Complex Systems course introduction

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http://mitpress.mit.edu/sites/default/files/titles/content/cbnhtml/home.html

Lecturers

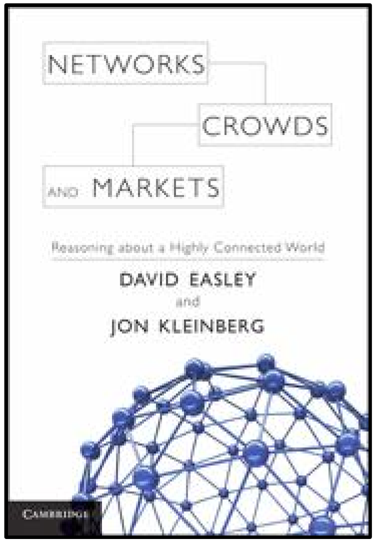
- Moreno Marzolla (4 CFU)
  - moreno.marzolla@unibo.it
  - http://www.moreno.marzolla.name/teaching/CS2013/
  - Office hours: on demand (please ask by email)
- Stefano Ferretti (2 CFU)
  - s.ferretti@unibo.it
  - http://sferrett.web.cs.unibo.it/CAS/
  - Office hours: wed 13:00—14:00 (please confirm by email)

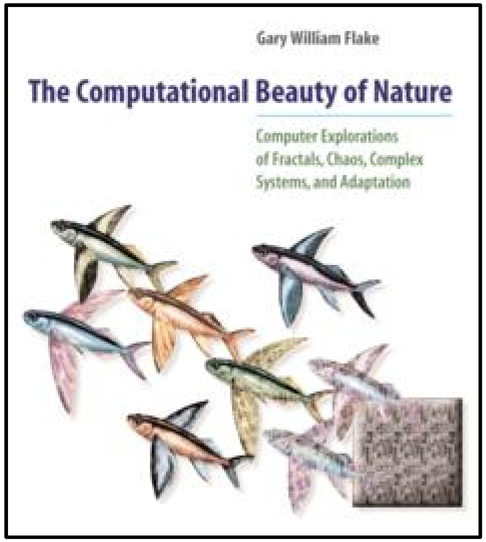
Introduction

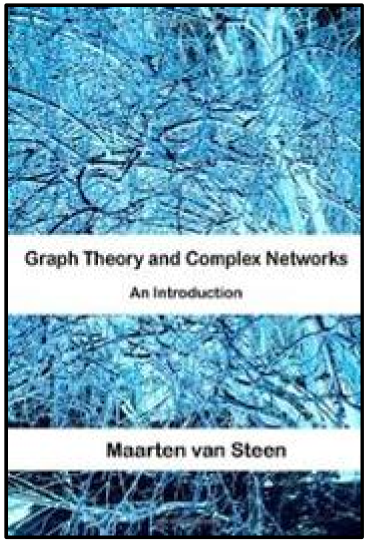
- The Complex Systems course is one course taught by two professors
  - Lectures will interleave rather than being strictly separated
- 6 CFU
- Prerequisites
  - Fundamentals of statistics, algorithms and data structures, discrete mathematics, elementary calculus
  - Programming skills (Java or C/C++)

Textbooks

- G. W. Flake. *The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation*, MIT Press, Cambridge MA. 2000.
- J. Kleinberg, D. Easley, *Networks, Crowds, and Markets: Reasoning about a Highly Connected World,* Cambridge University Press, 2010 [available online]
- M. van Steen. *Graph Theory and Complex Networks: An Introduction*, 2010 [available online]







Syllabus

- Moreno Marzolla
  - Nonlinear dynamics and chaos
  - Fractals
  - Cellular automata, multi-agent systems
  - Game theory
  - The Web as a complex system
- Stefano Ferretti
  - Peer-to-peer systems
  - Complex Networks, Random graphs, Small-world phenomena
  - Gossiping, cascading behavior, diffusion

Exam

- Project + Paper presentation
- Project
  - Programming project + written report
  - Projects must be done individually
  - We will propose some projects; you *may* propose your own (we can accept/request changes/reject your proposal)
  - Three deadlines (July 2014, September 2014, February 2015)
  - There will be no project discussion
- Paper presentation
  - You choose a research paper among a list proposed by us and give a 20-minutes presentation+general discussion before the end of the course; presentations must be done individually
  - If you can are unable to make the presentation, you will be required to give an oral examination (on the whole course program of study) during any of the official exam sessions

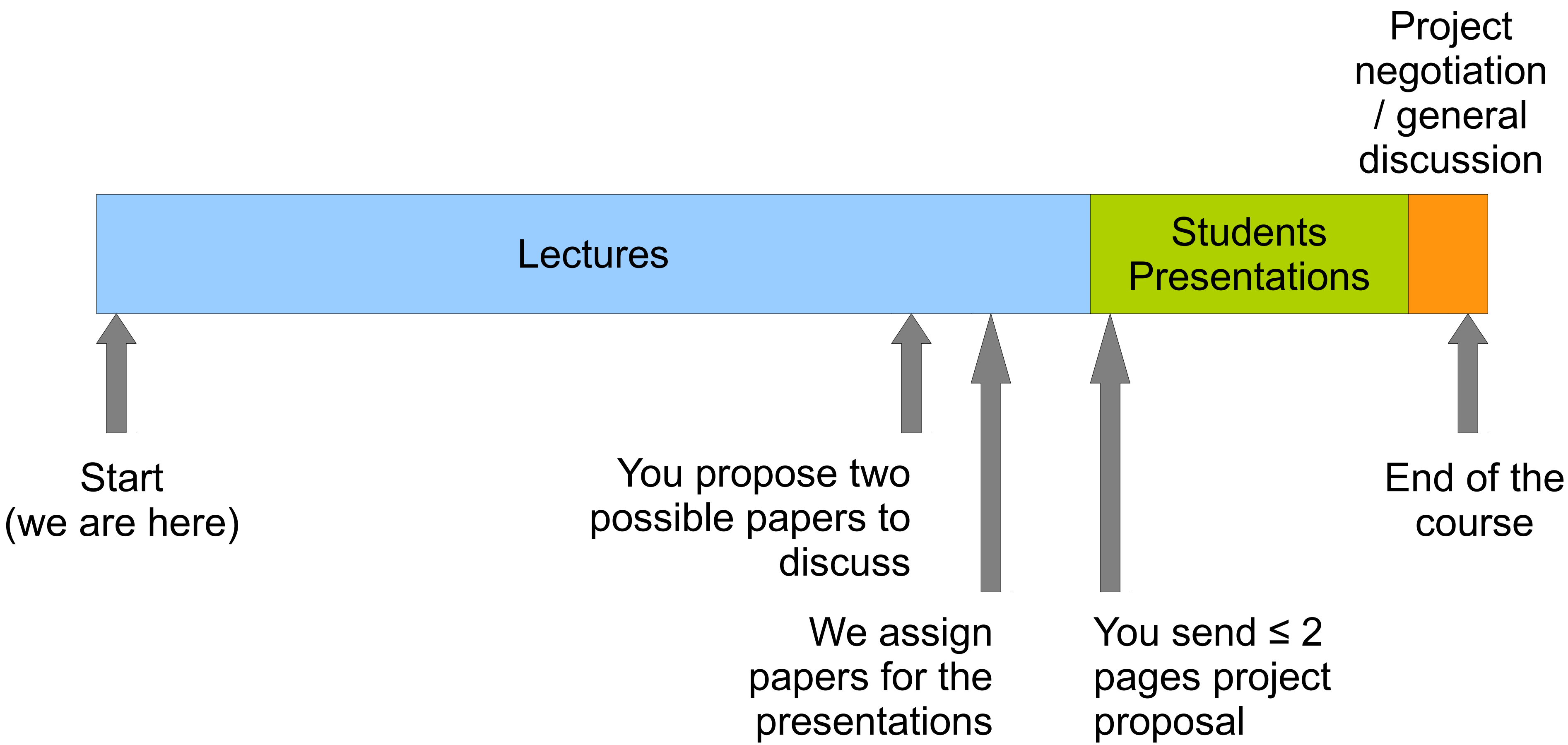
Paper Presentation

- You choose two papers among a list proposed by us
  - Papers less than 3 pages must be excluded
- We assign one paper to each student
- You prepare a 20 min presentation to be given at the end of the course (during class hours)
  - If you are unable to give the presentation before the end of the course, you are required to pass an oral exam on the whole content of the course during one of the regular exam sessions

Programming Project

- You make a written project proposal on one of the topics covered in the course
  - Max 1 page, possibly before the end of the course
  - Description, methodology, expected outcomes
- We will: Accept / Reject / ask to change and resubmit
- Projects canuse either PeerSim, NetLogo, or hand-made Java/C/C++/Octave programs
- Three deadlines
  - July, September, February
- Evaluation will be based on the written project report
  - max 15 pages, template will be made available on the course Web page

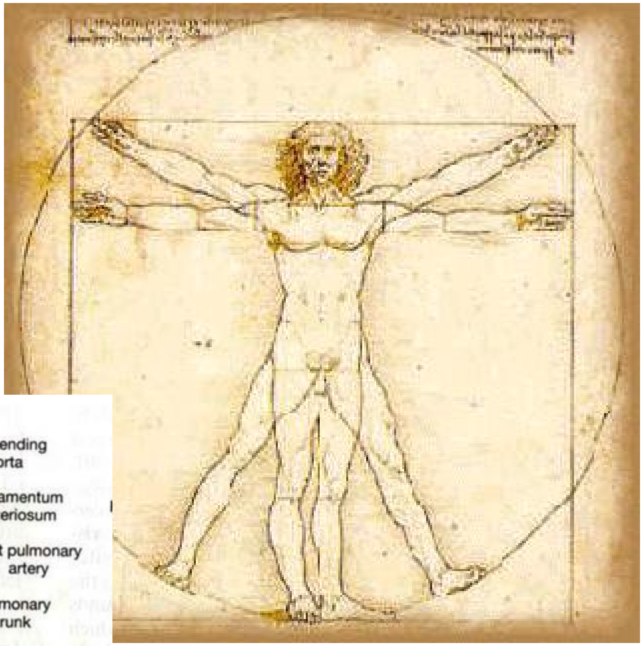
Course Timetable

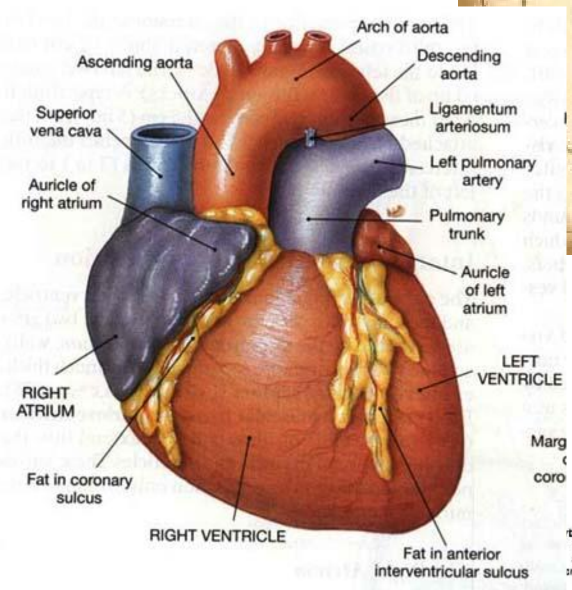


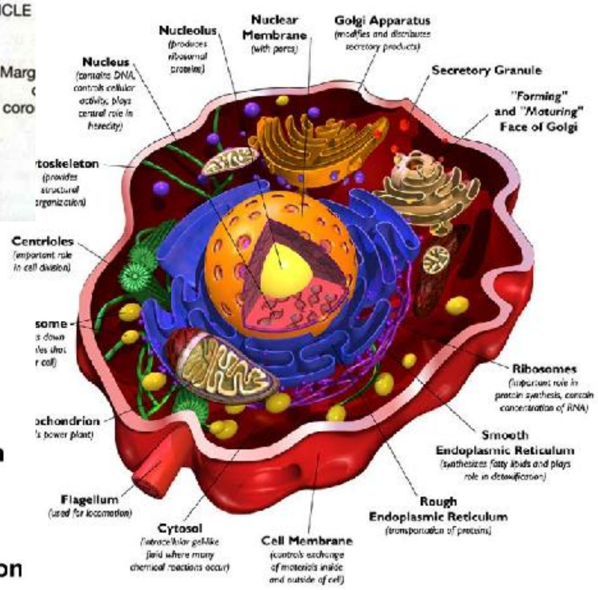
Complex Systems

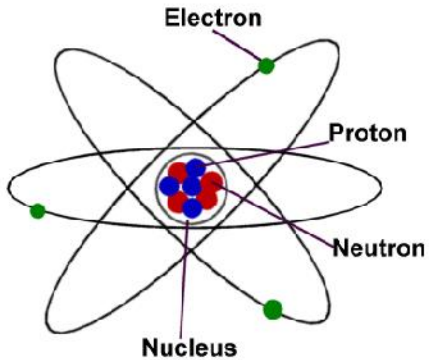
Understanding nature

- Reductionism
  - Understand complex things by breaking them into smaller parts and understanding the parts
- This works pretty well in many cases, but clearly has limitations
  - Why don't we cure diseases by analyzing the quantum state of the atoms making up the body?



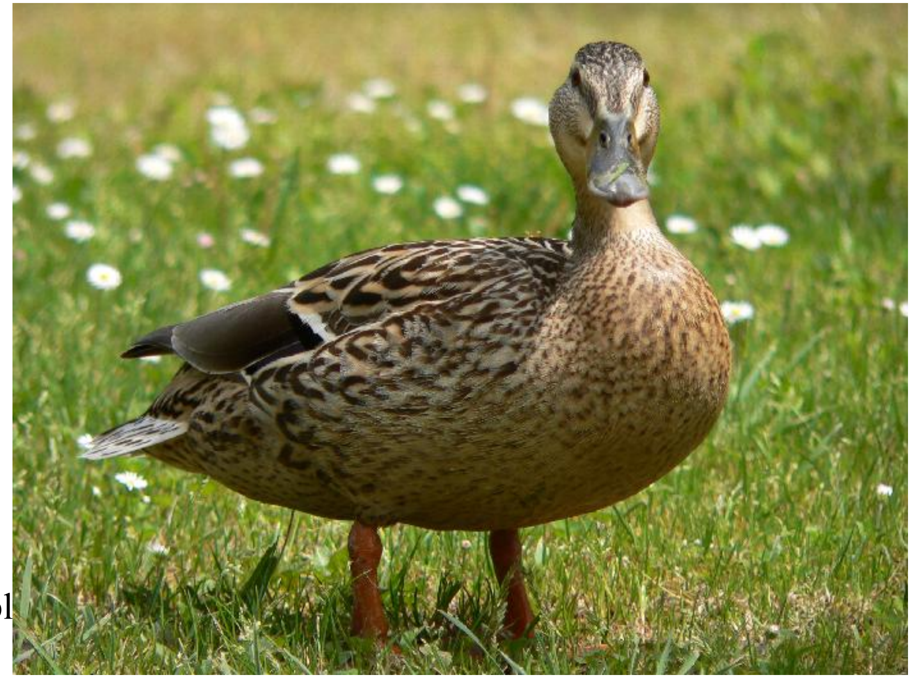






Understanding nature

- Describing things in isolation tells only half of the story
- It is equally (if not more) important to describe also how things behave and interact with each other
  - E.g., giving an accurate static description of a duck at the atomic level does not help very much in understanding what a duck *does*.
  - What does it eat?
    How does it reproduce?
    How does it fly?
    How does it swim?
    Why do ducks migrate?



nature = agents + interactions

- Agents
  - Molecules, cells, ducks, species
- Interactions
  - Chemical reactions, immune system response, mating, evolution
- Studying agents in isolation only provides partial information
- The reductionist approach fails when applied in the reverse direction
  - Trying to understand the whole by analyzing the parts

Example: ants

- A single ant can do few things
  - depending on its caste, search for food, defend the colony, lay eggs
- However, the ant colony as a whole exhibits a complex behavior
  - Build complex structures, cross rivers by forming chains, find shortest path to food
  - An ant colony is much more than a bunch of ants

Understanding nature

- Agents that exist at one level of understanding are quite different from agents on the other levels
  - Cells ≠ organs, organs ≠ animals, animals ≠ species
- Yet, the interactions at one level are often similar to the interactions at another level
  - How do we find self-similar structures in trees, leaves, snowflakes, mountains and clouds?
  - Is there a common reason why it is difficult to predict the stock market and also to predict the weather?
  - How do collectives such as ants colonies, human brains, stock markets self-organize to create complex behaviors?
  - What is the relationship between evolution, learning and adaptation found in social systems?

Nature is frugal

- The rules governing the behavior of agents are usually the simplest possible
  - The same kind of rule tend to be used in different places
- Collections, multiplicity and parallelism
  - Complex systems with emergent properties are usually highly parallel collections of similar units
- Iteration, recursion and feedback
  - For living things, iteration means reproduction. Moreover, almost all biological systems include structures that are made through recurrent processes
- Adaptation, learning and evolution
  - Adaptation can be seen as a consequence of parallelism and iteration in a competitive environment