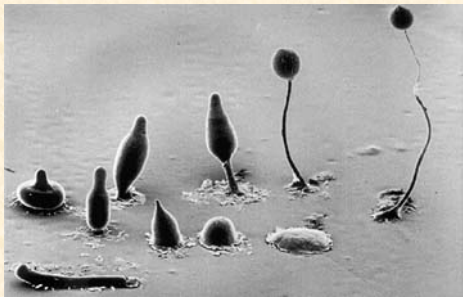


C.
Slime Mold
(Dictyostelium discoideum)
"Dicty"

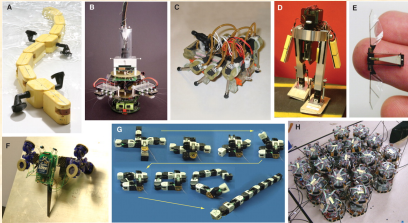
2015/1/30 1

Complete Life Cycle




2015/1/30 2

Self-organization in Bio-inspired Robotics




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

2015/1/30
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

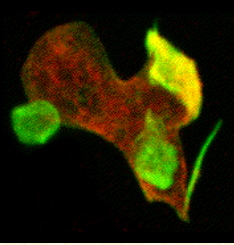
2015/1/30 4

Dicty Videos

- [Bonner's videos](#)
- [Aggregation](#)
- [Life cycle](#)

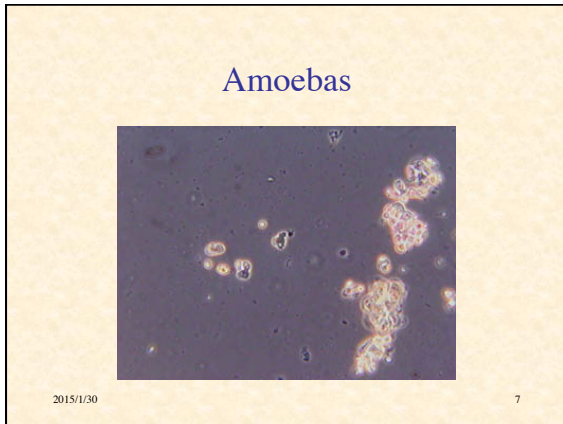
2015/1/30 5

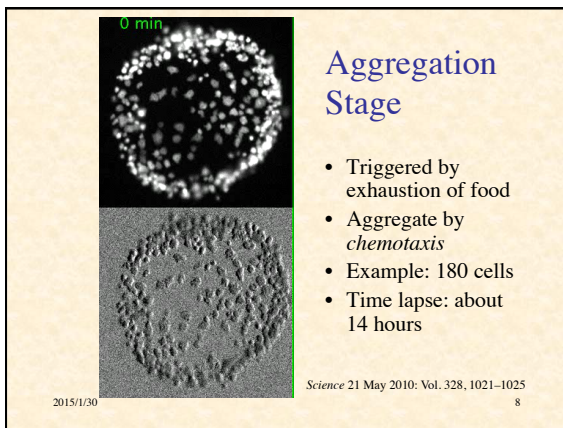
Amoeba Stage

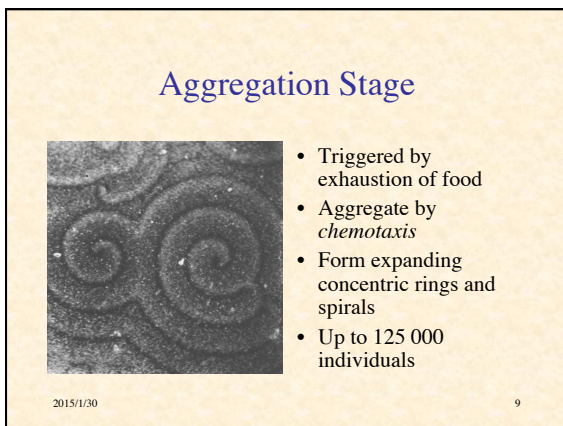


- Single cell
- Lives in soil
- Free moving
- Engulfs food (bacteria)
- Divides asexually

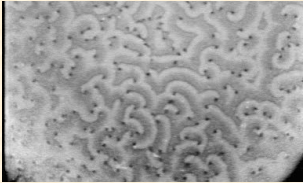
2015/1/30 6







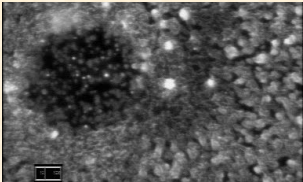
Spiral Waves



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

2015/1/30 (video < Zool. Inst., Univ. München) 10

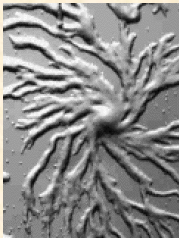
Center of Spiral



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

2015/1/30 (video < Zool. Inst., Univ. München) 11

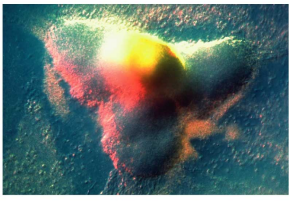
Stream Formation Stage



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

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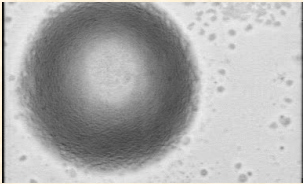
Mound Stage



- Cells differentiate
- Some form an elongated finger

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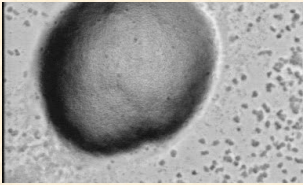
Concentric Waves in Mounds



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

2015/1/30 (video < Zool. Inst., Univ. München) 14

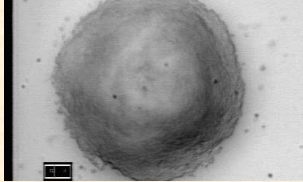
Multiple Centers



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

2015/1/30 (video < Zool. Inst., Univ. München) 15

Multi-armed Spirals



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

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(video < Zool. Inst., Univ. München)

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Formation of Acellular Sheath

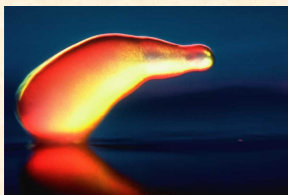


- Composed of cellulose & a large glycoprotein
- Covers mound and is left behind slug as trail
- Function not entirely understood:
 - protection from nematodes (worms)
 - control of diffusion of signaling molecules

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Slug Stage

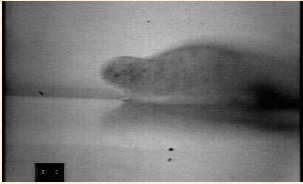


- Prestalk elongates, topples, to form slug
- Behaves as single organism with 10^5 cells
- Migrates; seeks light; seeks or avoids heat
- No brain or nervous system

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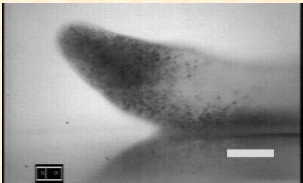
Movement of Young Slug



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

2015/1/30 (video < Zool. Inst., Univ. München) 19

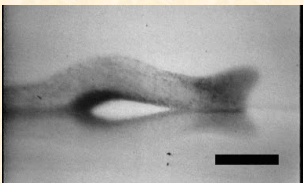
Movement of Older Slug



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

2015/1/30 (video < Zool. Inst., Univ. München) 20


Migration of Older Slug



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

2015/1/30 (video < Zool. Inst., Univ. München) 21

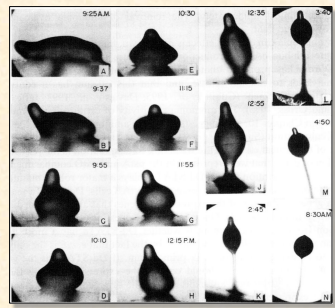
Culmination Stage



- 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

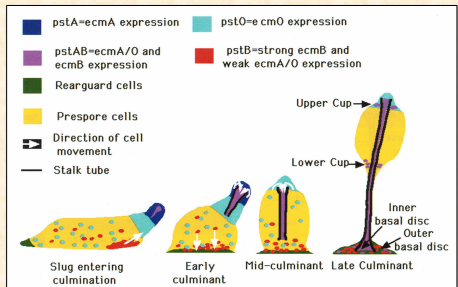
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Stages of Culmination



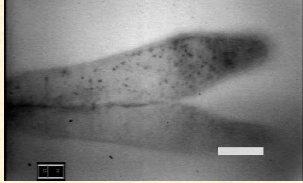
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Cell Differentiation at Culmination



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(figure from Kessin, *Dicystelium*)

Early Culmination



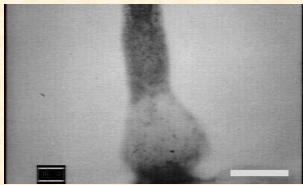
- During early culmination all cell in prestalk rotate
- Scale bar = 50 mm, 1 frame = 25 sec.

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(video < Zool. Inst., Univ. München)

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Late Culmination



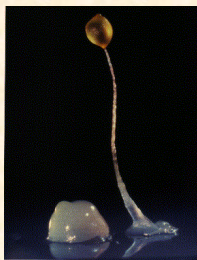
- Vigorous rotation at prestalk/prespore boundary
- Scale bar = 100 mm, 1 frame = 10 sec.

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(video < Zool. Inst., Univ. München)

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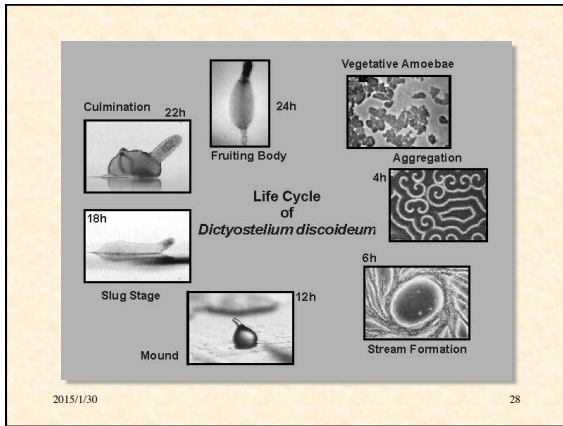
Fruiting Body Stage



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

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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?

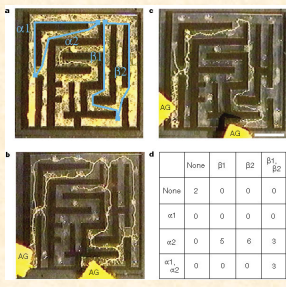
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Microbial Cooperation and Altruism

The image contains several panels: a large photograph of a mature slime mold with its stalk and fruiting body; a microscopic view of a branching, tree-like structure; a microscopic view of a cell with a blue-stained nucleus; and a microscopic view of a single, elongated cell.

2015/1/30
Published by AAAS
E. Pennisi Science 325, 1196-1199 (2009)
Science
AAAS

Slime Mold Solving Maze




	None	$\beta 1$	$\beta 2$	$\beta 1/\beta 2$
None	2	0	0	0
$\alpha 1$	0	0	0	0
$\alpha 2$	0	6	6	3
$\alpha 1/\alpha 2$	0	0	0	3

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

2015/1/30 [fig. < Nakagaki, Yamada & Tôth, *Nature* 407, 470 (28 September 2000)] 31

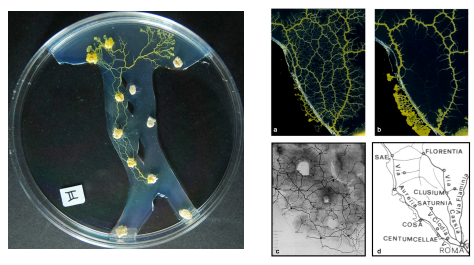
Slime Mold-Controlled Robot


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



2015/1/30 (Klaus-Peter Zauner, University of Southampton, UK, 2006) 32

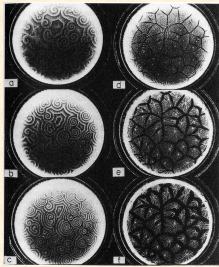
Slime Mold Computation of Roman Road Network





2015/1/30 Strano, Adamatzky & Jones, *Int. J. Nanotech. & Mol. Comp.*, in press 33

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)

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fig. from Solé & Goodwin

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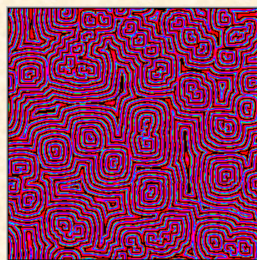
Belousov-Zhabotinski Reaction



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Hodgepodge Machine



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**Demonstration of
Hodgspode Machine**

Run NetLogo B-Z Reaction Simulator

or

**Run Hodgspode simulator at CBN
Online Experimentation Center**

mitpress.mit.edu/books/FLA0H/cbnhtml/java.html

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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*

5D

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