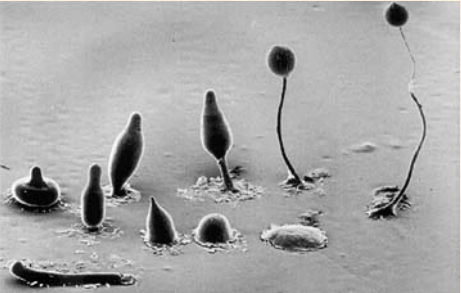


C. Slime Mold

(*Dictyostelium discoideum*)
“Dicty”

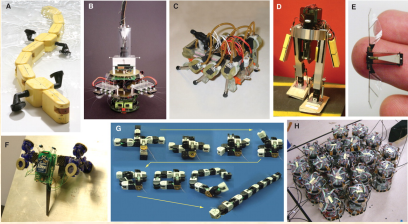
2015/1/30 1

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

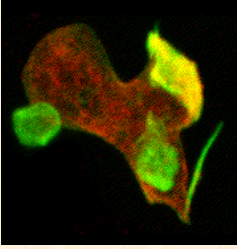
2015/1/30 4

Dicty Videos

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

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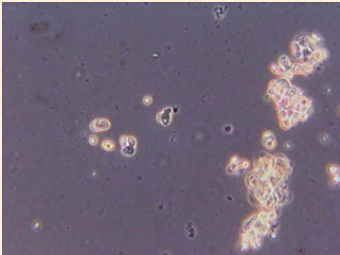
Amoeba Stage



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

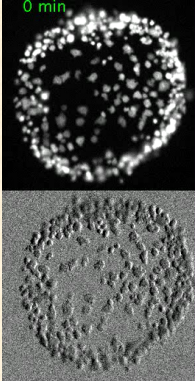
2015/1/30 6

Amoebas



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Aggregation Stage

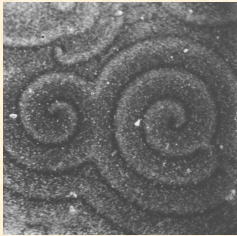


- Triggered by exhaustion of food
- Aggregate by *chemotaxis*
- Example: 180 cells
- Time lapse: about 14 hours

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

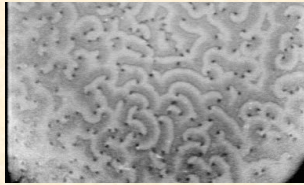
Aggregation Stage



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

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Spiral Waves

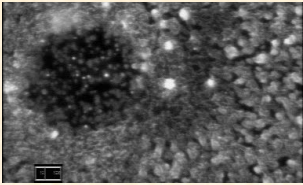


- Spiral accelerate cell aggregation (18 vs. 3 mm/min.)
- Waves propagate 120 – 60 mm/min.
- 1 frame = 36 sec.

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(video < Zool. Inst., Univ. München)

Center of Spiral

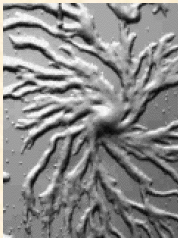


- Mechanisms of spiral formation are still unclear
- Involves symmetry breaking
- 1 frame = 10 sec.

2015/1/30 11

(video < Zool. Inst., Univ. München)

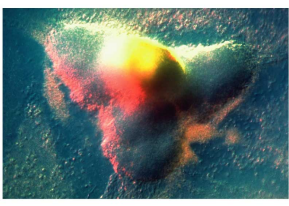
Stream Formation Stage



- 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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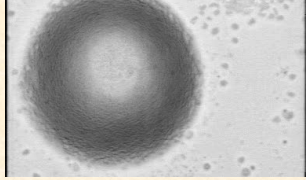
Mound Stage



- Cells differentiate
- Some form an elongated finger

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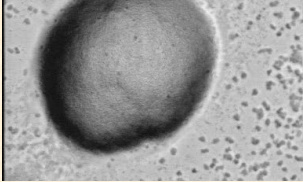
Concentric Waves in Mounds



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

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

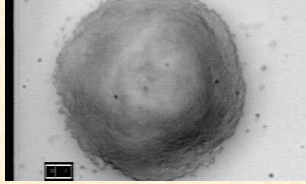
Multiple Centers



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

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(video < Zool. Inst., Univ. München)

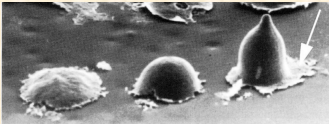
Multi-armed Spirals



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

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(video < Zool. Inst., Univ. München)


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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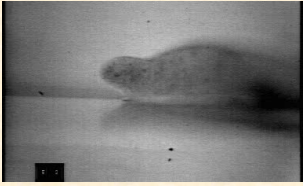
Slug Stage



- 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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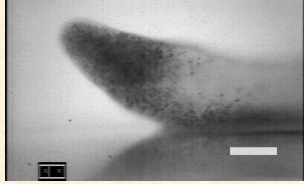
Movement of Young Slug



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

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

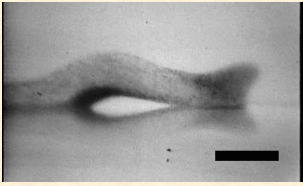
Movement of Older Slug



- 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

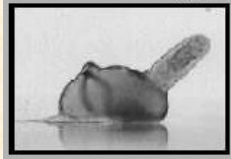
Migration of Older Slug



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

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

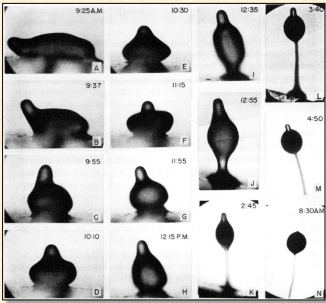
Culmination Stage



- 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

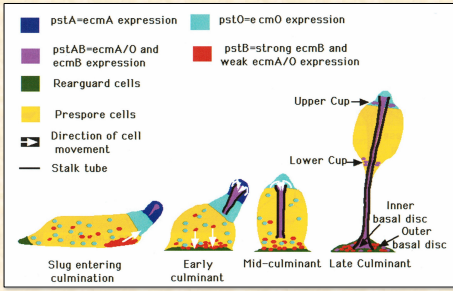
2015/1/30 22

Stages of Culmination



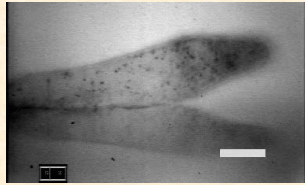
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Cell Differentiation at Culmination



2015/1/30 (figure from Kessin, *Dictyostelium*) 24

Early Culmination



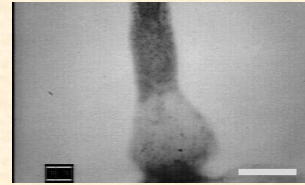
- During early culmination all cell in prestalk rotate
- Scale bar = 50 mm, 1 frame = 25 sec.

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(video < Zool. Inst., Univ. München)

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Late Culmination



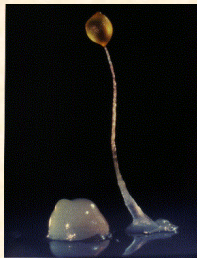
- Vigorous rotation at prestalk/prespore boundary
- Scale bar = 100 mm, 1 frame = 10 sec.

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(video < Zool. Inst., Univ. München)

26

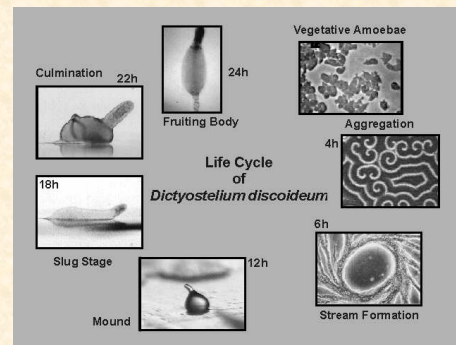
Fruiting Body Stage



- 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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2015/1/30

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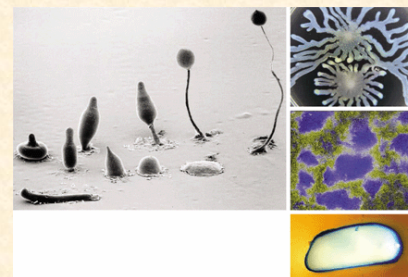
Cooperation and Altruism in Dicty

- 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

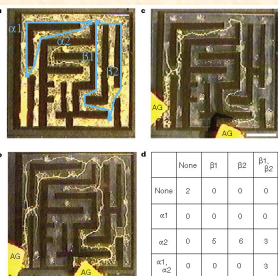


2015/1/30
Published by AAAS

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



Slime Mold Solving Maze




- 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)

	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

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

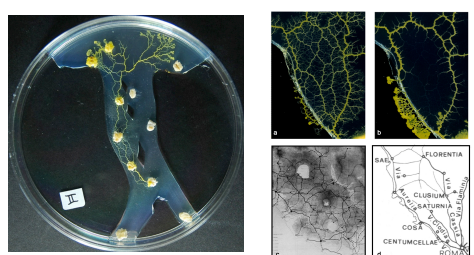
Slime Mold-Controlled Robot



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

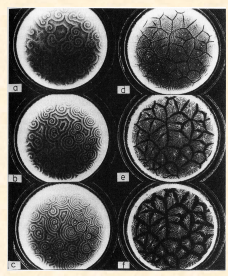
2015/1/30 (Klaus-Peter Zauner, University of Southampton, UK, 2006) 32

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)

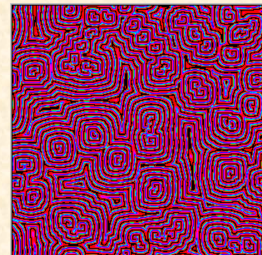
2015/1/30 fig. from Solé & Goodwin 34

Belousov-Zhabotinski Reaction



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Hodgepodge Machine



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**Demonstration of
Hodgepodge Machine**

[Run NetLogo B-Z Reaction Simulator](#)

or


[Run Hodgepodge simulator at CBN
Online Experimentation Center](#)

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

2015/1/30 37

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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