Lecture 5

Project 1

- Investigation of relation between Wolfram classes, Langton's λ, and entropy in 1D CAs
- **Due Sept. 20**
- Information is on course website (scroll down to "Projects/Assignments")
- Read it over and email questions or ask in class

Wolfram's Principle of Computational Equivalence

- "a fundamental unity exists across a vast range of processes in nature and elsewhere: despite all their detailed differences every process can be viewed as corresponding to a computation that is ultimately equivalent in its sophistication" (*NKS* 719)
- Conjecture: "among all possible systems with behavior that is not obviously simple an overwhelming fraction are universal" (*NKS* 721)

Computational Irreducibility

- "systems one uses to make predictions cannot be expected to do computations that are any more sophisticated than the computations that occur in all sorts of systems whose behavior we might try to predict" (*NKS* 741)
- "even if in principle one has all the information one needs to work out how some particular system will behave, it can still take an irreducible amount of computational work to do this" (*NKS* 739)
- That is: for Class IV systems, you can't (in general) do better than simulation.

Additional Bibliography

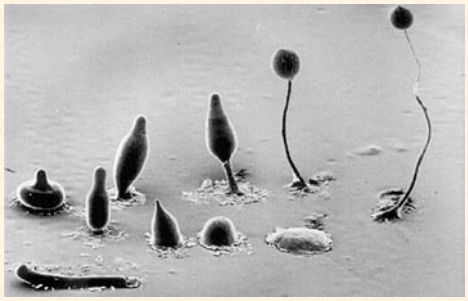
1. Langton, Christopher G. "Computation at the Edge of Chaos: Phase Transitions and Emergent Computation," in *Emergent Computation*, ed. Stephanie Forrest. North-Holland, 1990.
2. Langton, Christopher G. "Life at the Edge of Chaos," in *Artificial Life II*, ed. Langton et al. Addison-Wesley, 1992.
3. Emmeche, Claus. *The Garden in the Machine: The Emerging Science of Artificial Life*. Princeton, 1994.
4. Wolfram, Stephen. *A New Kind of Science*. Wolfram Media, 2002.

Slime Mold

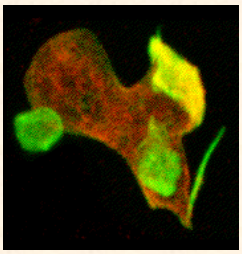
(*Dictyostelium discoideum*)

"Dicty"

Complete Life Cycle

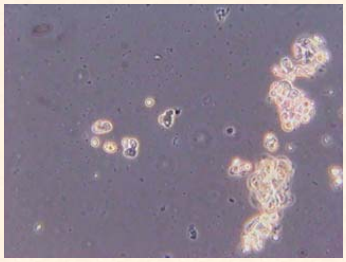


Amoeba Stage



- Single cell
- Lives in soil
- Free moving
- Engulfs food (bacteria)
- Divides asexually

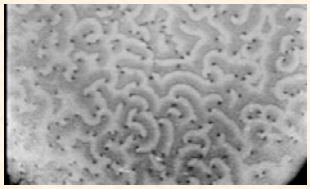
Amoebas



Aggregation Stage

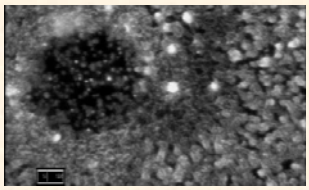
- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
- Form expanding concentric rings and spirals
- Up to 125 000 individuals

Spiral Waves



- Spiral accelerate cell aggregation (18 vs. 3 µm/min.)
- Waves propagate 120 – 60 µm/min.
- 1 frame = 36 sec.

Center of Spiral



- Mechanisms of spiral formation are still unclear
- Involves symmetry breaking
- 1 frame = 10 sec.

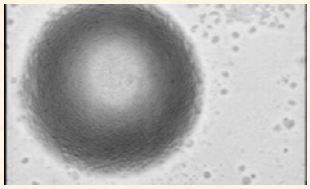
Stream Formation Stage

- Streams result from dependence of wave propagation velocity on cell density
- Breaks symmetry
- As density increases, begin to adhere
- Begin to form *mound*

Mound Stage

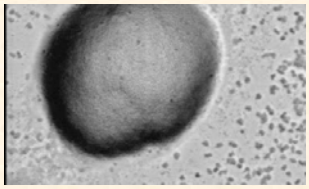
- Cells differentiate
- Some form an elongated finger

Concentric Waves in Mounds



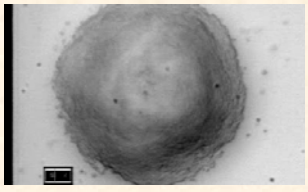
- Concentric or spiral waves
- Mound comprises 10^3 to 10^5 cells
- Cells begin to differentiate
- 1 frame = 20 sec.

Multiple Centers



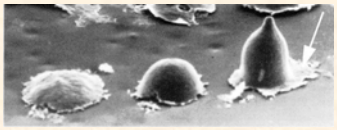
- Multiple pacemakers
- Wave fronts mutually extinguish (typical of excitable media)
- One center eventually dominates

Multi-armed Spirals



- This mound has 5 spiral arms
- Up to 10 have been observed

Formation of Acellular Sheath



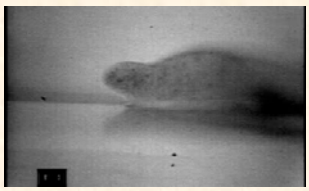
- Composed of cellulose & a large glycoprotein
- Covers mound and is left behind slug as trail
- Function not entirely understood:
  - protection from nematodes (worms)
  - control of diffusion of signaling molecules

Slug Stage

- Prestalk elongates, topples, to form slug
- Behaves as single organism with 10^5 cells
- Migrates; seeks light; seeks or avoids heat
- No brain or nervous system

9/6/07 19

Movement of Young Slug



- Time-lapse (1 frame = 10 sec.)
- Note periodic up-and-down movement of tip

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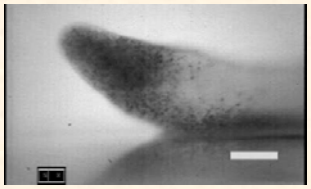
Movement of Older Slug



- Note rotating prestalk cells in tip
- Pile of anterior-like cells on prestalk/prespore boundary
- Scale bar = 50 μm, 1 frame = 5 sec.

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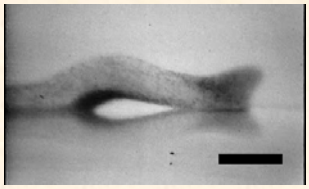
Migration of Older Slug



- Scale bar = 100 μm, 1 frame = 20 sec.

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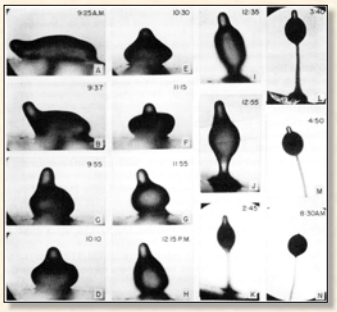
Culmination Stage

- Cells differentiate into base, stalk, and spores
- Prestalk cells form rigid bundles of cellulose & die
- Prespore cells (at end) cover selves with cellulose & become dormant

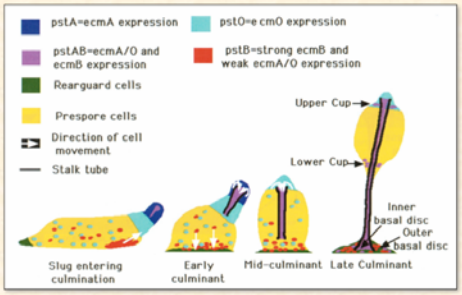
9/6/07 23

Stages of Culmination



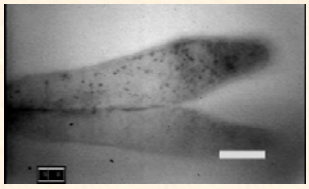
9/6/07 24

Cell Differentiation at Culmination



9/6/07 25

Early Culmination



- During early culmination all cell in prestalk rotate
- Scale bar = 50 μm, 1 frame = 25 sec.

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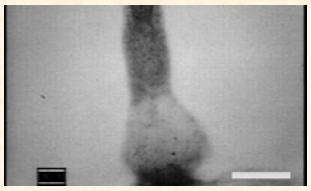
Late Culmination



- Vigorous rotation at prestalk/prespore boundary
- Scale bar = 100 μm, 1 frame = 10 sec.

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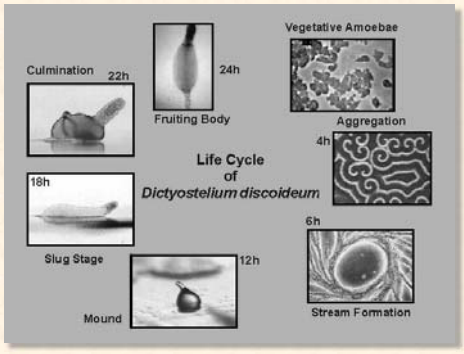
Fruiting Body Stage

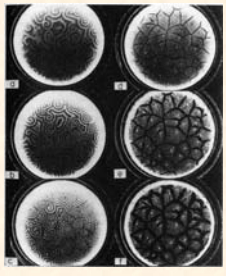
- Spores are dispersed
- Wind or animals carry spores to new territory
- If sufficient moisture, spores germinate, release amoebas
- Cycle begins again

9/6/07 28



9/6/07 29

Emergent Patterns During Aggregation

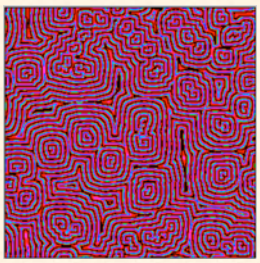


- a-c. As aggregate, wave lengths shorten
- d. Population divides into disjoint domains
- e-f. Domains contract into "fingers" (streaming stage)

9/6/07 fig. from Solé & Goodwin 30

Belousov-Zhabotinski Reaction

Hodgepodge Machine



Demonstration of Hodgepodge Machine

Run NetLogo B-Z Reaction Simulator

or

Run Hidgepodge simulator at CBN Online Experimentation Center

<mitpress.mit.edu/books/FLAOH/cbnhtml/java.html>

Universal Properties

- What leads to these expanding rings and spirals in very different systems?
- Under what conditions do these structures form?
- What causes the rotation?
- These are all examples of *excitable media*