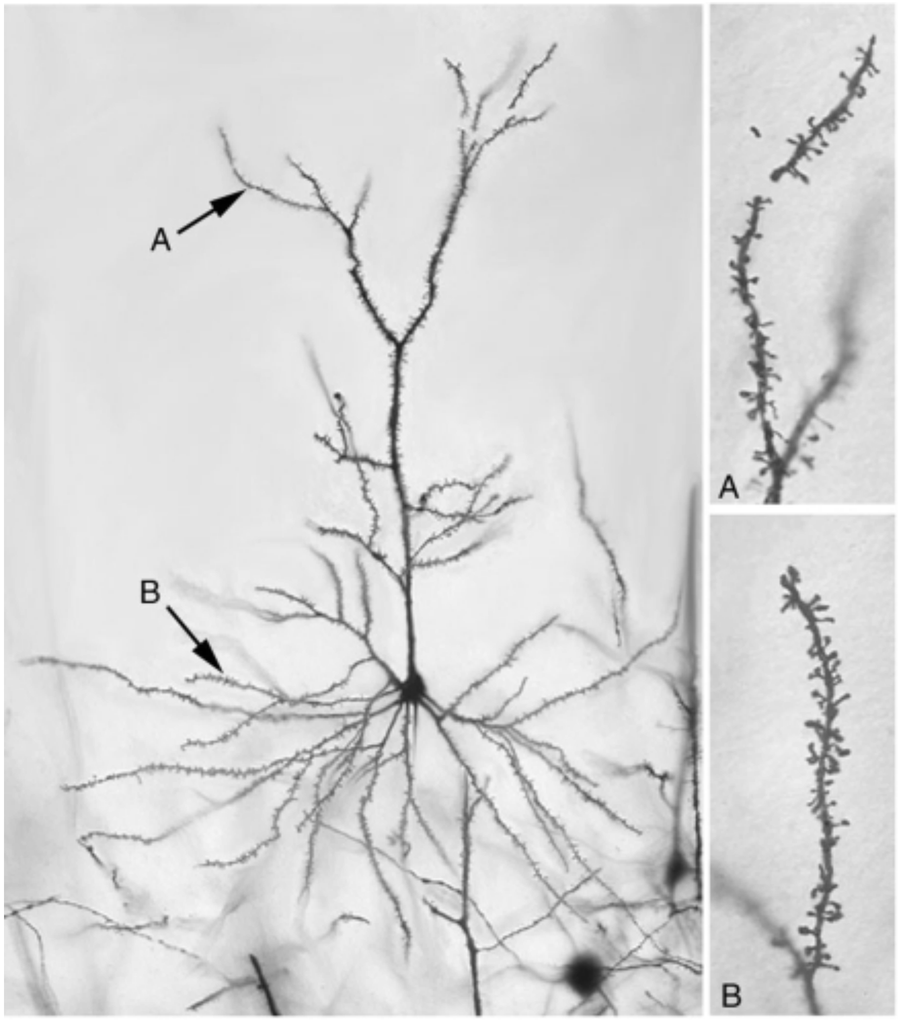
Projects in C++

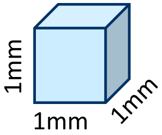
Project 1:
Spiking Network Simulation

A typical cortical pyramidal neuron



- A typical pyramidal neuron in the cortex has some 20,000 synapses
- A Purkinje cell in the cerebellum has even 100,000 synapses

In a cubic millimeter of cortex we find approximately:



- 100,000 neurons.
- 1,000,000,000 synapses

Integrate and fire models

- We use the Leaky Integrate and Fire model or Lapicque model in our project

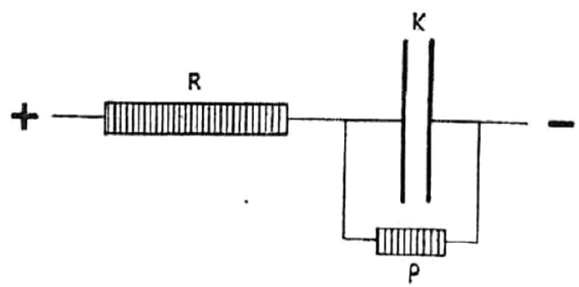


FIG. 1.

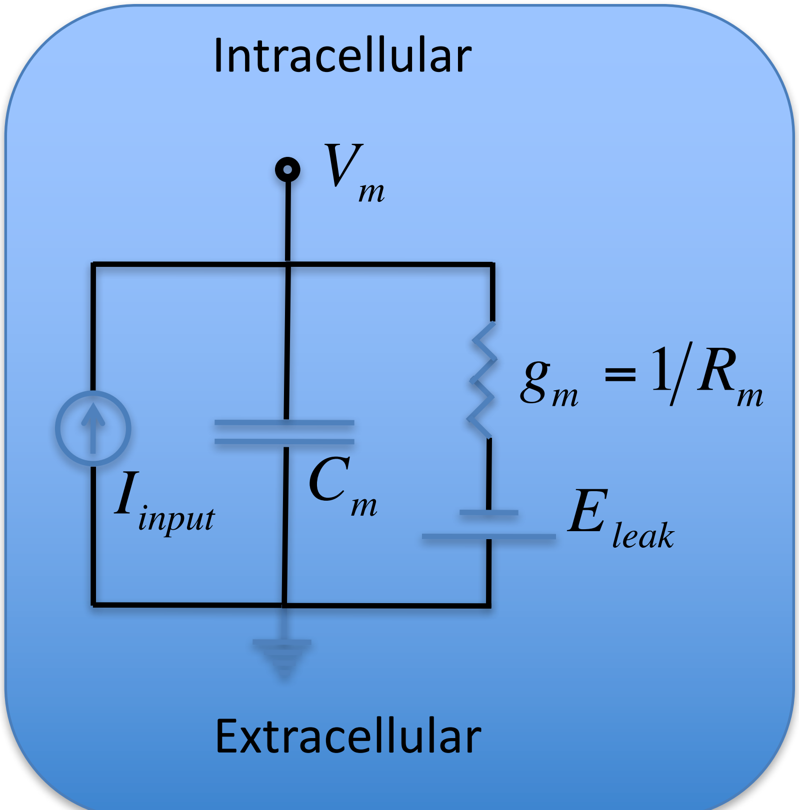
Louis Lapicque (1866 – 1952)

Time Constant: $\tau = R \cdot C$

Lapicque L (1907) Recherches quantitatives sur l'excitabilité'électrique des nerfs traitée comme une polarisation. J Physiol Pathol Gen 9: 620–635.

Integrate and fire models

- Leaky Integrate and Fire



Capacitor Current

$$Q = CV$$

$$\frac{dQ}{dt} = C\frac{dV}{dt}$$

$$I = C_m \frac{dV_m}{dt}$$

Resistor Current

$$V = IR$$

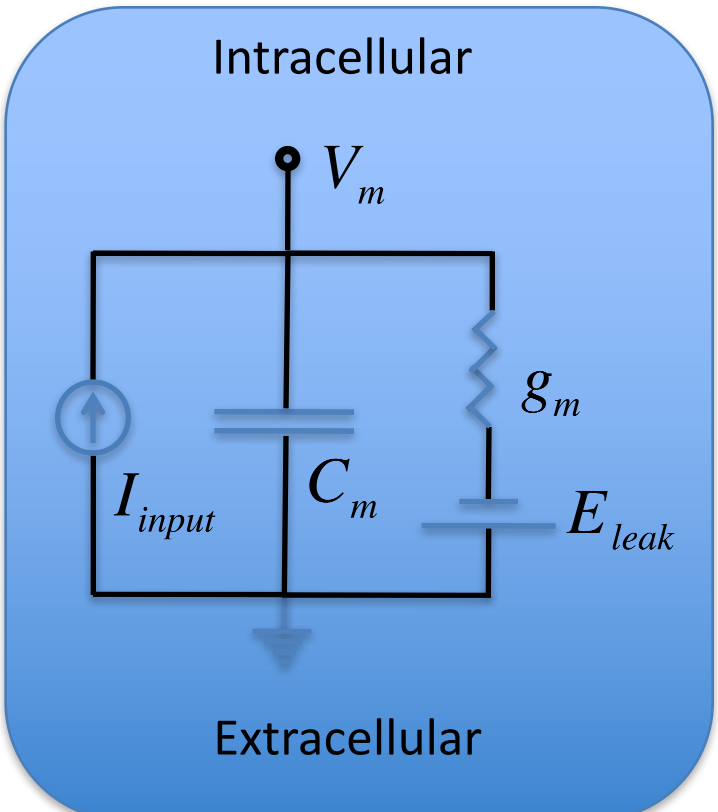
$$I = \frac{V}{R}$$

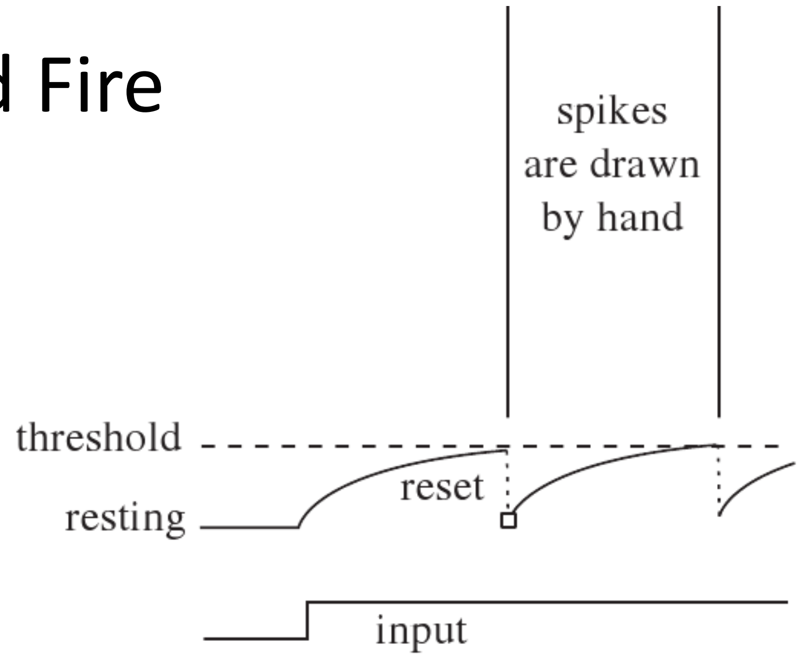
$$I = \frac{E_{leak} - V_m}{R_m}$$

$$C_m \frac{dV_m}{dt} = g_m(E_{leak} - V_m) + I_{input}$$

Integrate and fire models

- Leaky Integrate and Fire





If $V_m \geq V_{threshold}$

Set $V_m = V_{resting}$

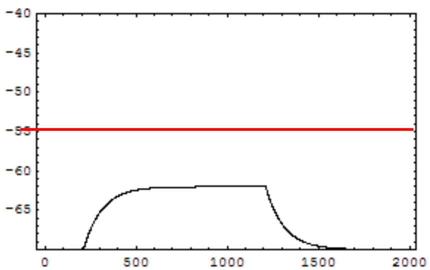
Example: two integrate-and-fire neurons

Membrane potential

$$\tau_m \frac{d}{dt} V = -V + R \sum_s I_s(t) + R \cdot I_{ext}(t)$$

$$\tau_m = R \cdot C$$

Θ



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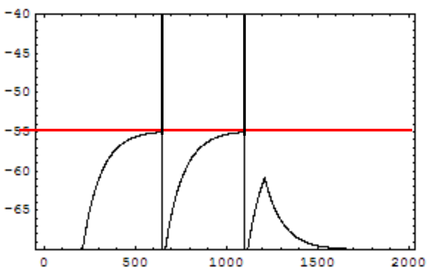

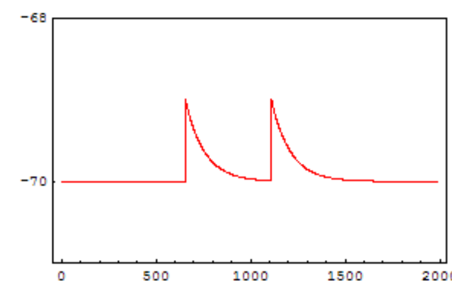

Post-synaptic potential

$$I_s(t) = \sum_i J_i \cdot \delta\left(t - t_i - \Delta_i\right)$$

Post-synaptic currents

Dynamics of Sparsely Connected Networks of Excitatory and Inhibitory Spiking Neurons

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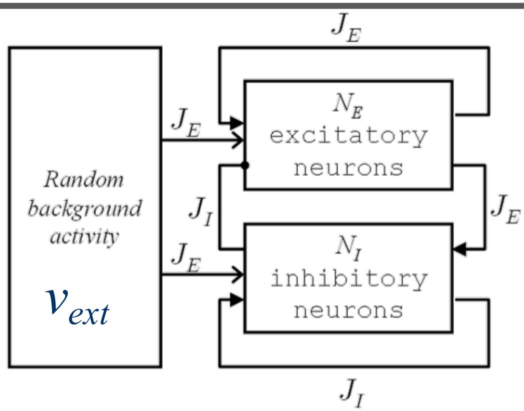
The Brunel's Model of spontaneous activity

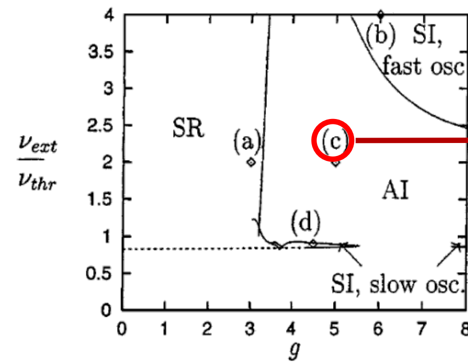


Amit&Brunel (1997); Brunel (2000)

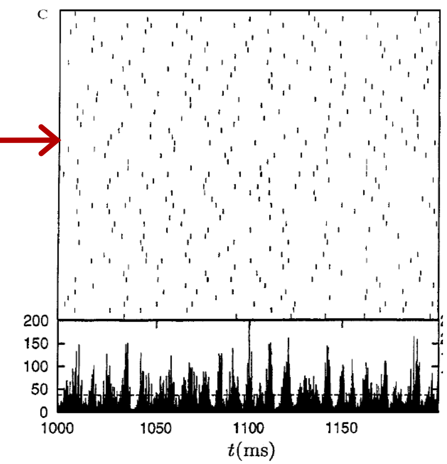
$$C_E = \varepsilon \cdot N_E, \;\; \varepsilon << 1$$

$$\frac{C_I}{C_E} = 0.25, \quad g = \frac{J_I}{J_E}$$

1. N_E excitatory and N_I inhibitory integrate and fire neurons
2. Each neuron receives C_E excitatory and C_I inhibitory connections
3. Every neuron receives additional random input with rate ν_{ext} from the rest of the brain.



Brunel (2000)



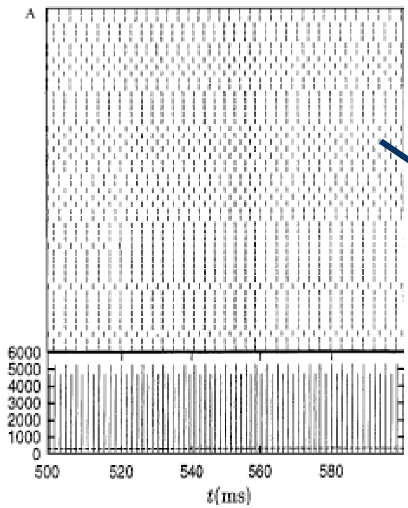
Solution uses mean-field theory, with

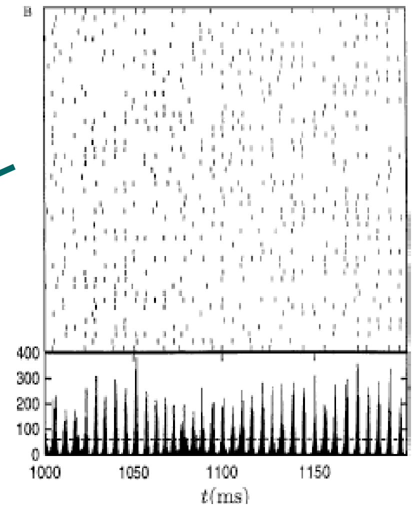
- small weights : J«Θ
- infinitely large networks : N→∞

→Wanted:
Self-consistent states where network and background fire at equal rate.

→Self-consistent states exist and are stable.

Dynamic regimes of balanced networks





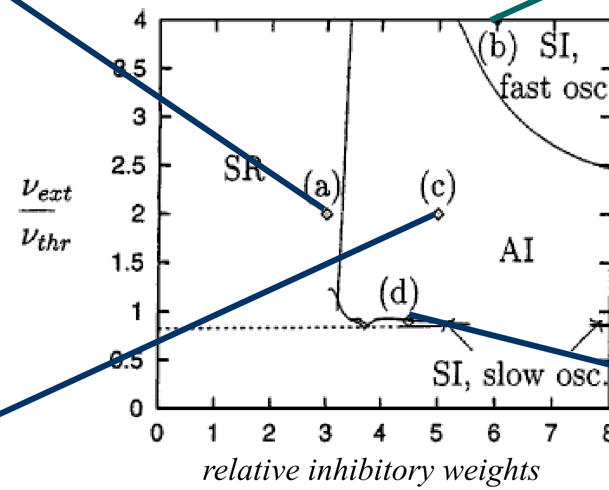
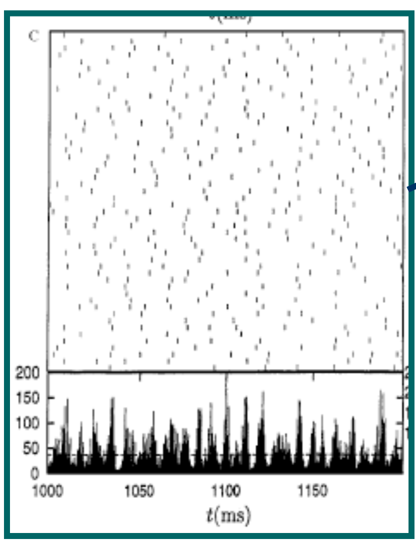
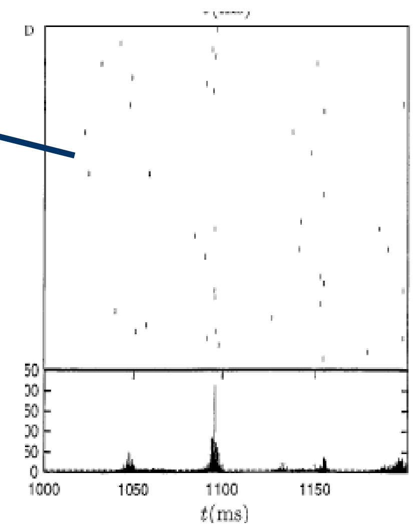


Figure 7. Phase diagram of the network characterized by the parameters of Fig. 8 ($C_E = 1000$, $C_I = 250$, $J = 0.1$ mV, $D = 1.5$ ms). Diamonds indicate the parameter sets chosen for the simulations shown in Fig. 8.





Brunel 2000

Brunel's balanced cortex model

The network model:

- 10 000 excitatory neurons,
- 2500 inhibitory neurons,
- Each neuron receives input from 10% of the other neurons.
- Connection strengths depend on the parameters *g* and *J*.

Nicolas Brunel *Dynamics of sparsely connected networks of excitatory and inhibitory spiking neurons*
J.Comp.Neurosci. 2000 vol 8, 183-208.

Project

1. Implement the recurrent spiking network, described in
   - *Brunel, N J. Comp Neuroscience 2000*.
2. Reproduce at least the results shown in Figure 8 of the paper
3. The network must have at least 12500 neurons with 10% connection probability
4. Program results can be validated against a NEST simulation (see the examples)
   1. www.nest-initiative.org
   2. http://en.wikipedia.org/wiki/NEST_(software))

Acceptance criteria

1. The simulation is written in C++, other languages, e.g. Python or Matlab, may be used for plotting the figures.
2. The code is fully documented for doxygen.
3. The code compiles and links without warnings, using the flags "`-W -Wall --pedantic`"
4. All important features of the project are tested with gtest
5. Compilation, testing, and documentation generation is done with CMAKE.
6. The project is in the EPFL git repository. The project history must be present. Commit early and regularly!