Binghamton University

EngiNet™

State University of New York
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ISE-483/SSIE-583 - spring 2023

Complex adaptive systems and computational intelligence (casci lab)

Resources
- web page: cascii.binghamton.edu/academics/i-bic/
- online class: Link on Brightspace
- blog: life inspired
- Brightspace: brightspace.binghamton.edu/d2l/home/204799

office hours:
- Luis M. Rocha: Wednesdays 9:00-12pm, EB S04
  binghamton.zoom.us/my/luismrocha

office hours:
- Samer Abubaker: TBA

rocha@binghamton.edu
cascii.binghamton.edu/academics/i-bic
for understanding social and biomedical complexity
what about you?

- Background
- Interests
- Course expectations
evolutionary systems and biologically-inspired computing

course materials

- **Lecture notes**
  - See course web page and blog

- **Class Handouts**
  - Web page and brightspace

- **Class Book**

- **Recommended or alternative books**
  - Prusinkiewicz and Lindenmeyer [1996] *The algorithmic beauty of plants*. 

**Bio-inspired computing** is a field devoted to tackling complex problems using computational methods modeled after **design principles encountered in nature**.

- Strongly grounded on the foundations of **complex systems** and **theoretical biology**.
- The goal is a deep **understanding** of the **distributed architectures of natural complex systems**, and how those can be used to produce **informatics tools** with enhanced robustness, scalability, flexibility and which can interface more effectively with humans.
- It is a **multi-disciplinary** field strongly based on biology, complexity, computer science, informatics, cognitive science, robotics, and cybernetics.

**Aims**

- Students will be introduced to fundamental topics in bio-inspired computing, and build up their proficiency in the application of various algorithms to real-world problems.
  - Computational intelligence, modeling and simulation, machine learning, evolutionary systems, artificial life, and biology itself.
adapted from Nunes de Castro

Natural Computing

- Computing Inspired by Nature
  - Evolutionary Algorithms
  - Artificial Neural Networks
  - Swarm Intelligence
  - Artificial Immune Systems

- Simulation and Emulation of Nature
  - Artificial Life (including Fractal Geometry)
  - Computational and Systems Biology

- Computing with Natural Materials
  - Molecular Computing (DNA Computing)
  - Quantum Computing

Complex Systems Science Approach
What is Life?
- Life and information, logical mechanisms of life

Imitation of Life
- L-Systems, fractals, chaos

Complex Systems and Artificial Life
- Life as self-organization: cellular automata, Boolean nets, neural nets

What is Computation?
- Universal computation, Life as computation

Life as Evolution of Turing Machines
- Open-ended evolution, natural selection, genetic and evolutionary algorithms

Collective Behavior and Swarm Intelligence
- Stigmergy, swarm intelligence, multi-agent simulation

Immunocomputing
- Multi-level complexity

Discussion Topics

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evolutionary systems and biologically-inspired computing

syllabus

rocha@indiana.edu
informatics.indiana.edu/rocha
Participation: 15%.
- Based upon attendance and participation.

Lab Assignments: 35% (ISE-483), 25% (SSIE-583)
- Students will complete 5 (4 best) assignments on algorithms presented in class.

SSIE-583 - Presentation and Discussion: 25%
- Students will present and lead the discussion of an article related to the class materials. This includes presenting concepts necessary to understand the article.

Project Paper: 50% (ISE-483), 35% (SSIE-583)
- Students can choose to tackle a real problem using bio-inspired algorithms, or write a term paper (in Conference Style).
  - Students are expected to continuously consult with the instructor regarding the scope and depth of the project paper. Reusing and expanding labs is highly encouraged.
SSIE-583 - possible presentations

Some classics

but collegiality above all

- **Attendance**
  - We expect that students will approach the course as they should a professional job – attend every class.
  - No mobile phones and laptops only for class materials
    - All materials available online

- **Academic Integrity**
  - As with other aspects of professionalism in this course, you are expected to abide by the proper standards of professional ethics and personal conduct. This includes the usual standards on acknowledgment of joint work and other aspects of the [Binghamton University Code of Student Conduct](informatics.indiana.edu/rocha). Cases of academic dishonesty will be reported to the Office of Student Conduct.

- **Incomplete Grade**
  - An incomplete (‘I’) final grade will be given only by prior arrangement in exceptional circumstances conforming to university and departmental policy which requires, among other things, that the student must have completed the bulk of the work required for the course with a passing grade, and that the remaining work can be made up within 30 days after the end of the semester.
### Definition of Grades

<table>
<thead>
<tr>
<th>Grade</th>
<th>Percentage</th>
<th>Description</th>
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<tbody>
<tr>
<td>A+</td>
<td>98%</td>
<td>Excellent Work. Student performance demonstrates thorough knowledge of the course materials and exceeds course expectations by completing all requirements in a superior manner.</td>
</tr>
<tr>
<td>A</td>
<td>94%</td>
<td>Excellent Work.</td>
</tr>
<tr>
<td>A-</td>
<td>90%</td>
<td>Excellent Work.</td>
</tr>
<tr>
<td>B+</td>
<td>85%</td>
<td>Very Good Work.</td>
</tr>
<tr>
<td>B</td>
<td>80%</td>
<td>Very Good Work.</td>
</tr>
<tr>
<td>B-</td>
<td>75%</td>
<td>Very Good Work.</td>
</tr>
<tr>
<td>C+</td>
<td>70%</td>
<td>Good Work.</td>
</tr>
<tr>
<td>C</td>
<td>65%</td>
<td>Good Work.</td>
</tr>
<tr>
<td>C-</td>
<td>60%</td>
<td>Good Work.</td>
</tr>
<tr>
<td>D+</td>
<td>55%</td>
<td>Marginal Work.</td>
</tr>
<tr>
<td>D</td>
<td>50%</td>
<td>Marginal Work.</td>
</tr>
<tr>
<td>D-</td>
<td>45%</td>
<td>Marginal Work.</td>
</tr>
<tr>
<td>F</td>
<td>Less than 45%</td>
<td>Fail.</td>
</tr>
</tbody>
</table>

Student performance meets designated course expectations and demonstrates understanding of the course materials at an acceptable level. Student performance meets designated course expectations and demonstrates understanding of the course materials at an acceptable level. Student performance demonstrates incomplete understanding of course materials.
### Lab Assignments: 35% (ISE-483), 25% (SSIE-583)
- Complete 5 (best 4 graded) assignments based on algorithms presented in class
  - Lab 0: January 30\textsuperscript{th}
    - *Introduction to Python* (No Assignment)
  - Lab 1: February 6\textsuperscript{th}
    - *Measuring Information* (Assignment 1)

### SSIE – 583 -Presentation and Discussion: 25%
- Present and lead the discussion of an article related to the class materials
  - Enginet students post/send video or join by Zoom
- First presentation January 30\textsuperscript{th}
biologically-inspired computing

lecture 1

What is life?
What is life?

historically, not a relevant question

Animism by Georgeanne
is life different from mechanistic matter?

how?

- Lucretius (ca 66 B.C)
  - How can choice arise if all *atoms* follow inexorable mechanical courses?
    - Titus Lucretius Carus
    - Epicurean Roman poet
  - Free Will vs. determinism
    - Also Aquinas…

- Universal Mechanism
  - The universe is best understood as a completely mechanical system
    - A system composed entirely of matter in motion under a complete and regular system of *laws of nature*.
  - Materialism, determinism
    - Laplace, Hobbes, ….

- Newton
  - everything explained according to the operation of a single mechanical principle
Webster’s dictionary

**life** adj.
- the general **condition that distinguishes organisms from inorganic objects and dead organisms**, being manifested by **growth** through **metabolism**, a means of **reproduction**, and internal **regulation in response** to the environment.
- the **animate existence** or period of animate existence of an individual.
- a corresponding state, existence, or principle of existence conceived of as belonging to the **soul**.
- the period of existence, activity, or effectiveness of something inanimate, as a machine, lease, or play.
- **animation**; **liveliness; spirit**: the force that makes or keeps something alive; the **vivifying or quickening principle**.
3 types of definitions for life

- **Organization** distinct from inorganic matter
  - with an associated list of properties
  - matter controlled by genomic information

- **Animated behavior**

- **Vitalism**
  - life as a special, incommensurable, quality
  - Not a viable scientific explanation, because for science nothing is in principle incommensurable.
  - Pertains to metaphysics.
    - If the agent of design cannot be observed with physical means, then it is by definition beyond the scope of science as it cannot be tested.
  - See Dennett’s and Polt’s pieces
Is life Fuzzy?

List of properties:
- Growth
- Metabolism
- Reproduction
- Adaptability
- Self-maintenance (autonomy)
- Self-repair
- Self-assembly
- Reaction
- Evolution
- Choice

Threshold of complexity:
- Closure (metabolic, functional)
  - Categorization and Control
  - Function (self-reference)
- Open-ended evolution
- (genomic) Information

Is there a synthetic criteria? How general can it be?
Is life Fuzzy?

- List of properties
  - Growth
  - Metabolism
  - Reproduction
  - Adaptability
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    - Categorization and Control
    - Function (self-reference)
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Is there a synthetic criteria? How general can it be?
Science often sees life as the complicated physics of a collection of moving bodies
- Reductionist search for answers in the nitty-gritty of biochemistry
  - Separable variables or near-decomposable modules (Simon)
- When do we reach a threshold of complexity after which matter is said to be living?
  - Which variables, networks, components, relations must be included?

Life as (emergent) organization
- Systems Thinking
  - Ludwig von Bertalanfy (1980)
  - What is important are not the actual physical components but the relations amongst them

But what about evolution and history?
- Conflict between (general) organization and specific components with their history
- What organization explains evolution?

“Seeking a connecting link, they had condescended to the preposterous assumption of structureless living matter, unorganized organisms, which darted together of themselves in the albumen solution, like crystals in their mother-liquor; yet organic differentiation still remained at once condition and expression of all life. One could point to no form of life that did not owe its existence to procreation by parents”. Thomas Mann [1924].
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Can there be several implementations of life?
- To study life do we need to find and synthesize the necessary threshold of complexity?
  - Hard Artificial Life
- Or is it enough to simulate the behavior of life?
  - Soft Artificial Life
- What about implementing “new” life in known biochemistry?
  - Wet Artificial Life or Synthetic Biology

Important to study the living organization
- What can be abstracted and implemented in a different medium?
- Understanding organization and design principles
  - Scientific advancement of the fundamental principles of life
    - Systems and Computational Biology, Artificial Life, Evolutionary Systems
  - Solving engineering and design problems
    - Bio-inspired computing
Life as emergent organization
- Impossibility of epistemological reduction of the properties of a system to its components
  - Whole is more than sum of parts
    - "Clockness": many possible material implementations
    - Several biological designs for similar function (e.g., flying)
    - The function of DNA does not lie in its dynamic (bio-chemical) characteristics
- Crux of complexity
  - Micro- vs. macro-level descriptions

Caveat
- Information and function are contextual and historical

How to understand/design matter and organization?
- Is systems thinking dualistic? Neo-vitalism?
- Complementarity: wave-particle duality

“First, nothing in biology contradicts the laws of physics and chemistry; any adequate biology must be consonant with the ‘basic’ sciences. Second, the principles of physics and chemistry are not sufficient to explain complex biological objects because new properties emerge as a result of organization and interaction. These properties can only be understood by the direct study of the whole, living systems in their normal state. Third, the insufficiency of physics and chemistry to encompass life records no mystical addition, no contradiction to the basic sciences, but only reflects the hierarchy of natural objects and the principle of emergent properties at higher levels of organization”. Stephen Jay Gould