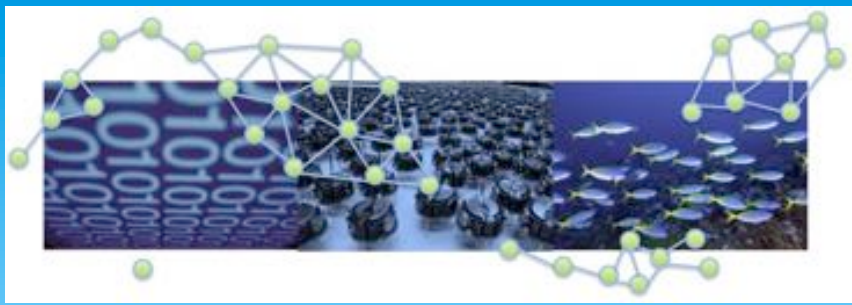

CS289
Bio-inspired Multi-agent Systems

Radhika Nagpal nagpal@g.harvard.edu or rad@eecs.harvard.edu

Fall 2021: Wed, Fri 3:45-5pm, SEC 1.316

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Announcements

* CS289 Course Staff
  * Radhika Nagpal (SEC 4.207)
  * **Website: main repository of all information on the class**
  * https://canvas.harvard.edu/courses/92485
* Next Wed: First Assignment due (Reading + Review)
  * There is a **paper reading and review due.**
  * You will email me a short review by 7am Wed morning, as explained on the website.

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What can a Group do
that an Individual cannot?

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Collective Intelligence in Nature

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Bio-inspired Collective Systems

* Collective Intelligence in Nature
  * Complex goals can be achieved by collectives of relatively simple and limited individuals
  * Parallelism, robustness, adaptability
* Emerging Novel Distributed Systems
  * Massive numbers, small scales, embedded
  * Challenge: *how do we construct robust and predictable systems?*

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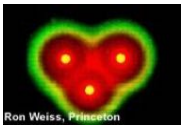
Emerging Distributed Systems











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Bio-inspired Collective Systems

* Collective Intelligence in Nature
  * Complex goals can be achieved by collectives of relatively simple and limited individuals
  * Parallelism, robustness, adaptability
* Emerging novel distributed systems
  * Massive numbers, small scales, embedded
  * Challenge: *how do we construct robust and predictable systems?*
* Collective "Artificial" Intelligence
  * Extract *robust and scalable engineering techniques* from our understanding of biological collectives.

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What This Course is About

Grad-level Research Area Course

* **Survey Bio-inspired Approaches and Applications**
  * Three main topic areas:
    * **Swarm Intelligence** ("social animals" as a metaphor)
    * **Cellular Automata & Self-Assembly** ("cell" as a metaphor)
    * **Evolutionary Computing** ("evolution" as a metaphor)

    Also some **Special Topics (ML for Swarms, Human collectives)**
* **Read papers (primary sources)**
  * Read papers on models of natural collectives
  * Read papers on applications to distributed systems design
  * Discuss and Present
* **Conduct Research (final project)**
  * Extend an existing paper's results, apply biological principle to a distributed systems problem, solve computational/theory problem related to collective intelligence, or model a biological system

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How This Class Works

- Reading and Class Participation
- Paper Reviews
- Lecture Presentation
- Class Project

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How This Class Works

- **Reading and Class Participation**
- Paper Reviews
- Lecture Presentation
- Class Project

* Reading and Class Participation
  * Each class has 2 papers assigned for reading, one primary paper and one for context (Interdisciplinary)
  * In class we will discuss the papers, lessons and implications, what "principle" can be generalized, etc.
  * Caveat: useless if you don't do the readings!

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How This Class Works

- Reading and Class Participation
- **Paper Reviews**
- Lecture Presentation
- Class Project

* Paper Reviews
  * Due by 7am before class day
  * Post to cs289 discussion board (email for now)
  * Format: See guidelines on the website
  * Paper review due before **next class:** send via email

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How This Class Works

- Reading and Class Participation
- Paper Reviews
- **Lecture Presentation**
- Class Project

* Presenter Days
  * Some classes are "presenter days"
  * Everyone does one presenter paper (in pairs).
  * The goal is for the presenter (you) to look into the subject in more depth and educate the class on an additional interesting topic.
  * Content: recent papers or special topics (TBD)

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How This Class Works

- Reading and Class Participation
- Paper Reviews
- Lecture Presentation
- **Class Project**

* Final Research Project (in pairs)
  * Goal is to explore a topic of *your interest* in more depth
  * Project: Theory, bio-inspired distributed systems application, models of biology, even robotics
  * Key: Choosing the *Scope* of the problem (1 month)
  * Deliverables: Presentation + Paper
  * **READ FINAL PROJECT GUIDELINES and examples online**

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How This Class Works

- Reading and Class Participation
- Paper Reviews
- Lecture Presentation
- Class Project

* Grades are roughly
  * 1/2 InClass Participation, Reviews, Presenter Day
  * 1/2 Final Project

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Schedule: See Online

Topics

Swarm Intelligence (4 weeks)
Cellular Computing (2 weeks)
Evo Computing (2 weeks)
Presenter Days (2.5 weeks)

Final Project Dates

*Scope: 1 month

Oct 15 Discussion & teams
Nov 1 Proposal due
Dec 1 and 3 Presentations
Dec 10 Final papers due.

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Introductions

* **Introduce yourself**
  * Help us get to know each other, and also help me pick/allocate presenter paper topics.
  * Name, Graduate program, Brief description of your research area and areas of interest for this class.

9/24/21

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Three Topics Areas

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing

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Swarm Intelligence

Social Animals as a Metaphor

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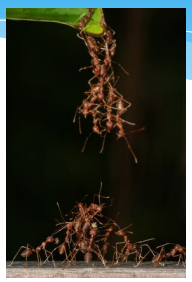
Swarm Intelligence

Social Animals as a Metaphor


* Simple rules
* Amazing Global properties
* Handbook of algorithms?

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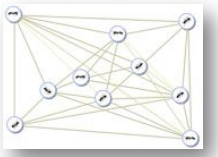
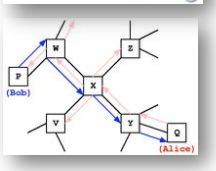
Swarm Intelligence

Inspire New Systems Design



- **Optimization algorithms** (ant-colony/particle swarm optimization)
- **Network algorithms** (e.g. distributed routing and synchronization)
- **Swarm Robotics!** (warehouses, aerial drones, underwater)

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Swarm Intelligence

* Models of social insects and animal coordination
  * *Primitives:* Search, Transport, Sync, Flocking, Construction
  * *Principles: e.g.* Stigmergy & Distributed Consensus
  * *Reading:* biology and applied math papers
* Algorithms and Applications
  * **Many "generic" algorithms that have wide application**
  * *Reading:* Applications to Optimization, Networks, Robotics
* *Open Question: Analysis and Synthesis*

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Three Topics Areas

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing

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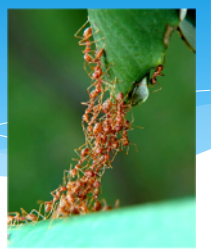
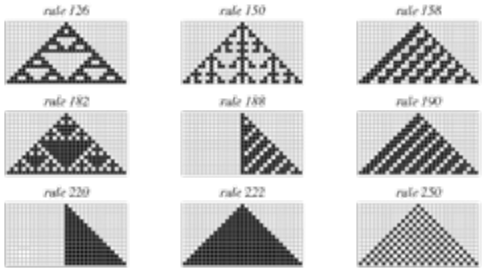
Cellular Computing

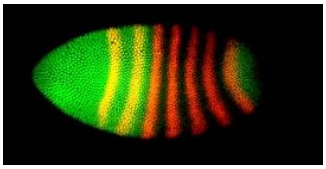
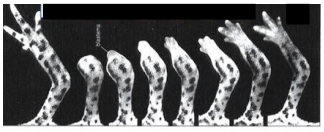
Cells as a Metaphor



* Pattern Formation, Self-assembly, Self-repair



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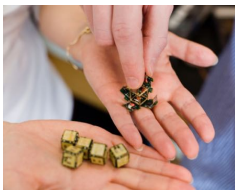
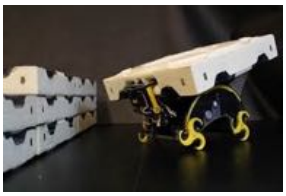
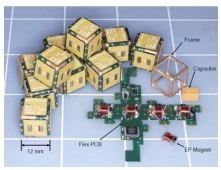
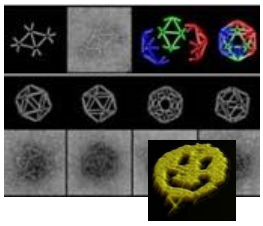
Cellular Robotics

Self-reconfiguring Robotics, also Collective Construction
Programmable Materials; DNA self-assembly

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Cellular Robotics

- Self-reconfiguring Robotics, also Collective Construction
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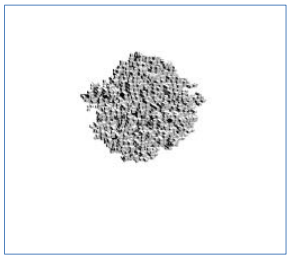

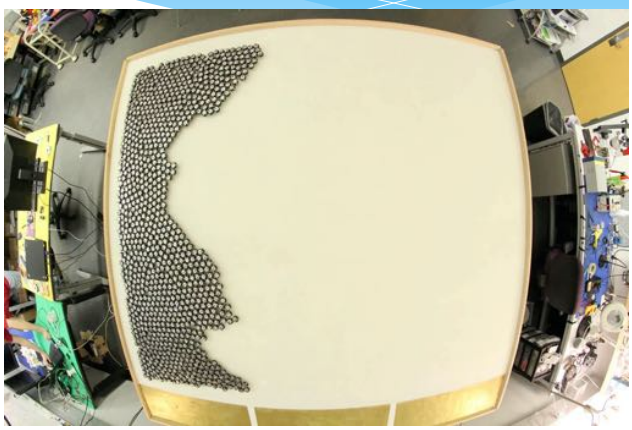

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Cellular Computing

- Models from Multi-cellular Biology
  - *Local:* Gradients, Directed growth, Stochastic rules
  - *Global:* Cellular Automata; Self-assembly; Regeneration
- Algorithms and Applications
  - **Global-to-local Compilers and Theory**
  - Algorithmic approaches to self assembly and self-repair
  - Robotics and Programmable Materials
- Open Question: Scalability and Hardware

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Three Topics Areas

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing

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Evolution as a metaphor

The World == Complex goals & Dynamic environments
An Amazing Variety of "Solutions"

* Evolution as Population + Variation + Selection
* Evolution as optimization/learning
* Evolution as a design process…

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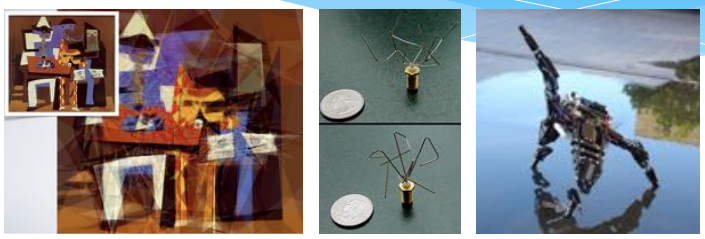
Evolution as a tool

Evolutionary algorithms for search and optimization, and applied to design and robotics



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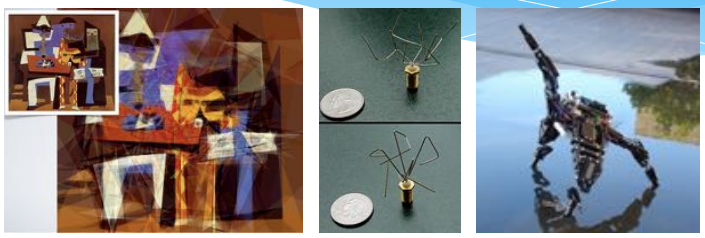

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Evolution-inspired Computing

* Evolutionary Computing
  * Evolution as optimization using a population of agents
  * Different algorithmic flavors (e.g. genetic programming)
* Applications
  * **General Algorithms: Optimization and Search problems**
  * Evolutionary Design and Programming "Invention"
  * Evolutionary Robotics and Robot Collectives
* Open Question: Applying evolution to collectives

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Three Topics Areas, plus

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing
* *Presenter Days:*
  * *Self-Assembly, ML & Swarms, Human Collectives*

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CS289

* Final Reminders
  * There are Papers to read for next week!
    * email reviews to Radhika
* Questions?

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