COMPLEX SYSTEMS SIMULATION
MASTER CACI

Facultad de Informática (UPM)

Complex systems

Characteristics of complex systems (Boccara):

1. They consist of a large number of interacting agents.
2. They exhibit emergence; that is, a self-organizing collective behavior difficult to anticipate from the knowledge of the agents' behavior.
3. Their emergent behavior does not result from the existence of a central controller.

A computer example: The game of life.

Modelization vs. simulation

Modelization vs. simulation (Boccara, John Maynard Smith): “The value of simulations is obvious, but their utility lies mainly in analyzing particular cases … The better a simulation is for its own purposes, by the inclusion of all relevant details, the more difficult it is to generalize its conclusions … For the discovery of general ideas different kinds of mathematical description, which may be called models, are called for. Whereas a good simulation should include as much detail as possible, a good model should include as little as possible”
In this course we will be somewhere in between these two extremes.

Learning outcomes

1. Understanding of theoretical models used to describe complex systems
2. Ability to design a simulation model for a real problem
3. Ability to implement a prototype applied to a real problem
4. Capacity to present with precision and concision the results of an applied work

Achievement indicators

1. Be able to analyze new problems and come up with their own efficient solutions using concepts and techniques from the course.
2. Know the basic notions of dynamical systems and chaos and their applications to simulate and analyze real processes.
3. Understand the usefulness of fractal techniques (iterated function systems, L-systems,) to simulate nature forms.
4. Be able to simulate complex systems made of many similar and simple parts (cellular automata, autonomous agents,).
5. Know different techniques for simulation of stochastic processes (Markov chains, stochastic models in queuing theory,).

Continuous assessment

Brief description of assessable activities	Time	Place
Resolution of exercises and practical works (with and without computer) related to concepts introduced in the classes	Developed and delivered through the course	Classroom and homework
Preparation and oral presentation of a subject of the course	Developed and delivered through the course	Classroom and homework

Grading criteria

In the theoretical classes, concepts and techniques for the simulation of complex systems will be presented in the classroom. Problems and practical exercises related with the theoretical classes will be proposed in the classes to the students. These will take 60

On the other hand, the students will have to prepare a lecture on one of the topics of the course. The lecture could be illustrated with a software application developed by the student. The weight of this activity in the evaluation will be 40

In order to pass the course it will be necessary to obtain half of the points in each of the evaluable activities.

Contents of the course

1. Dynamical systems and chaos
   i) Basic notions of dynamical systems. The logistic family. Stability and unstability. Bifurcations
   ii) Characteristics of Chaos
   iii) Strange attactor. Henon attractor, **Lorenz attractor**,...
   iv) Julia and **Mandelbrot set**
2. Cellular automata
   i) **Cellular automata**
   ii) **Autonomous agents and self-organization**
3. Fractals and iteration function systems
   i) Fractal geometry and self-similarity (Cantor set, Koch curve, Peano curve,). **Fractal dimensions**. **Random fractals** and **Brownian motion**
   ii) **L-systems** and Fractal growth
   iii) Iterated functions systems

References

1. Nino Boccara, Modeling Complex Systems, Springer, 2003
2. Gary W. Flake, The Computational Beauty of Nature: Computer Explorations of Fractals, Chaos, Complex Systems, and Adaptation, The MIT Press, 2000
3. Melanie Mitchell, Complexity: A Guided Tour, Oxford University Press, 2009
4. Barnsley, M.F., Fractals Everywhere. Academic Press, San Diego,1988
5. Peitgen, H.O.; Jürgens, H. and Saupe, D., Chaos and Fractals. New Frontiers of Science, Springer-Verlag, New York, 1992