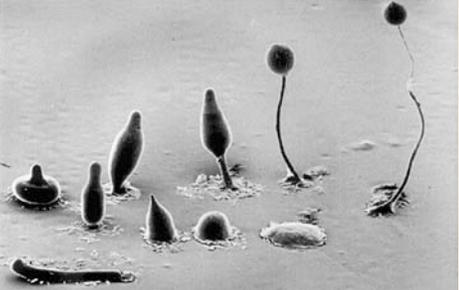


**C.
Slime Mold**
(Dictyostelium discoideum)
“Dicty”

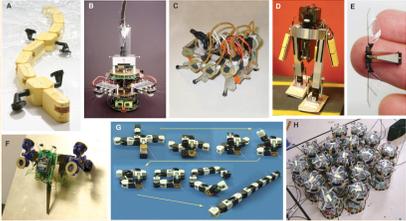
9/16/09 1

Complete Life Cycle



9/16/09 2

Self-organization in Bio-inspired Robotics



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

 3

9/16/09
Published by AAAS

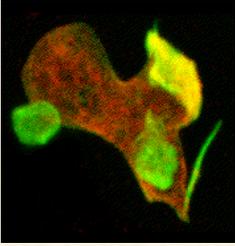
Self-copying Robot (2005)



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

9/16/09 4

Amoeba Stage



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

9/16/09 5

Amoebas



9/16/09 6

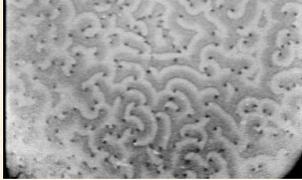
Aggregation Stage



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

9/16/09 7

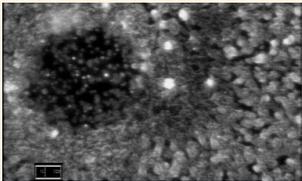
Spiral Waves



- 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.

9/16/09 8
(video < Zool. Inst., Univ. München)

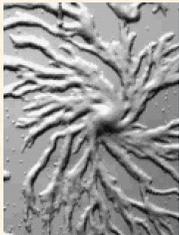
Center of Spiral



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

9/16/09 9
(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*

9/16/09 10

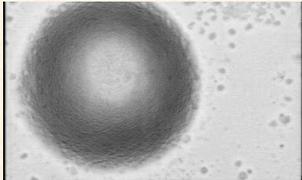
Mound Stage



- Cells differentiate
- Some form an elongated finger

9/16/09 11

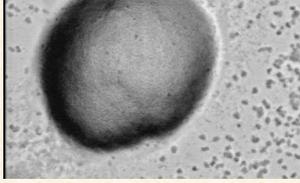
Concentric Waves in Mounds



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

9/16/09 12
(video < Zool. Inst., Univ. München)

Multiple Centers



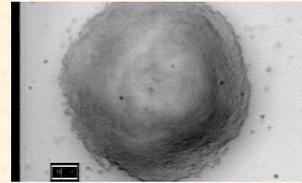
- Multiple pacemakers
- Wave fronts mutually extinguish (typical of excitable media)
- One center eventually dominates

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(video < Zool. Inst., Univ. München)

13

Multi-armed Spirals



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

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(video < Zool. Inst., Univ. München)

14

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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15

Slug Stage

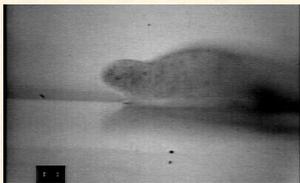


- Prestalk elongates, topples, to form slug
- Behaves as single organism with 10^5 cells
- Migrates; seeks light; seeks or avoids heat
- No brain or nervous system

9/16/09

16

Movement of Young Slug



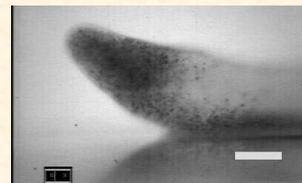
- Time-lapse (1 frame = 10 sec.)
- Note periodic up-and-down movement of tip

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(video < Zool. Inst., Univ. München)

17

Movement of Older Slug



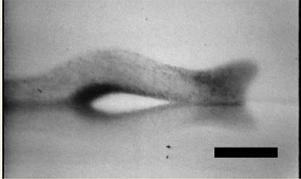
- Note rotating prestalk cells in tip
- Pile of anterior-like cells on prestalk/prespore boundary
- Scale bar = 50 μ m, 1 frame = 5 sec.

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(video < Zool. Inst., Univ. München)

18

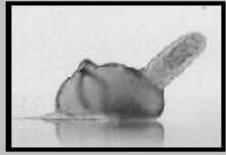
Migration of Older Slug



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

9/16/09 (video < Zool. Inst., Univ. München) 19

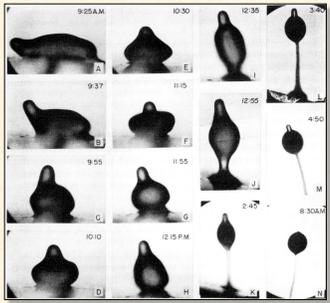
Culmination Stage



- 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

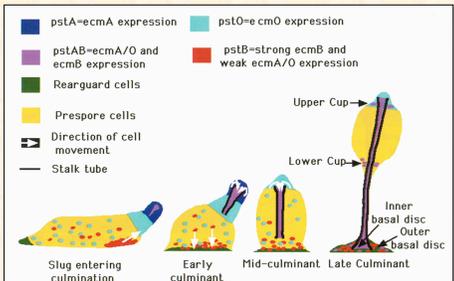
9/16/09 20

Stages of Culmination



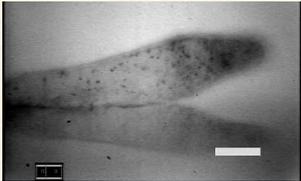
9/16/09 21

Cell Differentiation at Culmination



9/16/09 (figure from Kessin, *Dictyostelium*) 22

Early Culmination



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

9/16/09 (video < Zool. Inst., Univ. München) 23

Late Culmination



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

9/16/09 (video < Zool. Inst., Univ. München) 24

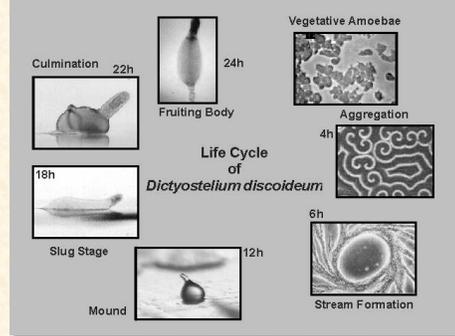
Fruiting Body Stage



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

9/16/09 25

Life Cycle of *Dictyostelium discoideum*



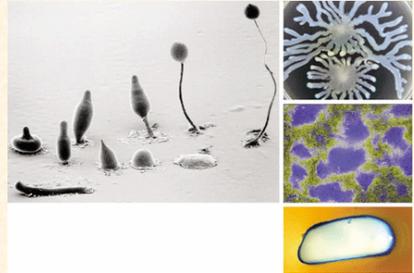
9/16/09 26

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?

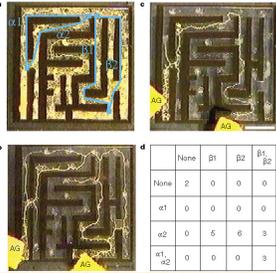
9/16/09 27

Microbial Cooperation and Altruism



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

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	5	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)

9/16/09 [fig.-c Nakagaki, Yamada & Tóth, Nature 407, 470 (28 September 2000)] 29

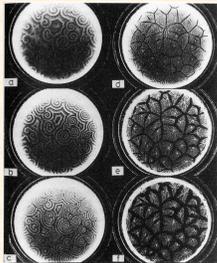
Slime Mold-Controlled Robot



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

9/16/09 (Klaus-Peter Zauner, University of Southampton, UK, 2006) 30

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)

9/16/09

fig. from Solé & Goodwin

31

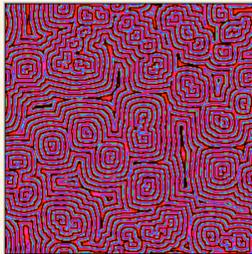
Belousov-Zhabotinski Reaction



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32

Hodgepodge Machine



9/16/09

33

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>

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34

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*

9/16/09

35

Reading

Read Flake, ch. 18

2D

9/16/09

36