What we mean by computational

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today we will learn

- what is neuroscience
- What we mean by computational Neuroscience?
- solve simple equation with python
- we will learn what is mne

- introduce some useful packages
- ...

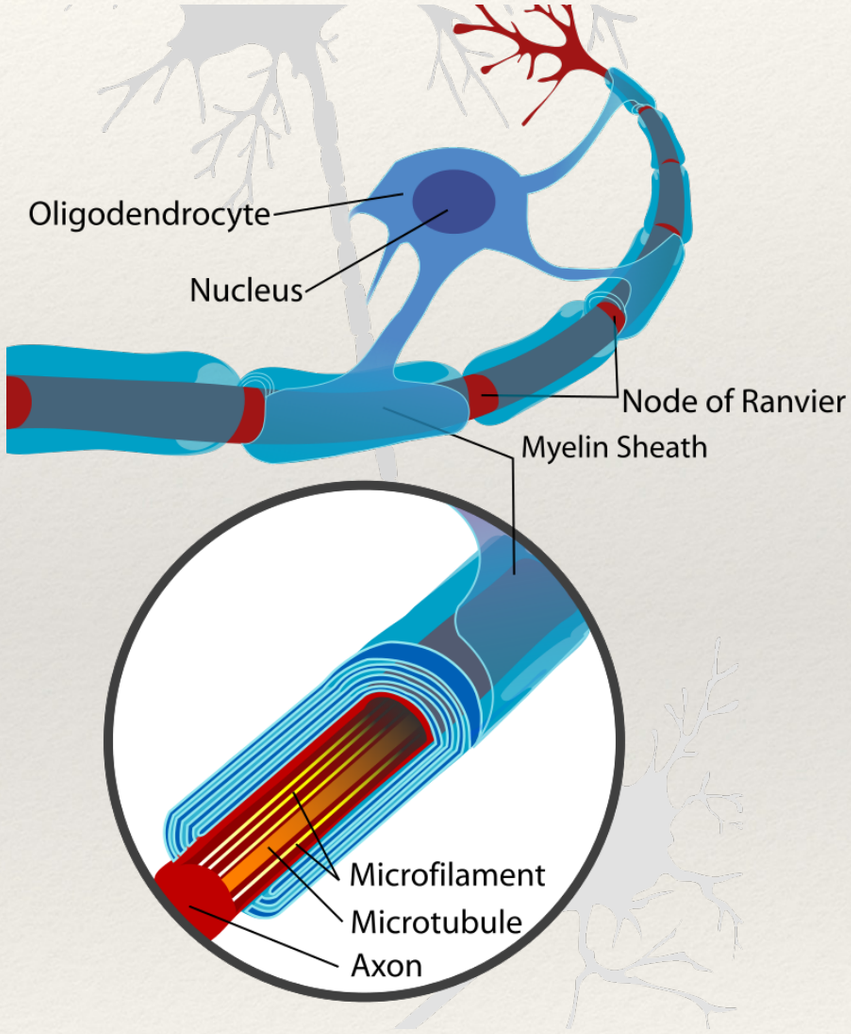
Neuroscience is by far the most exciting branch of science because the brain is the most fascinating object in the universe. Every human brain is different - the brain makes each human unique and defines who he or she is.

— *Stanley B. Prusiner*

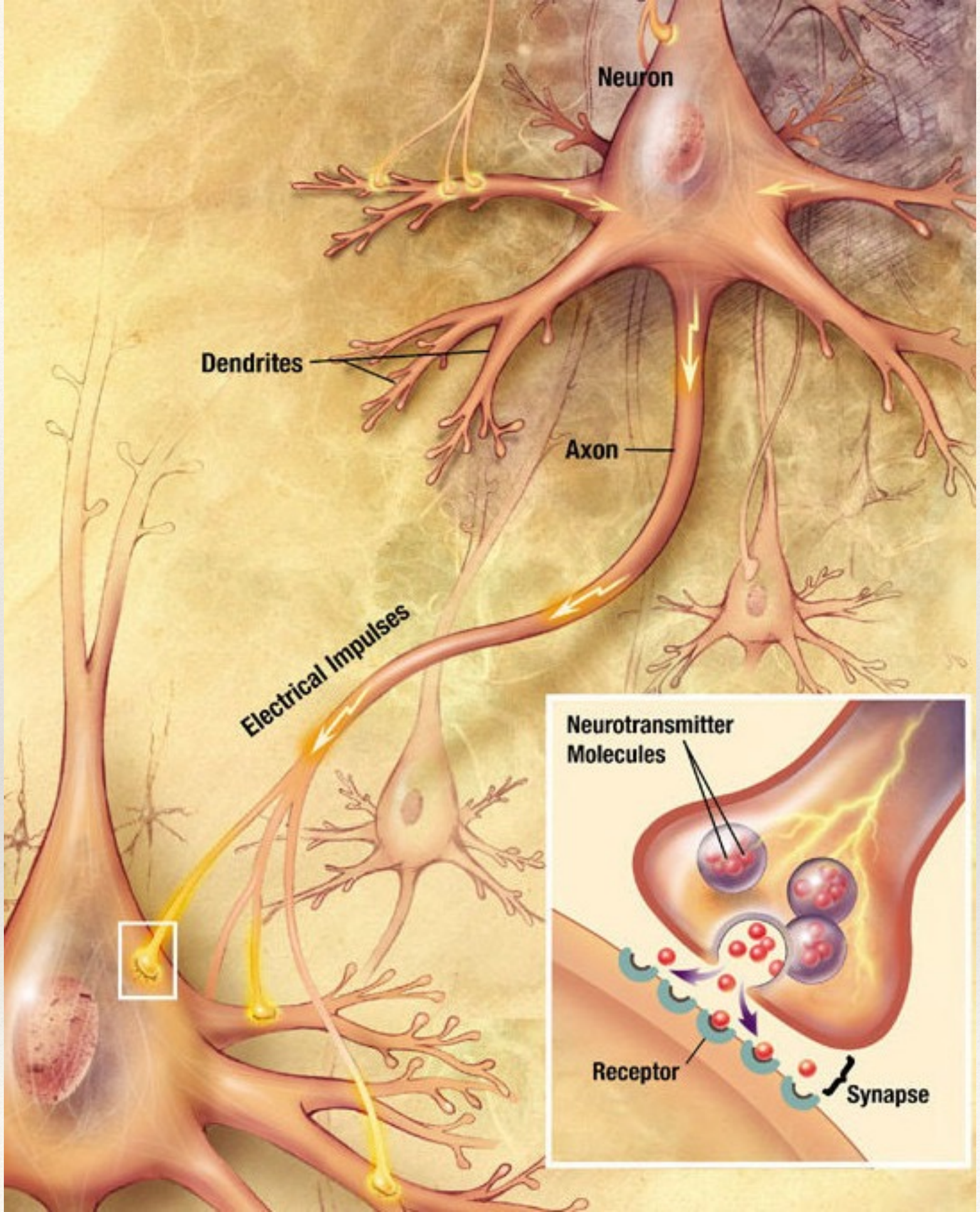
what is neuroscience?

- Neuroscience is the scientific study of the nervous system.
- it is currently an interdisciplinary science that collaborates with other fields such as chemistry, cognitive science, computer science, engineering, linguistics, mathematics, medicine (including neurology), genetics, and allied disciplines including philosophy, physics, and psychology.

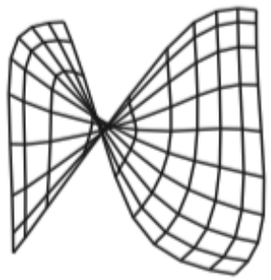
what is Central nervous system?

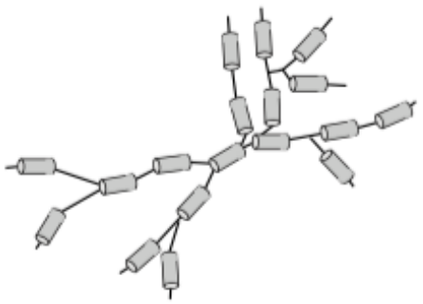


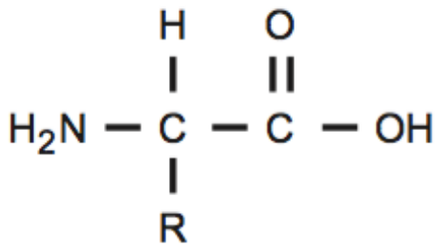
- The central nervous system CNS is responsible for integrating sensory information and responding accordingly. It consists of two main components:
- The spinal cord serves as a conduit for signals between the brain and the rest of the body. It also controls simple musculoskeletal reflexes without input from the brain.
- The brain is responsible for integrating most sensory information and coordinating body function, both consciously and unconsciously. Complex functions such as thinking and feeling as well as regulation of homeostasis are attributable to different parts of the brain.


Neuron
Dendrites
Axon
Electrical Impulses
Neurotransmitter Molecules
Receptor
Synapse

- There are two general types of tissue in the CNS:
- Gray matter consists of nerve cell bodies, dendrites, and axons. Neurons in gray matter organize either in layers, as in the cerebral cortex, or as clusters called nuclei.
- White matter consists mostly of axons, causing it to look white due to the myelin sheathing of the axons.







1 m — CNS

10 cm — System

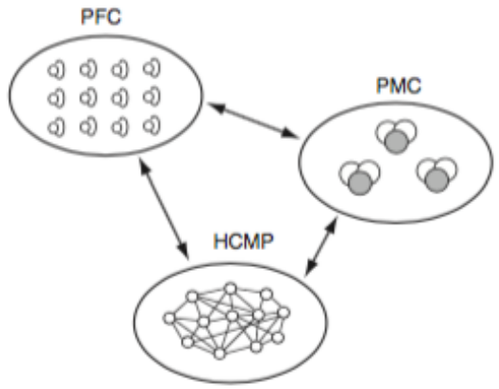
1 cm — Maps

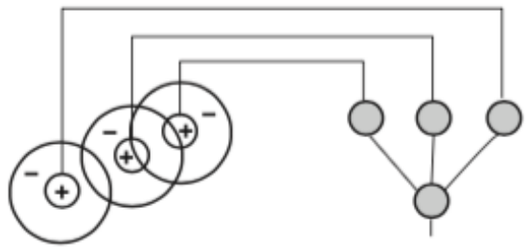
1 mm — Networks

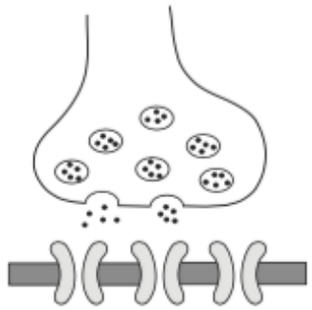
100 µm — Neurons

1 µm — Synapses

1 Å — Molecules







what is action potential

- an action potential is a short-lasting event in which the electrical membrane potential of a cell rapidly rises and falls
- An action potential is part of the process that occurs during the firing of a neuron

- Action potentials in neurons are also known as "nerve impulses" or "spikes", and the temporal sequence of action potentials generated by a neuron is called its "spike train". A neuron that emits an action potential is often said to "fire".

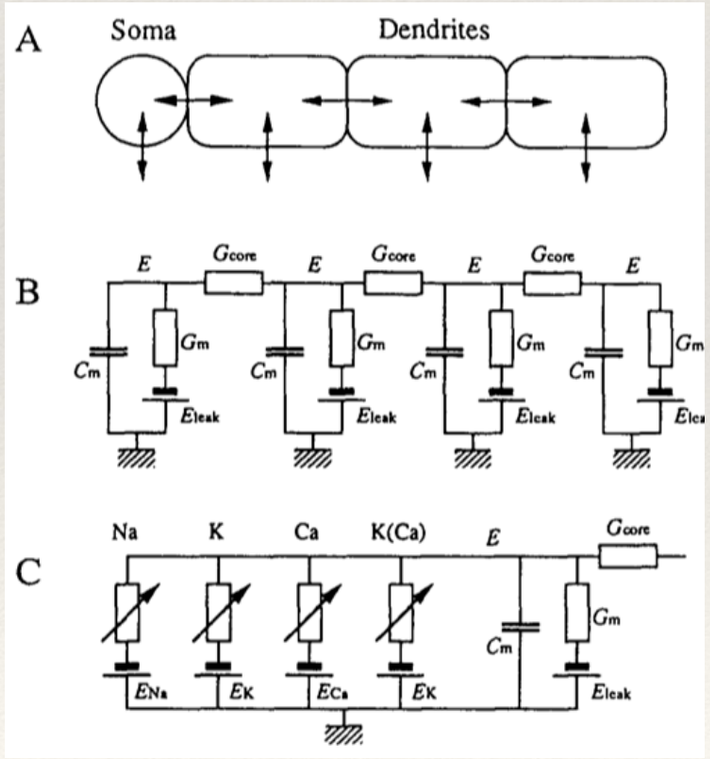
leaky Integrate and Fire

- In the leaky integrate-and-fire model, the memory problem is solved by adding a "leak" term to the membrane potential, reflecting the diffusion of ions that occurs through the membrane when some equilibrium is not reached in the cell.

$$\tau_m \frac{dv}{dt} = -v(t) + RI(t)$$

hodgkin huxley model

- The Hodgkin–Huxley model connects between ion currents crossing the neuron cell membrane to the membrane voltage



$$\frac{dE}{dt} = \frac{(E_{leak} - E)G_m + \sum \left(E_{comp} - E\right)G_{core} + I_{channels}}{C_m}$$

$$I_{Na} = (E_{Na} - E_{soma})G_{Na}m^3h$$

others

- Exponential integrate-and-fire
- FitzHugh–Nagumo
- Morris–Lecar
- Hindmarsh–Rose
- The Two State Markov Model
- ….

The brain is like a massive LEGO set, where each of the individual pieces is quite simple (like a single LEGO piece), and all the power comes from the nearly infinite ways that these simple pieces can be recombined to do different things

–Michael C. Frank

dynamical System

- a dynamical system is a system in which a function describes the time dependence of a point in a geometrical space.
- At any given time a dynamical system has a state given by a set of real numbers (a vector) that can be represented by a point in an appropriate state space

$$\frac{dx}{dt} = Ax - Bxy$$

$$\frac{dy}{dt} = -Cy + Dxy$$

predator prey model

- are a pair of first-order, non-linear, differential equations frequently used to describe the dynamics of biological systems in which two species interact, one as a predator and the other as prey
- for a set of fixed positive constants A (the growth rate of prey), B (the rate at which predators destroy prey), C (the death rate of predators), and D (the rate at which predators increase by consuming prey), the following conditions hold

$$\begin{aligned}
\frac{\mathrm{d}x}{\mathrm{d}t} &= \sigma(y - x), \\
\frac{\mathrm{d}y}{\mathrm{d}t} &= x(\rho - z) - y, \\
\frac{\mathrm{d}z}{\mathrm{d}t} &= xy - \beta z.
\end{aligned}$$

$$\frac{\partial}{\partial t}\left(\nabla^2 \phi\right) = \frac{\partial \psi}{\partial z}\,\frac{\partial}{\partial x}\left(\nabla^2 \psi\right) - \frac{\partial \psi}{\partial x}\,\frac{\partial}{\partial z}\left(\nabla^2 \psi\right) + \nu\,\nabla^2\left(\nabla^2 \psi\right) + g\,\alpha\,\frac{d\,T}{d\,x}$$

$$\frac{\partial T}{\partial t} = \frac{\partial T}{\partial z}\,\frac{\partial \psi}{\partial x} - \frac{\partial \theta}{\partial x}\,\frac{\partial \psi}{\partial z} + \kappa\,\nabla^2\,T + \frac{\Delta\,T}{H}\,\frac{\partial \psi}{\partial x}.$$

lorenz model

- The Lorenz system is a system of ordinary differential equations (the Lorenz equations, note it is not Lorentz)
- It is notable for having chaotic solutions for certain parameter values and initial conditions.
- In particular, the Lorenz attractor is a set of chaotic solutions of the Lorenz system which, when plotted, resemble a butterfly.

Computational neuroscience

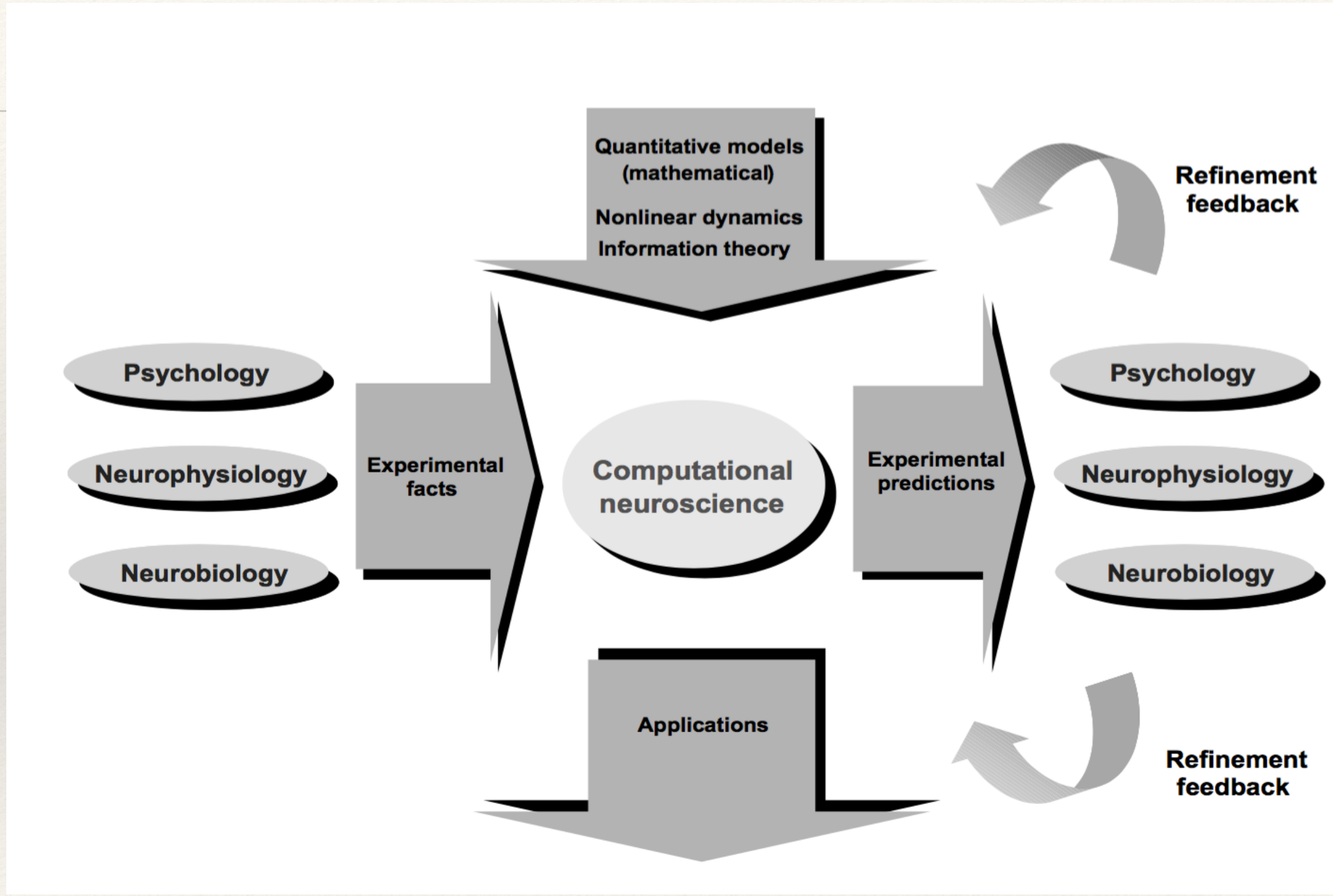
- mathematic
- physics
- computer science
- statistics
- neuroscience
- .....

some routine computational neuroscience major

- Single Neuron Modeling
- Cognition, discrimination, and learning
- Clinical Neuroscience
- Sensory processing
- memory and synaptic plasticity
- behaviours of networks

why should we use python (my reason)

- easy integration of C code for performance
- advances programming tools , scale well
- huge range of libraries from all areas


Quantitative models
(mathematical)
Nonlinear dynamics
Information theory
Refinement
feedback
Psychology
Neurophysiology
Neurobiology
Experimental
facts
Computational
neuroscience
Experimental
predictions
Psychology
Neurophysiology
Neurobiology
Applications
Refinement
feedback

neural network property

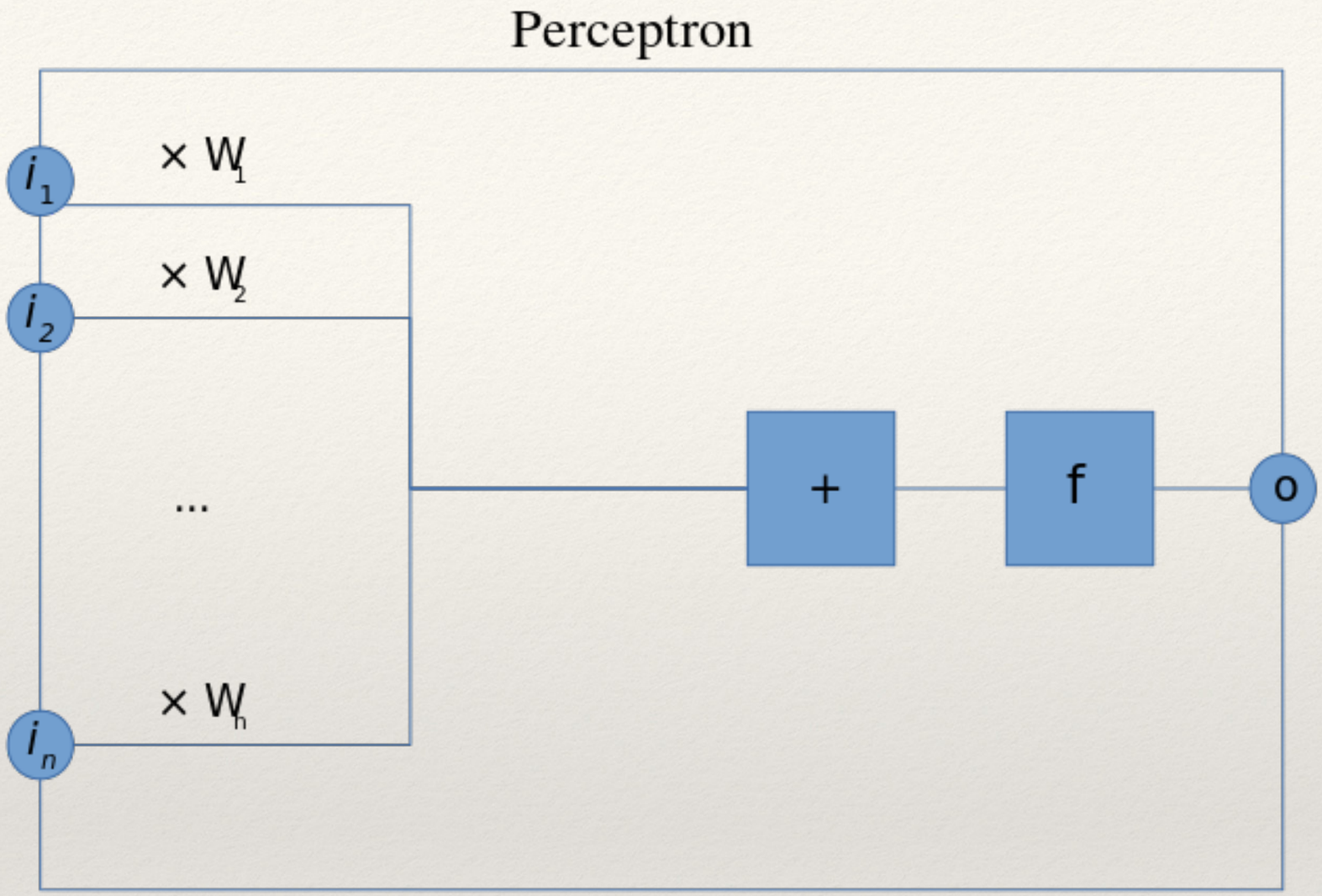
- nonlinearity
- parallelism
- contextual processing
- adaptivity
- graceful degradation

neural network applications

- aerospace: aircraft autopilot systems
- Banking : Credit card Evaluation, Credit card fraud
- military : sonar object classification; image identification; who knows what else
- Industrial : process control; equipment failure prediction
- medical : diagnosis; screening

Rosenblatt

- In the modern sense, the perceptron is an algorithm for learning a binary classifier: a function that maps its input x (a real-valued vector) to an output value f(x) (a single binary value):
- if w.x+b > 0 : return 1 else : return 0



$$o = f\left(\sum_{k=1}^{n} i_k \cdot W_k\right)$$

Multi Layer Network

- A multilayer perceptron (MLP) is a feedforward artificial neural network model that maps sets of input data onto a set of appropriate outputs
- MLP utilizes a supervised learning technique called backpropagation for training the network.

Unsupervised Learning

- Unsupervised learning is the machine learning task of inferring a function to describe hidden structure from unlabeled data
- Among neural network models, the self-organizing map (SOM) and adaptive resonance theory (ART) are commonly used unsupervised learning algorithms.

Hopfield network

- content-addressable memory systems
- binary threshold nodes.
- They are guaranteed to converge to a local minimum
- but convergence to a false pattern (wrong local minimum) rather than the stored pattern (expected local minimum) can occur
- .Hopfield networks also provide a model for understanding human memory

MNE is a community-driven software package designed for for processing electroencephalography (EEG) and magnetoencephalography (MEG) data providing comprehensive tools

–MNE Web Sites

why m/eeg?

- M/EEG captures both slowly and rapidly changing dynamics of brain activations at a millisecond time resolution. This enables the investigation of neuronal activity over a wide range of frequencies that can offer potentially complementary insights regarding how the brain works as a large system

(API) and Data Structures

- M/EEG data analysis typically involves three types of data containers coded in MNE-Python as Raw, Epochs, and Evoked objects

- The raw data comes straight out of the acquisition system
- these can be segmented into pieces often called epochs or trials
- which generally correspond to segments of data after each repetition of a stimulus; these segments can be averaged to form evoked data.

why python (mne reason)

- Python is a real language that allows to design clean and powerful APIs (e.g. can be object oriented)
- Runs on all systems (Linux, Mac and Windows)
- Free
- Full control of the memory you use for your analysis
- Packaging, software engineering tools are shared across disciplines (not only scientific computing)
- Parallel processing
- Caching functions

what we can do with mne?

- Process raw files: In short everything you do with mne_process_raw (filtering, computing SSP vectors, downsampling etc.)
- Independent Component Analysis: on raw and epochs data.
- Epoching: Define epochs, baseline correction, drop bad epochs, handle epochs across conditions etc.
- Averaging to get Evoked data
- Compute contrasts between conditions, between sensors, across subjects etc.
- Linear inverse solvers (dSPM, MNE, MxNE, beamformer)
- Interactive MNE source estimates visualization
- Time-frequency analysis with Morlet wavelets (induced power, phase lock value) also in the source space
- Connectivity Estimation visualize and analyse connectivity between sensors or between ROIs in source space.
- Non-parametric statistics in time, space and frequency (including with cluster-level)
- Scripting (batch and parallel computing)
- Export data embedded export to other Python libraries, i.e. NiTime and Panda, using methods provided for raw, epochs, and evoked objects

Conclusion

some awesome package

- neurotools
- mdp-tools
- brain2
- OpenElectrophy
- libNeuroML
- and Sumatra

thank you