Part 2C: Slime Mold

C. Slime Mold

*(Dictyostelium discoideum)*

“Dicty”

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Complete Life Cycle

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Self-organization in Bio-inspired Robotics

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Self-copying Robot (2005)

- Hod Lipson, Cornell
- Programmable blocks
- 2 swiveling pyramidal halves
- Magnetic connections
- 10 cm across
- One stack can assemble another

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Dicty Videos

- Bonner’s videos
- Aggregation
- Life cycle

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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
- Example: 180 cells
- Time lapse: about 14 hours

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 \(\mu\)m/min.)
- Waves propagate 120 – 60 \(\mu\)m/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
Part 2C: Slime Mold

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
Part 2C: Slime Mold

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

**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.

**Migration of Older Slug**
- Scale bar = 100 µm, 1 frame = 20 sec.

**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

**Stages of Culmination**

**Cell Differentiation at Culmination**

(figure from Kessin, *Dictyostelium*)
Part 2C: Slime Mold

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

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

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

Cooperation and Altruism in Dicty
- Cooperation is essential to Dicty signaling and aggregation
- “Altruism” is essential in stalk formation
- How is cooperation encouraged and cheating discouraged?
- In one case the same gene prevents cheating and allows cohesion
- Green-beard genes?

Microbial Cooperation and Altruism

Published by AAAS
E. Pennisi Science 325, 1196-1199 (2009)
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)

Belousov-Zhabotinski Reaction

Hodgepodge Machine

Demonstration of Hodgepodge Machine

Run NetLogo B-Z Reaction Simulator
or
Run Hodgepodge simulator at CBN Online Experimentation Center
<mitpress.mit.edu/books/FLASH/ch0html/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

Slime Mold Solving Maze

- Different slime mold: Physarum polycephalum
- Lengths: α1 (41mm), α2 (33), β1 (44), β2 (45)
- AG = food sources
- (a) initial, (b) exploring possible connections (4 hrs), (c) shortest (4 more)
Slime Mold- Controlled Robot

- Robot sensors relayed to remote computer
- Light image shines on slime mold
- Slime mold retracts
- Motion tracked and used to control robot
- *Physarum polycephalum*

Slime Mold Computation of Roman Road Network


(Klaus-Peter Zauner, University of Southampton, UK, 2006)