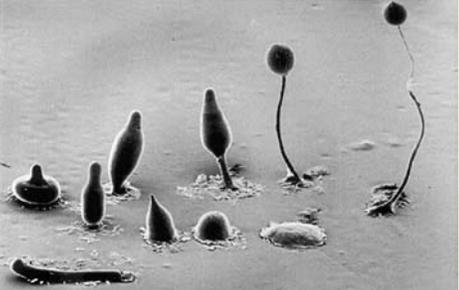


C. Slime Mold

(*Dictyostelium discoideum*)
“Dicty”

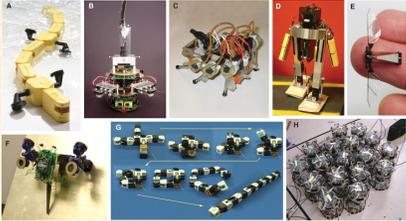
2/2/12 1

Complete Life Cycle



2/2/12 2

Self-organization in Bio-inspired Robotics



R. Pfeifer et al., *Science* 318, 1088-1093 (2007)




2/2/12 Published by AAAS 3

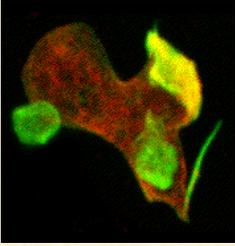
Self-copying Robot (2005)



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

2/2/12 4

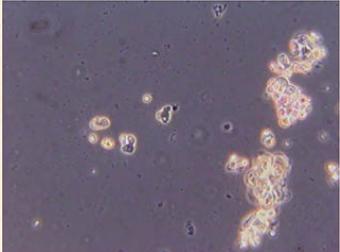
Amoeba Stage



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

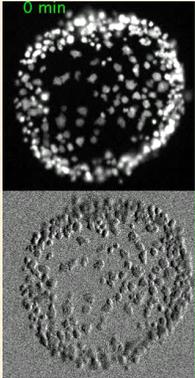
2/2/12 5

Amoebas



2/2/12 6

Aggregation Stage



- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
- Example: 180 cells
- Time lapse: about 14 hours

Science 21 May 2010: Vol. 328, 1021–1025

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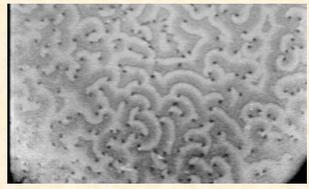
Aggregation Stage



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

2/2/12 8

Spiral Waves

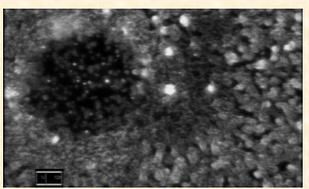


- Spiral accelerate cell aggregation (18 vs. 3 $\mu\text{m}/\text{min}$.)
- Waves propagate 120 – 60 $\mu\text{m}/\text{min}$.
- 1 frame = 36 sec.

(video < Zool. Inst., Univ. München)

2/2/12 9

Center of Spiral

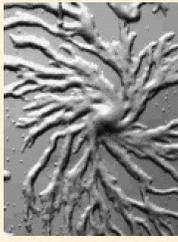


- Mechanisms of spiral formation are still unclear
- Involves symmetry breaking
- 1 frame = 10 sec.

(video < Zool. Inst., Univ. München)

2/2/12 10

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*

2/2/12 11

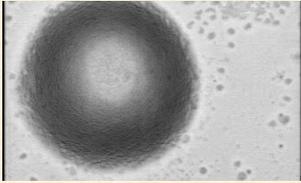
Mound Stage



- Cells differentiate
- Some form an elongated finger

2/2/12 12

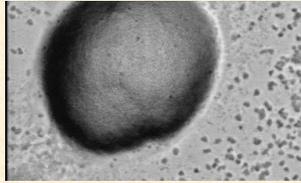
Concentric Waves in Mounds



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

2/2/12 (video < Zool. Inst., Univ. München) 13

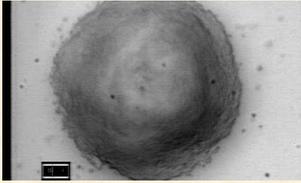
Multiple Centers



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

2/2/12 (video < Zool. Inst., Univ. München) 14

Multi-armed Spirals



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

2/2/12 (video < Zool. Inst., Univ. München) 15

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

2/2/12 16

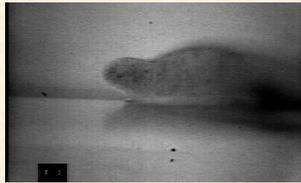
Slug Stage



- 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

2/2/12 17

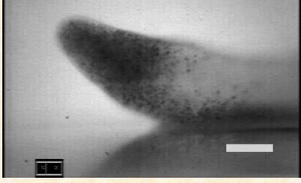
Movement of Young Slug



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

2/2/12 (video < Zool. Inst., Univ. München) 18

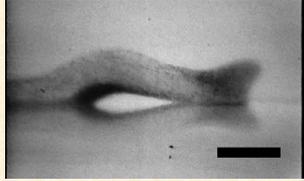
Movement of Older Slug



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

2/2/12 (video < Zool. Inst., Univ. München) 19

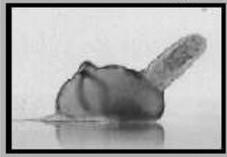
Migration of Older Slug



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

2/2/12 (video < Zool. Inst., Univ. München) 20

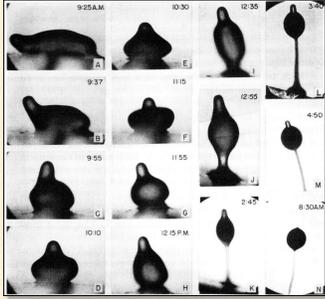
Culmination Stage



- 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

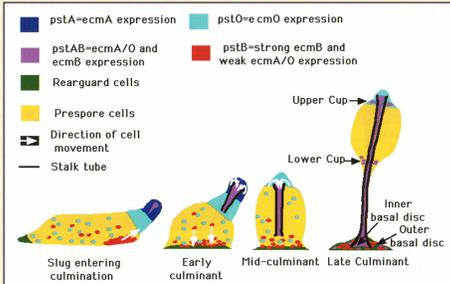
2/2/12 21

Stages of Culmination



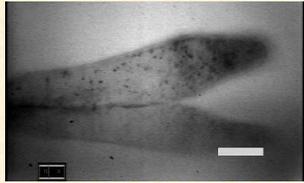
2/2/12 22

Cell Differentiation at Culmination



2/2/12 (figure from Kessin, *Dicryostelium*) 23

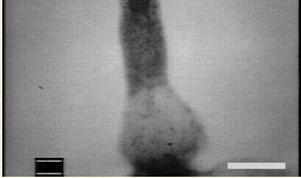
Early Culmination



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

2/2/12 (video < Zool. Inst., Univ. München) 24

Late Culmination



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

2/2/12 (video < Zool. Inst., Univ. MÜNchen) 25

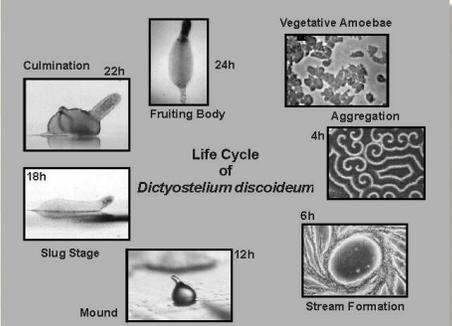
Fruiting Body Stage



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

2/2/12 26

Life Cycle of *Dictyostelium discoideum*



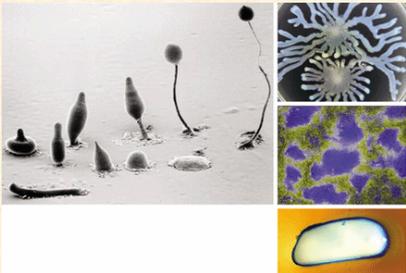
2/2/12 27

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?

2/2/12 28

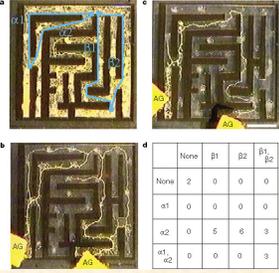
Microbial Cooperation and Altruism



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



Slime Mold Solving Maze



- Different slime mold: *Physarum polycephalum*
- Lengths: α 1 (41mm), α 2 (33), β 1 (44), β 2 (45)
- AG = food sources
- (a) initial, (b) exploring possible connections (4 hrs), (c) shortest (4 more)

	None	β 1	β 2	β 1, β 2
None	2	0	0	0
α 1	0	0	0	0
α 2	0	5	6	3
α 1, α 2	0	0	0	3

2/2/12 [fig. < Nakagaki, Yamada & Tóth, Nature 407, 470 (28 September 2000)] 30

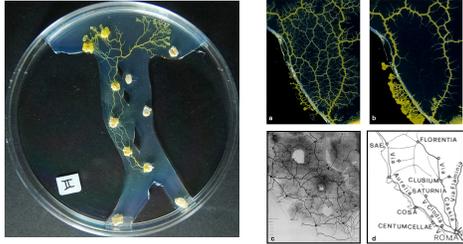
Slime Mold-Controlled Robot

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



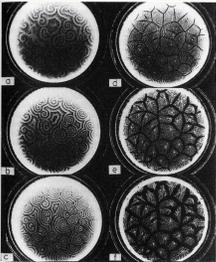
2/2/12 (Klaus-Peter Zauner, University of Southampton, UK, 2006) 31

Slime Mold Computation of Roman Road Network



2/2/12 Strano, Adamatzky & Jones, *Int. J. Nanotech. & Mol. Comp.*, in press 32

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)

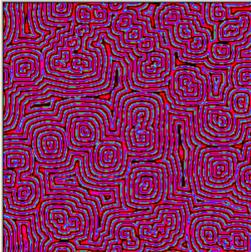
2/2/12 fig. from Solé & Goodwin 33

Belousov-Zhabotinski Reaction



2/2/12 34

Hodgepodge Machine



2/2/12 35

Demonstration of Hodgepodge Machine

[Run NetLogo B-Z Reaction Simulator](#)
or
[Run Hodgepodge simulator at CBN Online Experimentation Center](#)
<http://mitpress.mit.edu/books/FLAOH/cbnhtml/java.html>

2/2/12 36

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*

2/2/12

37

Reading

Read Flake, ch. 18

2D

2/2/12

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