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CC 106

Lecture Eleven – March 4th, 2008

Self-Organization and the Emergence of Complexity

Wayne Snyder
Department of Computer Science
College of Arts and Sciences

Lecture Outline

Part I. Motivation: What's the big idea?

Part II. Definition: What is a self-organizing system?

Part III. Computer simulation: Conway's Game of Life

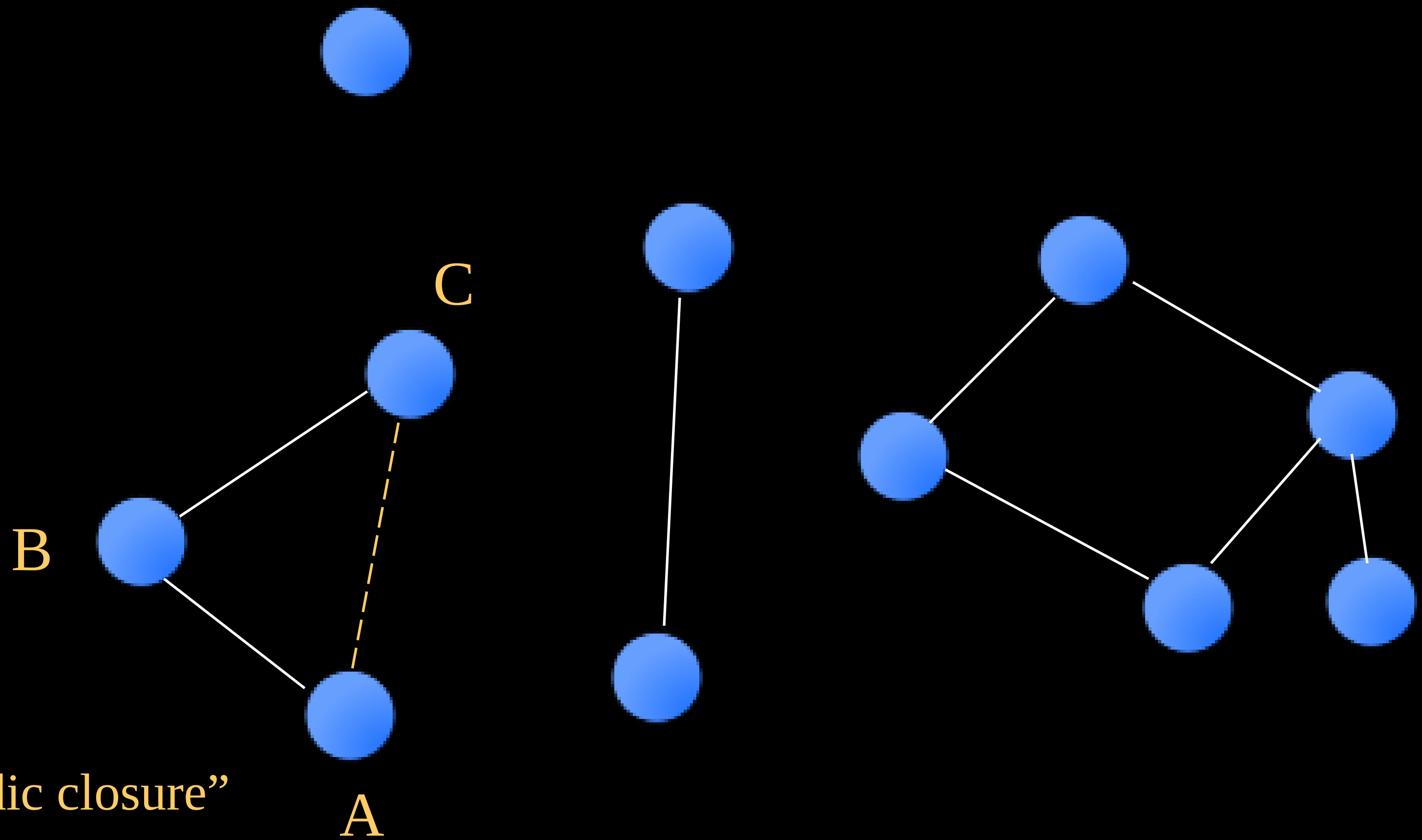
Part IV. Self-Organization in Biological Systems

- Swarming or schooling of fish, insects, birds….
  - Examples of animal behavior
  - Computer simulations of swarming

Before we begin……

Happy Birthday!

How's your Social Network?



"Triadic closure"

BU's network is more complex!

Part I: What's the Big Idea?

Where did the complexity come from?

Group sing of Happy Birthday:

- ❖ Script (you know the song)
- ❖ Conductor is <u>centralized control</u> of performance

Formation of BU's social network:

- ❖ Unconscious, no script
- ❖ No leader, <u>no centralized control</u>
- ❖ Local, small decisions by each member:
  - ❖ I want that person as my friend! ☺
  - ❖ Hm…. I'm kinda busy, I don't think I can spend time on that friendship…. ☹

Part II: What is Self-Organization?

Self-Organization is the process by which a system (e.g., a population of individual entities) develops complex structures or behaviors without being guided or managed from outside the system.

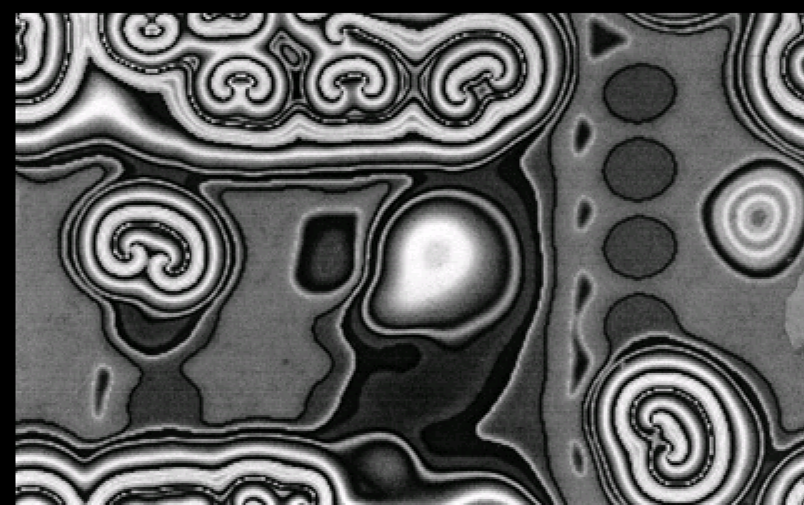
Typical features of a self-organized system:

- ❖ Group of simple entities with simple behavior and only local knowledge;
- ❖ No group communication;
- ❖ There is no “leader” who directs the activities of the group;
- ❖ Complex, often surprising, patterns of structure or behavior arise spontaneously in the group as a whole.

Examples of Self-Organization

Sand dunes

Benard
Convection



Belousov-Zhabotinski Reaction

Examples of Self-Organization

Ant Bridge

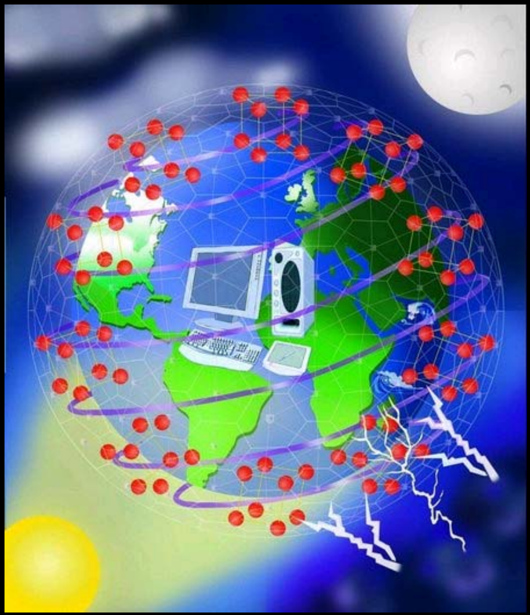
Termite Mound

Slime Mold

Examples of Self-Organization

And it's not just about biology……

Free market capitalism



TCP/IP Computer Networks

Caveat: Not all complexity is self-organized, even if there is no obvious leader!

Implicit control can come from

- Environment
- Memory
- Genes

Litmus test: Does the behavior depend on being in a group?

One more caveat: self-organization is often not the <u>only</u> mechanism present!

- ❖Capitalism
- ❖Fashion and culture
- ❖Brain function
- ❖And almost any really complex phenomenon in the real world….

BUT, it is worth examining self-organization so that we do not misunderstand the source of complexity, and to understand how complexity arises *ab initio*…..

How to investigate self-organization?

Well, I'm a computer scientist, so here is what I would do:

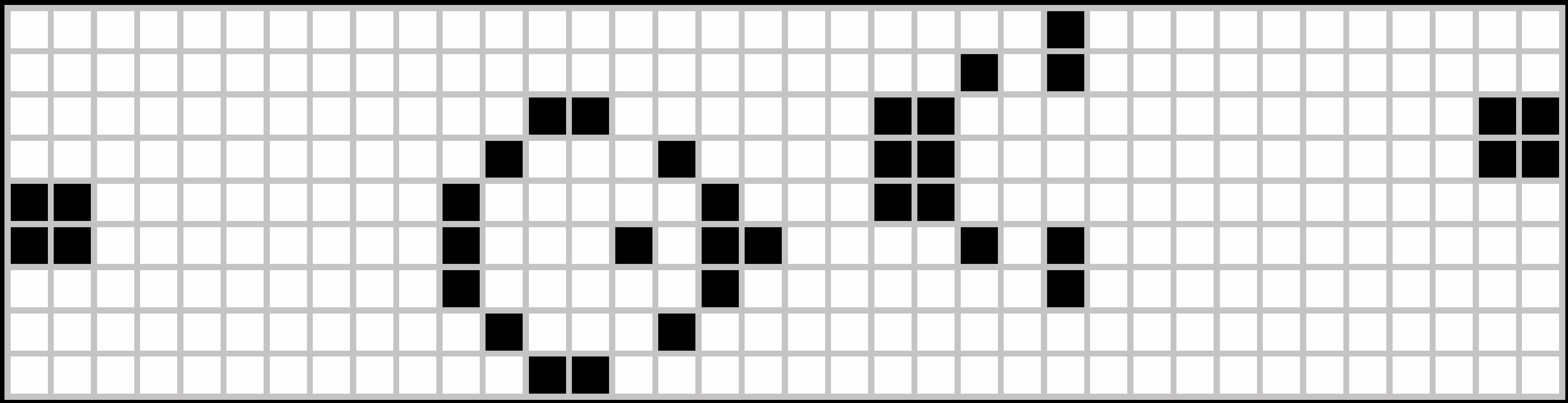
- ❖Define a simple model of a (potentially) self-organized system:
- ❖Simple entities with only local information and simple rules for behavior;
- ❖Write a computer program to explore what happens when a large group of these entities interact;
- ❖Play around with it for a long time; and
- ❖Think about what intuitions or evidence this give for self-organization in biology and other domains.

Part IV: Conway's Game of Life

History: John Conway wanted to answer an open problem in mathematics: can we design a machine that can make a copy of itself?

The board is a 2D grid of squares infinite in four directions;

Cells are alive or dead, and are each touched by 8 neighbors:



Conway's Game of Life

Rules:

A cell which is <u>alive</u> will <u>die</u> if

- ❖Less than 2 neighbors (as if of *loneliness*);
- ❖More than 3 neighbors (as if of *overcrowding*);
- ❖Otherwise (if it has 2-3 neighbors) it remains alive.

A cell which is <u>dead</u> will come to <u>life</u> if it has

- ❖Exactly 3 neighbors;
- ❖Otherwise it remains dead.

Let's take a look……

What’s the Point?

NOT that we can design complex behaviors by coming up with more and more complicated initial configurations --- that is in fact Intelligent Design!

What is more interesting is to observe the mechanism by which complexity arises from something very simple, maybe only a couple of cells.

Some very simple configurations result in very complicated behaviors…. Food for though about the origins of life itself……

Intermission

Part IV: Flocking and Swarming Behavior

A large variety of social organisms exhibit group behavior that is self-organizing in nature: flocking, swarming, herding, schooling, ……

Reading: “From Ants to People, an Instinct to Swarm,” New York Times.

The rules of engagement…..

- Stay near your neighbors;
  - But don’t get too near to neighbors or obstacles;
  - Try to match speed and direction with neighbors;
  - Move towards food;
  - Move away from predators. …

Note: All local decisions, no group control.

Biological Examples

Schooling fish

Swarming Bees

Just when you thought the computer stuff was over……..

- Boids are bird-oids created by computer animation;
- They follow the simple rules just presented;
- We’ll look at two implementations, one by your’s truly, and one by the originator of the Boids concept, Craig Reynolds….