UNIVERSITÀ
DEGLI STUDI DI MILANO-BICOCCA

COURSE SYLLABUS

Complex and Uncertain Systems

2627-1-F1802Q135

Aims

In line with the educational objectives of the Master Degree in Computer Science, the course aims at providing the knowledge to formally face models describing complex systems and uncertain systems. Moreover, the student will be able to deal with real problems also by techniques from collective intelligence, soft computing and machine learning.

Knowledge and understanding

This course provides basic knowledge and understanding on:

- What a complex system is, what the uncertainty is and from which different sources it comes
- Cellular Automata as models of collective intelligence for complex systems: formal properties associated to reachability, reversibility, stability, instability, and chaos. Decision algorithms/undecidability of formal properties
- Tile sets, tiling, and Domino Problem, undecidable properties of Cellular Automata, hint of self-assembly (DNA computing)
- Symbolic Dynamics: subshifts and languages, entropy of a subshift, Perron Frobenius Theorem, data coding/decoding schemas based on subshifts
- Applications (Complex Systems): cryptography by Cellular Automata, simulation of real phenomena by Cellular Automata,
  Google's PageRank algorithm and data storage (subshifts), Reaction Systems as a model for simulations of biochemical reactions
- Many valued logics and Fuzzy Sets: Three valued logics and applications (NULL value in database); Logics with truth values in [0,1]: t-norms, t-conorms and residuated lattices; Fuzzy sets and linguistic variables; Fuzzy rule based systems
- Introduction to knowledge representation with evidence theory and possibility theory
- Rough Sets: Concept Approximation; Learning of rules and feature selections with applications in data mining; Link with many-valued logics; Application to Dynamical systems
- Introduction to uncertainty handling in machine learning: Soft Clustering; multi-label learning; Three-way

strategy

Ability to apply knowledge and understanding

- Ability to face the problem of modelling a (local and uniform in space) phenomenon by Cellular Automata
- Ability to establish certain properties of a Cellular Automaton
- Ability to represent a system of strings subject to constraints by means of a subshift and ability to establish how to coding any sequences into sequences of such a system and vice versa
- Ability to appropriately represent uncertainty
- Ability to handle different types of uncertainty in machine learning

Making judgements

Ability to identify the most suitable classes of Cellular Automata for modelling specific Complex Systems
Ability to identify the most appropriate method to represent and manage uncertainty

Communication skills

Ability to explain in a clear and rigorous way, the theoretical contents, including the proofs, the decision algorithmic of some formal properties, and the reduction techniques for proving the undecidability of other properties

Learning Skills

Ability to independently search for and learn new for models for Complex Systems
Ability to understand new properties of formal models for Complex Systems and related decidability/undecidability issues
Ability to deal with new situations where uncertainty has to be managed

Contents

Formal treatment and applications of complex and uncertain systems.

Cellular Automata, Tiling and applications inside collective intelligence (modelling of real systems and cryptography), symbolic dynamics and applications (coding, data storage, Google's PageRank algorithm), many-valued logics, evidence theory, fuzzy sets, rough sets; uncertainty handling in machine learning.

Detailed program

1) Introduction

- what a complex system is, what the uncertainty is and from which different sources it comes

- revision of basic notions: classical propositional logic, partially ordered sets and Boolean algebra

2) Cellular Automata as models of collective intelligence for complex systems :

- formal properties associated to reachability, reversibility, stability, instability, and chaos. Related classifications

- decision algorithms/undecidability of formal properties

3) Tilings:

- Tile set, tiling, simulation of a Turing machine, and Domino Problem

- undecidable properties of Cellular Automata

- hint of self-assembly (DNA computing)

4) Symbolic Dynamics:

- subshifts and languages

- subshifts of finite type, sofic subshifts and related representations

- entropy of a subshift, Perron Frobenius Theorem, data coding/decoding schemas based on subshifts

5) Applications (Complex Systems):

- cryptography (secret sharing schemes and pseudo-random number generation) by Cellular Automata

- simulation of real phenomena by CA

- Google's PageRank algorithm and data storage (subshifts)

- Reaction Systems as a model for simulations of biochemical reactions

6) Many valued logics and Fuzzy Sets
- Three valued logics and applications (NULL value in database)
- Logics with truth values in [0,1]: t-norms, t-conorms and residuated lattices
- Fuzzy sets and linguistic variables
- Fuzzy rule based systems

7) Introduction to knowledge representation with evidence theory and possibility theory

8) Rough Sets:
- Concept Approximation
- Learning of rules and feature selections with applications in data mining
- Link with many-valued logics
- Application to Dynamical systems

9) Introduction to uncertainty handling in machine learning
- Soft Clustering
- Multi-label learning
- Three-way strategy

Prerequisites

Basic Knowledge from the Computer Science Degree.

Teaching form

Lectures and practice exercises all in presence.

Lectures (8 three-hour lectures and 4 two-hour lectures, for a total of 32 hours) will be carried out in unidirectional lecture mode.
Practice exercises (4 three-hour activities and 4 two-hour activities, for a total of 20 hours) will be carried out with an initial part in unidirectional mode and a second part in interactive mode.

E-learning support for individual study with material provided by the instructors.

The teaching language is Italian. However, the course may be provided in English language if a foreign student attends lectures and exercises.

Textbook and teaching resource

D. Lind, B. Marcus. An introduction to Symbolic dynamics and coding. Cambridge University Press, 1995.

J. Kari. Cellular Automata. Lecture Notes. http://users.utu.fi/jkari/ca/

P. Kurka. Topological and symbolic dynamics. Société Mathématique de France, 2004.

Alberto Dennunzio. Lecture Notes on Cellular Automata.

Witold Pedrycz: An Introduction to Computing with Fuzzy Sets - Analysis, Design, and Applications. Intelligent Systems Reference Library 190, Springer 2021, ISBN 978-3-030-52799-0
https://doi.org/10.1007/978-3-030-52800-3

D. Ciucci, "Rough Sets and Non-Classical Logics", Lecture Notes
A. Campagner "Uncertainty in Machine Learning" Lecture Notes

Semester

Spring Semester

Assessment method

Oral exam.
The exam consists of two parts.

part 1. An oral exam on all the topics concerning the Complex Systems (items 1, 2, 3, 4, and 5 of the detailed program). The Theorem's proofs will be required only on a part choosen by the candidate.

part 2. Regards to the uncertainty part, some exercises will be assigned on different topics of the course, including a written dissertation on a topic agreed with the lecturer, which will be the subject of an oral discussion.

Each part is assessed by a mark (maximum mark: 30/30, possibly cum laude).

The final assessment takes into account equally the assessments of both the parts (mean value of the marks regarding the two parts).

Office hours

On appointment

Sustainable Development Goals