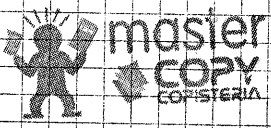
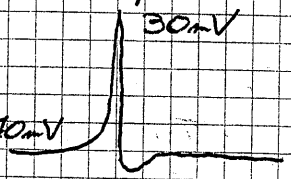
NEURAL MODELING (VALENZA)

Neuroscience is a not well defined discipline. It is a mixture of medicine, engineering and philosophy.
Computational neuroscience has two main branches: neural dynamic modeling and artificial intelligence. Second topic came before; however, we'll deal with the first one.
Brain can be divided on a cytoarchitectonic level, but we're more interested in functional division. This is achieved through Broadmann brear. We are particularly interested in the division of neo-cortex. Neo-cortex can be subdivided in six layers, with increasing dimension, considering a deeper one. Potential produced in deeper level is so high that can be measured

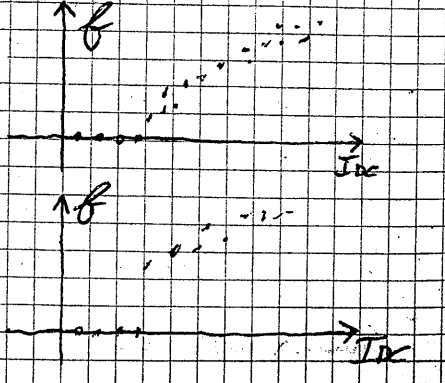


NEURAL SIGNAL

A neuron can be seen as a network with inputs (dendrites), computational centre (soma) and output (axon). In neural modeling, it is important to focus on your aim, on what we want to represent.
The output of a neuron is a spike.



However, in the reality, output dynamics is different. 20 possible outputs to same input can be seen. This doesn't mean only 20 kinds of neuron exists. Moreover, we don't want 20 models, but only one to simulate all these behaviours
Historically, there were three classes of neural excitability, two with frequence dependencies showed and a third one, which produces only one spike, independently by stimulus intensity.
The actual clarification has six kinds of excitability



three of them represent eccitatory neurons, the other three inibitory neurons. An inhibitory neuron will be interpreted as a negative current in input to the next neuron.

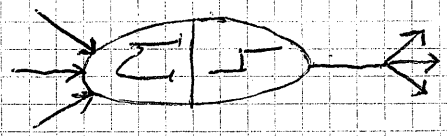
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SINGLE NEURON MODELING

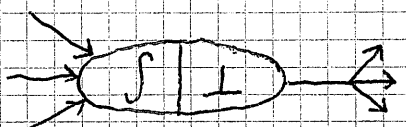
A single-neuron modeling can reproduce its behaviour really detailledly. However, it can require too much time and needs detailed informations, not always available.

Most simple neural model is Mc-Culloch perceptron, where

$$x^{out} = \begin{cases} 1 & \text{if } h > \theta \\ 0 & \text{otherwise} \end{cases}, \quad h = \sum_i x_i^{in}$$

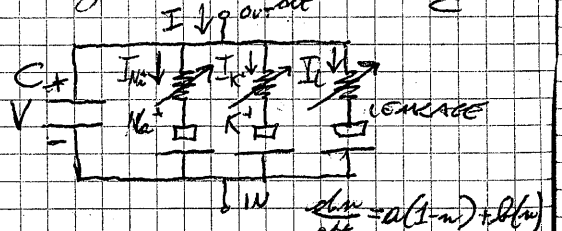


This was then followed by perceptron. It simulates a spiking neural model, where the weighted sum is the integration and activation function produces the spike. However, here time has not been taken into account yet.



The first neural model was Hodgkin-Huxley's. It is complicated and it's inspired to an analog circuit. Here it is possible to estimate membrane potential as a function of conductances. $C\dot{V} = f(g)$. It's a practical model for bridagists, but not for engineers. For a ms of simulation 1200 flops are needed. Flops stand for floating point operations. This model is able to only perform the record historical behaviour showed, with a minimum firing rate of 58 Hz.

$$\frac{dV}{dt} = \frac{I - (I_{Na} + I_K + I_L)}{C}$$

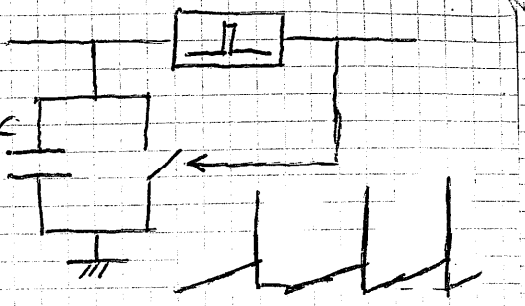


Big thinking precision offered by this model is not needed, so integrate-and-fire model born. By seeing the tendency of spikes, it simply integrates the input. When it overcomes a threshold output goes to 1. It is inspired to a controlled capacitor, by

* Analog equivalent was required, because digital simulation was not so practical yet

remembering that

$$\frac{dv}{dt} = \frac{I}{C} \qquad V(t) = V_{TR} \Rightarrow \text{FIRE + RESET}$$



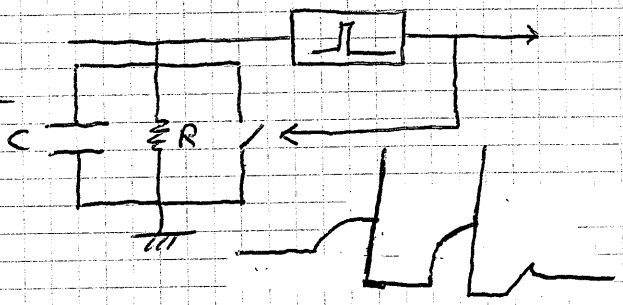
Here, firing rate can be unlimited, integration is perfect, neuronal response is linear

Another one is the leaky integrate-and-fire.

In this one

$$\frac{dv}{dt} = \frac{I}{C} - \frac{v - V_{TR}}{RC} \qquad V(t) = V_{TR} \Rightarrow \text{FIRE + RESET}$$

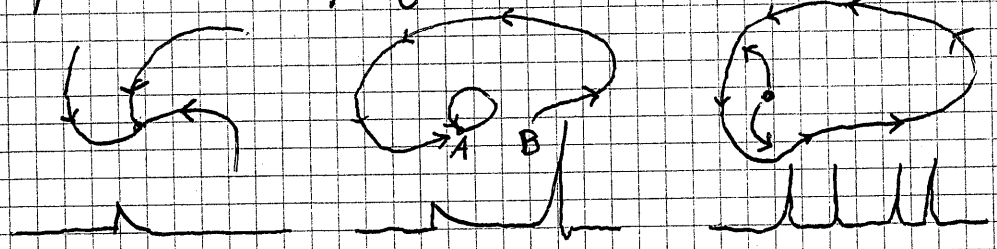
$$V(t) = V_{TR} \Rightarrow \text{FIRE + RESET}$$

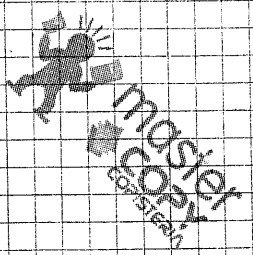


THE PHASE SPACE

Phase space treat neurons as dynamical system. A dynamical system is generally intended as a non-linear system.

In this representation, two variables are plotted one against the other. Phase space has to be thought as a space with specific behaviour





We change the value of input in the time and look at how the output changes in time. Input has to be intended like an equilibrium perturbation

This space is defined through equations of the form

$$\begin{cases} \mu x' = f(x,y) \\ y' = g(x,y) \end{cases}$$

For the complete description of the system, we need a second equation to describe another value, called recovery variable

In this space, assert a lot of models can be

described. Most important is the Izhikevich model.

$$\begin{cases} v' = 0,04v^2 + 5v + 140 - u + I \\ u' = a(bv - u) \end{cases}$$

It is the most efficient, because its computation only needs 13 flops ~~with~~ for ms of simulation. However, it is not a bio-inspired model, but it's capable of simulating all 20 dynamics.

THE INFORMATION IN THE NEURAL SIGNAL

Which feature of a neural signal brings useful information? It is not known yet.
With experiments on frogs, first hypothesis was firing rate (also experiments on vertebral beings). It is defined as

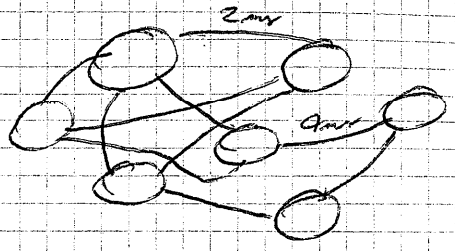
$$r(t) = \frac{1}{\Delta t} \int_{t}^{t+\Delta t} \rho(\tau)\, d\tau$$

(IT IS AN AMBIGUOUS INFORMATION, BECAUSE IT DEPENDS ON CHOSEN THE WINDOW)

Firing rate is calculated with probability distribution of these spikes. So, it is a risky information on its own. It is useful, but not alone, because it is affected by network topology. Time carries relevant informations. It has been demonstrated through theory of neuronal group selection. Edelman demonstrated DNA doesn't provide all the information, but also stochastic rules together through deterministic ones are relevant. Edelman hypothesized brain regions are connected one to each other by neural groups, characterized by biological selection, experience and DNA. There are links ~~be~~ among neural groups, made through reentries, axons much longer than normal ones. Connected areas can be far away from the origin of the signal. Due to these reentries, we cannot avoid taking consideration of time in our analysis anymore.
In implementing a model like Izhikevich one, we have to define weights and delays of connection. Weights

are ~~enhanced~~ enhanced when sincronization occurs in that connection. They are changed through the law

$W = W_0 e^{-t/\tau}$



where t is the delay between two synchronized activations. In running the model, we see 5 oscillation in the first 20 minutes, then no oscillations, and then 5 oscillation after a hour.
All these phenomena are included in Polychronous Neural Group (PNG). A polychronized group ~~is not~~ has group with same behaviour, where activations are delayed in time.
Spike timing is also involved in the theory of working memory.

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ASTROCYTES

Central nervous system is composed not only of neurons, but also of glial cells. Neurons are responsible of electrical activity, glial cells of biochemical activity. Most abundant types of glial cells are astrocytes.
Until '90s, it was thought their role in the system was only methabolic support. Then, the following experiment was performed. In a culture of neurons and astrocytes, bradykinin was introduced. It enhances the concentration of Ca^{2+} in the astrocytes, which propagates ~~in~~ like a wave in all the others. When this wave reached the astrocyte near a synapse, ~~it is~~ Ca^{2+} ~~is~~ flows into the neuron, so its activity is enhanced.
Then, other experiments occurred, bringing as discoveries other important functions:

- stimulation and inhibition of synapse formation;
- induction and maintenance of synaptic plasticity;
- neurological disorders and neurodegenerative diseases.