# The complex systems definitions

## Introduction to the complexity science for the Complex Dynamic Systems Master Course

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# Complex systems

Complex systems consist of a large number of components that interact with each other to produce nontrivial phenomena that cannot be explained by analyzing the individual constituent elements.

# Some examples

- Many real systems are complex systems, such as:
- the human body, with its cells and processes
- financial markets
- social organizations
- traffic
- climate

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# The study of complex systems

- The key problems of complex systems are the difficulties that arise in their formal modeling and simulation
- For this reason we start by analyzing their main properties

# SELF-ORGANIZATION

- In complex systems the organization emerges spontaneously from local interactions between parts of s system that initially is disordered
- Local interactions determine the formation of behavior at the global level
- The organization is decentralized, distributed over all the components of the system
- It is typically robust, making the system able to survive or self-repair negative disturbations
- The behavior of self-organized systems is often umpredictable

# COLLECTIVE BEHAVIOR

- Many social insects show collective behavior, i.e. global behavior emerging from local interactions. See for example birds, fishes, insects, such as ants and bees
- Humans also show collective behaviors, see for example the dynamics of social networks

# NETWORKS

- A complex system is composed of many components and their interactions
- For this reason it can be represented by a network in which nodes represent the components and links represent their interactions

# EVOLUTION AND ADAPTATION

- Natural systems behave under the genetic drift of evolution and natural selection, which induce changes of some characteristics, which become more common or more rare in the population. Evolution gave rise to biodiversity at all scales, from species to microorganisms and molecules

- Adaptation results from the dynamic evolution and makes systems able to reach states resilient to external potentially damaging factors

# PATTERN FORMATION

- Pattern formation refers to the generation of complex organizations
- This can be observed in cell reproduction and organization in space and time
- See also some chemical reactions. It is also observed in human systems, like the traffic

# SYSTEMS THEORY

- Systems theory is the interdisciplinary study of systems
- System are composed by interacting interdependent parts, exchange energy with the environment, have a given structure, objective, and functioning
- They are usually more than the sum of their parts if they show synergistic relationships or emergent behavior

# NONLINEAR DYNAMICS

- In nonlinear systems the change of the output is not proportional to the change of the input. Most systems are inherently nonlinear in nature

- Nonlinear dynamical systems, described by variables changing over time, may appear chaotic, unpredictable, or counterintuitive, contrasting with much simpler linear systems