

Neuroinformatics 2022

February 23, 2022

Introduction

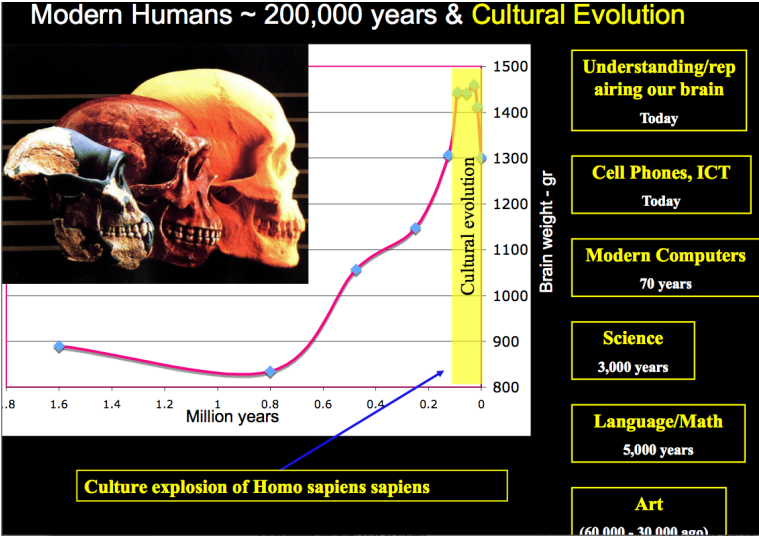
What is Computational Neuroscience?

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?

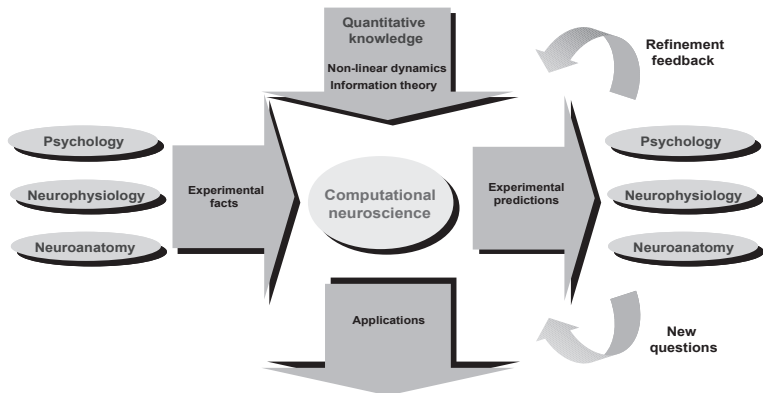
Brain r-evolution



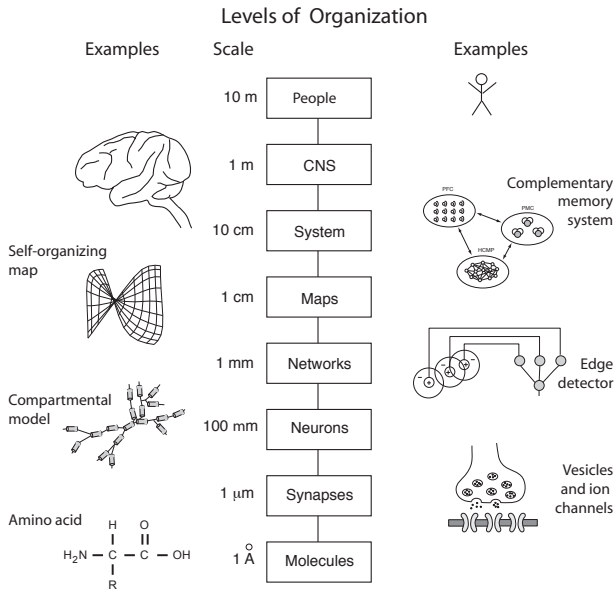
Tools in Neuroscience?

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

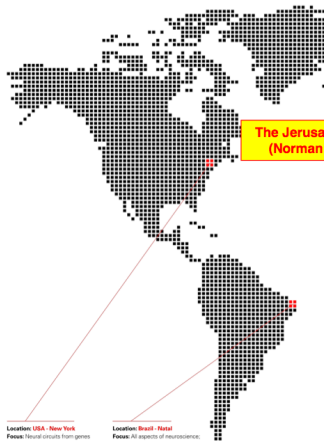
Computational/theoretical tools in context



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, 1000 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



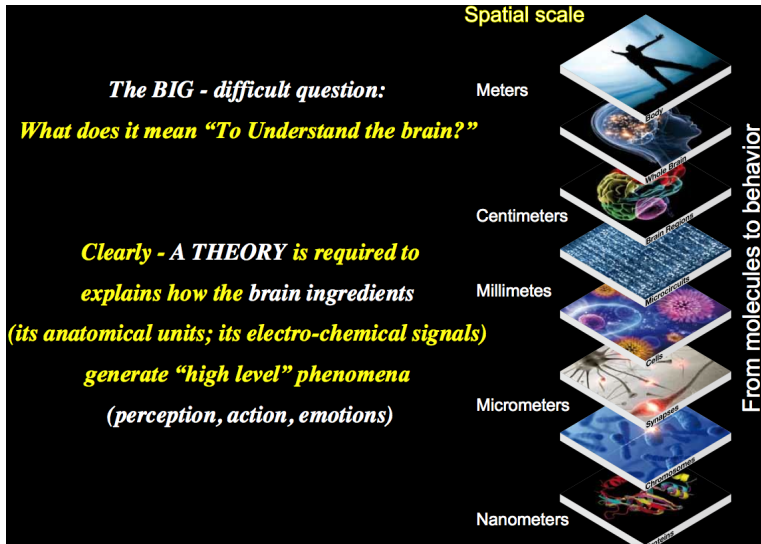
Jerusalem Brain - view from inside



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)

Scale



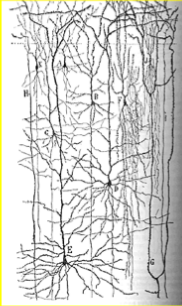
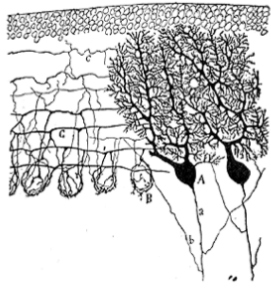
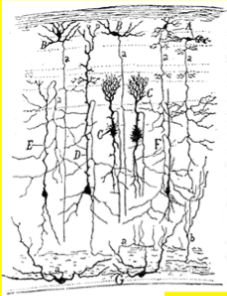
Recent Brain-Excitements

- 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

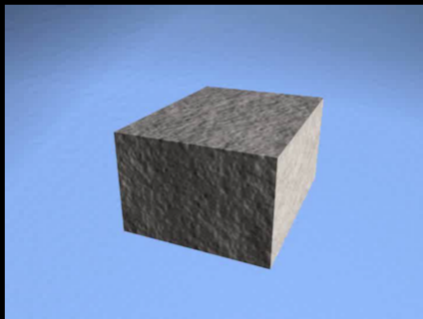
The neuron doctrine (Cajal)
Our brain is built from individual cells
(neurons)

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)**

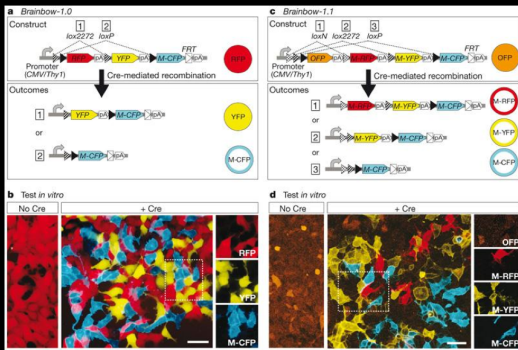


Courtesy of Mitya Chklovskii (Janelia Farm)
Based on hippocampus data from Kristen Harris (U. Texas, Austin)

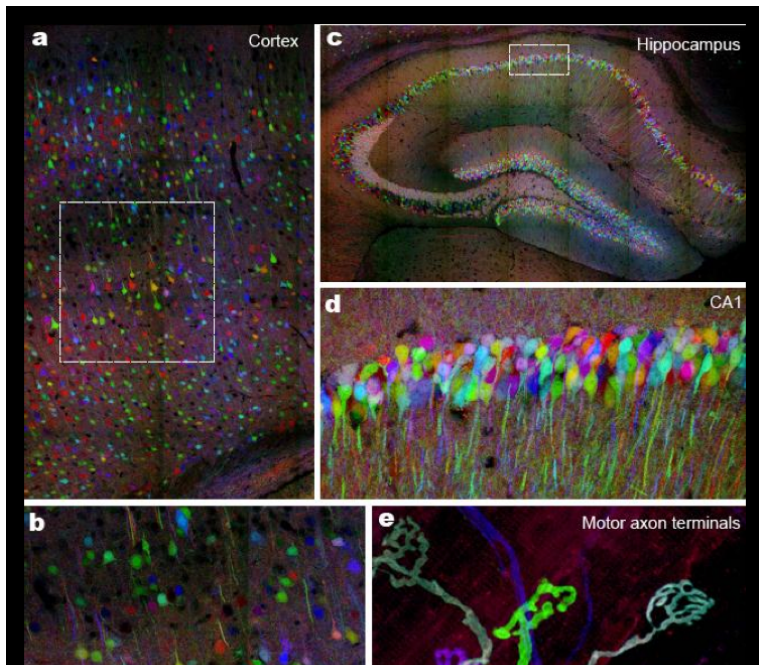
Frontiers 2. "Brainbow" technology

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

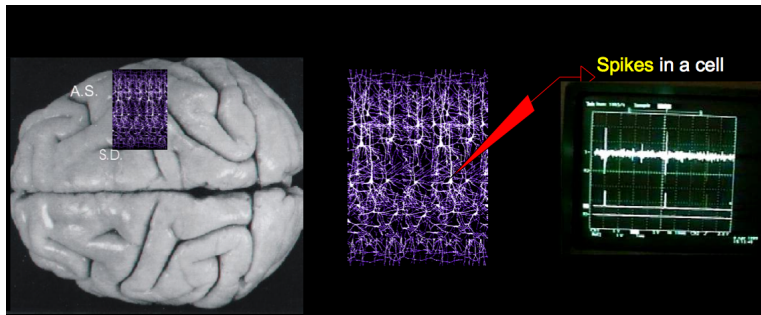
Courtesy of Jeff Lichtman, Jean Livet and Joshua R. Sanes



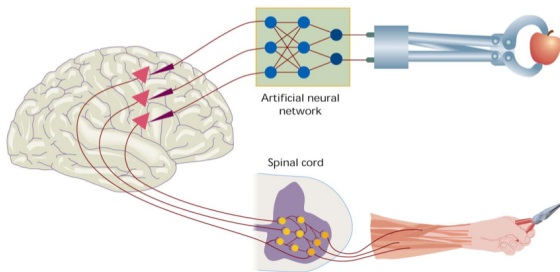
Brainbow



Brain Computer interface

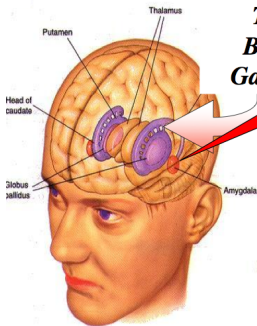


Brain-activated robot arm



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



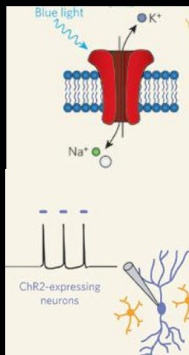
Parkinson



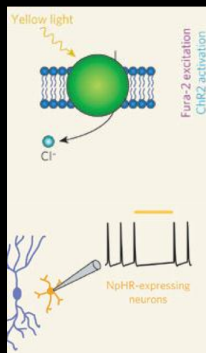
Optogenetics

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



Fura-2 excitation
ChR2 activation

Hausser and Smith, Nature 2007

Blue Brain Project

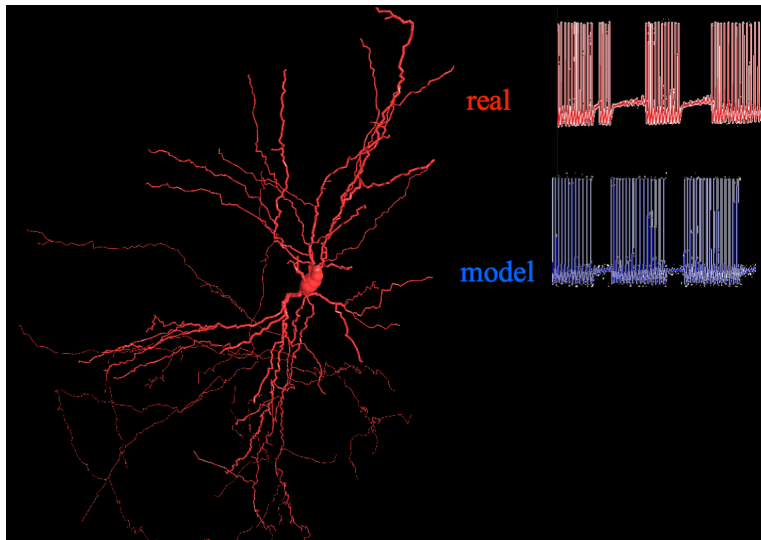
The Blue Brain Project

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

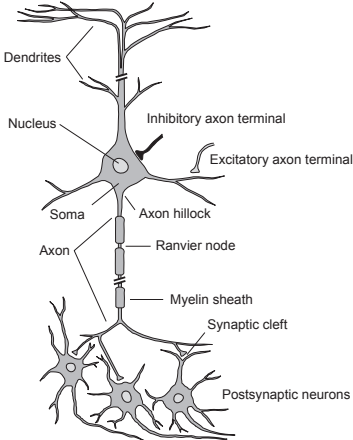
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Basic physiology and conductance-based model

Biological background

A. Schematic neuron



B. Pyramidal cell



C. Granule cell



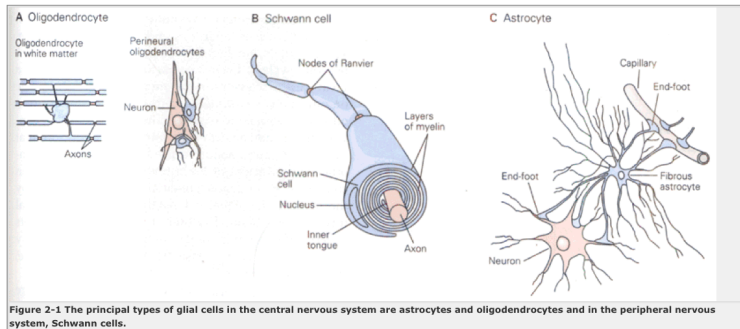
D. Spiny cell



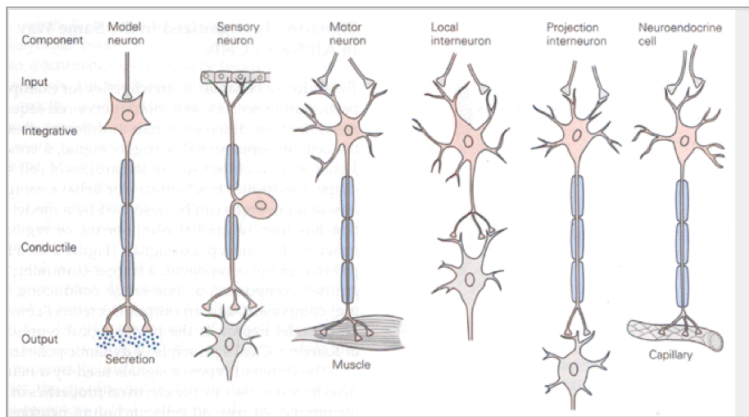
E. Purkinje cell



Glial cells

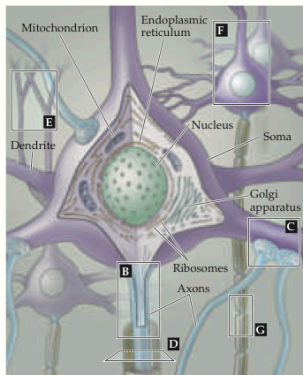


Four components of neurons

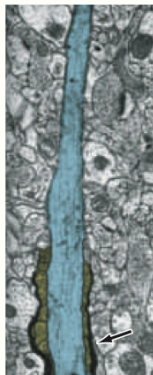


Microscopical features of neurons

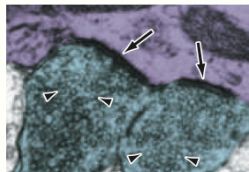
(A)



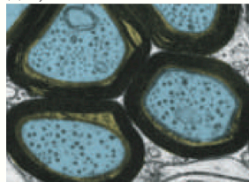
(B) Axon



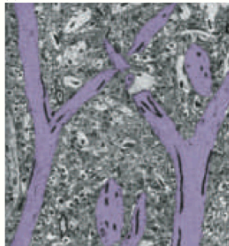
(C) Synaptic endings (terminal boutons)



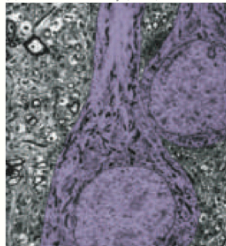
(D) Myelinated axons



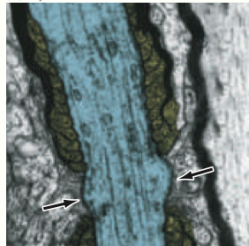
(E) Dendrites



(F) Neuronal cell body (soma)

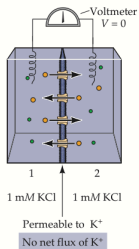


(G) Myelinated axon and node of Ranvier

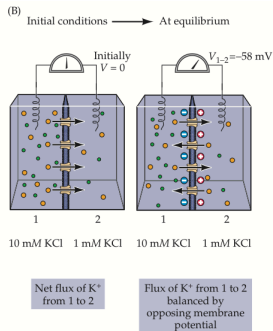


Nerst potential

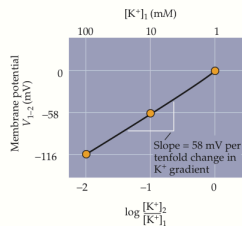
(A)



(B)

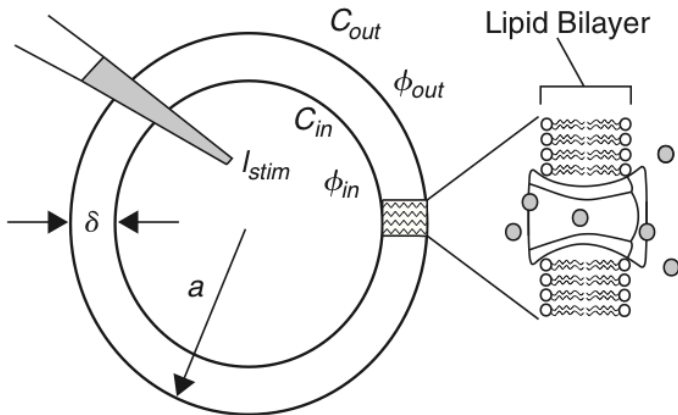


(C)



Calculation of Nerst potential

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



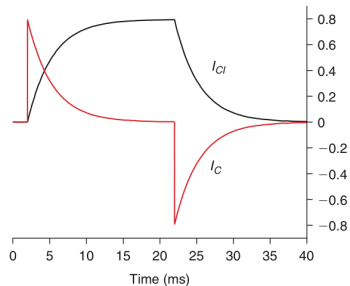
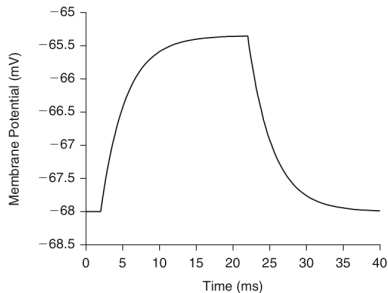
Membrane simulation

- ▶ 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
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- Christof Koch (1999), **Biophysics of computation; information processing in single neurons**, Oxford University Press
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- 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.