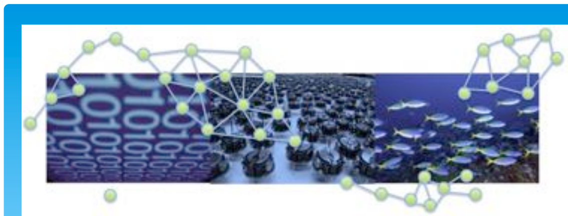


CS289
Bio-inspired Multi-agent Systems

Radhika Nagpal rad@eecs.harvard.edu
Fall 2019: Wed, Fri 10:30-11:45, Pierce 100F

Announcements

* CS289 Course Staff
  * Radhika Nagpal (MD 235, rad@eecs)
  * Website: main repository of all information on the class
  * https://canvas.harvard.edu/courses/60467
* **Limited Enrollment Process**
  * Please fill out
    * **Google Enrollment Form** on the website **by Tonight**, and
    * **Add the class to your crimson cart.**
  * I will get back to you tomorrow (Thurs) about the final enrollment decisions and wait lists. And I will approve crimson carts on Friday.
* Next Class Friday: First Assignment due (Reading + Review)
  * There is a **paper reading due friday**. You will email me a short review by 7am Friday morning, as explained on the website.

Collective Intelligence in Nature

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?*

Emerging Distributed Systems

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.

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, **Human Collectives** (as student presentations)
* **Read papers (primary sources)**
  * Read papers on models of natural distributed systems
  * Read papers on applications to 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

How This Class Works

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

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!

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 to rad@eecs.harvard.edu

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.
  - This year presenter days focus on human collectives

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**

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

Schedule: See Online

Roughly

Swarm Intelligence (4 weeks)
Cellular Computing (2 weeks)
Evo Computing (2 weeks)
------ FINAL PROJ PROPOSAL -------
Presenter Days (2 weeks)
----- FINAL PROJECT DUE-------

*Final project scope: 1 month
(no readings and reviews)

Final Project Dates (tentative)

Oct 16 (tentative)
Discussion & teams formation.

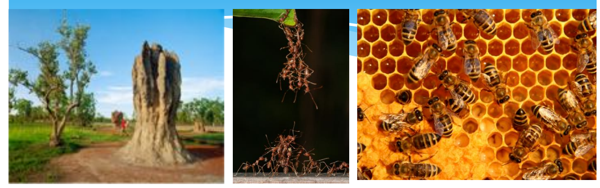
Nov 1
Proposal due
Nov 20 and 22
Presentations
Dec 9
Final papers due by 5pm

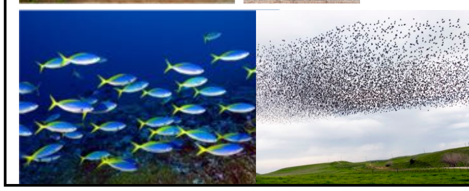
Three Topics Areas

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing

Swarm Intelligence
Social Animals as a Metaphor

Swarm Intelligence
Social Animals as a Metaphor





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

Swarm Intelligence
Inspire New Systems Design

- Optimization algorithms
- Networks (e.g. Routing, Synchronization)
- Swarm Robotics! (movie1 movie2)

Swarm Intelligence

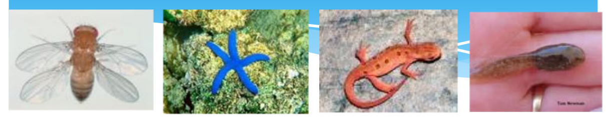
- Models of social insects and animal coordination
  - *Primitives:* Search, Transport, Sync, Flocking, Construction
  - *Principles: e.g.* Stigmergy & Distributed consensus
  - *Reading:* biology and applied math papers
- Algorithms and Applications
  - **Many "generic" algorithms that have wide application**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

Three Topics Areas

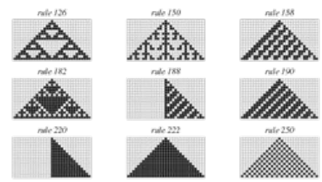
- Swarm Intelligence
- Cellular Computing
- Evolutionary Computing

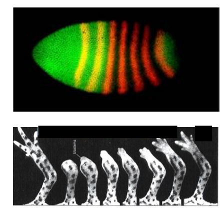
Cellular Computing

Cells as a Metaphor



- Pattern Formation, Self-assembly, Self-repair



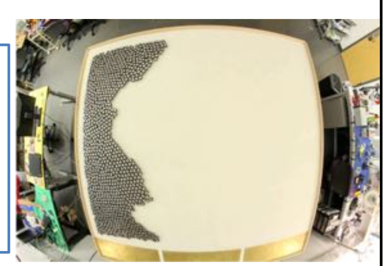


Cellular Robotics

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

Cellular Robotics

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



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

Three Topics Areas

* Swarm Intelligence
* Cellular Computing
* Evolutionary Computing

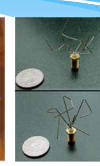
Evolution as a metaphor

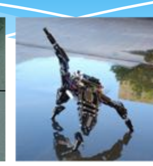
The World == Complex goals & Dynamic environments
An Amazing Variety of "Solutions"

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

Evolution as a tool

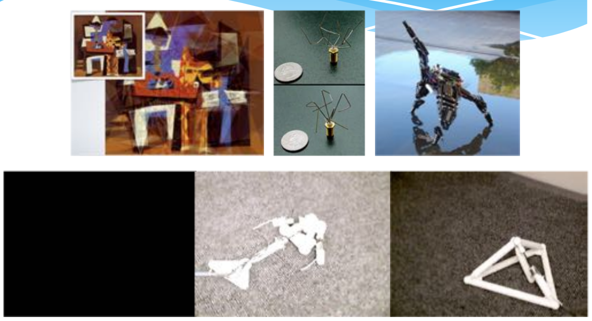
Evolutionary algorithms for search and optimization, and applied to design and robotics





Evolution as a tool

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



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

Three Topics Areas, plus

- Swarm Intelligence
- Cellular Computing
- Evolutionary Computing
- *Presenter Days: Human Collectives*

CS289

- Final Reminders
  - Fill out the **Google Form** (link on cs289 website)
  - There are Papers to read for next class!
    - email review to Radhika
- Questions?