (2000), **Principles of neural science**, McGraw-Hill, 4th edition
- Gordon M. Shepherd (1994), **Neurobiology**, Oxford University Press, 3rd edition.
- Christof Koch (1999), **Biophysics of computation; information processing in single neurons**, Oxford University Press
- Christof Koch and Idan Segev (eds.) (1998), **Methods in neural modelling**, MIT Press, 2nd edition.
- C. T. Tuckwell (1988), **Introduction to theoretical neurobiology**, Cambridge University Press.
- Hugh R. Wilson (1999) **Spikes, decisions and actions: dynamical foundations of neuroscience**, Oxford University Press. See also his paper in J. Theor. Biol. 200: 375–88, 1999.