Corso di Laurea in Informatica - Università di Bologna

Progetto per il Corso di Complex Systems and Network Science

AA 2016/2017

Ozalp Babaoglu   Francesco Gavazzo
Dipartimento di Informatica - Scienza e Ingegneria Università di Bologna

April 10, 2017

General Information, how and what to submit

The student is required to choose one of the project listed below or to make his/her own project proposal (according to the parameter below described). The project must be carried out individually. The project must be handed in electronically, by email to

francesco.gavazzoATgmail.com.

The deadline for submission is 1 July 2016, at 23 : 59. Please use your official university email address (studio.unibo.it); the subject of your mail must be

"CS Project 20162017"

You will receive a confirmation message (this may take a couple of days, please be patient). Your mail must contain a compressed archive (only .tar.gz and .zip formats are accepted; avoid .rar and other formats) containing the following items:

- Source code you have developed;
- A short paper, in pdf format, describing the experiments that have been performed and a detailed discussion of the results (see the project description for details).

Simulations and experiments have to be performed using either NetLogo or PeerSim. The source code must be adequately commented and well written (following good programming habits). The paper can be written either in Italian or English, and should be organized like a technical paper with a title, abstract and (short) bibliography. You can use any document editor to write the paper, but you must send only the pdf version to us. This project must be done individually. No sharing of source code or technical papers is allowed, either in part or in full. However you can − and are actually encouraged to − discuss any issues with your fellow students and/or with the instructors. We suggest you write no more than 16 pages using the Latex or Word/OpenOffice template from Springer LNCS.

- Doc template: http://www.moreno.marzolla.name/teaching/complex-systems/2013-2014/word_template.zip
- Latex template: http://www.moreno.marzolla.name/teaching/complex-systems/2013-2014/latex_template.zip

You are required to put your full name, email address and personal ID number (numero di matricola) on the paper, on each source file and in your mail.

Grading policy

These are the minimum requirements of your project:

- You must develop your project as required in project description. Extensions and personalization are encouraged, provided previous approval by the members of the teaching staff.
- Simulations and experiments have to be performed using either NetLogo or PeerSim.
- In case you select PeerSim as the simulation tool, you should use the cycle-driven simulation engine of PeerSim; your simulator must be configurable by means of the standard PeerSim configuration file.
- The final report has to describe both the topic you choose and the work you did. In particular, you have to justify your designing choices, formulate previsions and analyze the results you achieved: you have to explain the results, and possibly interpreting them. The paper might describe implementation details if necessary (i.e. if these are of theoretical relevance), but keep in mind that we can look at the source code, so be concise.

As a general suggestion, we recommend you to write simple models, focusing on a limited set of experiments but proving that you have actually understood the results. Be modular: try to understand the basic features of the model you want to build, and to construct a simple model exhibiting all these features. Proceed gradually to enrich this model in a modular way. This will make things much simpler and faster (besides, it will make your work much more scientifically appreciable and readable). You have limited time, so use it wisely. If you are interested in these topics (e.g., you want to build a better model, or you want to study similar systems), you are encouraged to talk to us when you are looking for a thesis topic.

Project Description

In this project you will study and analyze in detail an application of cellular automata of your choice. You can either choose a project from the list of project proposals (see below) or to make your own proposal. In the latter case, your proposal has to satisfy the criteria described in this document, to be relevant with the course and has to be first approved by the teaching staff.

Introduction. *Cellular Autamata* (CA, for shorts) were first introduced in the 1940s by Ulam and von Neumann while they were working at Los Alamos National Laboratory. Von Neumann was studying the notion of self-replicating systems whereas Ulam was working on the problem of crystal growth using a lattice model. The interaction from those works led to the notion of cellular automaton. Although studied during the 1950s and 1960s it was not until the 1970s and Conway's Game of Life that interest in the subject expanded beyond academia. In the 1980s Stephen Wolfram published a number of papers detailing his study of the universality of cellular automata and the complexity of their patterns. These studies culminated in the publication of A New Kind of Science, a 1280 page book, in 2002. Wolfram's main claim is that cellular automata have applications in many fields of science (Wolfram's assistant Matthew Cook in fact proved Turing-completeness of CA).

Preliminaries Cellular automata are (usually space-time discrete) dynamical systems. Concretely, a cellular automaton consists of a regular finite dimension grid of cells, each in one of a finite number of states. That is, we have an n-dimensional grid C^n of cells and a finite set S of states such that each cell $\mathbf{c} \in C^n$ has a state $s \in S$. For each cell, a set of cells called its neighborhood is defined relative to the specified cell. That is, we have a neighborhood function N associating to each cell $\mathbf{c} \in C^n$ the set of its neighborhood cells $N(\mathbf{c}) \subseteq C^n$.

The dynamic of the automaton works as follows. An initial time instant (time $t = 0$) is selected by assigning a state for each cell. A new generation is created (advancing t by 1), according to some fixed rule (generally, a mathematical function) that determines the new state of each cell in terms of the current state of the cell and the states of the cells in its neighborhood. Typically, the rule for updating the state of cells is the same for each cell, does not change over time, and it is applied to the whole grid simultaneously (but this is not strictly necessary, see the below project proposals).

The Project Your task is to to model a complex system of your choice using CA. More specifically, you have to choose a complex phenomenon studied in a scientific field of your choice (computer science, physics, biology, social sciences etc) and show how to model such phenomenon using CA. Some suggestions on possible topics are given below.

In your report you are supposed to give the reader the necessary background knowledge on the problem/phenomenon you have chosen, as well as motivations for that choice (e.g. why this is an interesting problem, which applications it has etc).

The simulation/modeling of the phenomenon using CA has to be justified as clearly as possible. For instance, you should give the full details of your encoding/simulation of the phenomenon as a cellular automaton as well as argue why this encoding/simulation is a good one. This is not a formal work and you are not supposed to formally proved the above statement: it could be enough to show that your encoding/simulation makes correct prediction on the behavior of the phenomenon. If you have doubts about that please do not hesitate to contact us.

Please keep in mind that this is *not* a research project. You are not supposed to come up with new applications of CA. Your task is to study in detail a (possibly already existing) application of CA.

Project Proposals Here we list some possible topics for your final project.

- *Navier–Stokes equations, Lattice Gas Automata and Fluid Dynamics.* Lattice gas automata are cellular automata used to simulate fluid flows being possible to derive the macroscopic Navier-Stokes equations (which describe the motion of viscous fluid substances). In this project you study how to simulate fluid dynamics with this kind of CA, providing both theoretical explanations and implementations. A good starting point is simply the Wikipedia page.

- *Universality of Conway's Game of Life.* Conway's Game of Life (GoL) provides a universal model of computation, meaning that it is capable to compute any computable function. The aim of this project is to study this result. You are not asked to actually implement a universal Turing Machine in the Game of Life (this will take too much time); rather, you should analyze the computational power of GoL, providing some relevant implementations (for instance implementing logical gates), and thus providing a step-by-step explanation of universality of GoL (as well as the meaning of such result). A good starting point could be this paper. If you are interested in the subject, you could also look at Paul Rendell's works (where an actual encoding of a universal Turing Machine in GoL is given).

- *Cellular Automata and Ordinary/Partial Differential Equations.* Ordinary/Partial Differential Equations (ODEs and PDEs, respectively) are powerful mathematical tools widely used to model dynamical systems (e.g. in physics, biology, ecology etc). CA can be used as an alternative way to describe such dynamical system (see, for instance, the first project proposal). In this project you study the relationship between ODEs/PDEs and CA, providing examples (with relevant implementations). The project focuses on the 'big picture', meaning that your analysis and implementations are not supposed to be as details as those required in the first project proposal (which focuses on a specific dynamical system). A good starting point is this paper.

- *Cellular Automata and Tumor Growth.* In 1984 Düchting and Vogelsaenger published a paper describing how CA can simulate tumor growth and proposing some applications to tumor treatment. Since then several researches have been conducted on the applicability of CA in modeling tumor growth. In this project you survey the main results achieved in this filed, reproducing relevant implementations as examples (depending on the complexity of the example you choose, even a single implementation can be enough). A good starting point is this survey.

- *Applications of Cellular Automata in Biology.* This is a fairly open project and follows the same pattern of the third proposed project. You can start by reading this paper (which also contains several ideas for further projects).

- *Stochastic Cellular Automata.* Stochastic CA are simply CA in which the rule describing the dynamic of the automaton is stochastic (i.e. probabilistic). Such automata have been shown to have several applications as well as a rich mathematical theory. In this project you explore this family of CA, either focusing on a single application in detail, or working on a more general level on their theory and applicability by means of (several) examples. For instance, you could either review one of the above project in a probabilistic setting, or focusing on probabilistic versions of Conway's Game of Life. A good starting point for this project is the Stochastic Cellular Automata Wikipedia page.

- *Cellular Automata with Memory.* This is a variation of standard CA in which each cell remembers the history of its previous states (up to a certain depth). The dynamic of the automata will then be a function depending both on the neighborhood of a cell and on its previous history. This project follows the same pattern of the above one, but with CA with memory instead of stochastic ones. You can start from this paper. If you want to try something new and more advanced, you can experiment with different forms of knowledge. e.g. equipping each cell with partial or total knowledge of the states/histories of other cells (partial knowledge can be modeled in a probabilistic fashion). Game Theory could be a great source of inspiration.

- *Nesting of Cellular Automata.* This project follows the same pattern of the previous two, but with Nested Cellular Automata. Nested Cellular Automata come from the simple observation that agents in complex systems are often complex systems themselves. Similarly, one could study CA in which cells are themselves CA.

If you are interested in one of this project, you have a proposal for a new one or you simply have questions and you need some clarifications, please do not hesitate to contact Francesco Gavazzo.