Modelação de Sistemas Complexos

Modelling of Complex Systems

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Modelação de Sistemas Complexos

Modelling of Complex Systems

Introduction

- What is the aim of this course?

The aim of this course is to introduce students to the main ideas, concepts, and tools of the modern theory of complex systems (physical, biological, technological, and social), including theoretical and computational methods.

Modelação de Sistemas Complexos

Modelling of Complex Systems

Introduction

- What are complex systems?

Complex systems have no general definition accepted by *all* scientists (yet?). However, there are a few generic features that a system should have to be considered a complex system, such as:

- Many interacting parts
- Disorder and stochastic processes
- Non-linearity
- Emergent collective phenomena

The course consists of 14 lectures and 5 practical projects (executed during 13 practical classes).

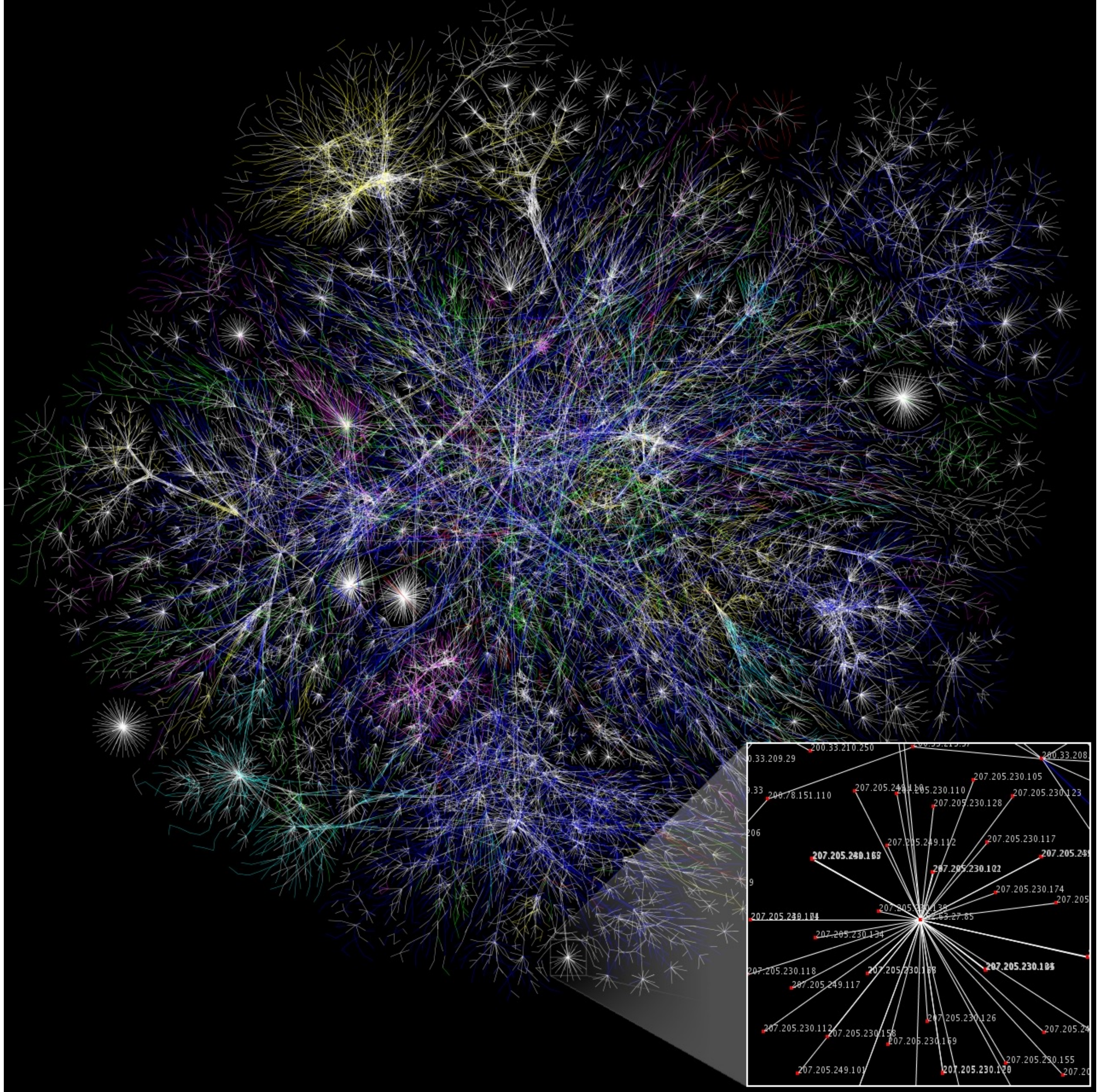
The projects are individual, and develop the topics discussed on the theoretical lectures. Each project includes several tasks. To solve these tasks, the students must write a code and make numerical simulations (in MATLAB, Python, C, or any other language). In a report, a student must present numerical and analytical results, plot figures, and discuss obtained results.

The evaluation is based on evaluations of the 3rd and 5th projects (60%) and a final exam (40%).

In the lectures we will consider complex systems consisting of many interacting agents such as spins, oscillators, neurons, bacteria, animals, people, etc.

These systems often contain a substantial degree of disorder/stochasticity, requiring us to take a statistical approach. To this end, we will extensively make use of the tools of statistical physics.

Internet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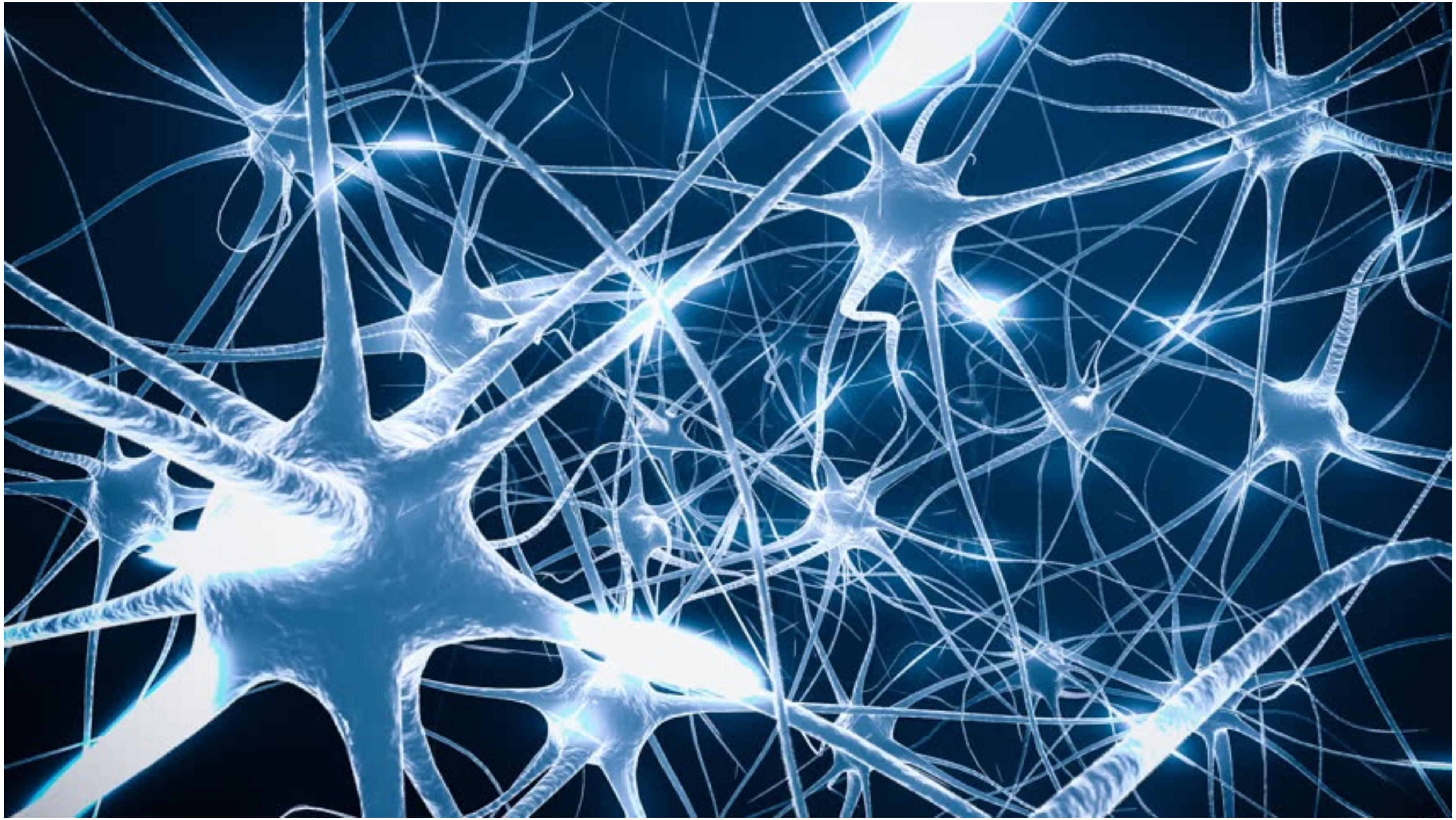
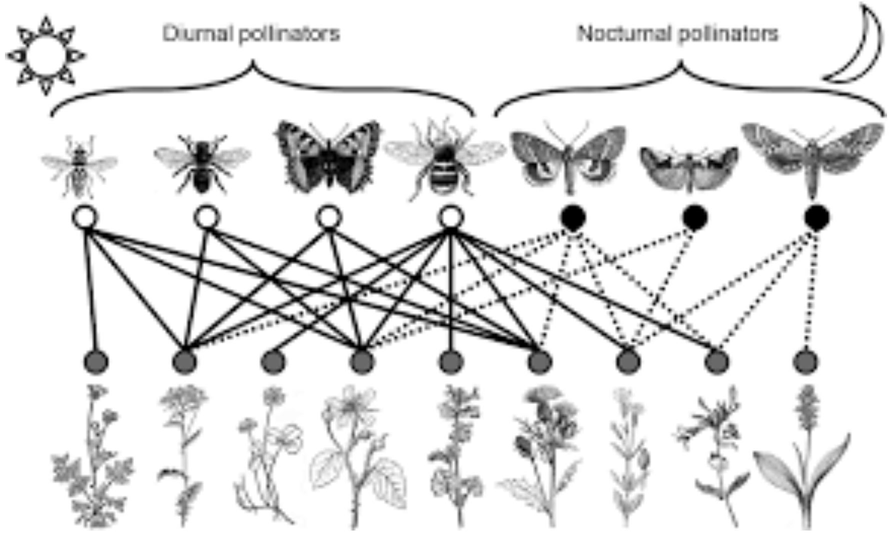
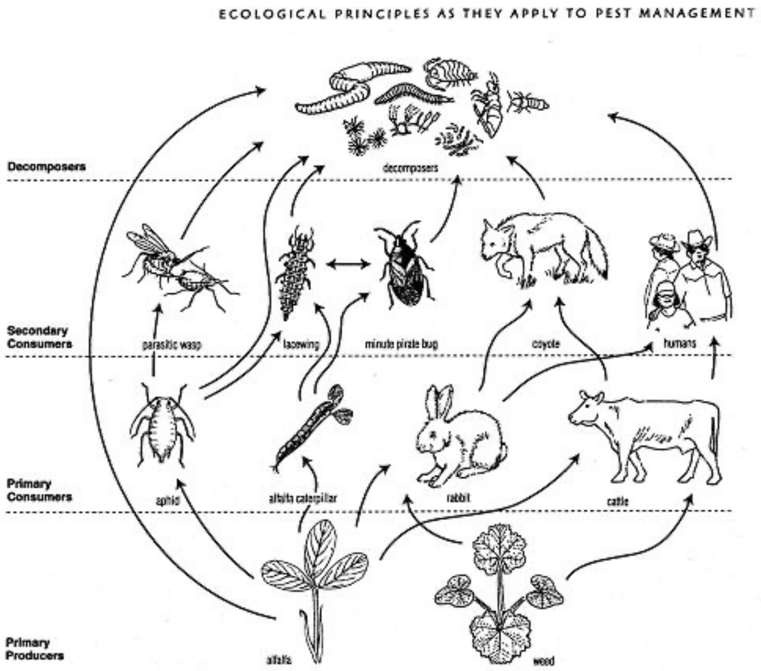
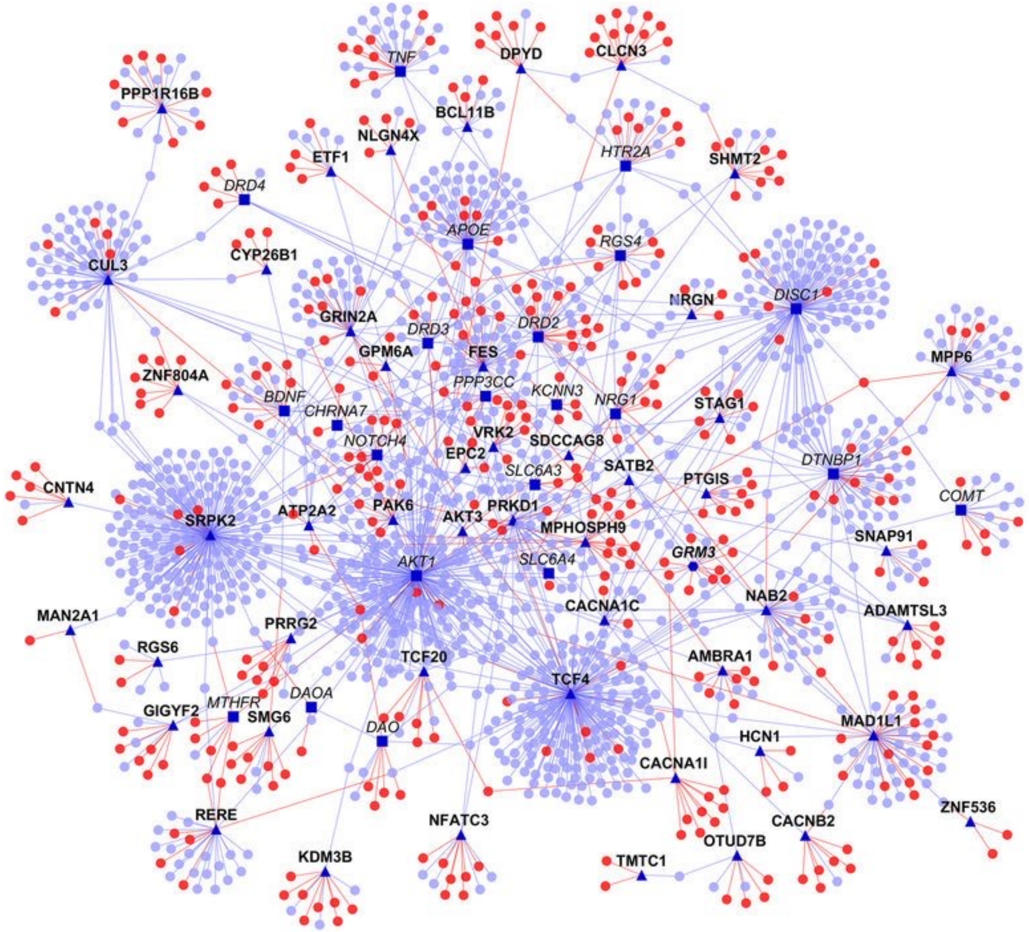
Brain neuronal networks



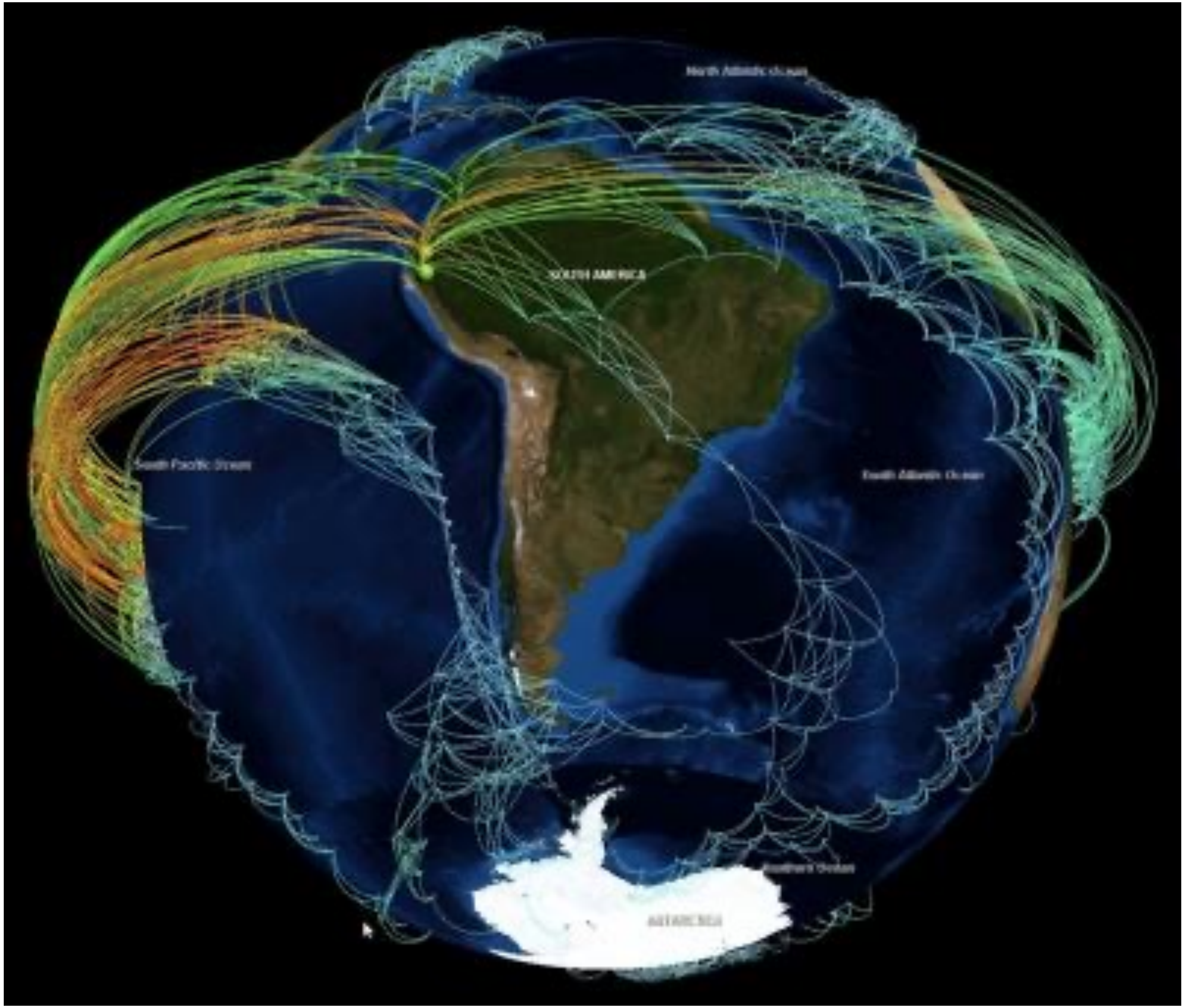
Biological networks







Climate networks



We will consider dynamical processes in classical systems.

In classical mechanics, the dynamics is determined by Newton´s laws.

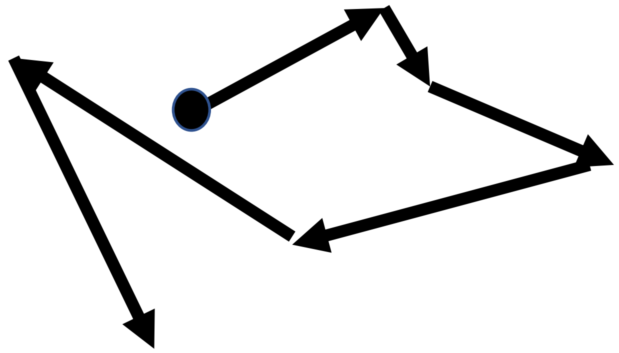
If we have *N* particles having masses m_n , velocities v_n, and positions r_n, then their motion is determined by a set of coupled equations

$$m_n \frac{dv_n}{dt} = F_n(r_1 , r_2, \dots r_N)$$

Here $F_n(r_1 , r_2, \dots r_N)$ is a force acting on *n*th particle from the others particles.

However, there are numerous (stochastic) processes that in practise cannot be described by these classical equations.

Trajectory of a random walk of a small particle in floating in a glass of water or the path of a drunk man:



In a classical mechanics approach we would had to find the trajectories of all the particles in the glass, including collisions, etc.

Brownian motion of small particles in gases and liquids is a representative example of stochastic process.

In practise, classical equations of motion are useless to describe this trajectory. To deal with such systems, we are forced to abandon our passion for determinism, and regard the trajectory as the result of a random process.

In order to describe all possible trajectories of random walks **we must develop new ideas and theoretical methods that allow to deal with stochasticity.**

"Chaos was the law of the nature. Order was the dream of man."
Henry Adams

A stochastic process can be associated with a series of **random numbers** that appear with certain frequencies (or **probabilities**).

→ Probability mass/density distribution functions of random numbers.

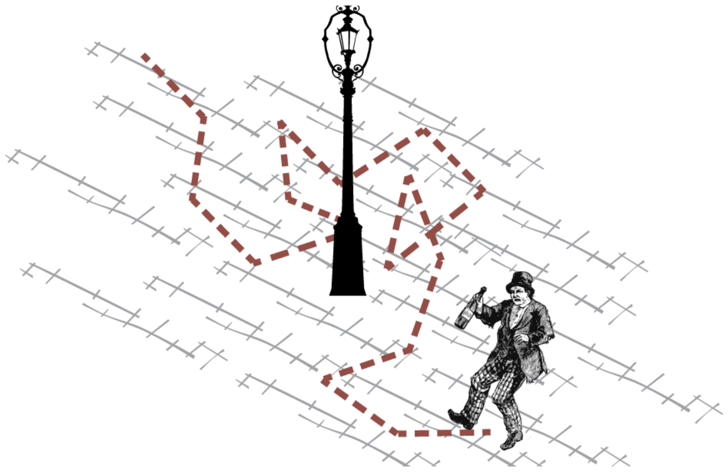
How can we generate random numbers to study them?

Gambling in Casino

Playing Russian roulette

Or, in a computer experiment, using a **pseudo-random number generator**.

Observing random walks of particles or drunk men



What will these studies allow us to understand?

Diffusion of molecules, electrons, etc
Activity of neurons in the brain
Properties of polymers
….

Nature displays numerous **transitions from one state of matter to another one**:

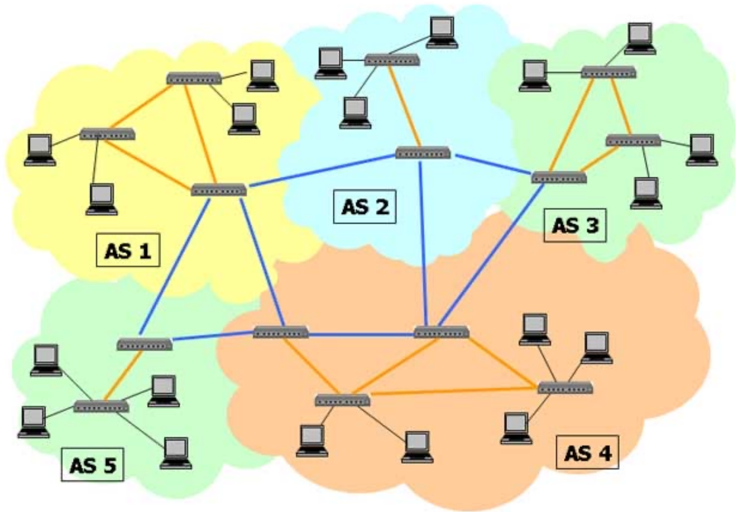
- Water ←→ liquid
- Magnetics spins are aligned at low temperature (e.g., ferromagnetism)
- Percolation (if you will cut one by one physical connections between computers then at a certain moment the Internet will look like a set of *small* computer clusters)
- Neurons in the brain are firing together (brain rhythms)
- Bacteria can die together
- Mass extinctions in ecological systems (Earth´s loss of biodiversity)

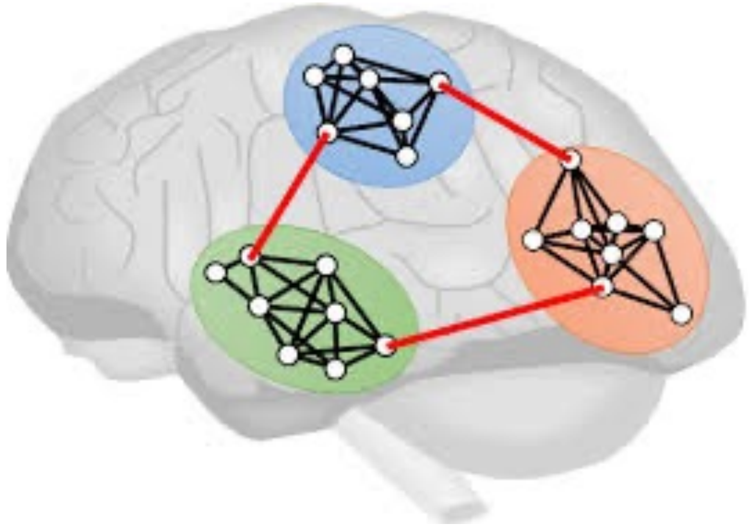
What is the origin of phase transitions? What is the role of stochasticity (fluctuations) in **phase transitions**?

Complex networks

We know that the crystal structure is very important to understand thermal, electric, magnetic and other properties of condensed matter systems.

What can we say about **disordered systems** where structure has no order, for example, the Internet or brain?





Theory of random complex networks (graph theory) allows us to describe the structure of this kind of disordered systems, and understand the effects of that structure on processes taking place in them.

The five projects that will be proposed to students are devoted to five topics discussed above. In this course, student are expected to

- find and analyse probability distribution functions,
- model random walks (1D and 2D),
- study phase transitions,
- model random complex networks.

The course materials will be available at https://elearning.ua.pt.