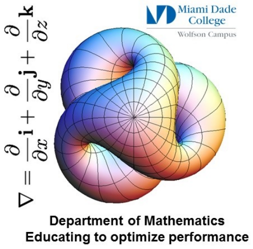

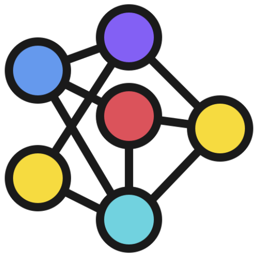

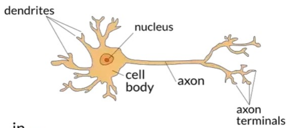

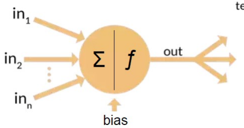

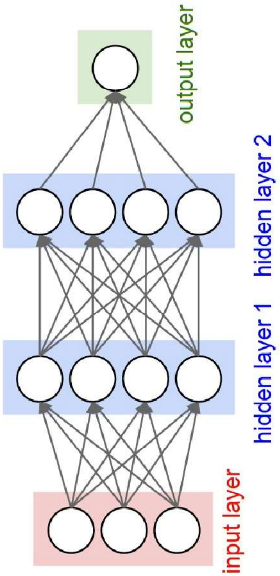

Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

David Quesada – Saliba

Department of Mathematics, Wolfson Campus, Miami Dade College,300 NE 2nd Avenue, Miami FL 33132

Abstract:

The present communication is aimed at creating the biophysical and mathematical foundations for the understanding of the current trends in the use of Machine Learning, Networks, and Artificial Intelligence in the study of Neuroscience. Besides that, these foundations will permit to define the methodologies behind Cognitive Neuroscience, Neuromorphic Computing, Quantum Machine Learning, and Quantum Artificial Neural Networks.

Resumen:

La presente comunicación va dirigida a crear las bases teóricas en matemática y biofísica para comprender los modelos usados en el Aprendizaje de Máquina, Redes, e Inteligencia Artificial para el estudio de las Neurociencias. Además, estas bases permitirán definir las metodologías detrás de la Neurociencia del Conocimiento, Computación Neuromórfica, Aprendizaje de Máquina Cuántico y Redes Neuronales Artificiales Cuánticas.

$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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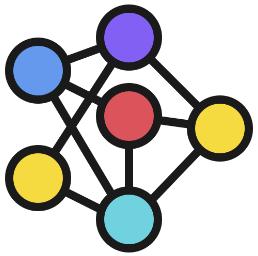
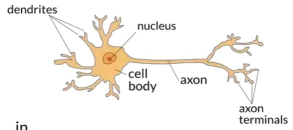
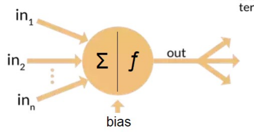
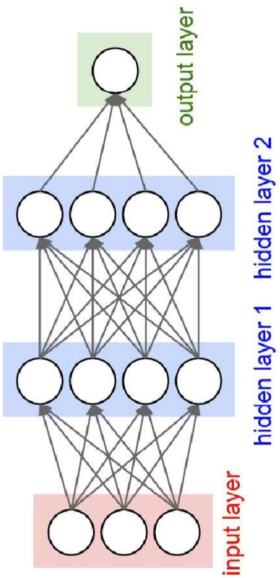








Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Tentative Layout

Context of the presentation and the topic.

Part 1: The foundations: dynamical systems, and complex networks in Brain Science.

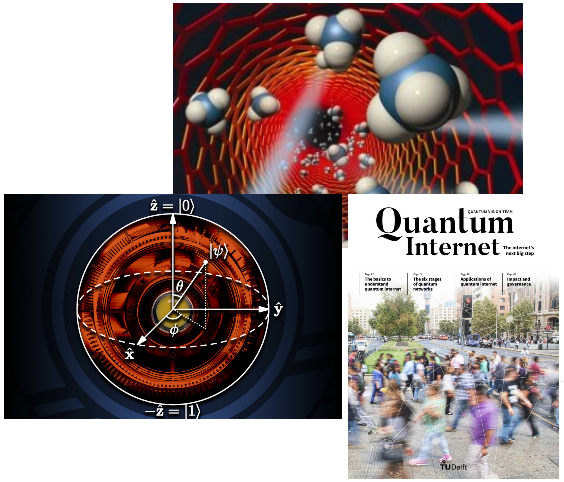
- History of the problem.
- Computational Neuroscience and Dynamical Systems.
- Graph theory, networks, feedback loops.
- Brain networks: anatomical, functional, and layered.

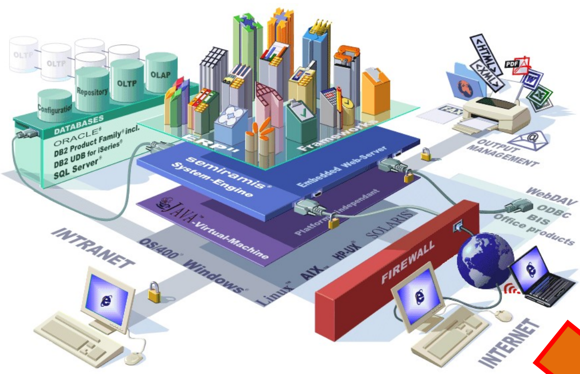
Part 2: Deep Learning, Machine Learning, and Artificial Intelligence in Brain Science.

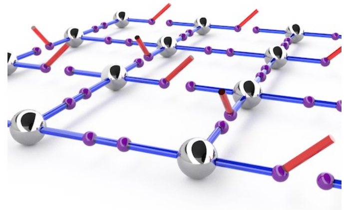
- Machine learning for Brain Science fundamentals.
- Artificial Neural Networks for Brain Science.
- Artificial Intelligence for and from Brain Science.
- Neuromorphic Computing, Quantum Computing, Quantum Machine Learning and Brain Science.

Current Context

Big Data and Data Analytics
(Information Revolution)

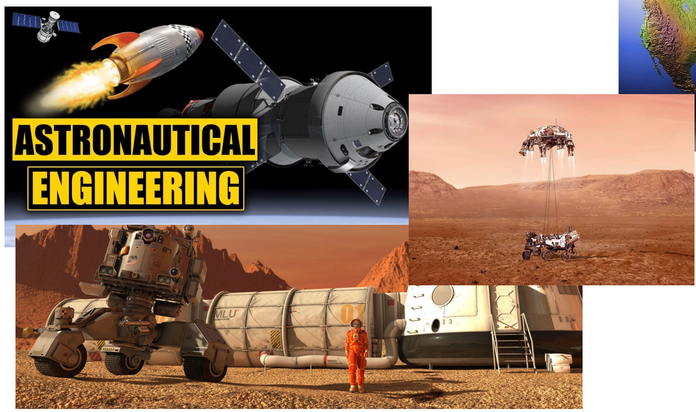






Nanotechnology
Quantum Computing
(Quantum Revolution)

Graph Theory and
Networks (Quantum)



Bioinformatics
Biomedical Engineering
Personalized Medicine
Physiome, MyExposome,
Quantum Biology

Space and Materials
Engineering

Global Warming
Biometeorology
Environment

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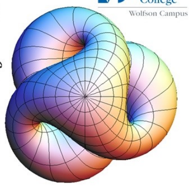

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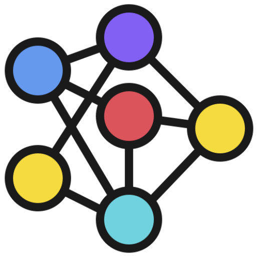
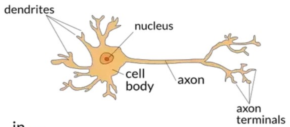
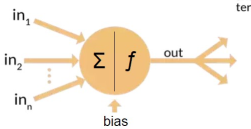
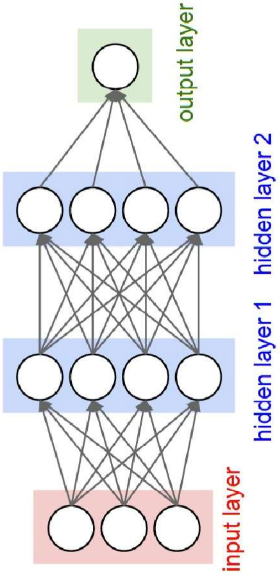
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

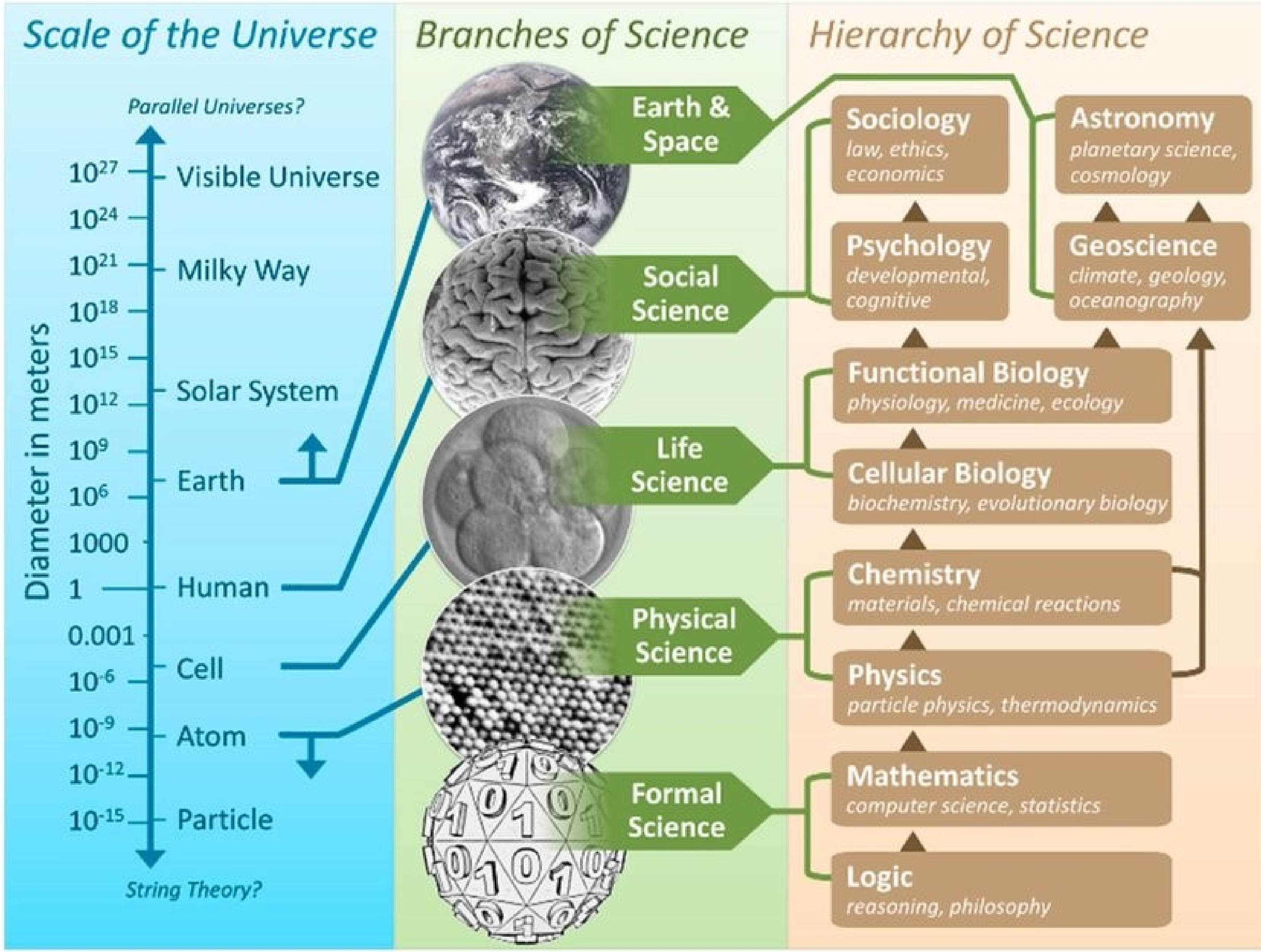
The context of the topic











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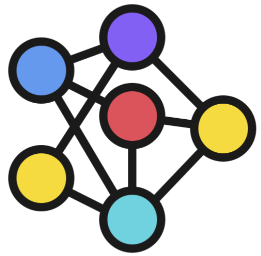
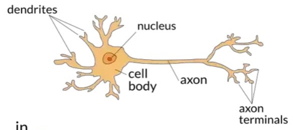
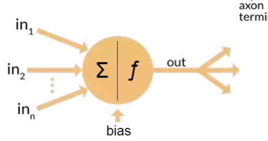
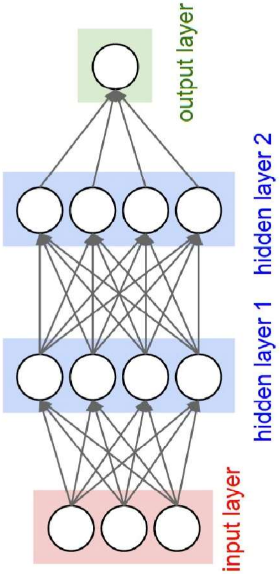
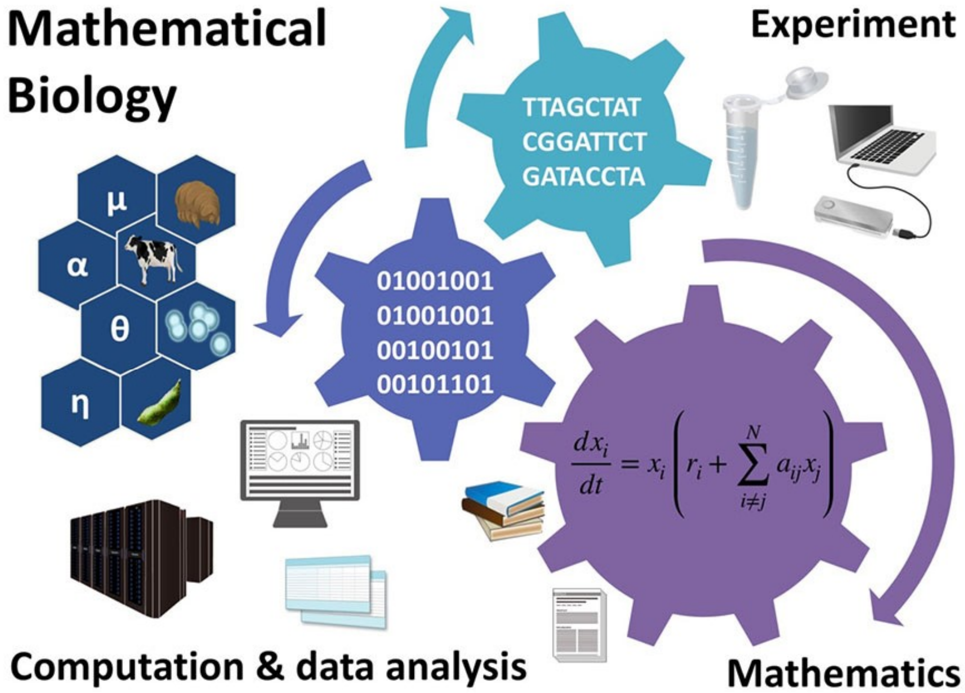


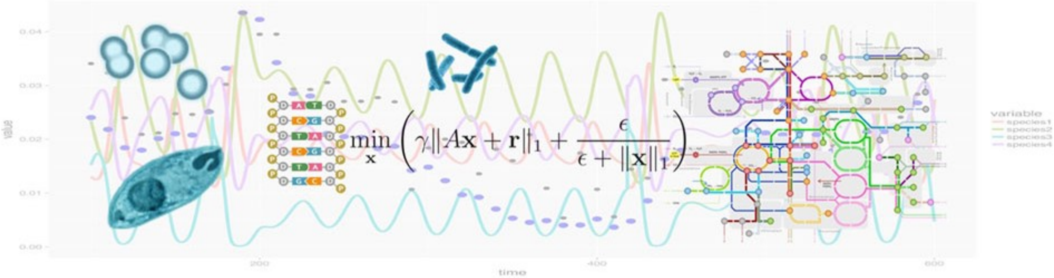






"… **Mathematics** compares the most **diverse phenomena** and discovers the secret analogies that **unite them**… "
Joseph Fourier





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Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

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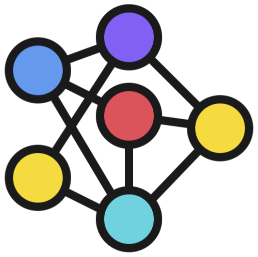

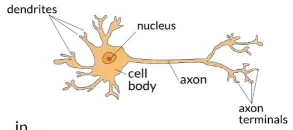

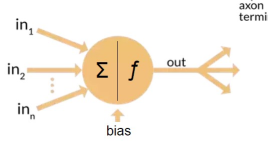

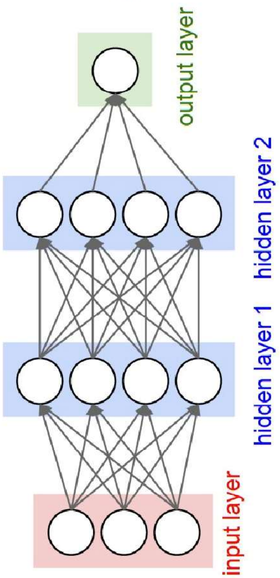

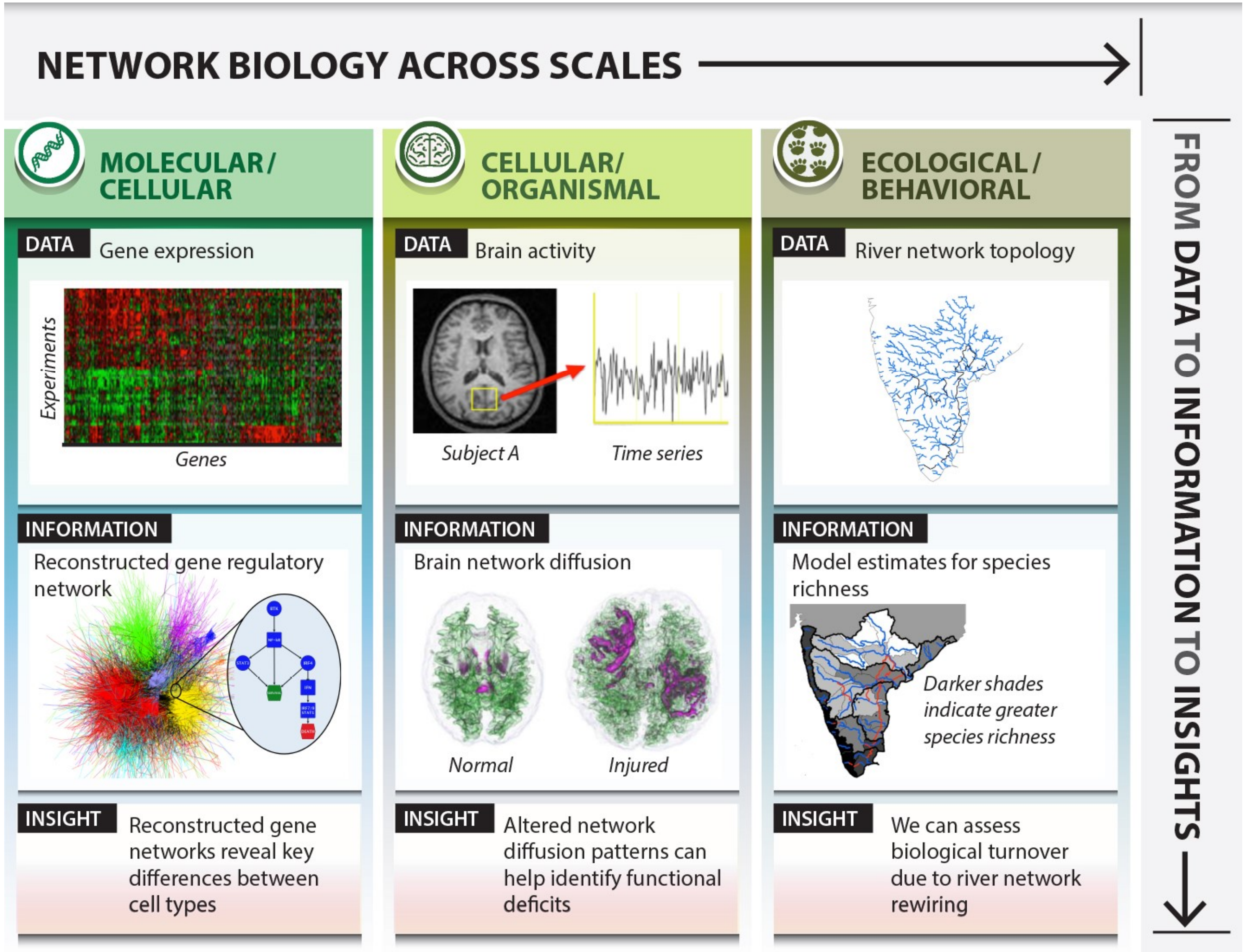

$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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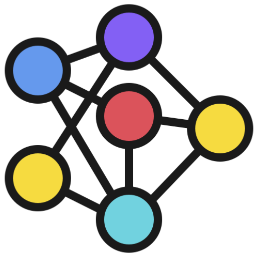
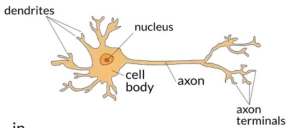
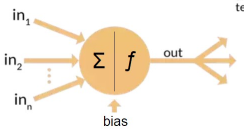
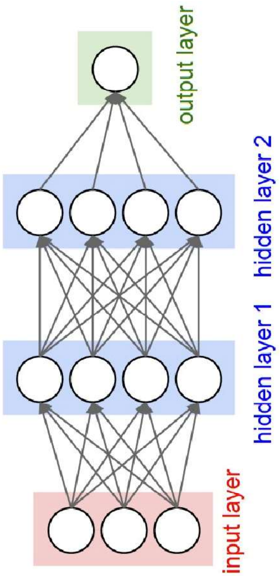
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

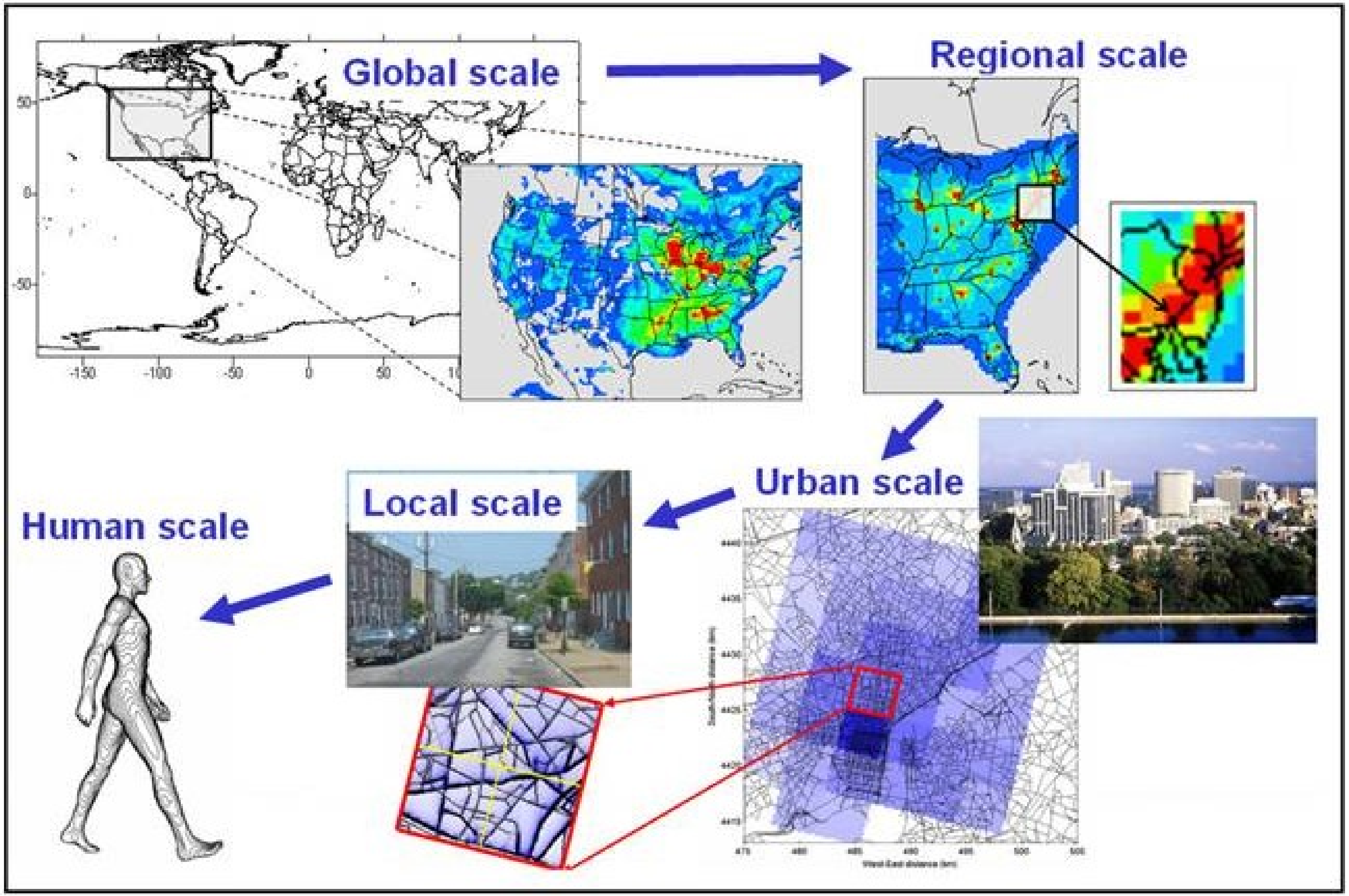
Scales of Modeling and the love for Fractions !!!











$$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$$

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Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

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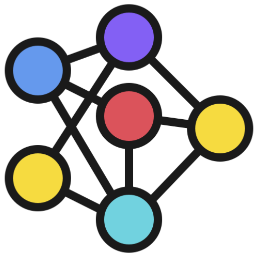

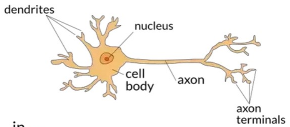

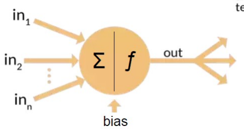

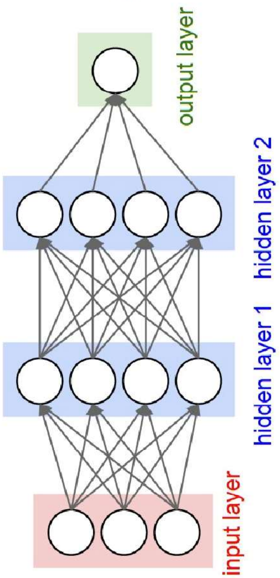

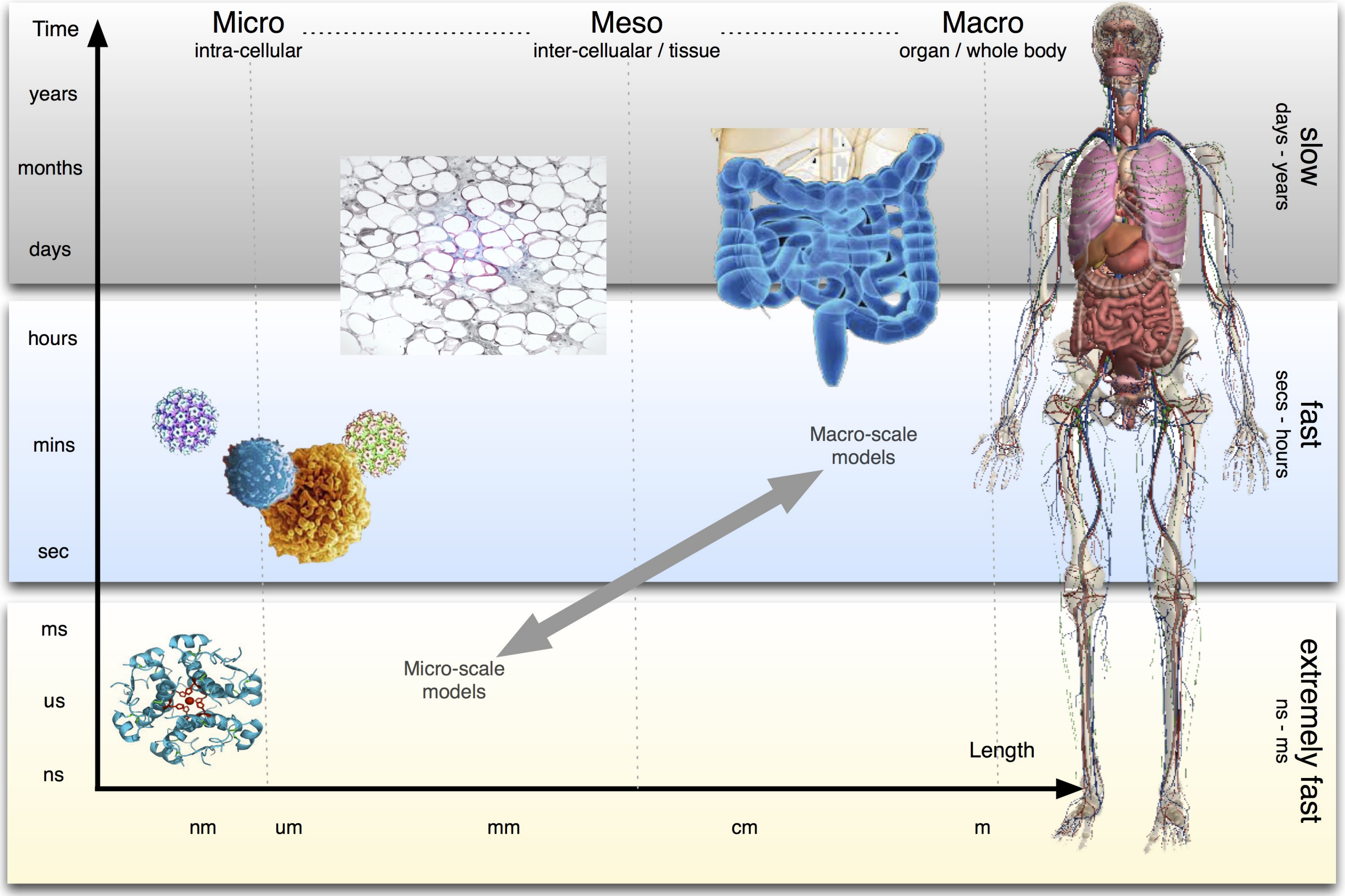

Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

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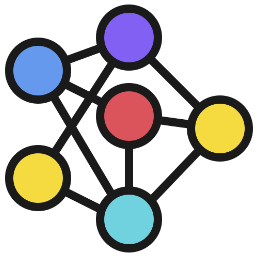
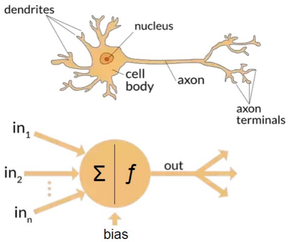
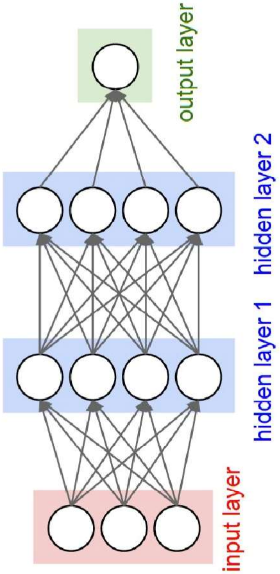
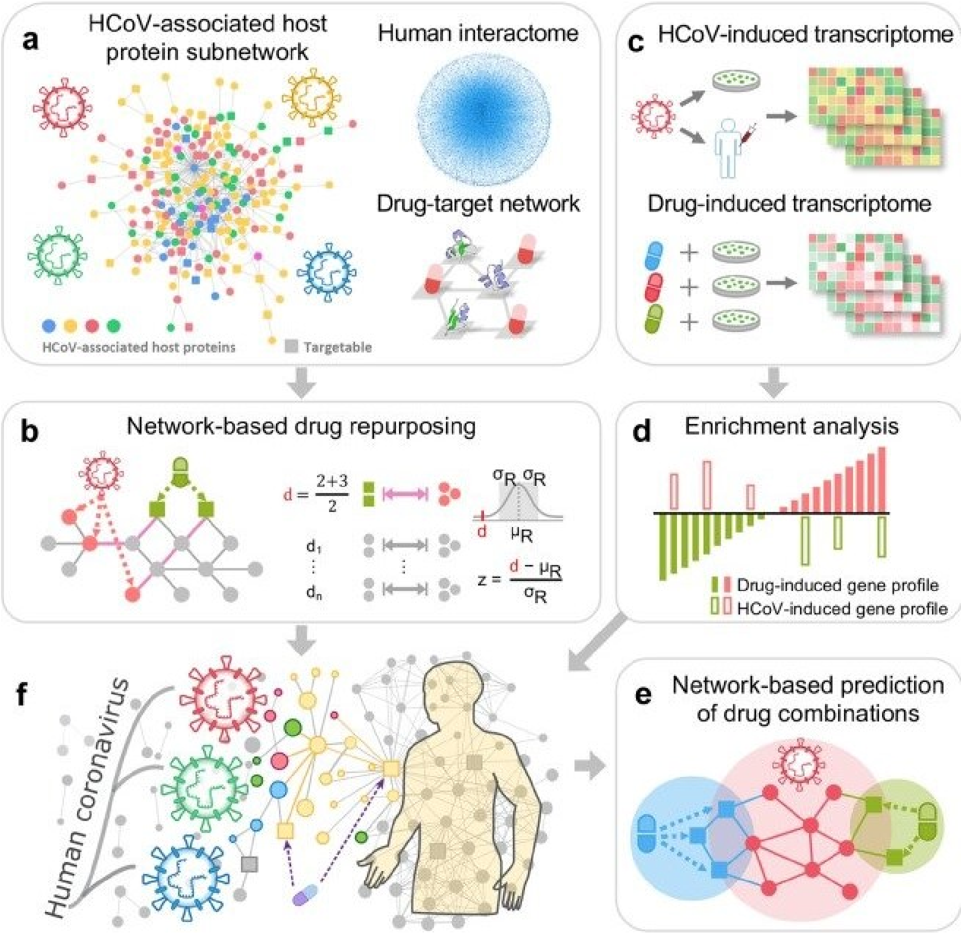
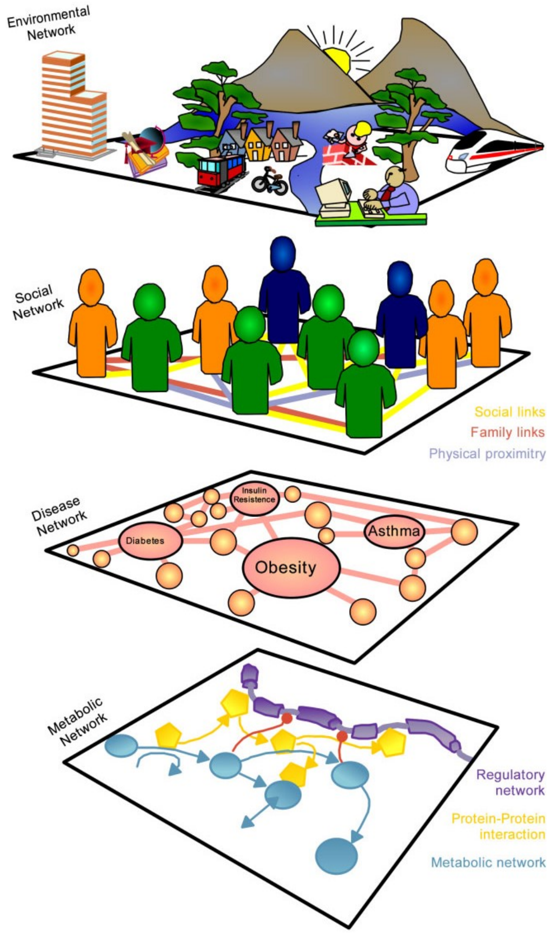
Network Medicine and Systems Biology











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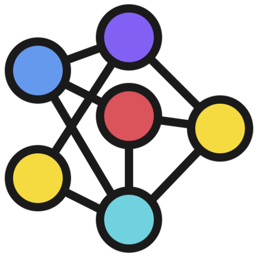

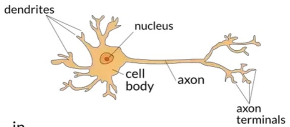

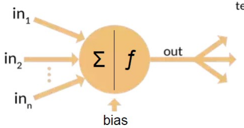

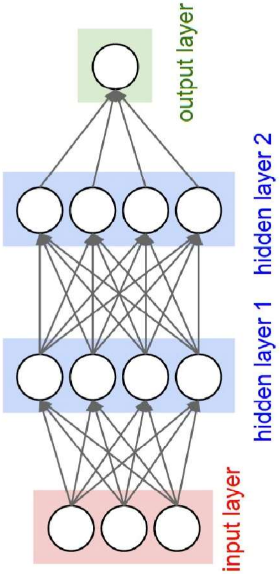

Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Part 1: The foundations: dynamical systems, and complex networks in Brain Science.

- History and Motivation of the problem.
- Basic ideas about the Nervous System and Neurons.
- Basic ideas about Electro-encephalography (EEG), Magnetic Resonance Imaging (MRI), Functional MRI (fMRI), and Superconducting Quantum Interferometer Devices (SQUIDs).
- Computational Neuroscience and Dynamical Systems (Hodgkin-Huxley, Fitzhugh-Naguno, Izhikievich, Morris-Lecar, Hammarsh-Rose, Li-Rinzel, Wilson-Cowan, Kuramoto, Hopfield, Spin Glass, and Cellular Automata)
- Graph theory, networks, feedback loops.
- Brain networks: anatomical, functional, and layered.

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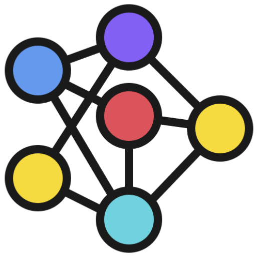
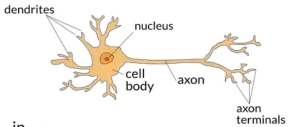
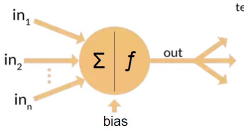
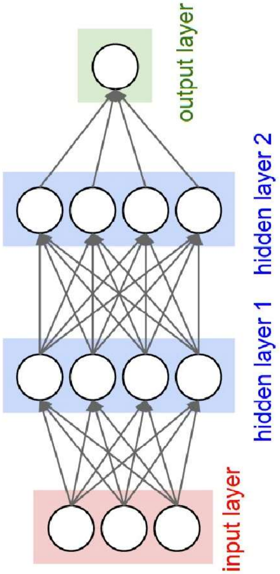


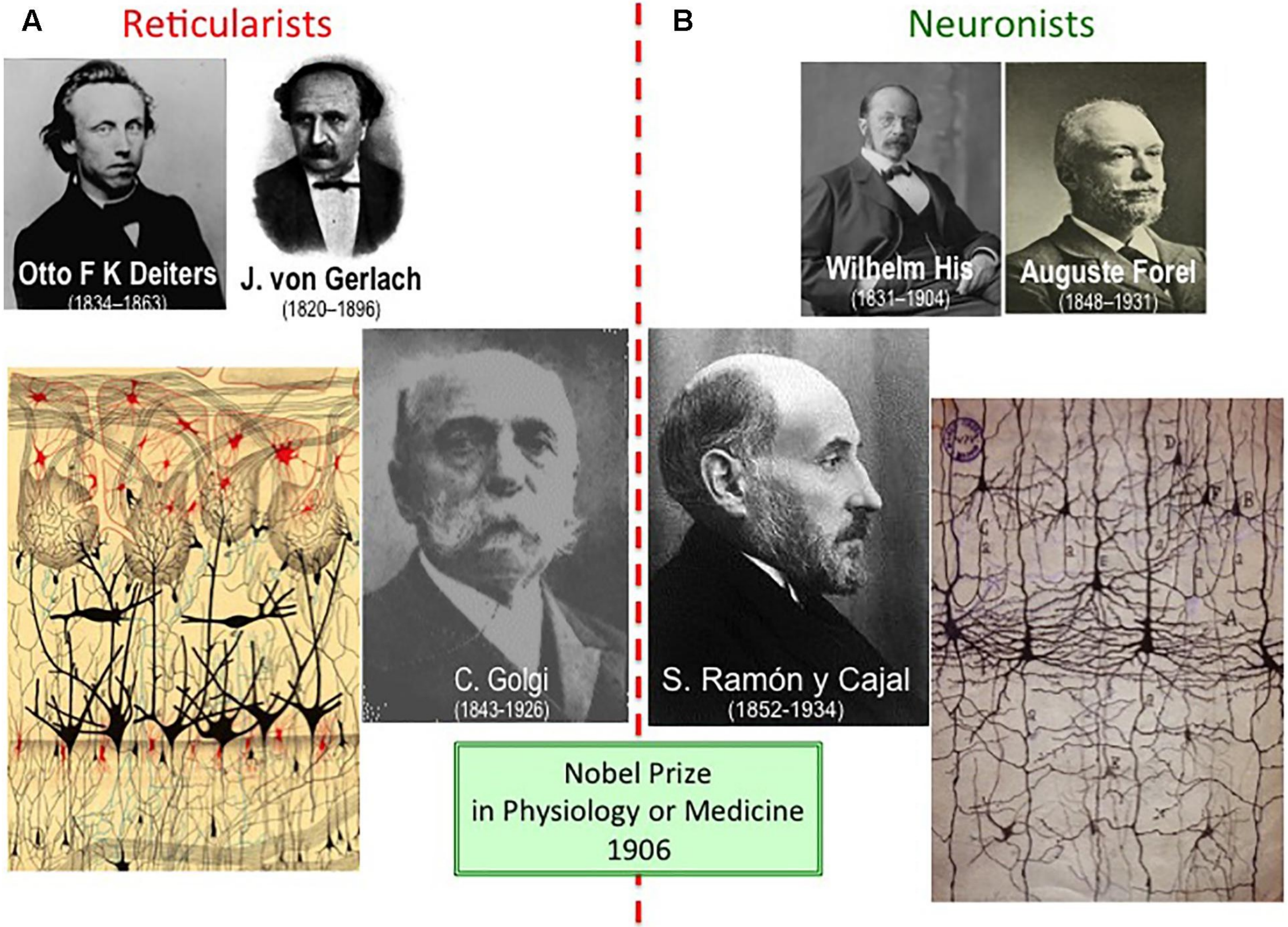


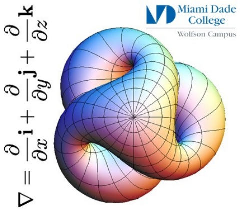




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

A Brief History of Neuroscience





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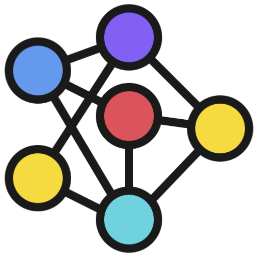
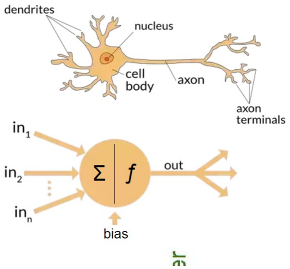
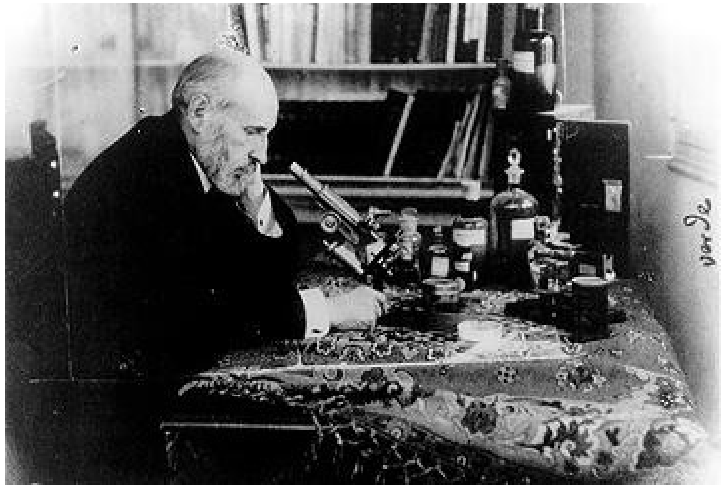
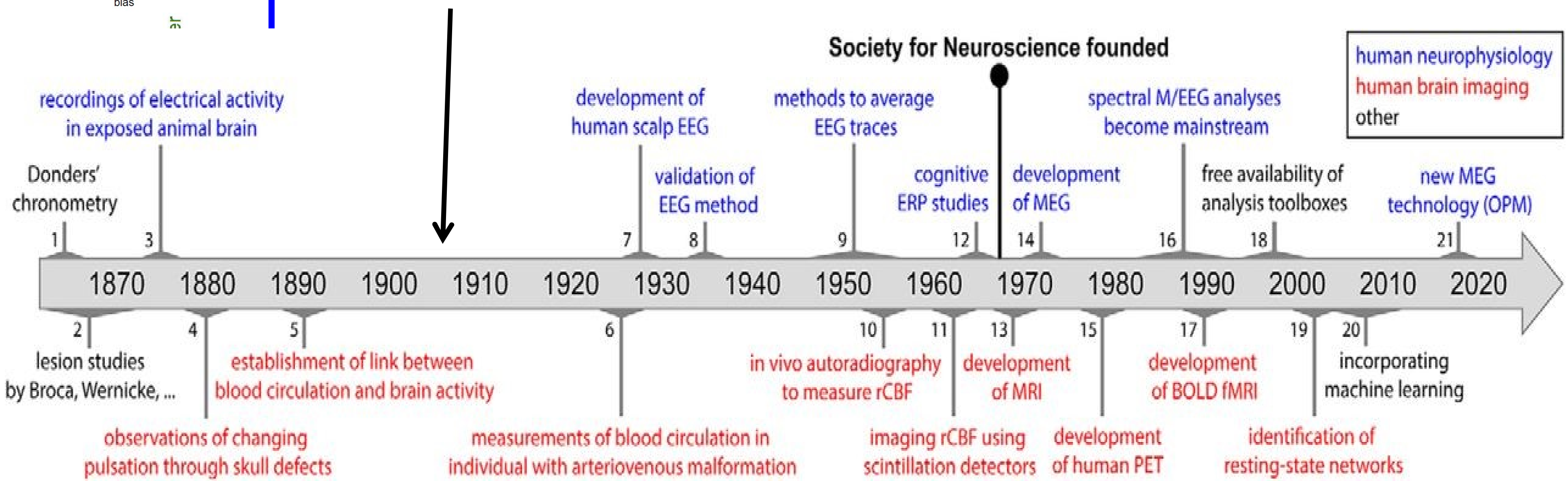
A Brief History of Neuroscience







Santiago Ramon y Cajal (1852 – 1934) is considered the father of modern neuroscience. After his pioneering contributions to the anatomy and histology of the brain, he proposed the existence of the nerve cell, the neuron. His **Neuron Doctrine**, as discrete units, the brain is made of, marked a beginning to a deeper understanding of the brain activity.



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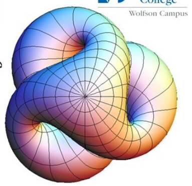

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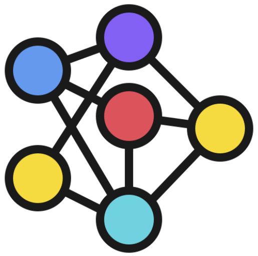
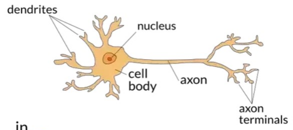
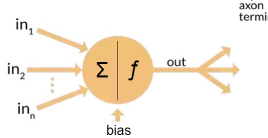
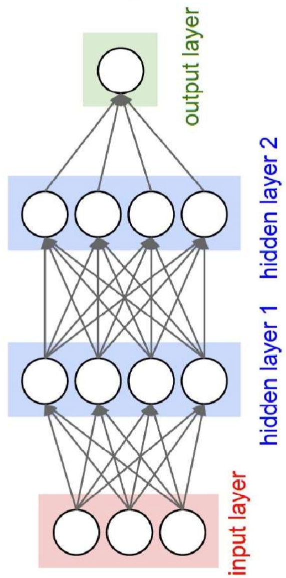
A Brief History of Neuroscience

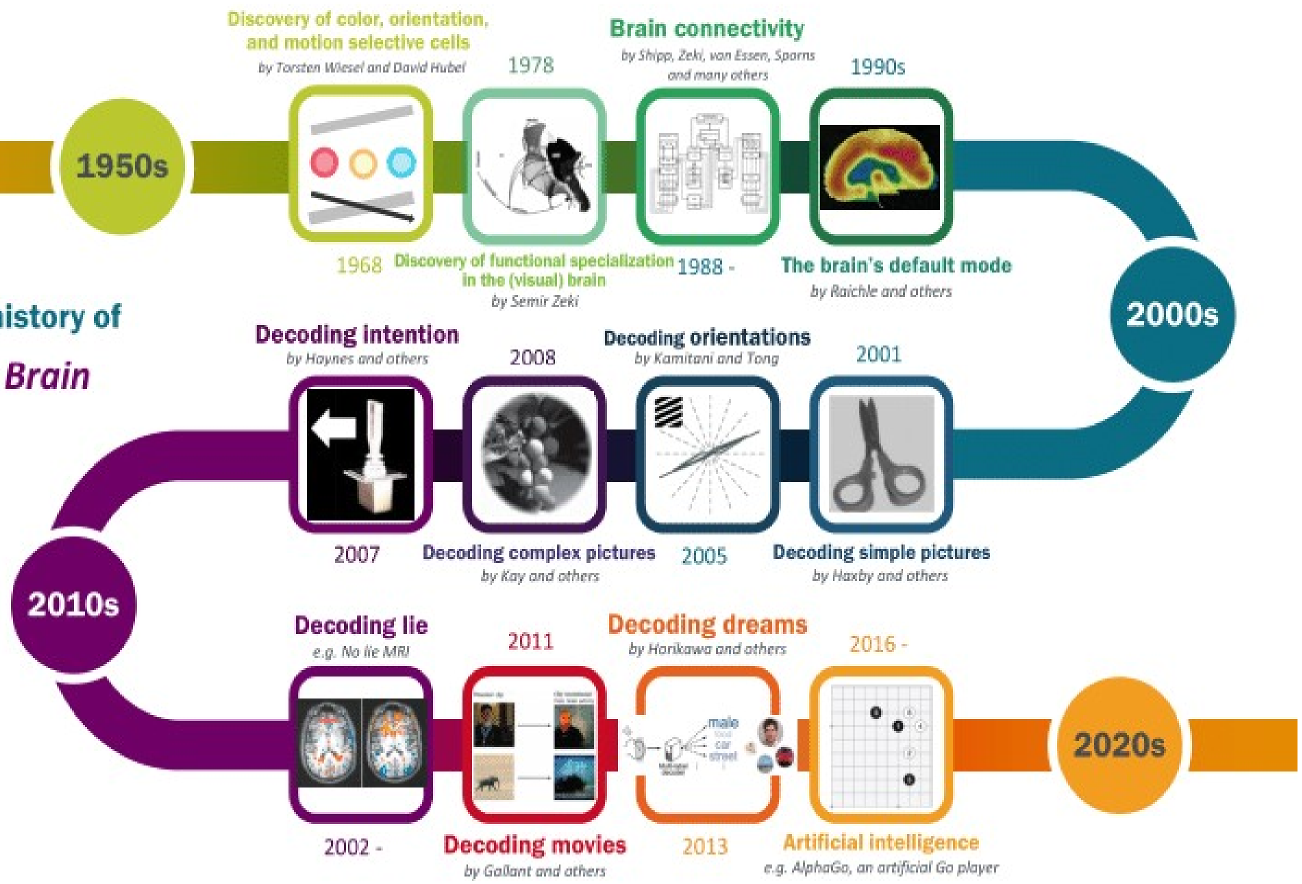


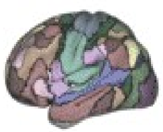






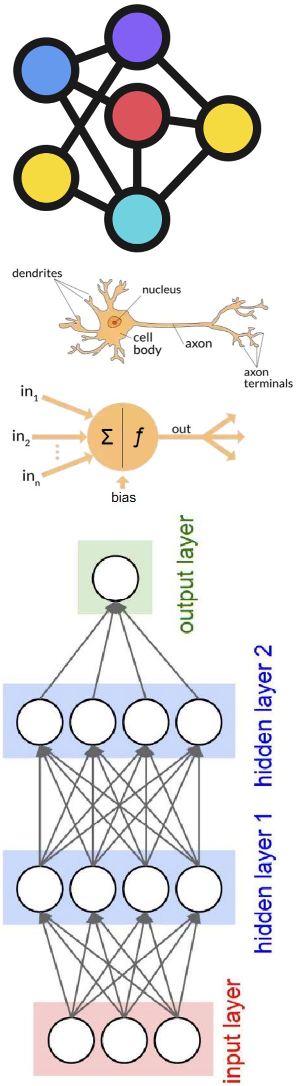
A brief recent history of *Decoding the Brain*

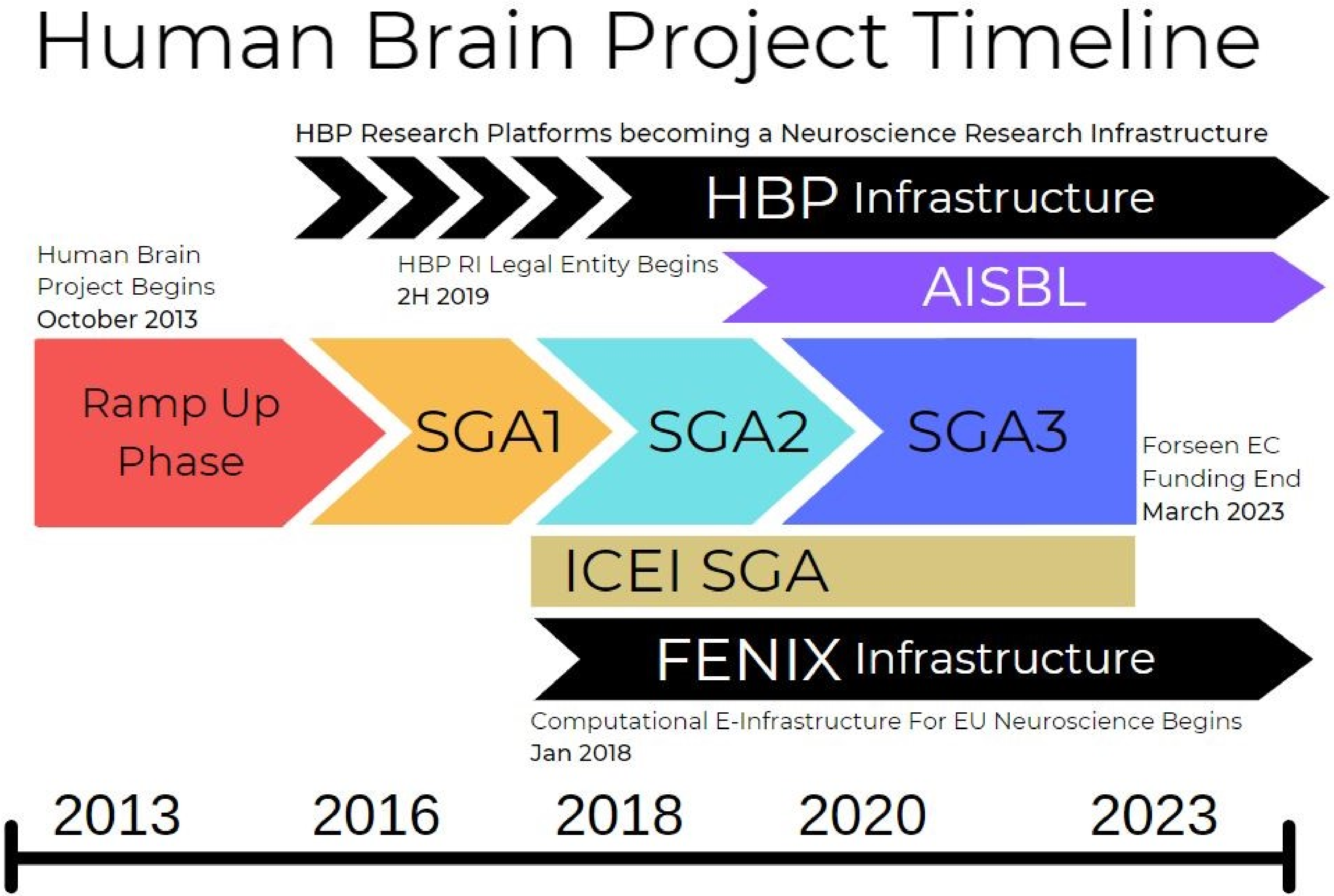




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

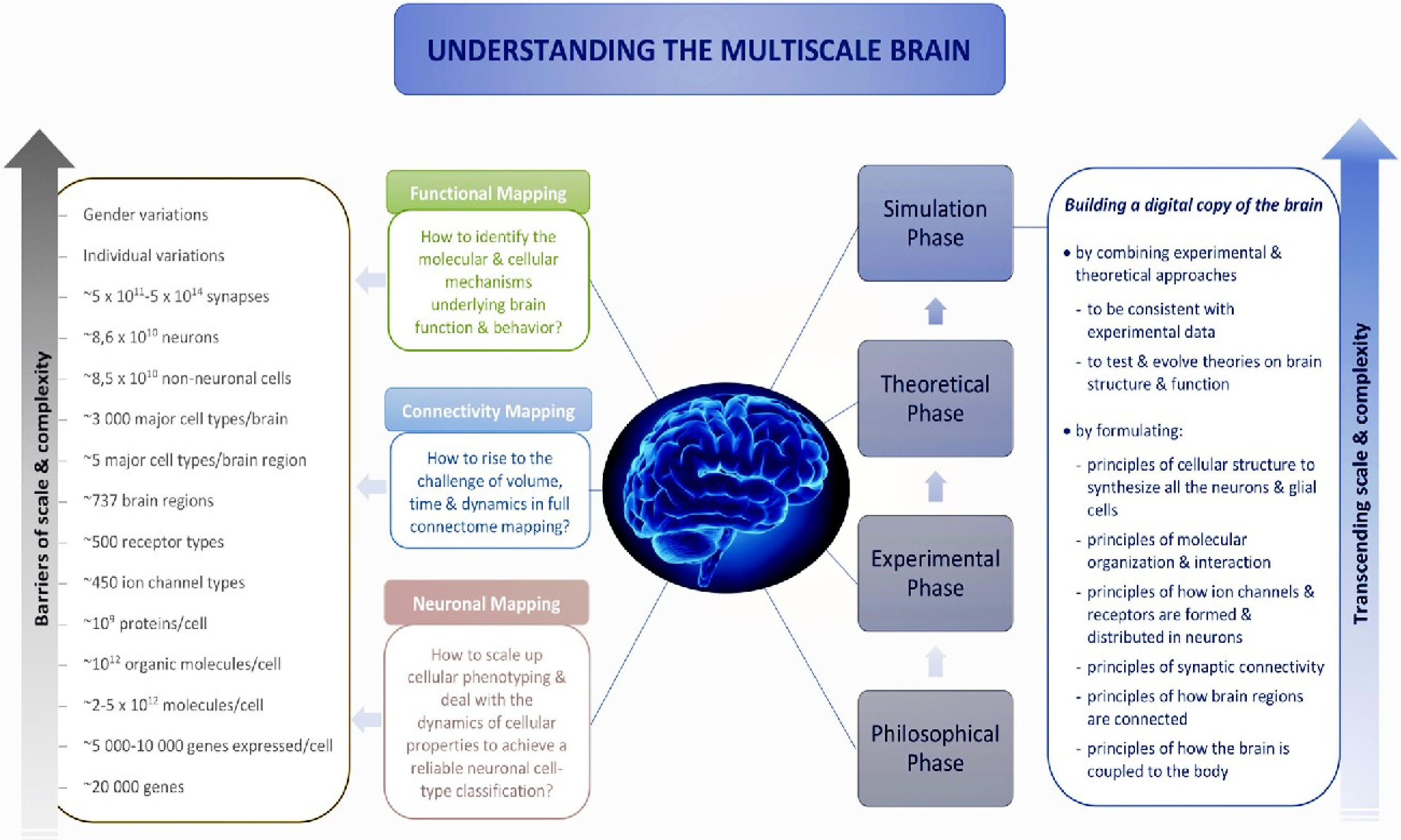
A Brief History of Neuroscience





Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.



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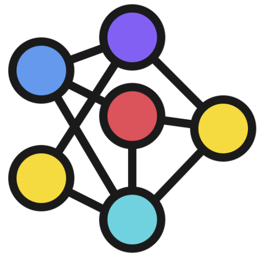
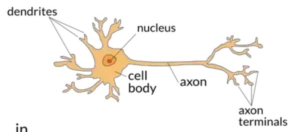
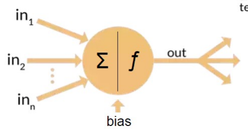
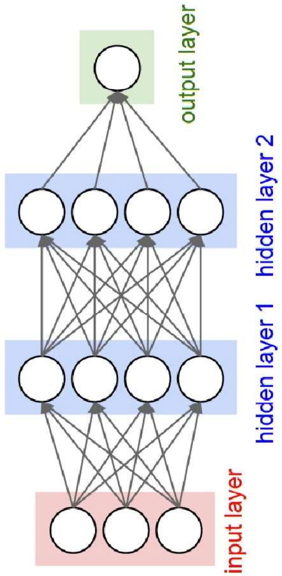




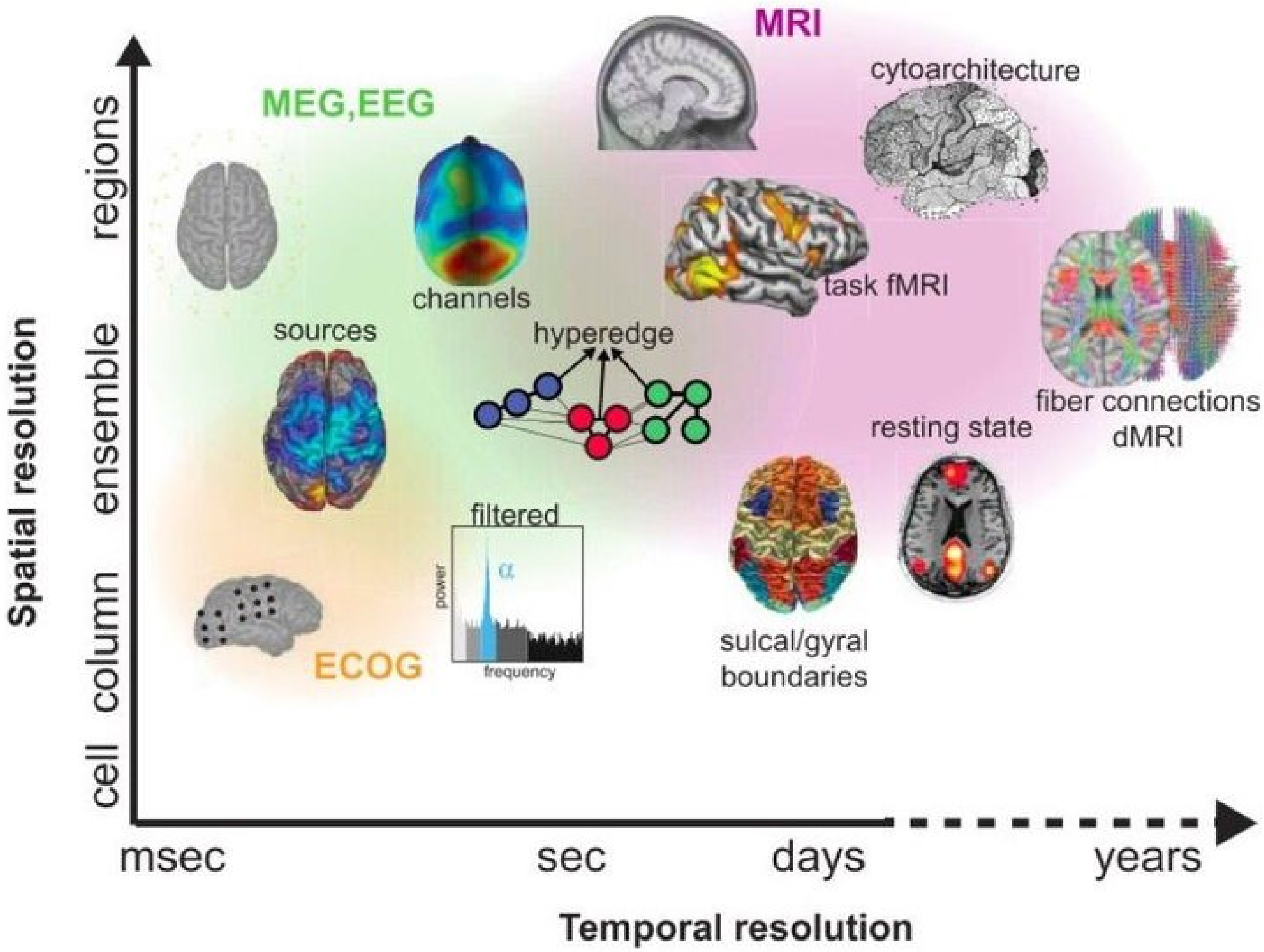




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.

Timeframes of Brain Activity



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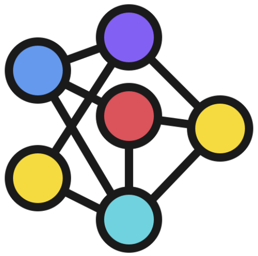

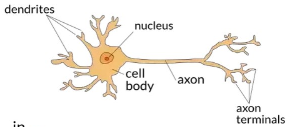

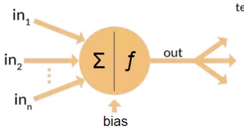

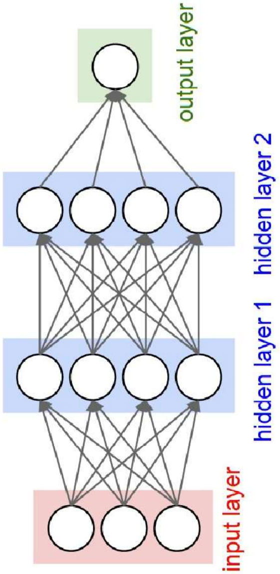

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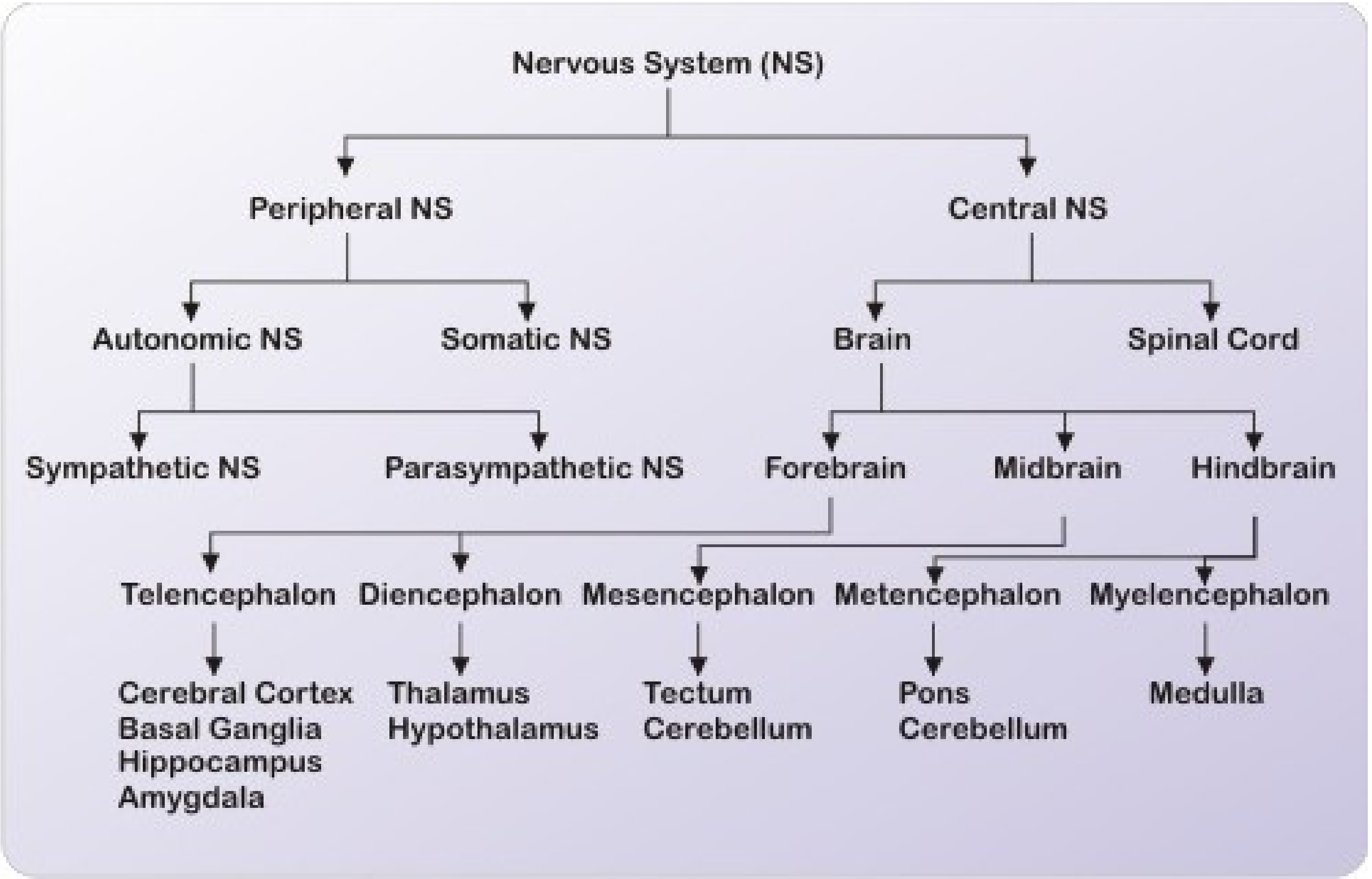
Basic ideas about the Nervous System and Neurons.



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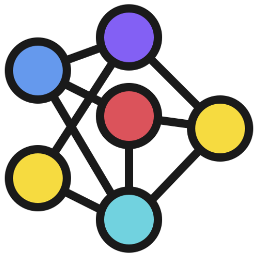
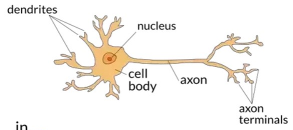
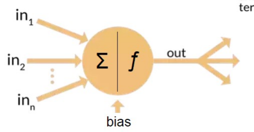
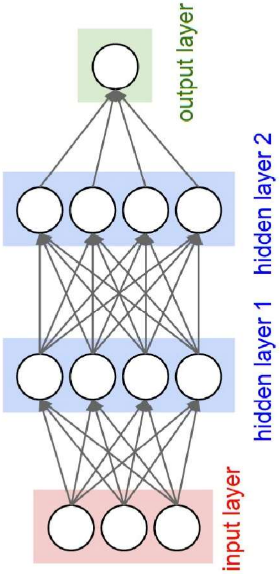


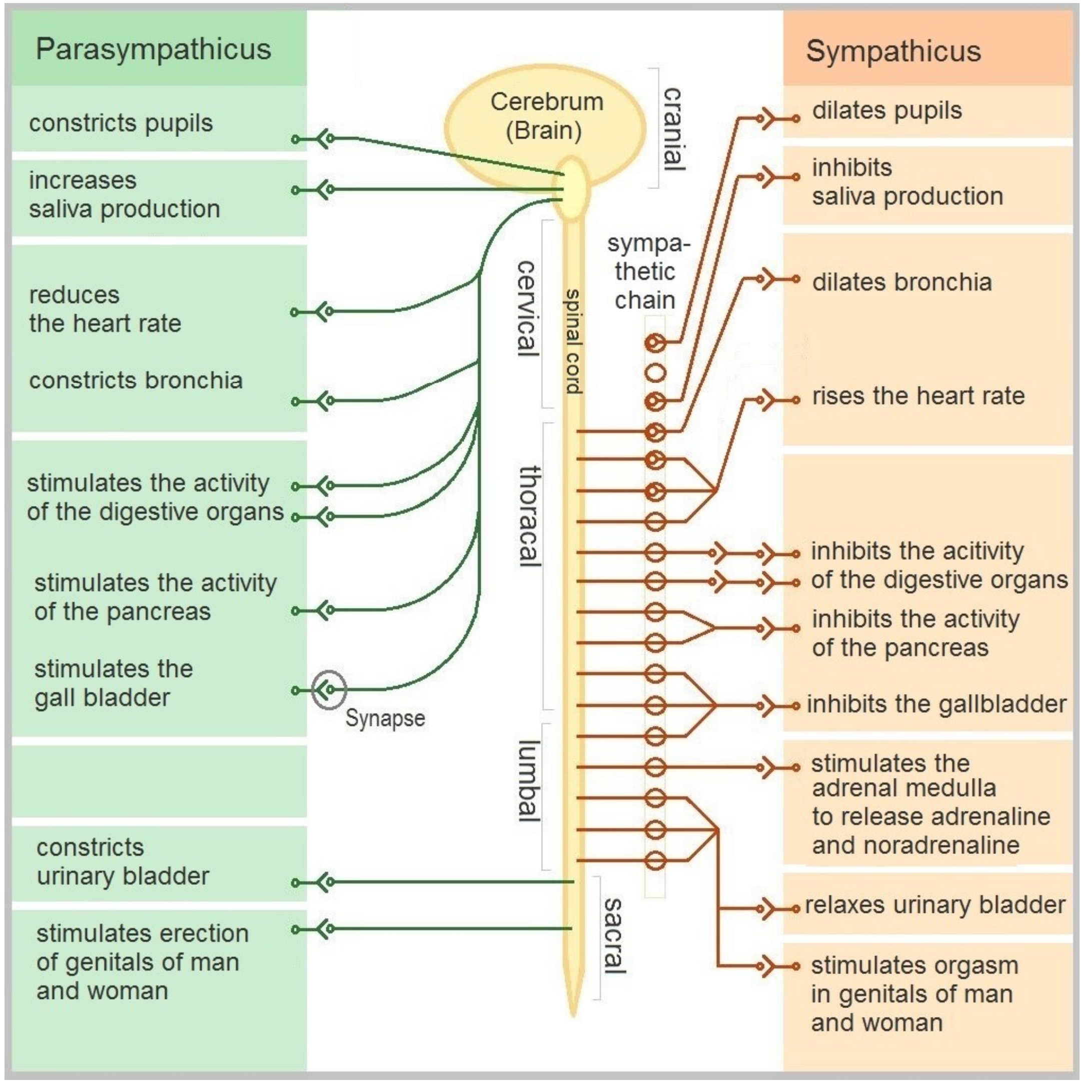






Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.



$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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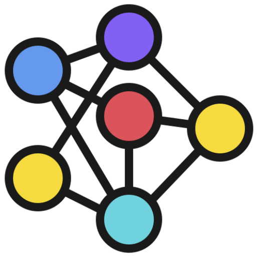
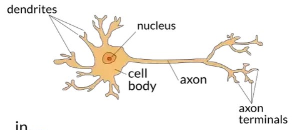
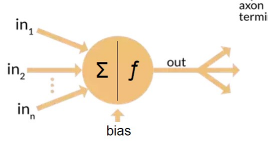
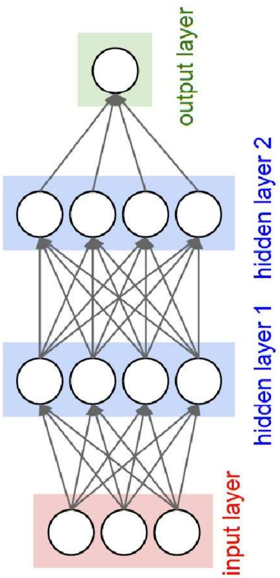


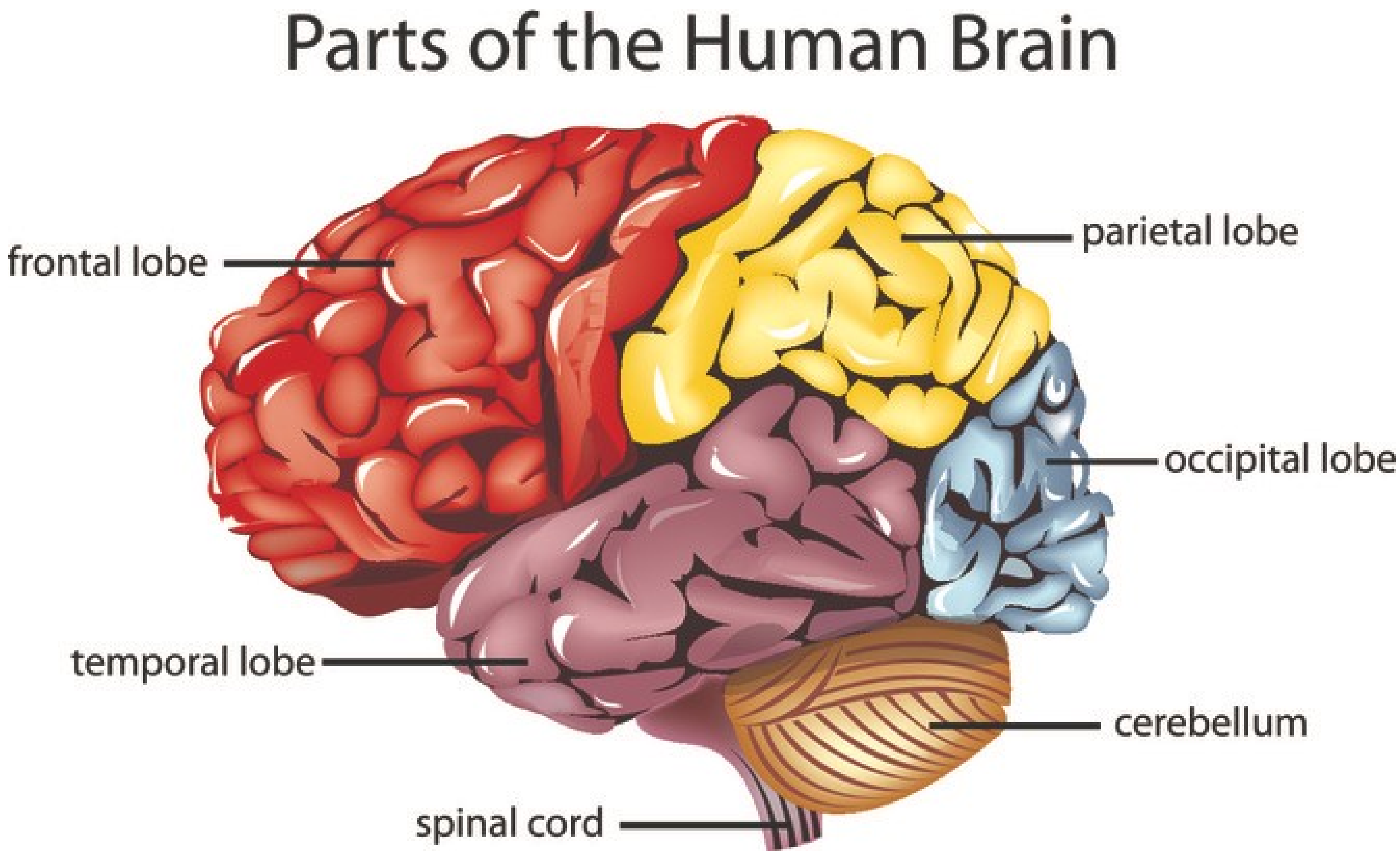






Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.



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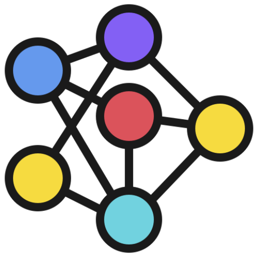
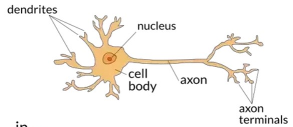
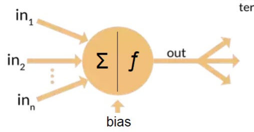
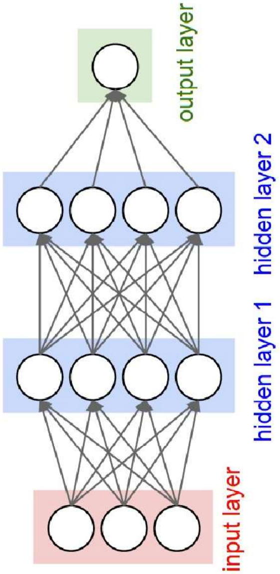




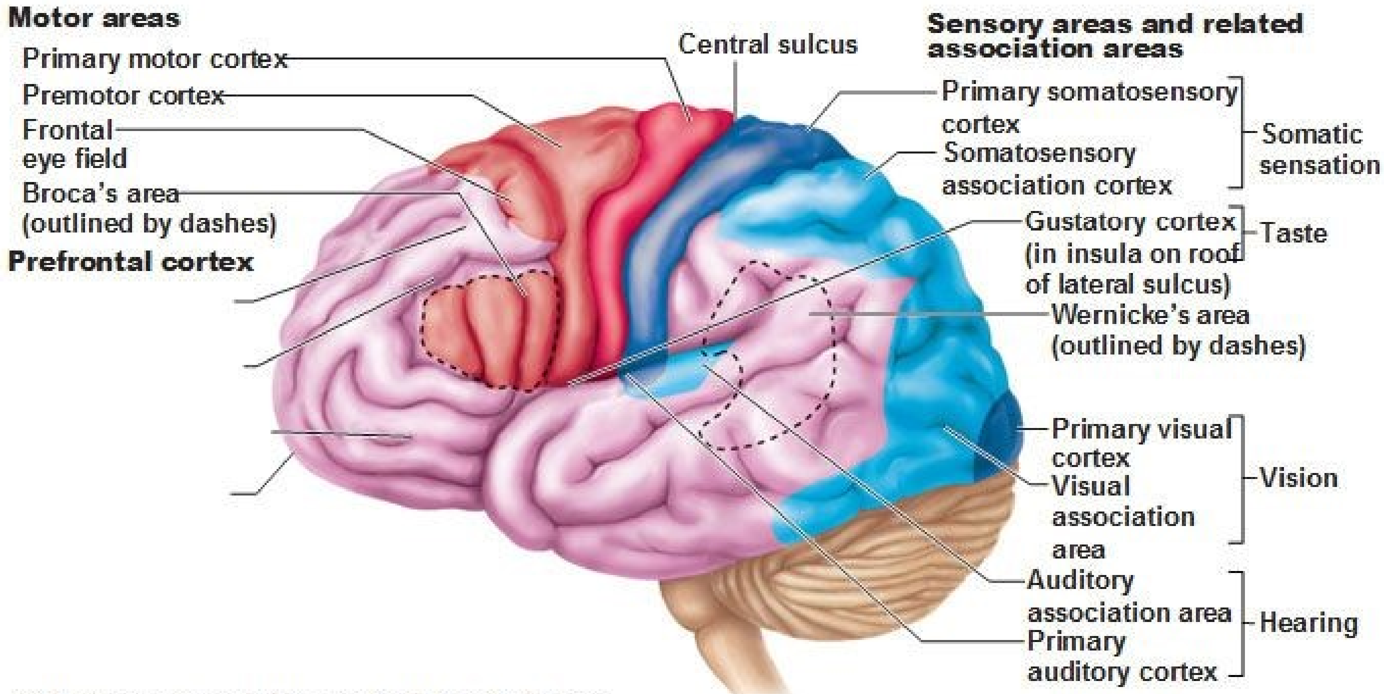




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.

Functional Areas of the Cerebral Cortex



(a) Lateral view, left cerebral hemisphere

$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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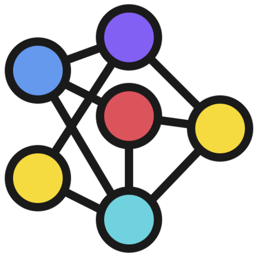
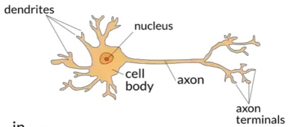
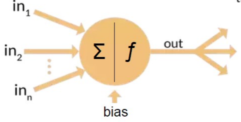
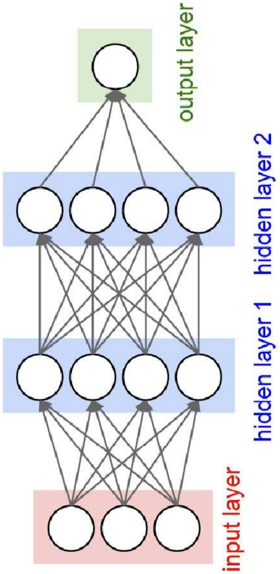






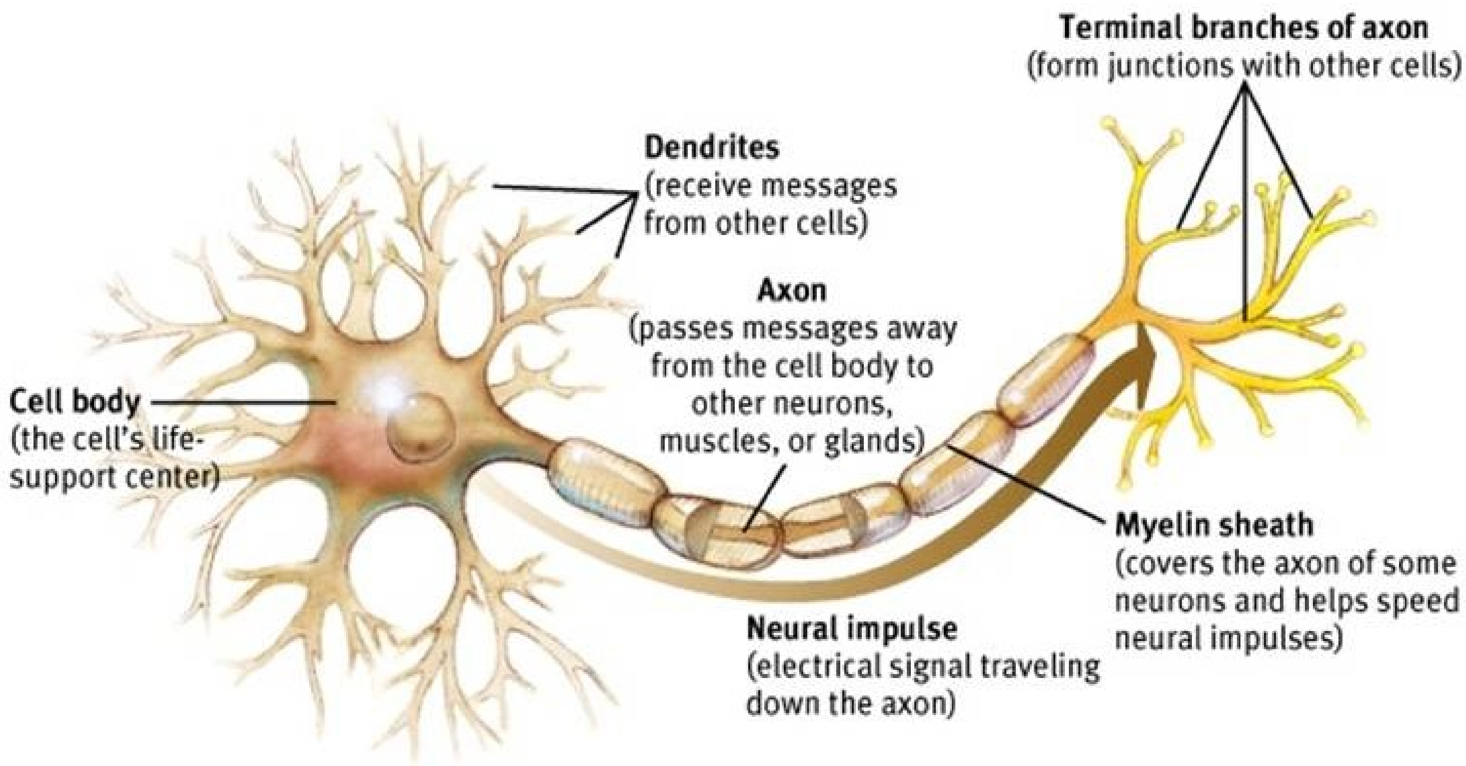


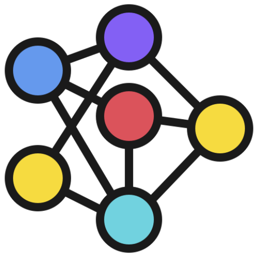
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

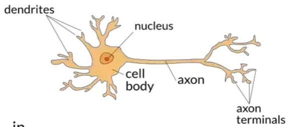
Basic ideas about the Nervous System and Neurons.

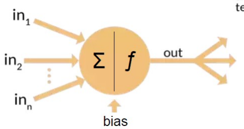
Basic Unit of the nervous system – the **Neuron**

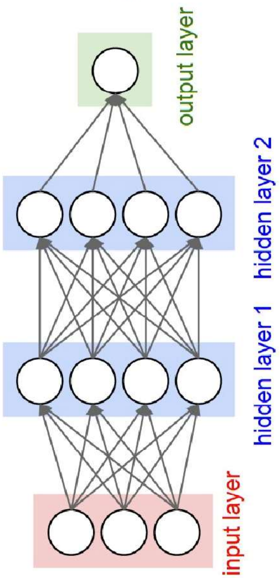
The legacy of Santiago Ramon y Cajal





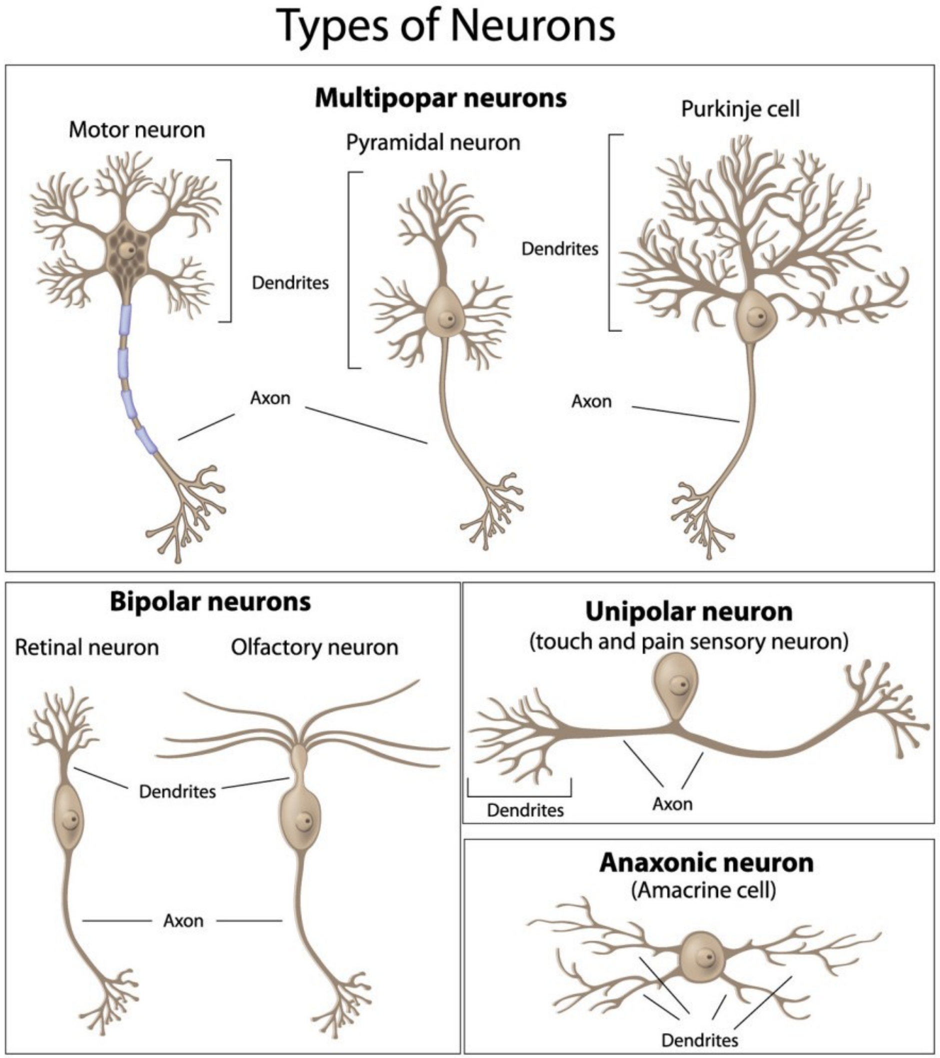






Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.



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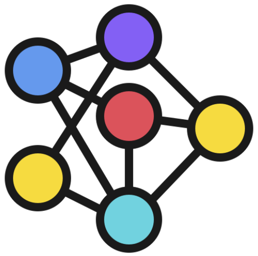

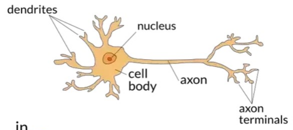

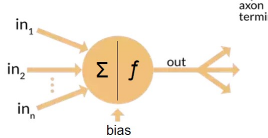

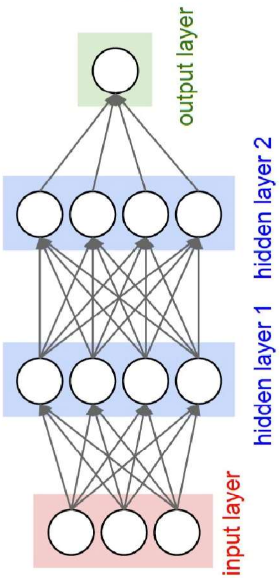

Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.

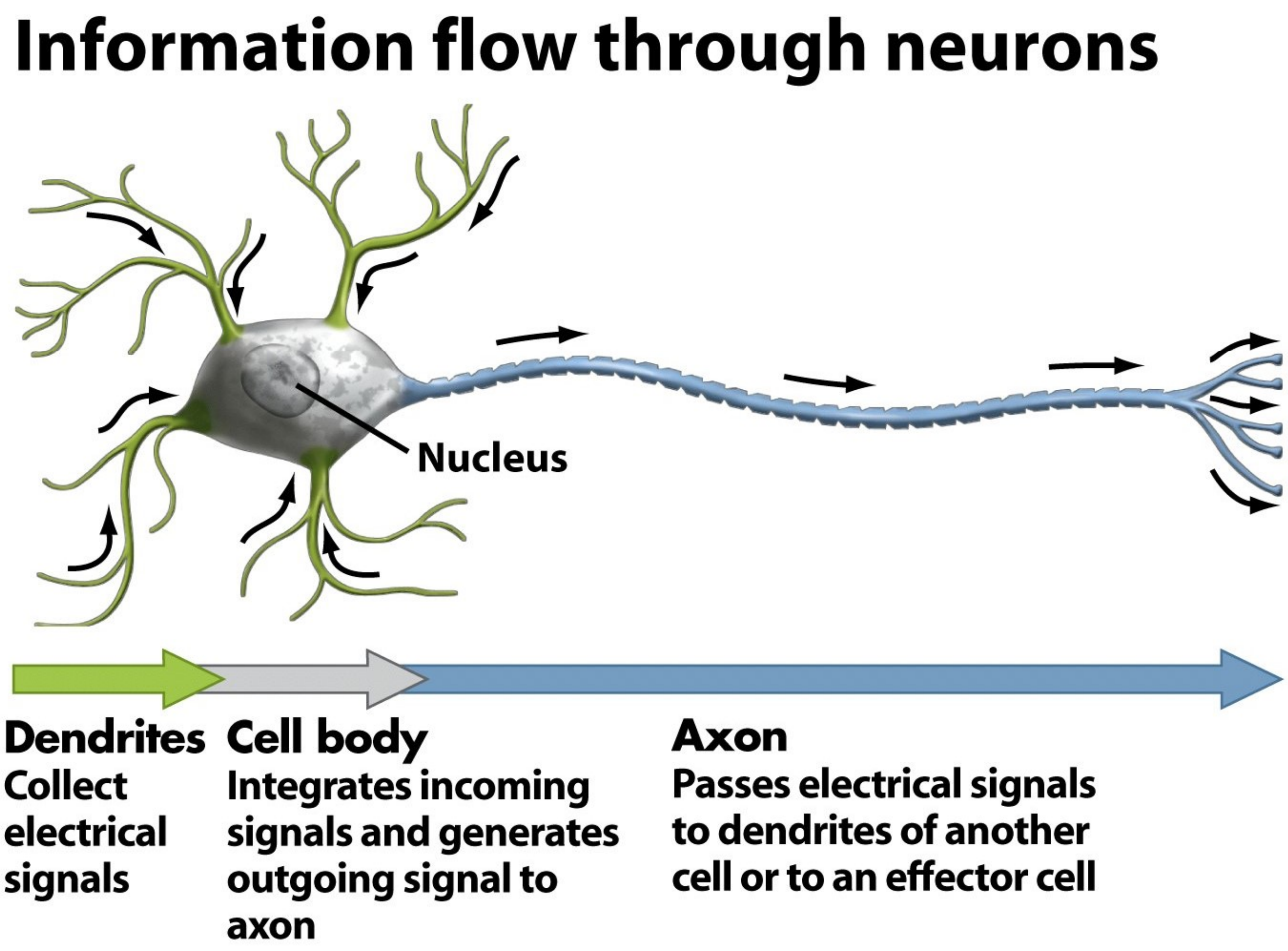

Figure 45-2b Biological Science, 2/e

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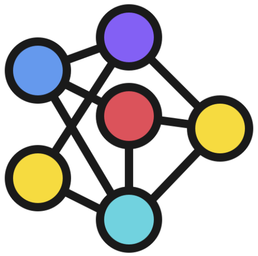
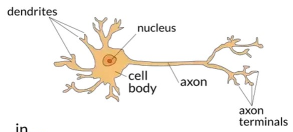
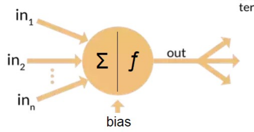
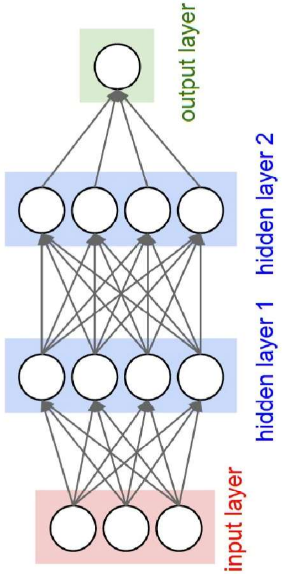
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

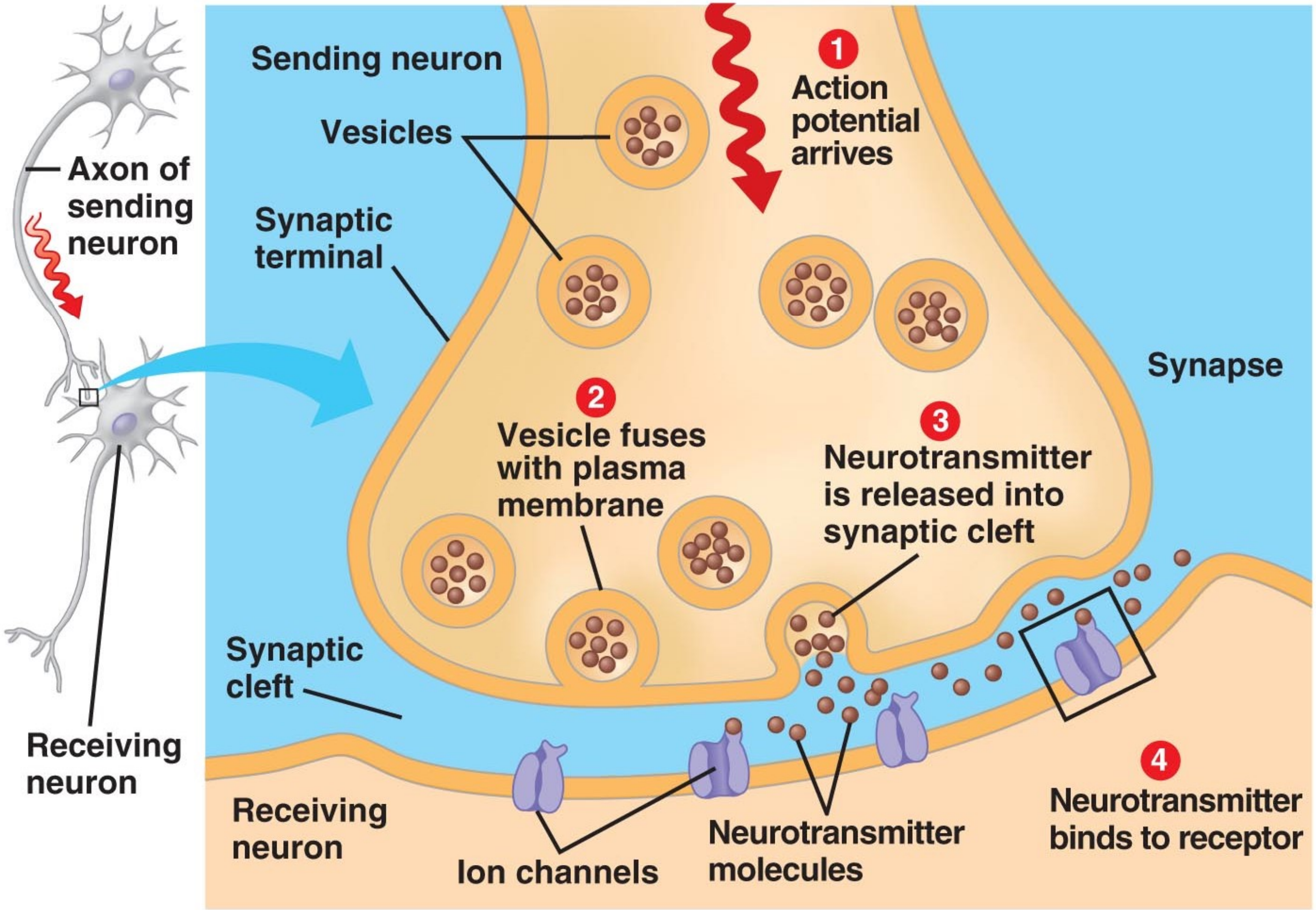
Basic ideas about the Nervous System and Neurons.











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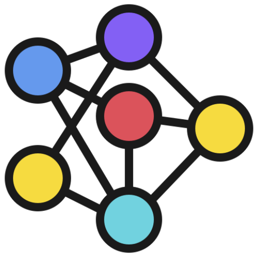
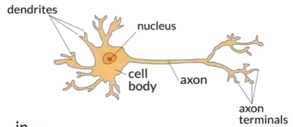
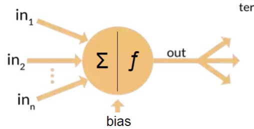
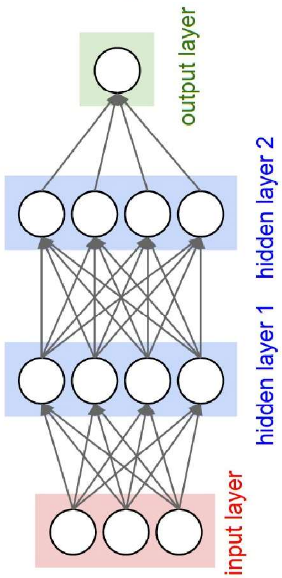
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.









BRAIN SIZE AND NEURON COUNT

Cerebral cortex mass and neuron count for various mammals.

Capybara	Rhesus Macaque	Western Gorilla	Human	African Bush Elephant
non-primate	primate	primate	primate	non-primate
48.2 g	69.8 g	377 g	1232 g	2848 g
0.3 billion neurons	1.71 billion neurons	9.1 billion neurons	16.3 billion neurons	5.59 billion neurons

$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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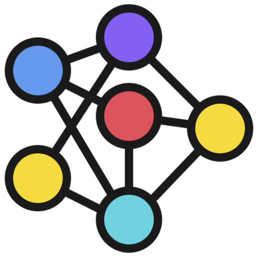
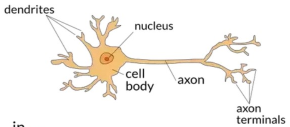
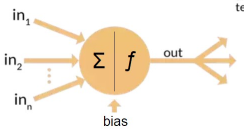
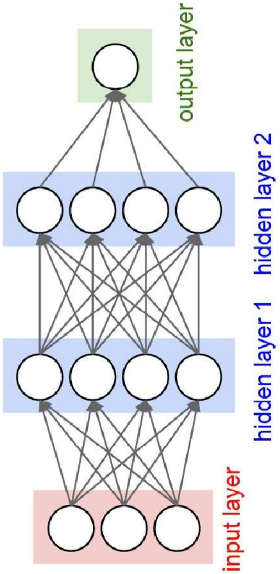




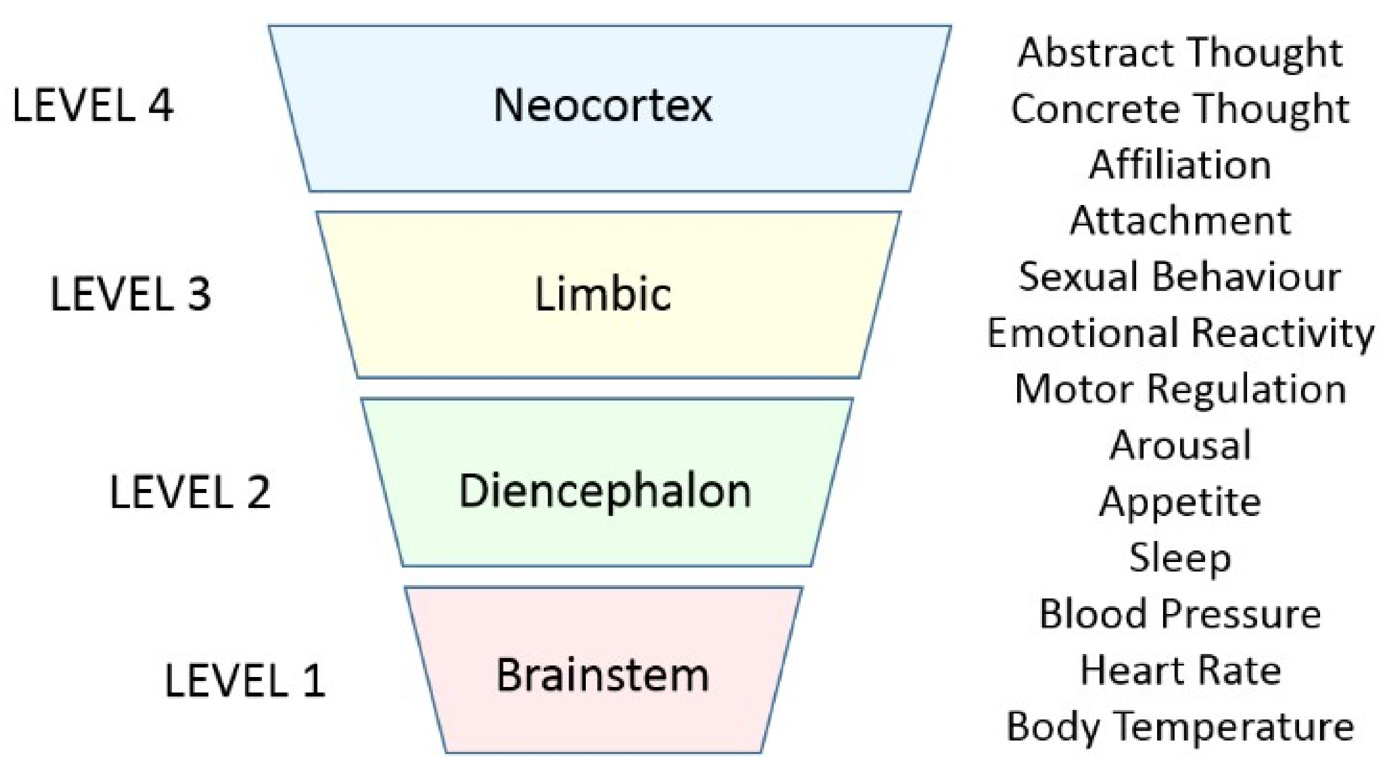




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

Basic ideas about the Nervous System and Neurons.

Hierarchy of brain function



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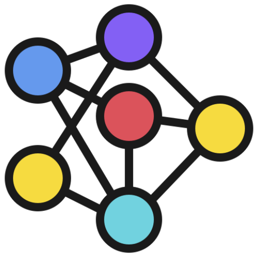
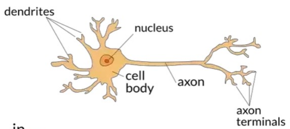
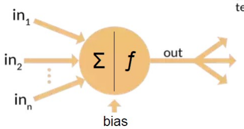
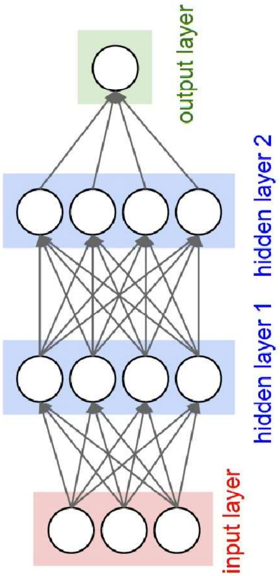
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

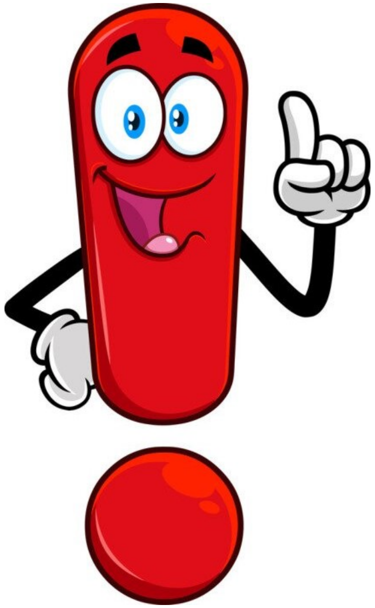
Basic ideas about the Nervous System and Neurons.











- The study of the **dynamics of the Nervous System** is the study of the dynamics of a complex system with regulatory feedback loops (**control system theory**), where self-organization and cooperation (**synergetics**) operate in the background of a large complex network (**graph theory and networks**).

- Such a system has the ability of **self-learning** with a high level optimization. The process of self-learning occurs following a sequence of **unsupervised** and **supervised** learning.

- Brain dynamics is an example of **structure – function** problems. Two types of connections: structural (anatomical), dynamical (functional). Therefore, the understanding of the activation of functional networks of neurons behind behaviors, response to stimuli, and central nervous system degenerative diseases is of tremendous importance.

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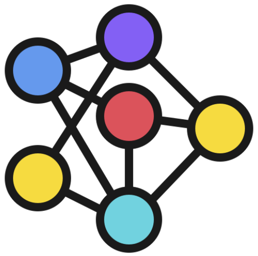

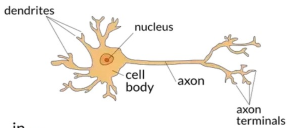

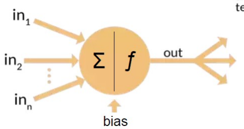

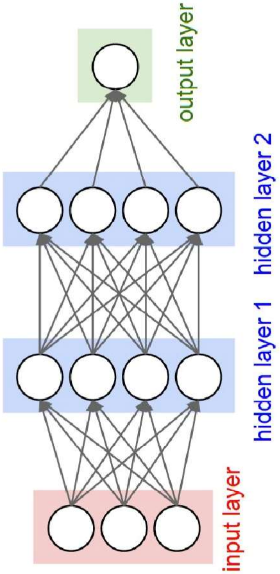

Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

How to collect information about the dynamics of neurons and the brain?

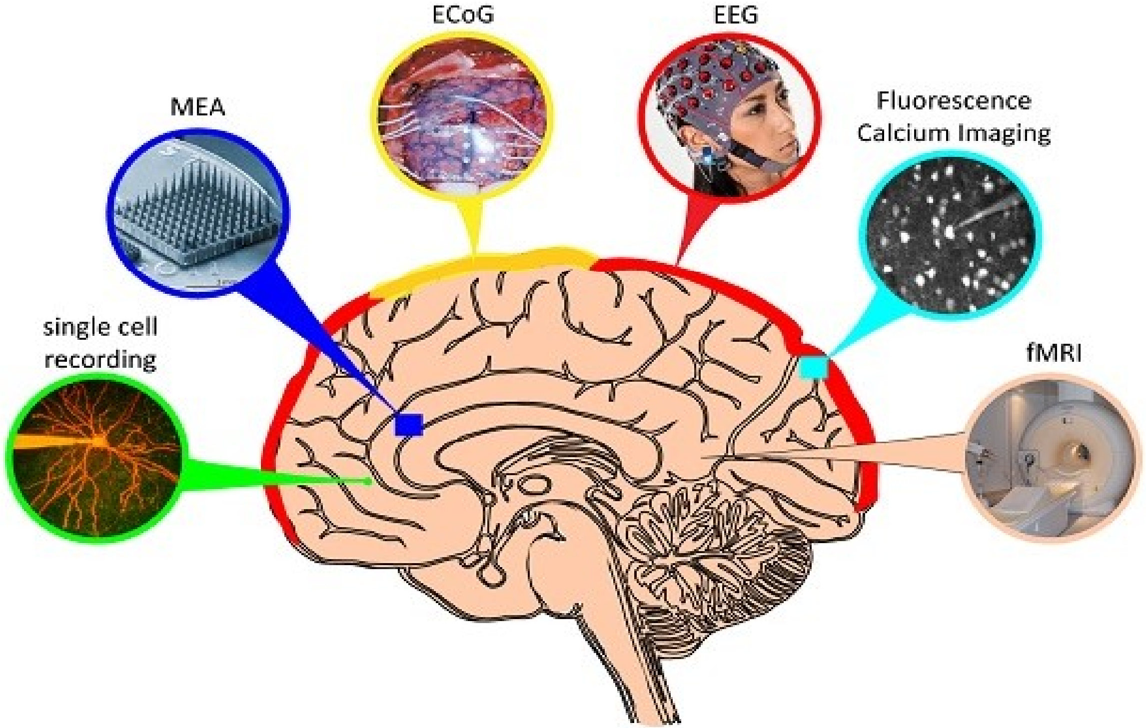

Figure 1. *Commonly used techniques for recording brain activity. From left to right, temporal resolution decreases, from <1 ms for single cell and multielectrode array (MEA) recordings to ~1 sec for fMRI. The colours indicate the approximate physical scale of the activity that can be recorded with each approach, as well as the approximate depth limits of each technique. ECoG, EEG, and fluorescence imaging are limited to recording from the brain's outer surface. Note that human recording techniques (ECoG, EEG and fMRI) cover much larger areas than technologies used in animals. This comes at the expense of detail.*

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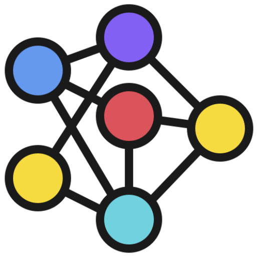
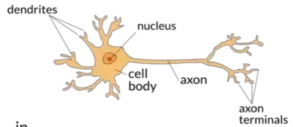
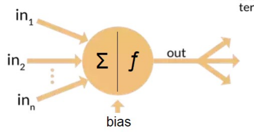
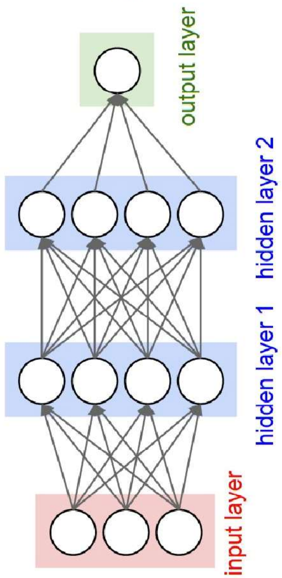




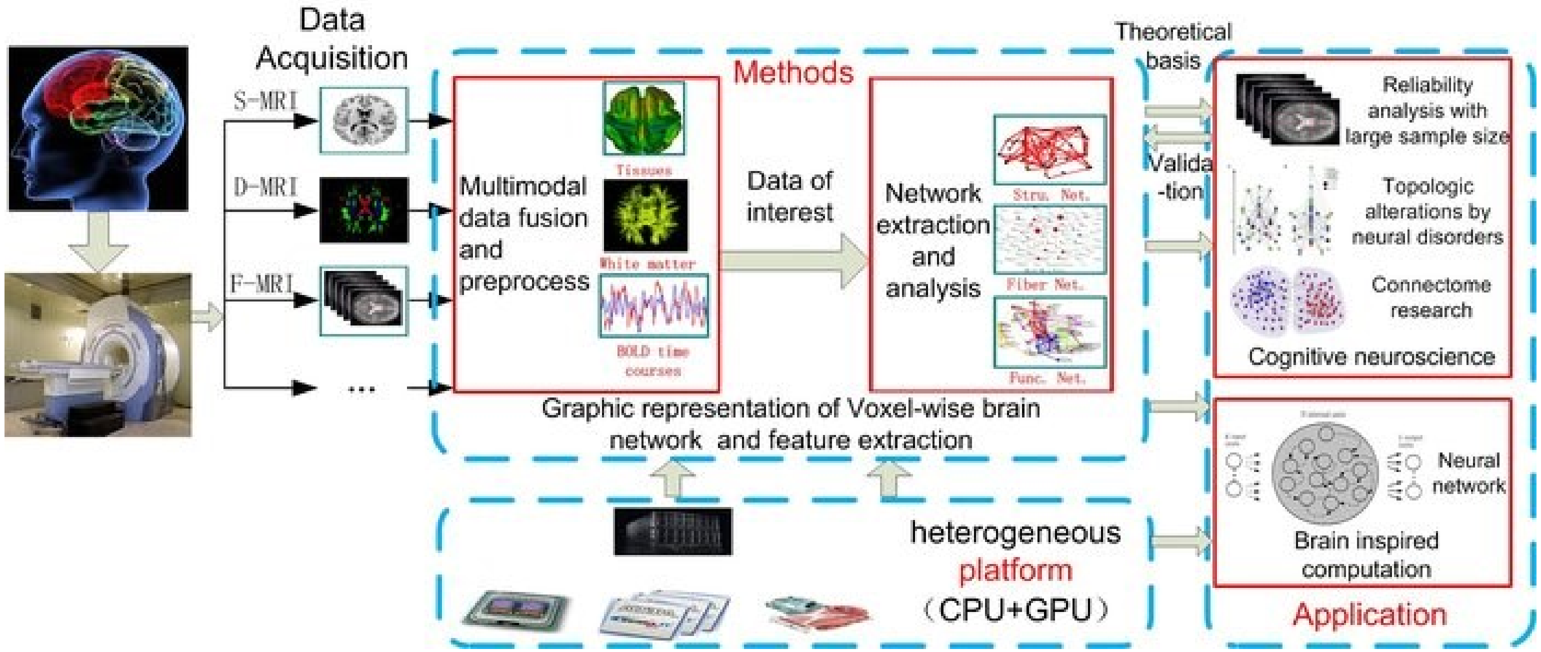




Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

How to collect information about the dynamics of neurons and the brain?

Resonance Magnetic Imaging (MRI) and Functional MRI



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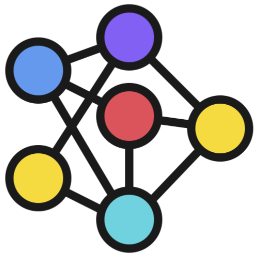

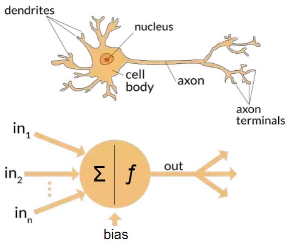

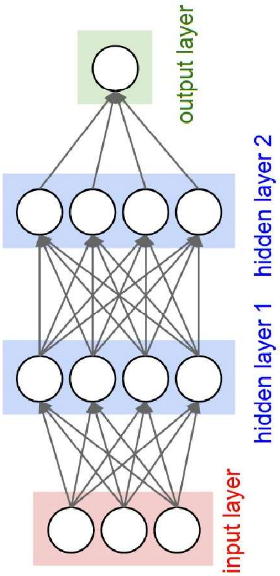

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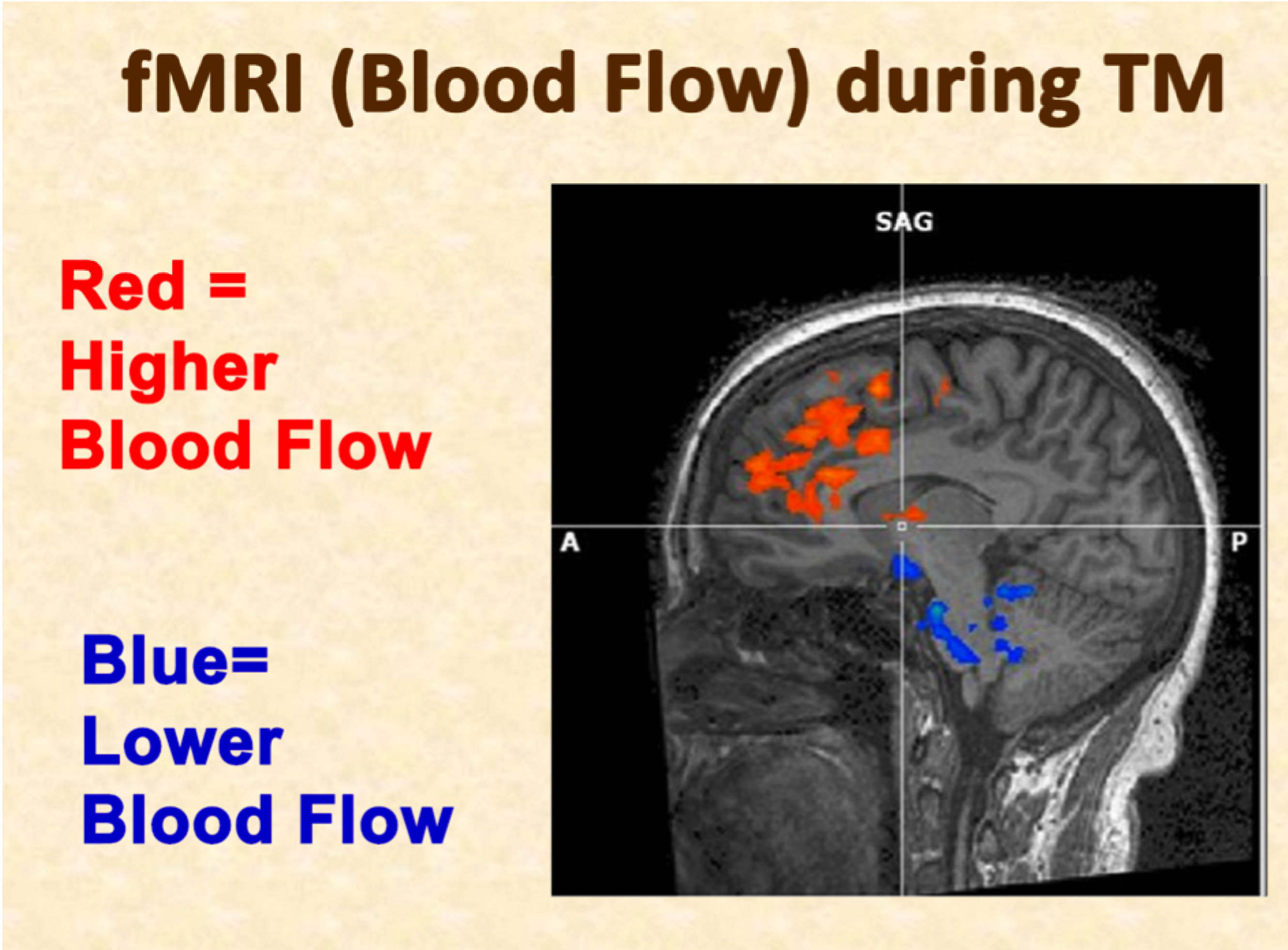

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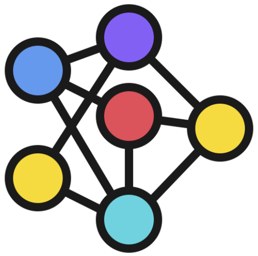

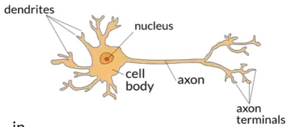

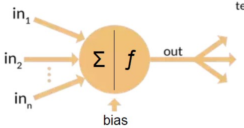

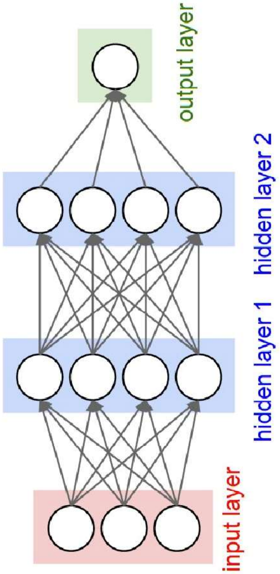

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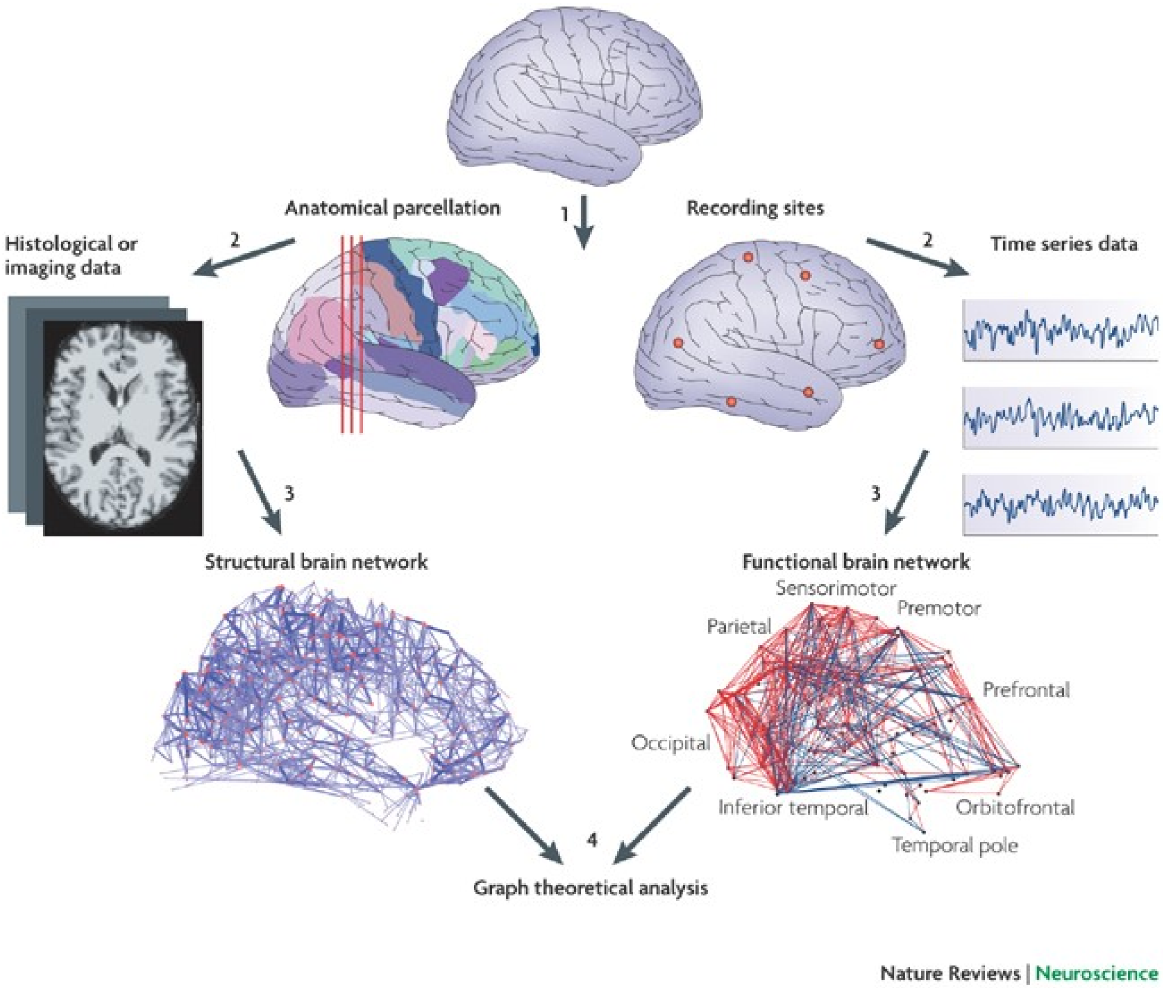

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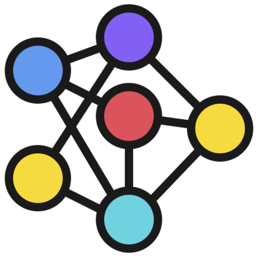

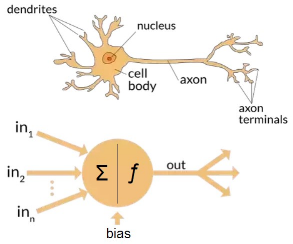

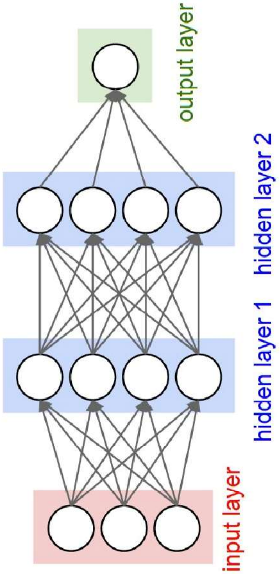

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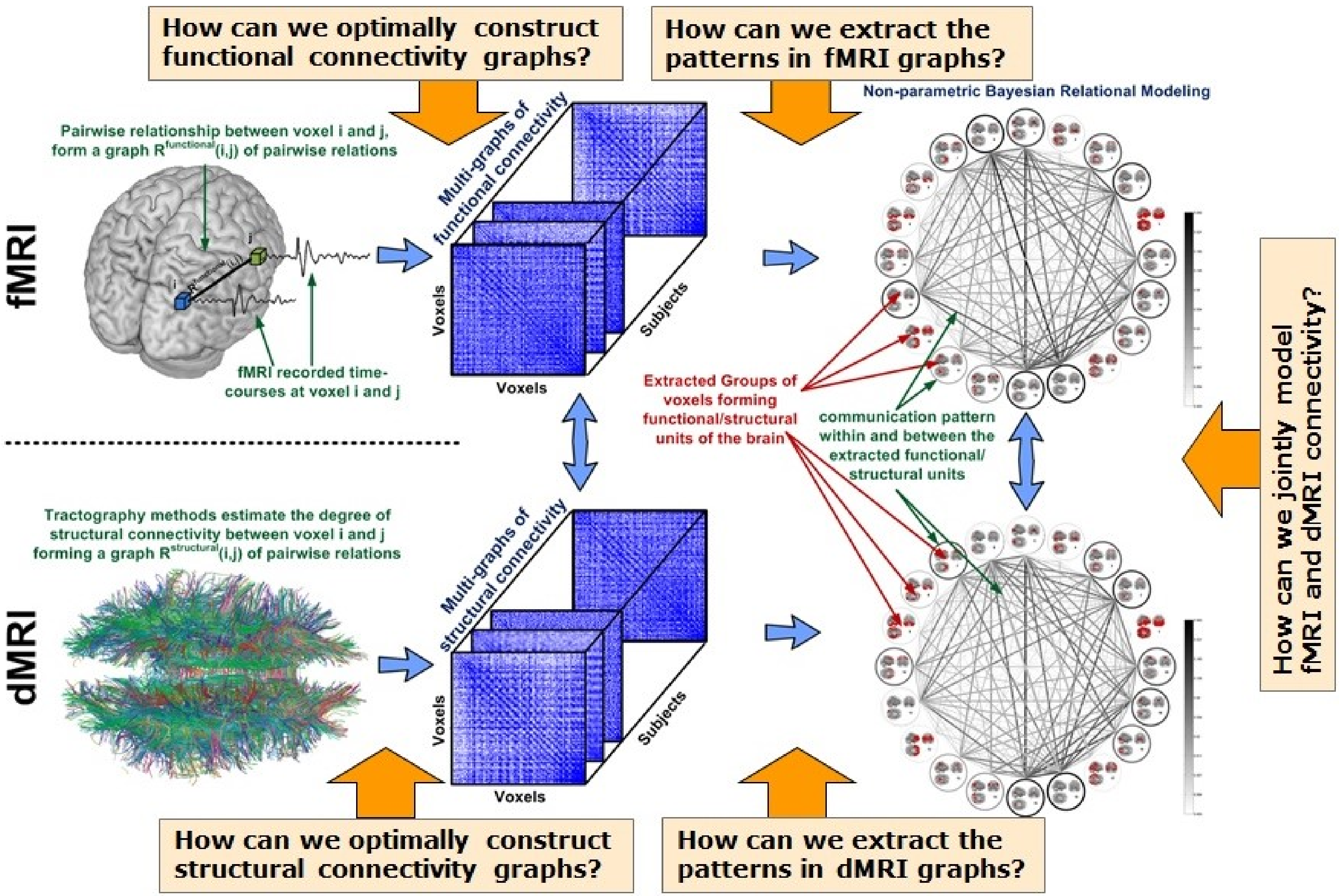

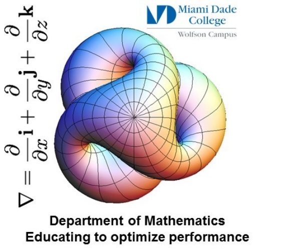

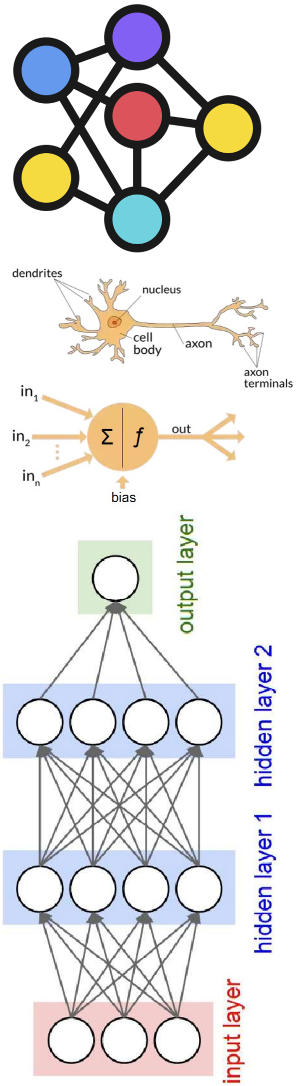

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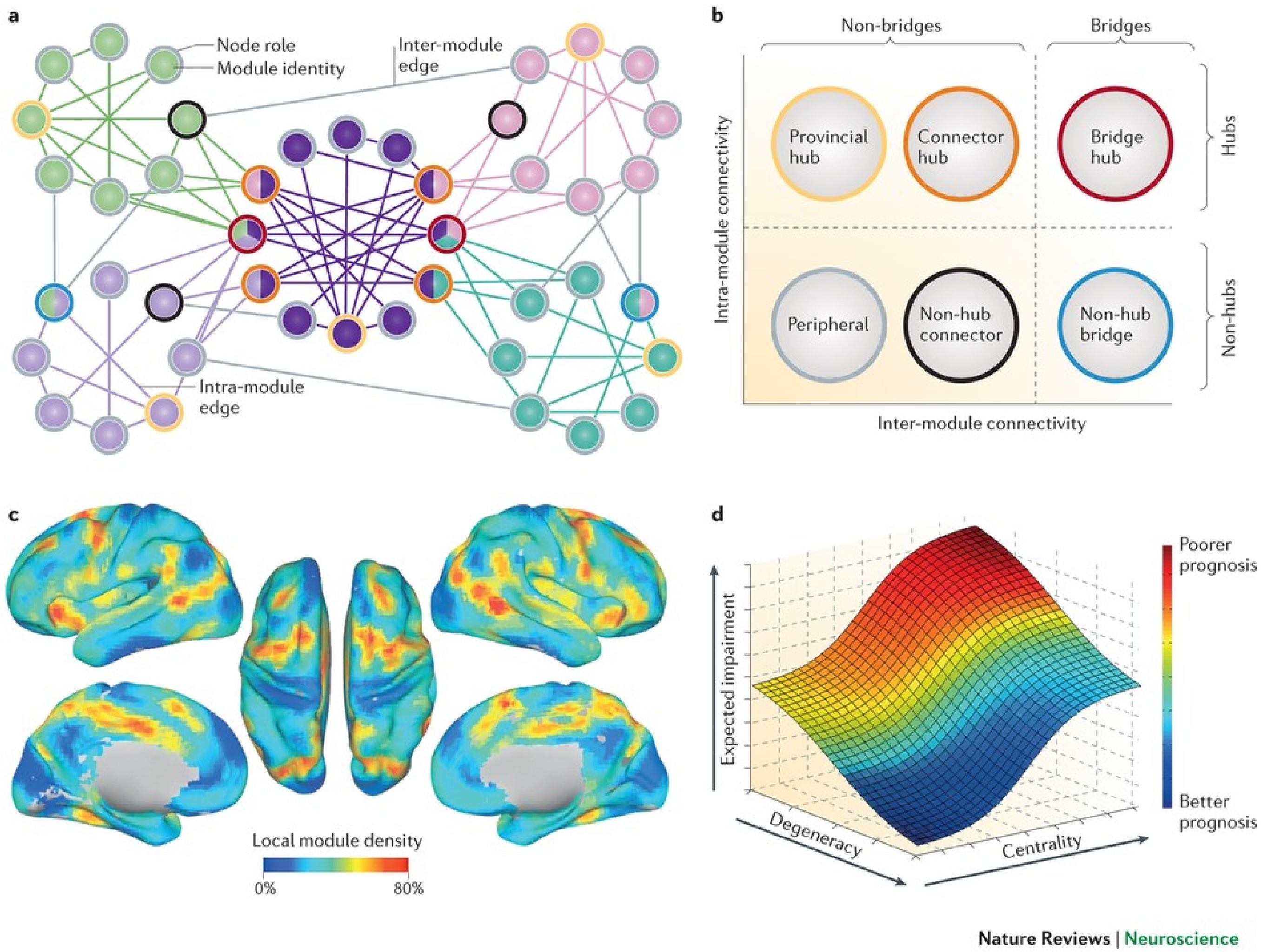

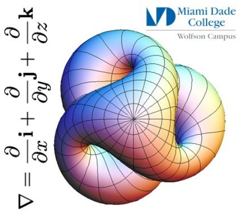

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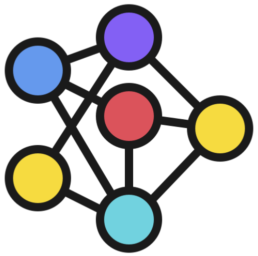
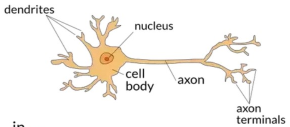
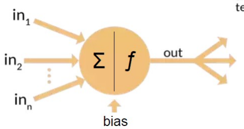
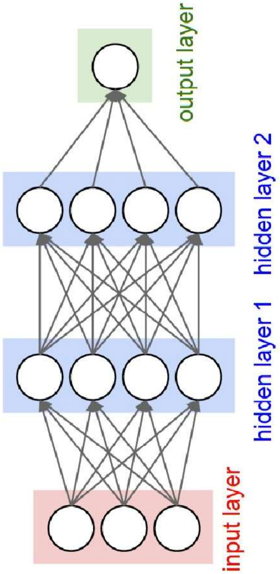






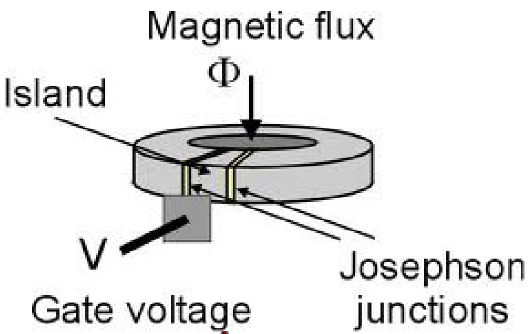


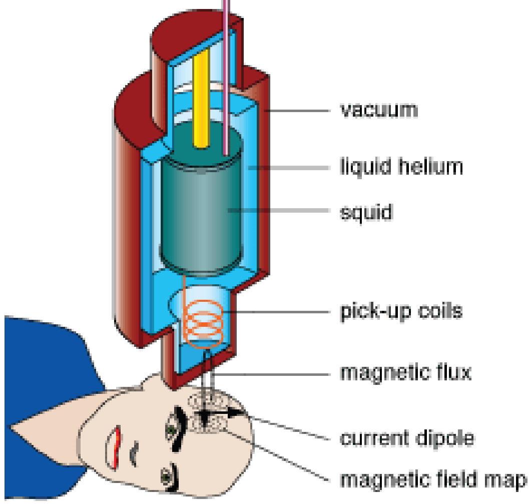
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

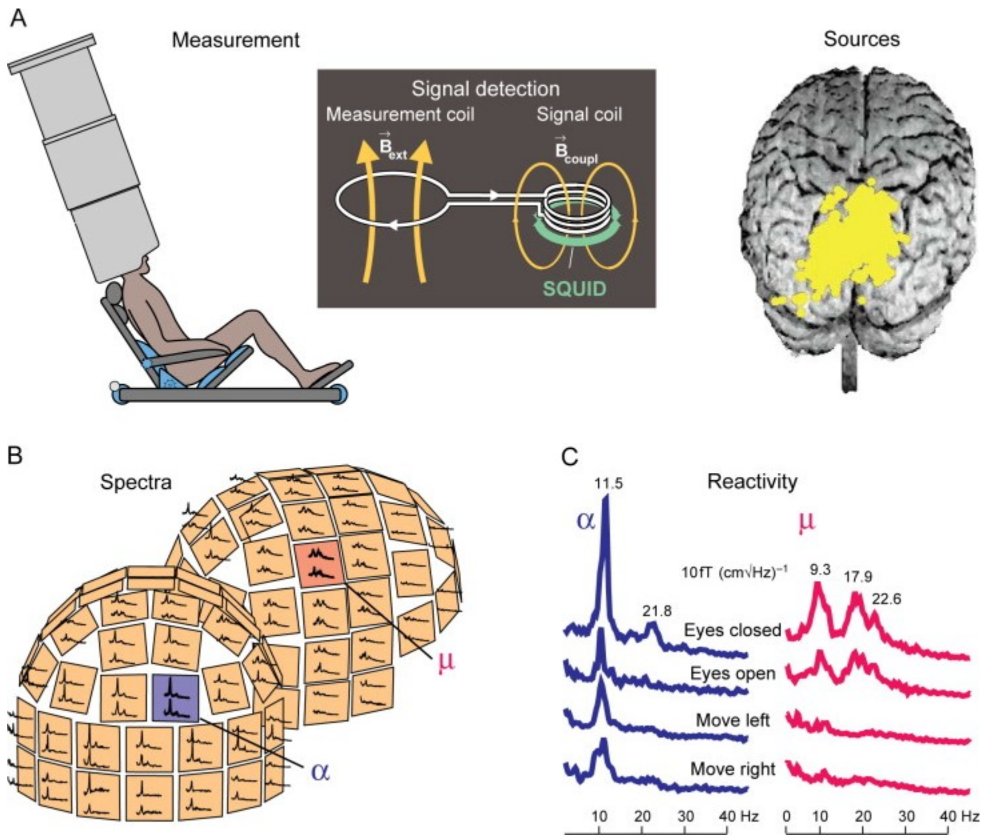
How to collect information about the dynamics of neurons and the brain?

Superconducting Quantum Interferometer Device – SQUID
Magneto - encephalography

Macroscopic Wave Function







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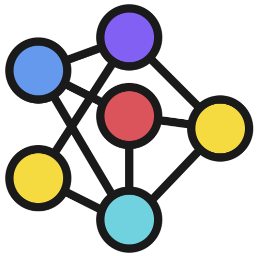
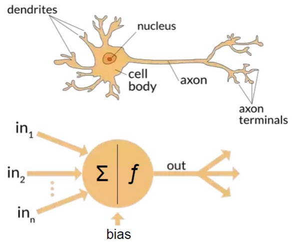
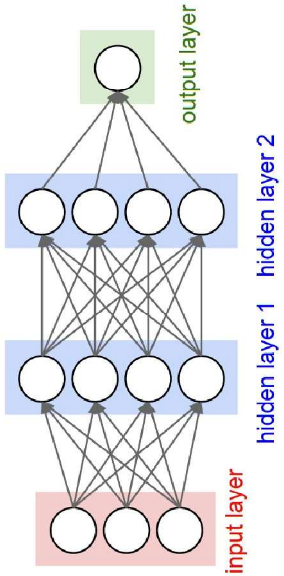
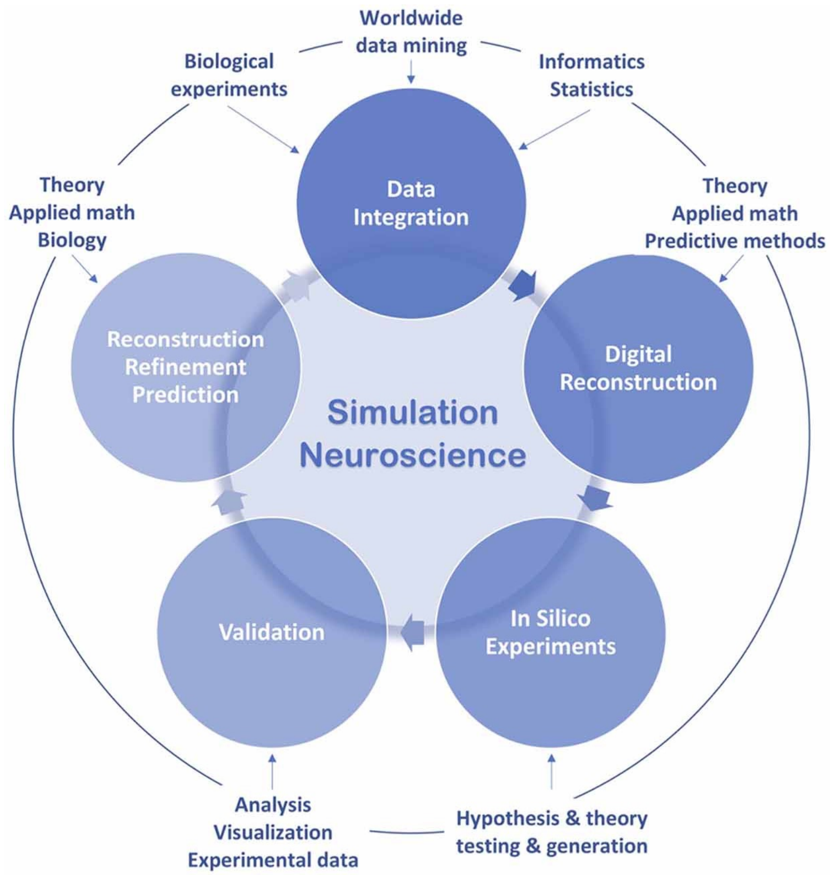
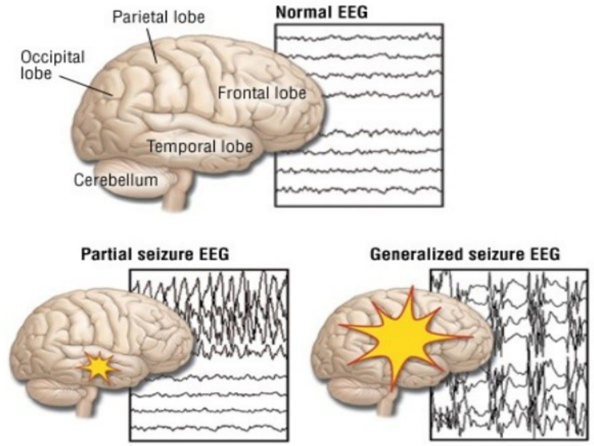
How to collect information about the dynamics of neurons and the brain?











The EEGs images of the epileptic person showing areas of major activity.

Time series analysis of the EEG signals for Epilepsy seizure forecast, Cing M.S. and **Quesada D.**, *In Proceedings of the MOL2NET, International Conference on Multidisciplinary Sciences*, Sciforum Electronic Conference Series, Vol. 3, 07003; http://doi:10.3390/mol2net-03-05102 , http://sciforum.net/conference/161/paper/5102

Complex networks and machine learning: From Molecular to Social Sciences (editorial article), **D.Quesada**, M. Cruz-Monteagudo, T. Fletcher, A. Duardo-Sanchez, and H. Gonzalez-Diaz, Applied Sciences, applsci-626592 http://doi:10.3390/app9214493 (2019).

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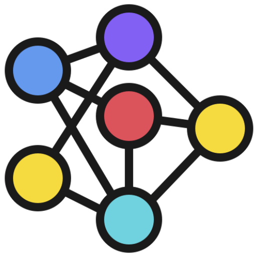

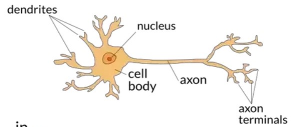

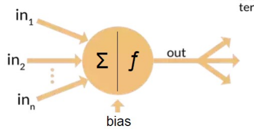

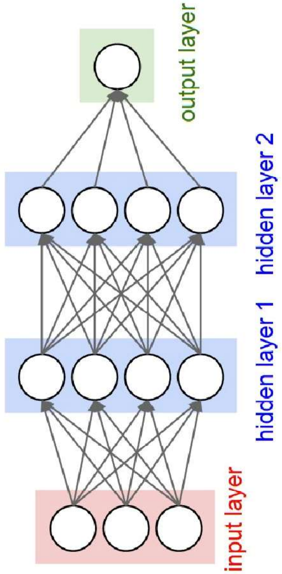

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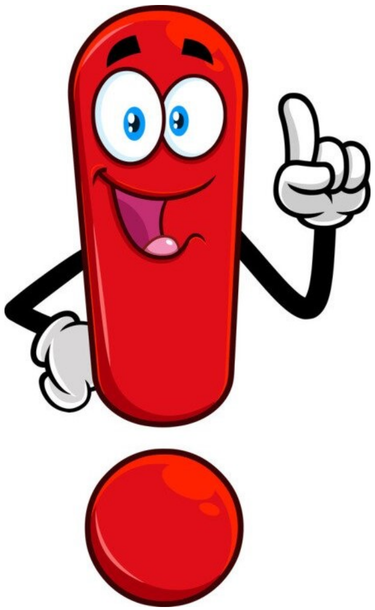


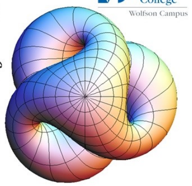
- Data generated by the **Human Brain Project** until today requires techniques from **Data Mining**, **Machine Learning**, **Pattern Recognition**, and **Deep Learning** in order to make sense of them, to integrate data across scales and time, and to find patterns from spikes distributions in connection to different stimuli.

- Different techniques produce **data with different spatial and temporal resolutions**, therefore we need to find out **how to interpolate** across scales.

- **Mathematical modeling** based on synthetic networks should shed light on patterns obtained from data. Mathematical modeling of the brain activity is demanding a huge computer power, **Exascale High Performance Computing** (Ex-HPC). Foundations of **precision medicine**.

- Might **Quantum Computing** help with HPC and precision medicine?

$$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$$



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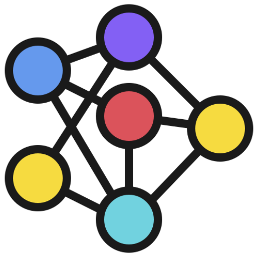
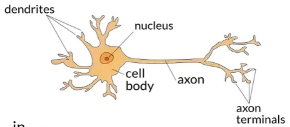
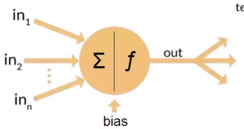
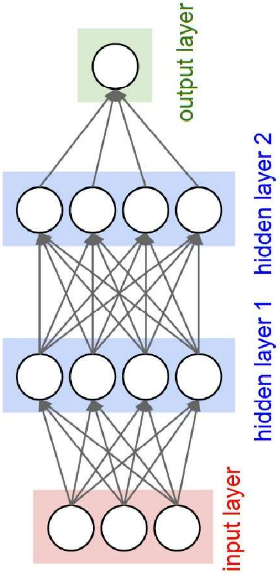
Brain Networks Dynamics – From Dynamical Systems to Complexity and Artificial Intelligence

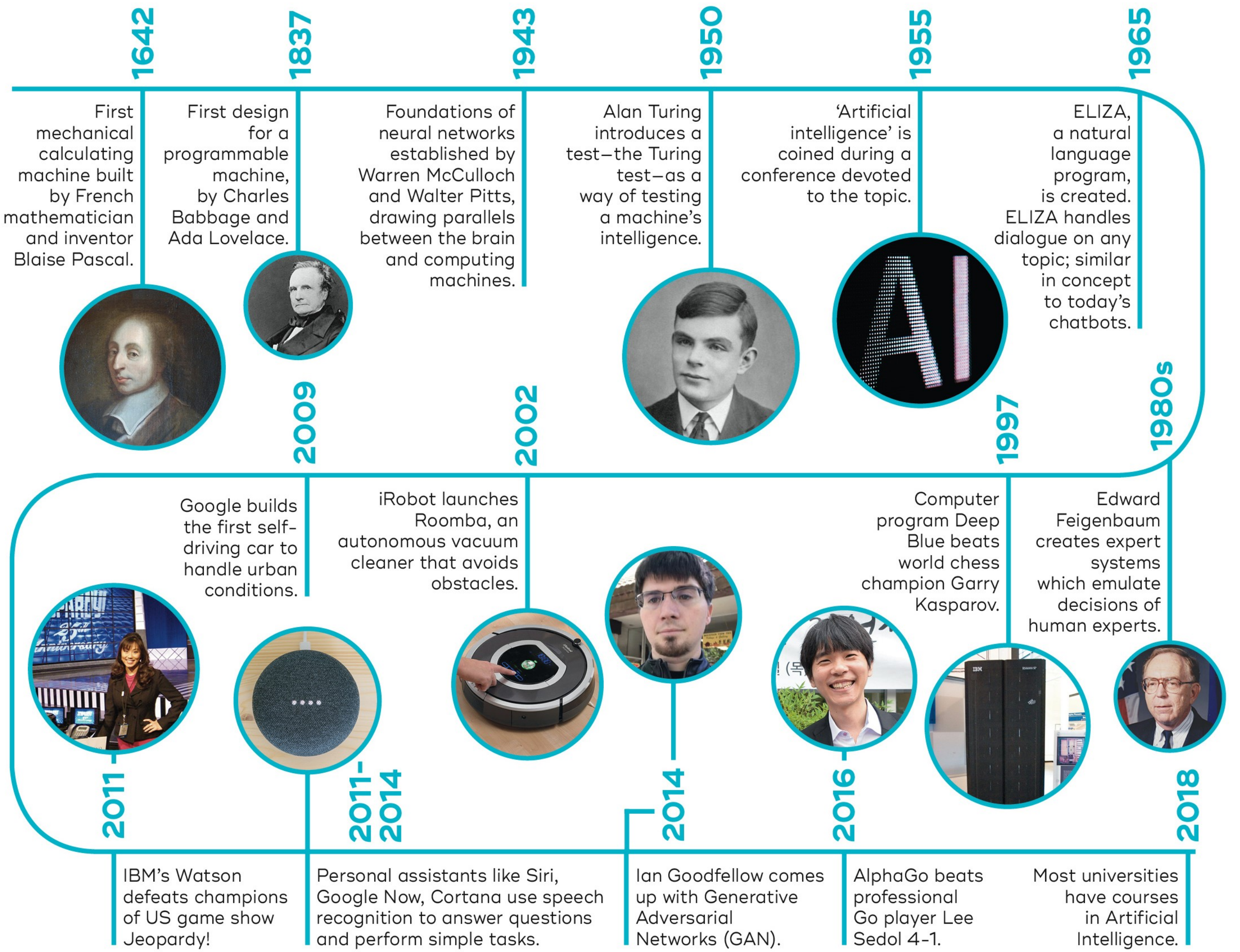
What is coming next to dynamical systems on networks? Cognitive Computing and Artificial Intelligence











$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$

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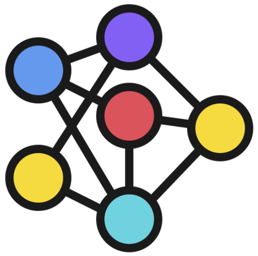
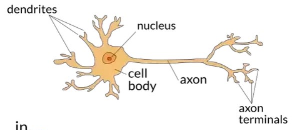
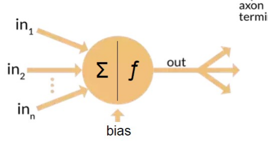
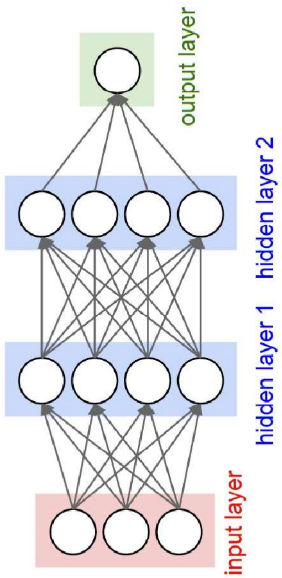
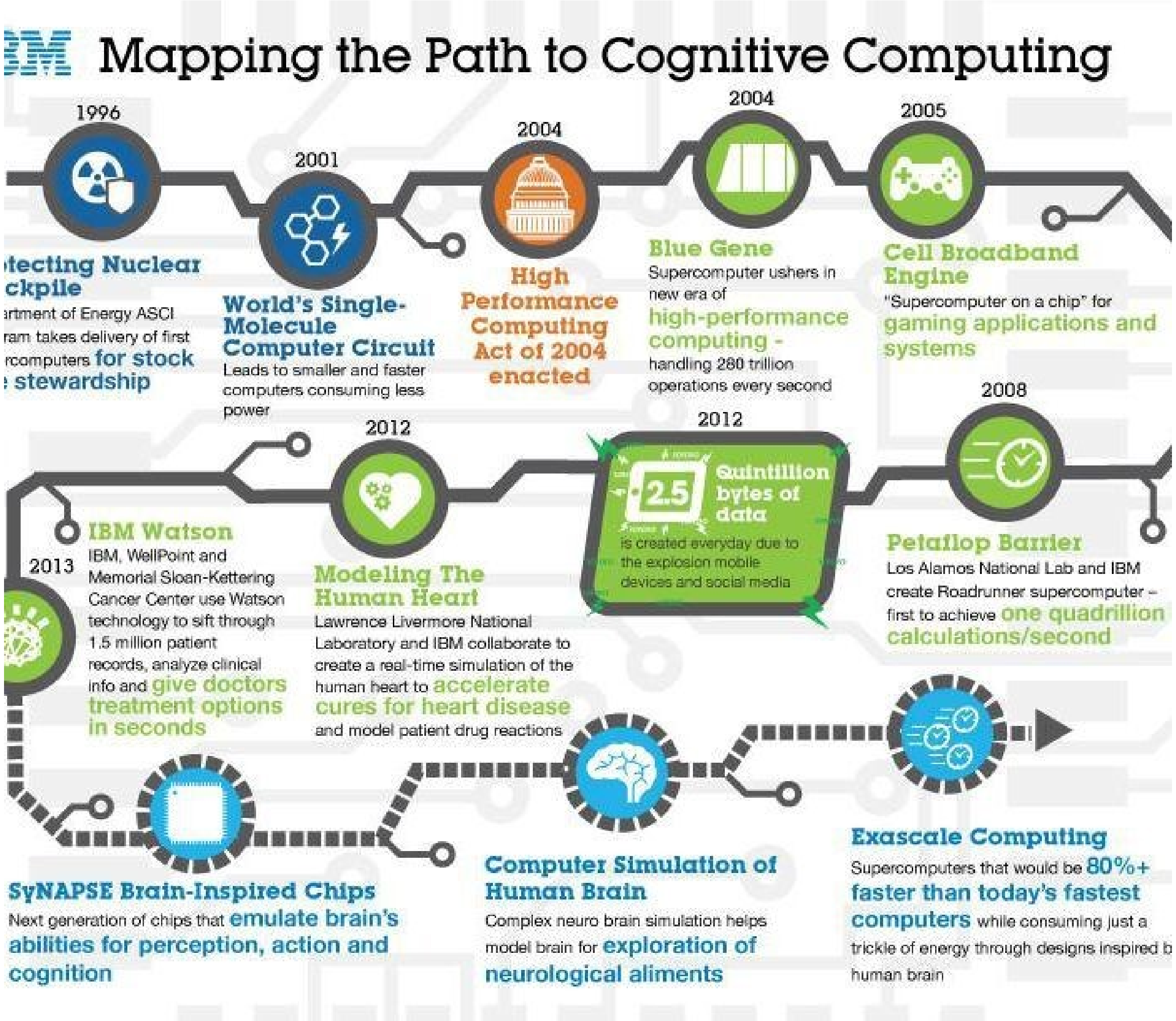
What is coming next to dynamical systems on networks? Cognitive Computing and Artificial Intelligence











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What is coming next to dynamical systems on networks?
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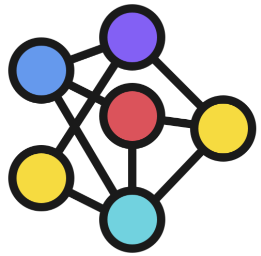

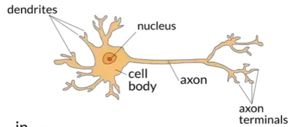

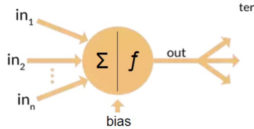

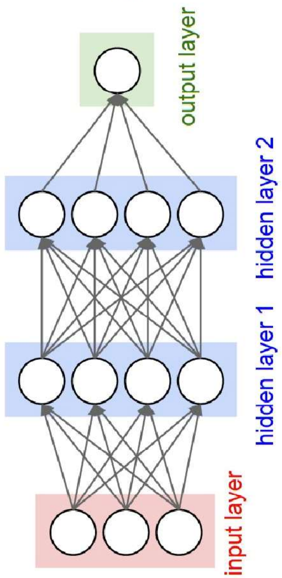

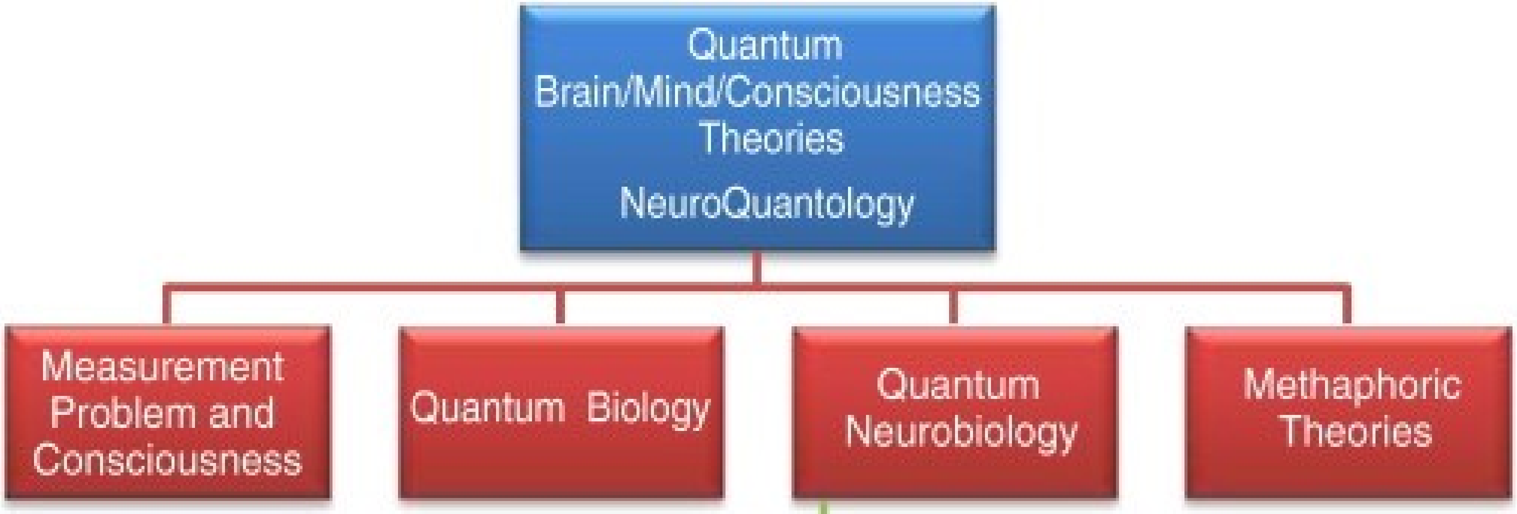

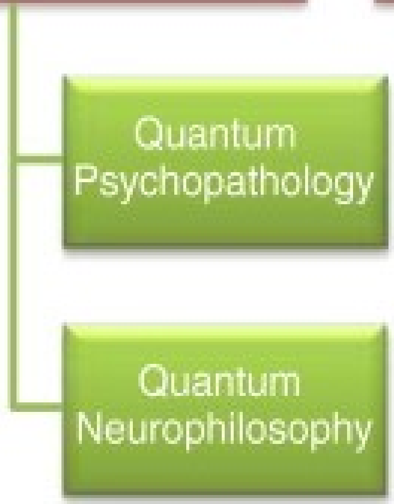

Human Brain Project

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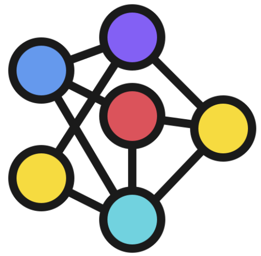

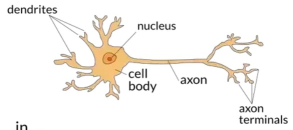

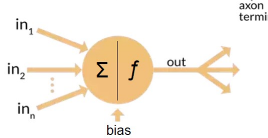

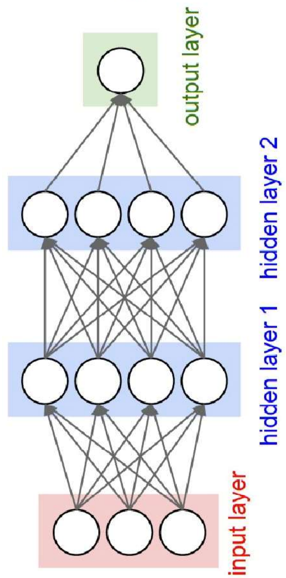

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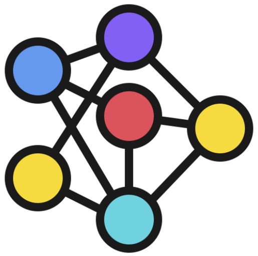
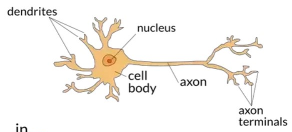
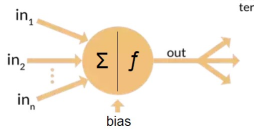
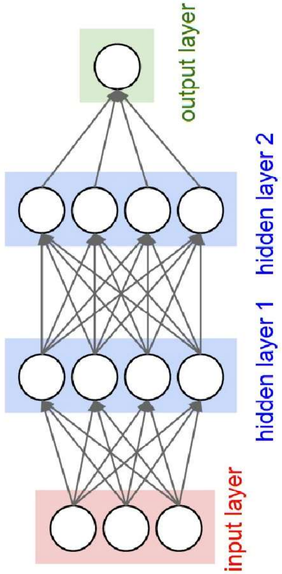
References and Additional Reading









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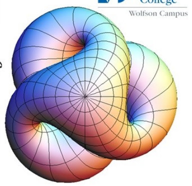
$\nabla = \frac{\partial}{\partial x}\mathbf{i} + \frac{\partial}{\partial y}\mathbf{j} + \frac{\partial}{\partial z}\mathbf{k}$



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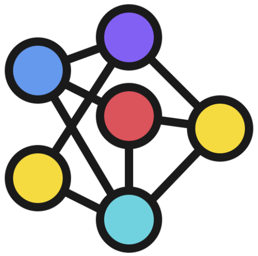

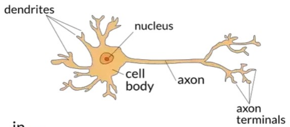

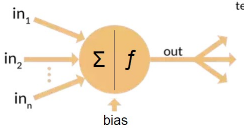

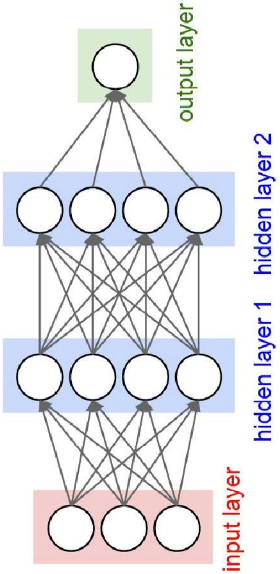

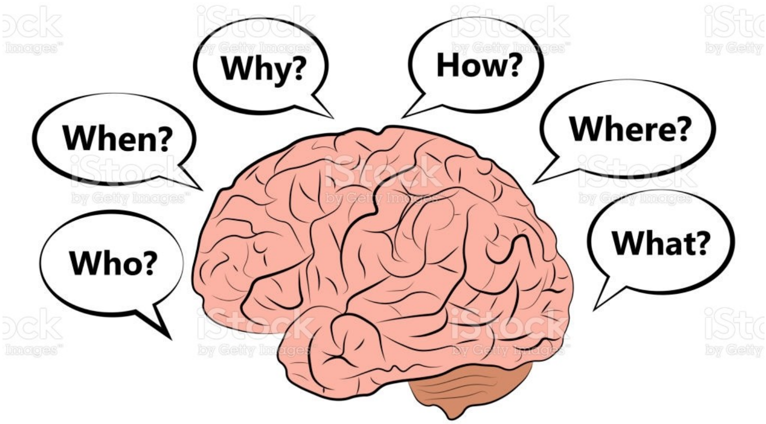

Preguntas?

Questions?

Вопросы?

Des questions?

Domande?