Capire la Complessità
Understanding Complexity

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WHICH COMPLEXITY?

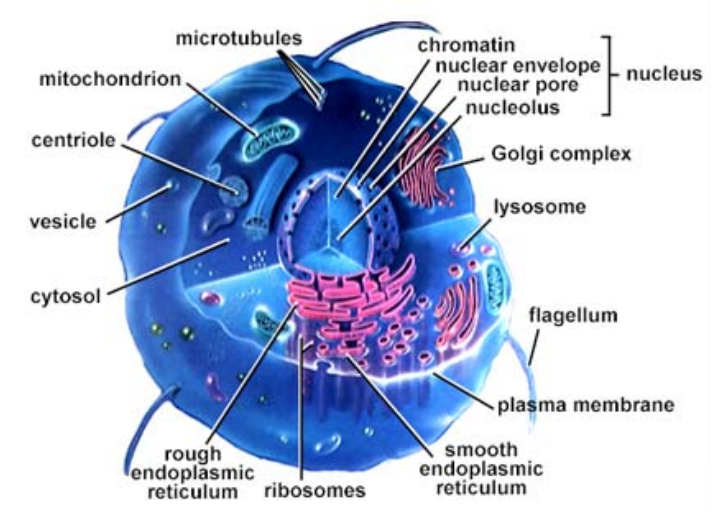
A physical system is just that: a physical system. What is systematized is matter itself, and the processes in which the system is realized are also material.
But a biological system is more complex: it is both biological and physical — it is matter with the added component of life; and a social system is more complex still: it is physical, and biological, with the added component of social order, or value.

M.A.K. Halliday (2005, p.68)

COMPLEX SYSTEMS

Complex systems are everywhere around us.

- Biological systems
- Ecological systems
- Computer systems
- Socio-economical systems
- ...



cell

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Brain

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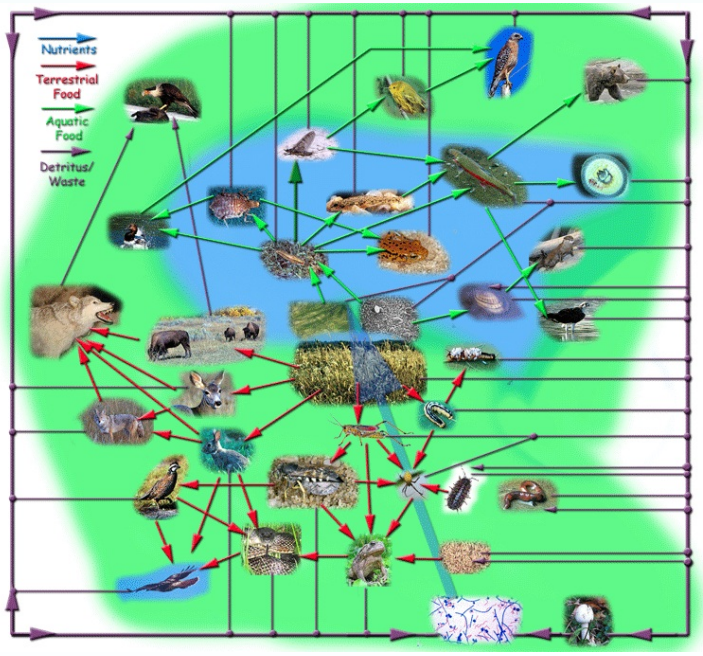

interaction among species

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Internet

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social network

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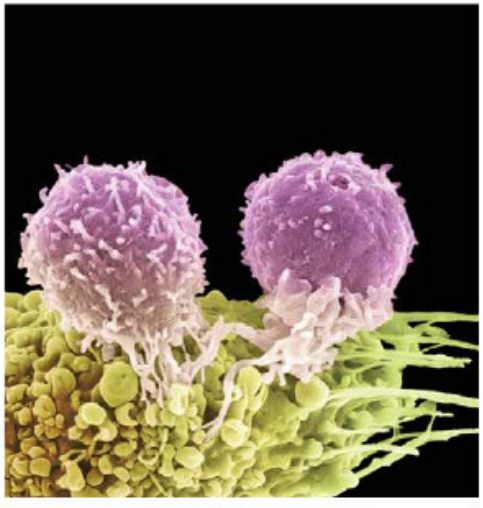

T lymphocytes and cancer cell

Coloured scanning electron micrograph (SEM) of two T lymphocyte cells attached to a cancer

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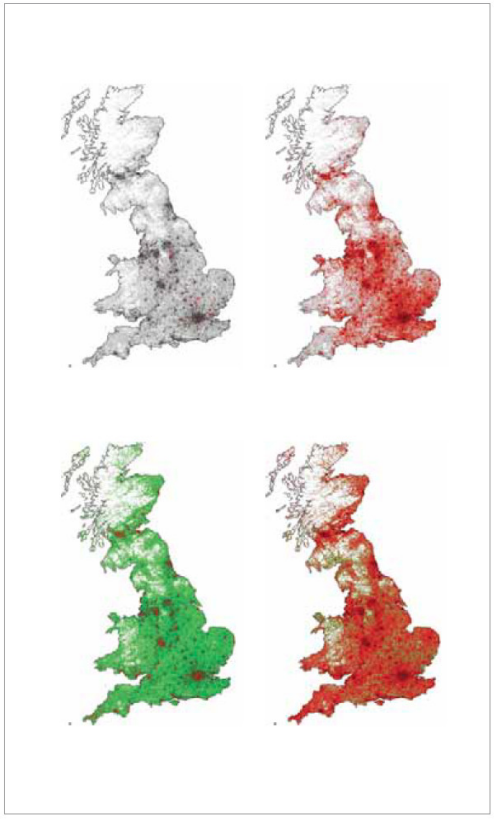

Epidemic modelling

Simulation of the first 77 days of an avian H5N1 influenza epidemic in the United Kingdom

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- Control new (natural or artificial) epidemics outbreaks
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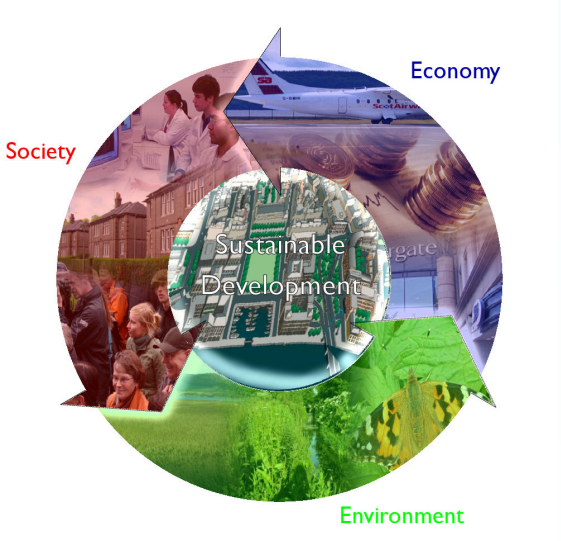
- Move to a sustainable economy



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This is the major scientific challenge of the 21^{st} Century!

Complex Systems: a high level view

High level view

Complex systems are made up of entities interacting in complex ways.

Entities

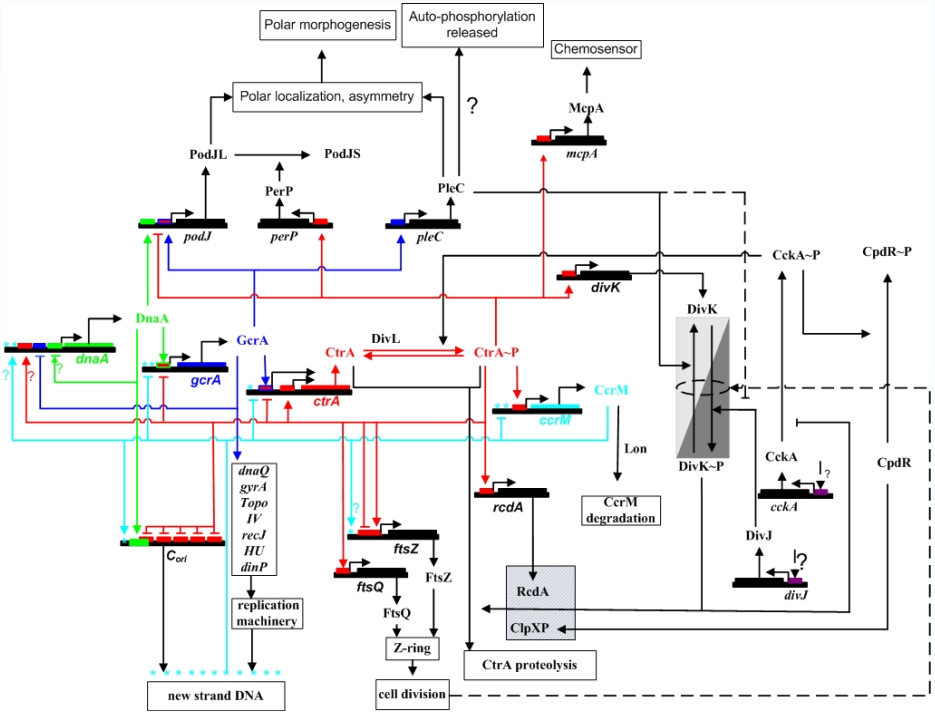
Entities can be of different nature: molecules, cells, animals, computer jobs, processors, humans, ...

Interactions

Interactions can involve a small or large number of entities, and may depend in complex ways from the environment or the global state of the system (non-linearity)

AN EXAMPLE: GENE NETWORKS

- Genes are pieces of DNA coding for a protein
- Proteins are the building blocks of living beings. Some control the expression of genes (transcription factors).
- Genes regulate each other in a complex ways.
- Complexity of life is in such regulatory processes (human and bananas share 50% of their genomes)



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Mathematical modelling

- Construct mathematical models (Which mathematics? How to find the right level of abstraction?)
- Analyse the models, discovering their properties.
- Compare with experimental data.

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The role of computer science

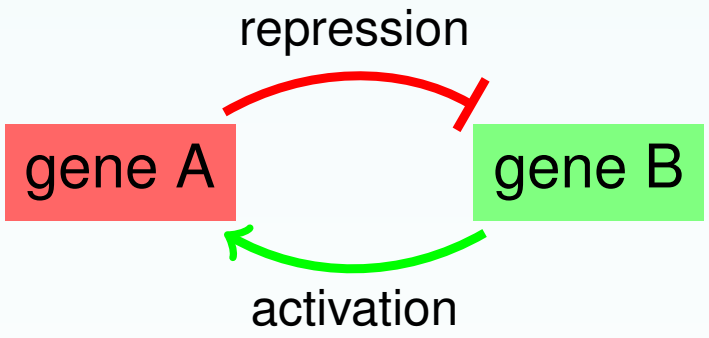
- The models are too large and too complex. They can be analysed/ simulated only with a computer
- Computer science has developed sophisticated tools to design large software systems, which are made of many pieces of code interacting together in complex ways...

How can we understand such complexity?

The level of complexity and the size of those systems, the large amount of experimental data, require a new approach based on mathematics and computer science.

We are still far from being able to model, analyse, and control large scale systems (e.g. a cell, an ecosystem, a social network).

EXAMPLE: A SIMPLE GENETIC NETWORK



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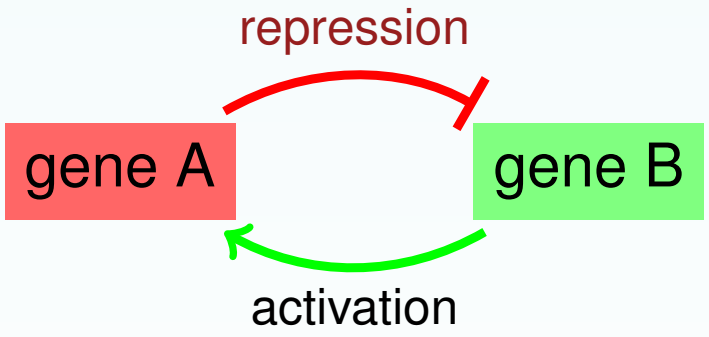

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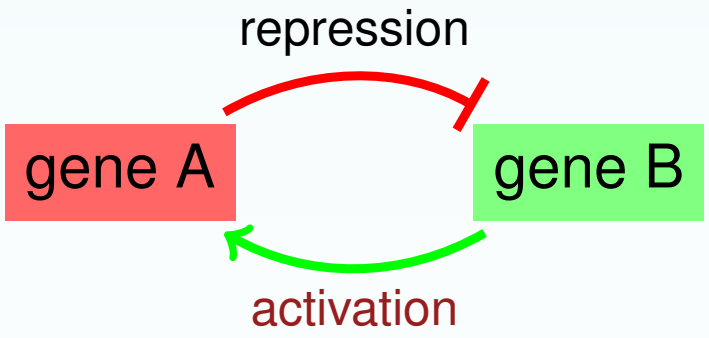

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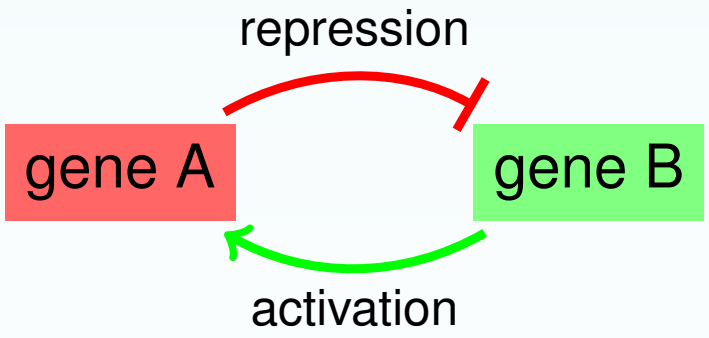

- The product of gene A (protein A) represses the production of gene B
- The product of gene B (protein B) activates the production of gene A
- What is the behaviour of the gene network? How does the protein concentrations vary with time?

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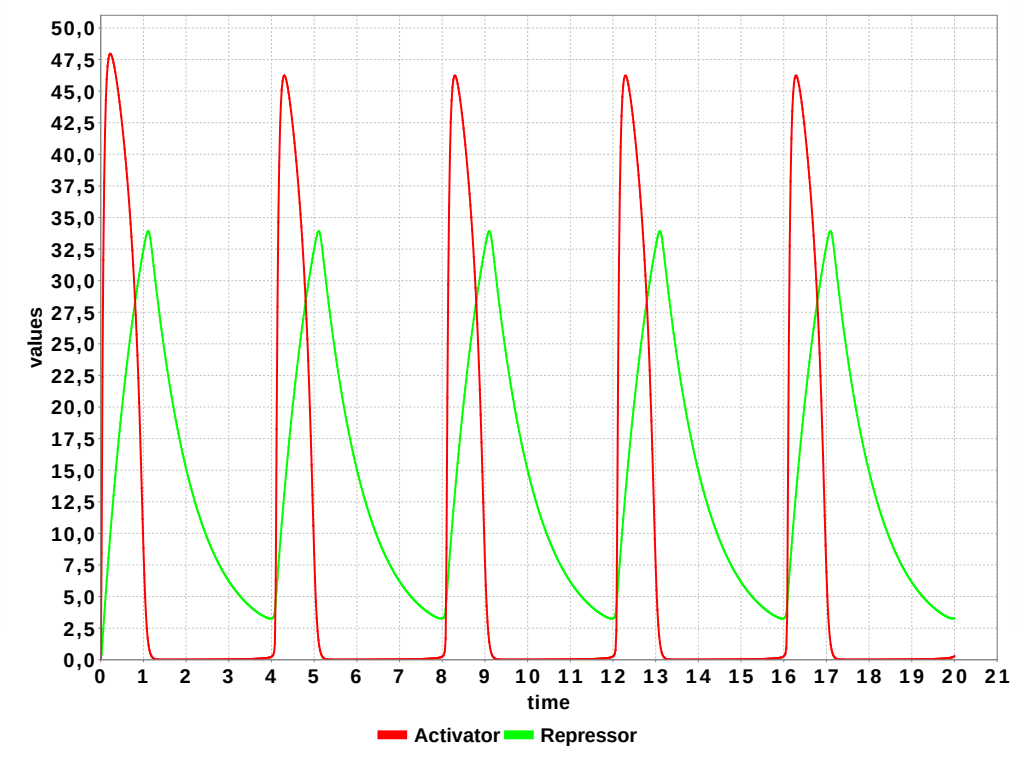

Example: ant foraging

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Hypothesis

They communicate by releasing in the environment pheromone molecules, and moving (with high probability) in the direction in which they sense more pheromone.

EXAMPLE: ANT FORAGING

We can test this hypothesis in silico with a model in which ants move randomly in space, with a probability depending on the amount of pheromone. They release new pheromone when they are carrying food and returning to the nest.

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- We face the impelling scientific and technological need of understanding and (partially) controlling them.
- The only way to obtain a systemic understanding is to build on mathematical and computational tools.
- We are still at the beginning of this new scientific revolution.

THANKS FOR THE ATTENTION

Question time

DOMANDONE FINALE

Man mano che la nostra comprensione di sistemi complessi, quali le cellule, aumenterà, saremo sempre più in grado di ingegnerizzare organismi viventi sintetici per svolgere le più svariate mansioni: batteri per produrre farmaci, batteri per ripulire il mare dal petrolio, alghe per produrre carburante, piante più produttive e resistenti ai parassiti per eliminare fertilizzanti e pesticidi, . . .

Gran parte di tutto questo non è fantascienza, è già realtà.

Pensate che tutto ciò travalichi i limiti consentiti alla scienza?
Ritenete giusto che l'unico motore dietro questa tecnologia sia il profitto?
O preferireste che l'obiettivo fosse incrementare il benessere collettivo?

E come potete cercare di influenzare questi processi?

An example: El Bottellón.

El bottellòn refers to a phenomenon in the city of Granada, Spain: people in the nights spontaneously gather in a square in the city and start a big drinking party.

An example: El Bottellón.

- Each person in a square tries to speak with everybody in the square. If she finds somebody to speak, remains there. She leaves the square otherwise.
- The probability with which a person in the square is a friend to talk to is c.
- n squares, N people in total, X_i: people in square i
- The probability of leaving the square is then $(1 - c)^{X_i - 1}$
- Emerging parties in a square if $c > \frac{n}{N}$