CABDyN
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How does an amoeba tackle some geometrical puzzles?

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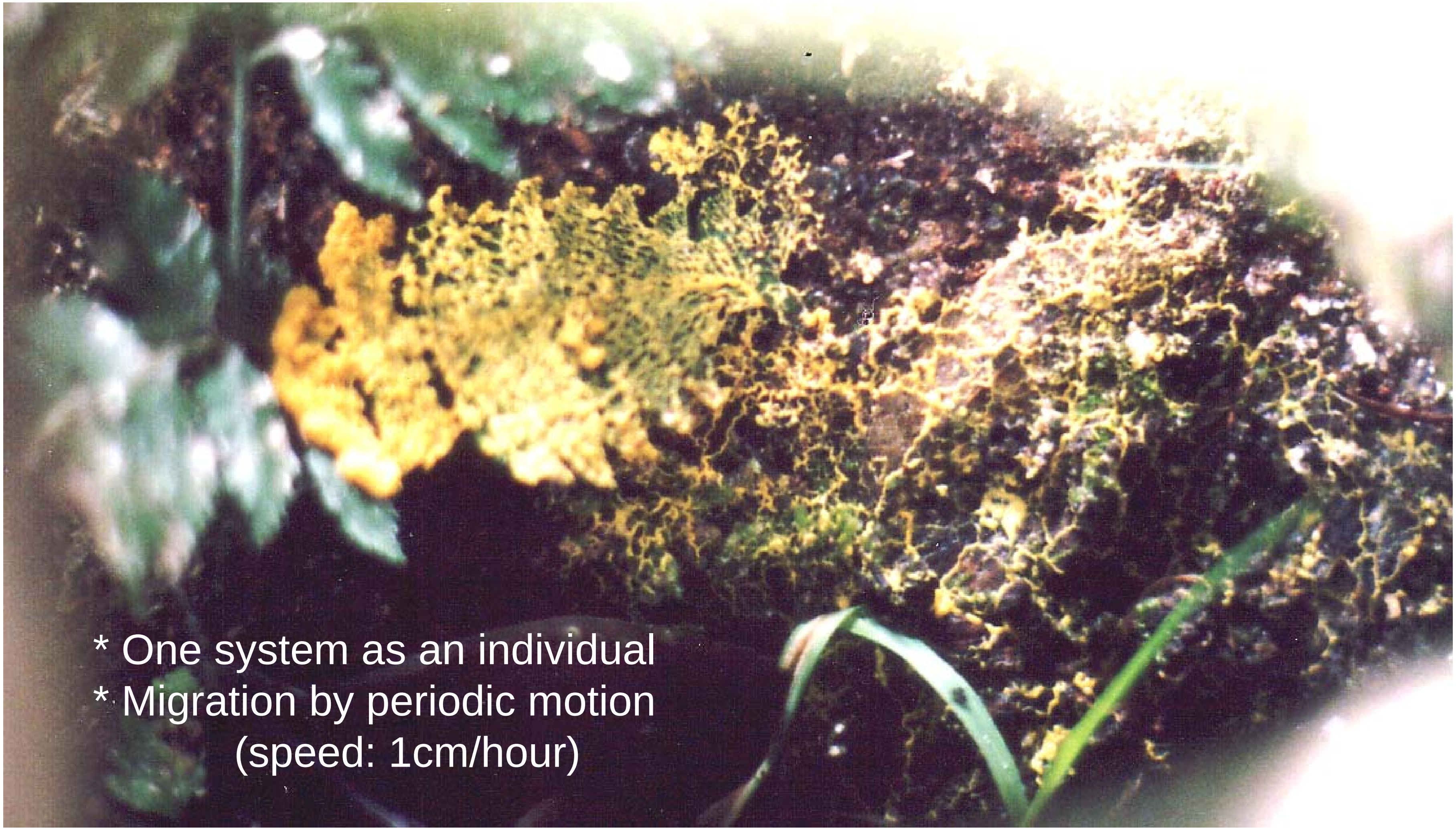
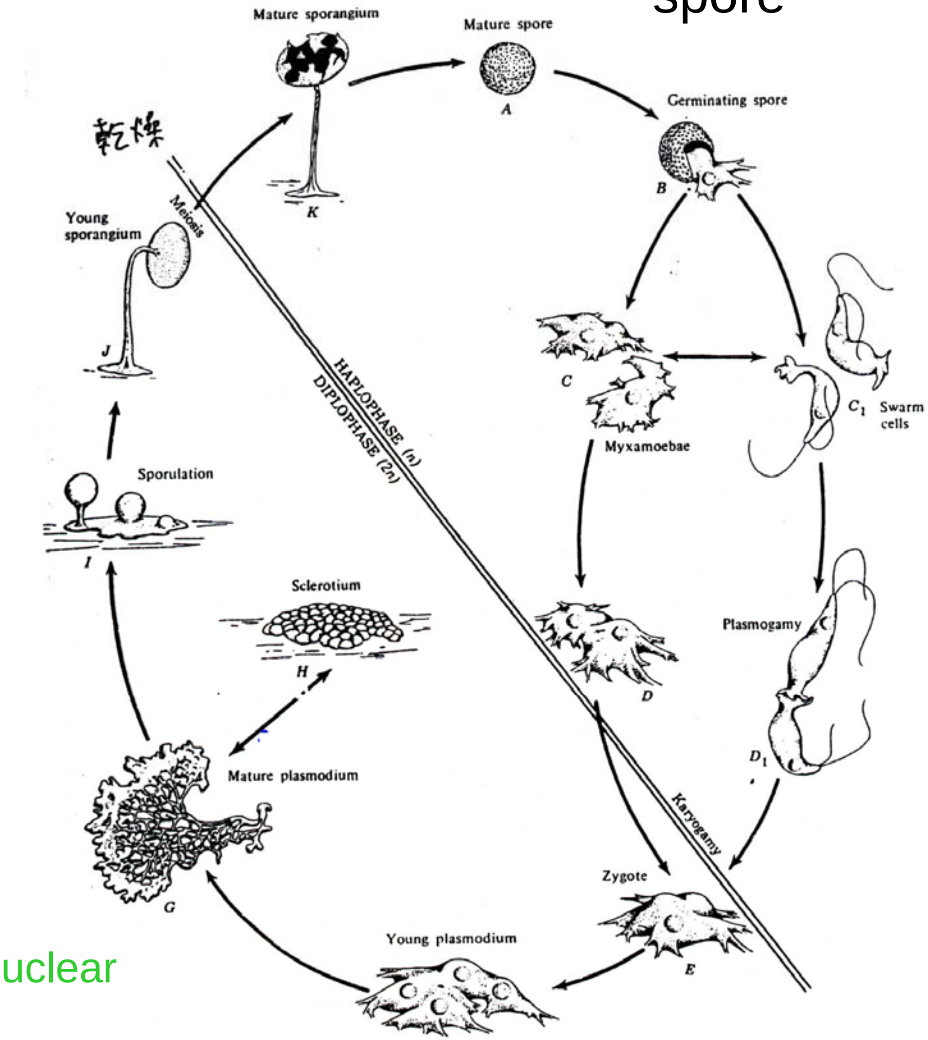
True slime mold,
the plasmodium of *Physarum polycephalum*



Life cycle

spore



plasmodium

* Giant amoeboid
  unicellular and multinuclear

From Introductory Mycology
（Alexopolus and Mims)

The biggest in Guinness record (1989)

--- dedicated to Prof. W-Botterman in University of Bonn ---

fed by R. Stiemerling

P.p.

TV program in Germany

Like Nothing On Earth

The Incredible Life of Slime Moulds

Slime moulds is a somewhat unattractive name, but it describes a fantastic and fascinating life form. Slime moulds - scientists call them myxomycetes - crawl over the ground like rippling monsters, hunting innocent woodland creatures. To reproduce, they change into delicate, plant-like forms, unmatched for their individual beauty and shimmering colours.

Slime moulds are evolutionary outsiders. Magical creatures, they lie somewhere between the two great kingdoms, animals and plants. They have, literally, their own way of life.

Karlheinz Baumann has studied these amazing creatures for more than twenty years, in the cloud forests of Canada, in the Emperor's Garden in Tokyo, and in the woodlands on his own doorstep. His camera takes us into a strange and exciting world, mostly invisible to the naked eye, where days pass in seconds, and microscopic creatures become terrifying giants. The world of the slime moulds outdoes anything science fiction can offer.

Now a new, electrifying report comes from Japan: at the University of Sapporo scientists have developed an intelligence test for slime moulds. The film shows the experiment - and its unexpected, almost frightening results.

It is hard to resist the fascination of these weird creatures - and not only for scientists. Slime moulds have their fans all over the world - an endearingly eccentric crowd, recognising no international borders, united in their passion for their beloved "myxos".

KARLHEINZ BAUMANN
Naturfilme
LINDENSTRASSE 40
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Karlheinz Baumann

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Like Nothing On Earth

KARLHEINZ BAUMANN *Naturfilme*

Like Nothing On Earth

The Incredible Life of Slime Moulds

VHS/Colour/43 Min.

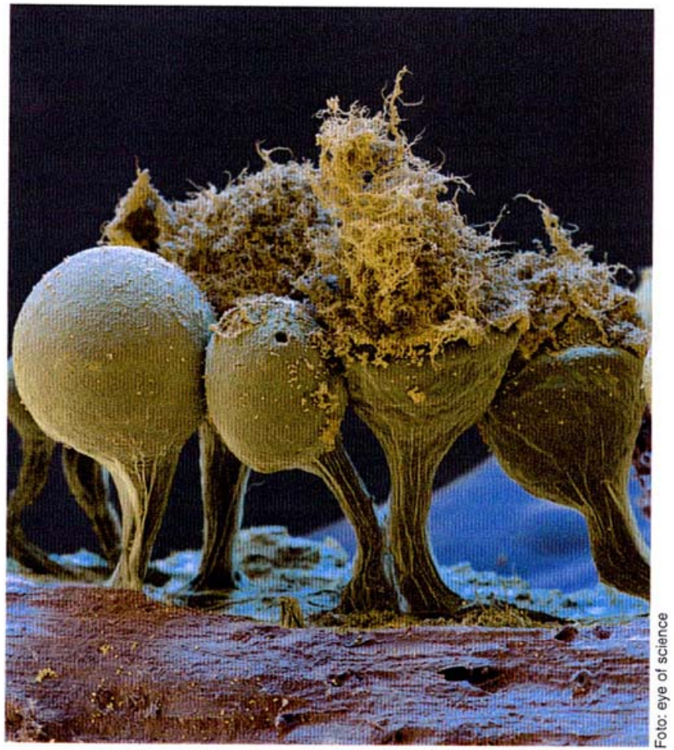
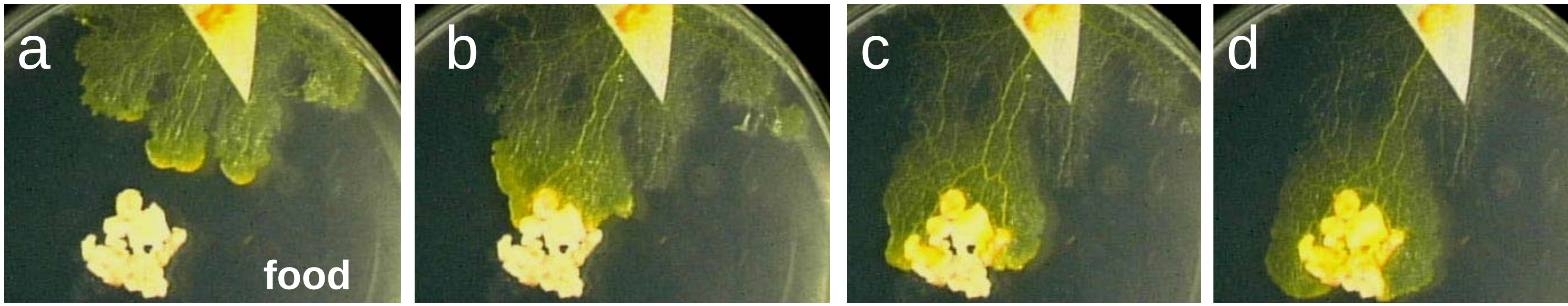


Foto: eye of science

KARLHEINZ BAUMANN *Naturfilme*

Behavior: drastic changes in body shape

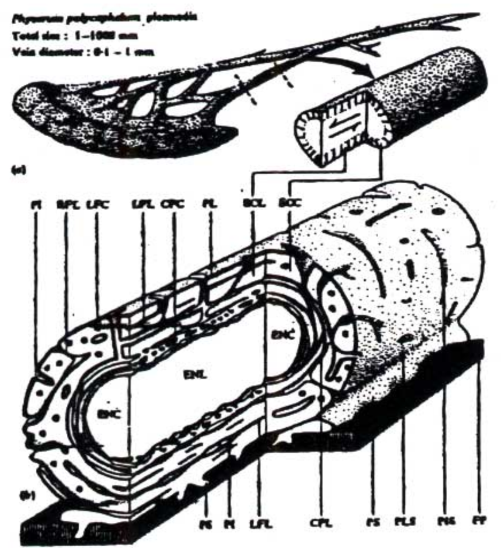


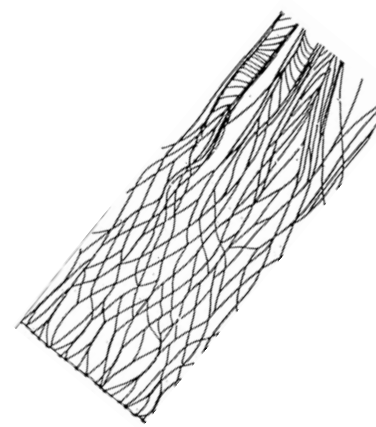
every 2 hours

Tube-network:

- * contraction rhythm
- * actomyosin array
- * shuttle flow

  Poisueille flow:
  High flow rate
  in Thick and short
- * as signal highways
- * as legs to move





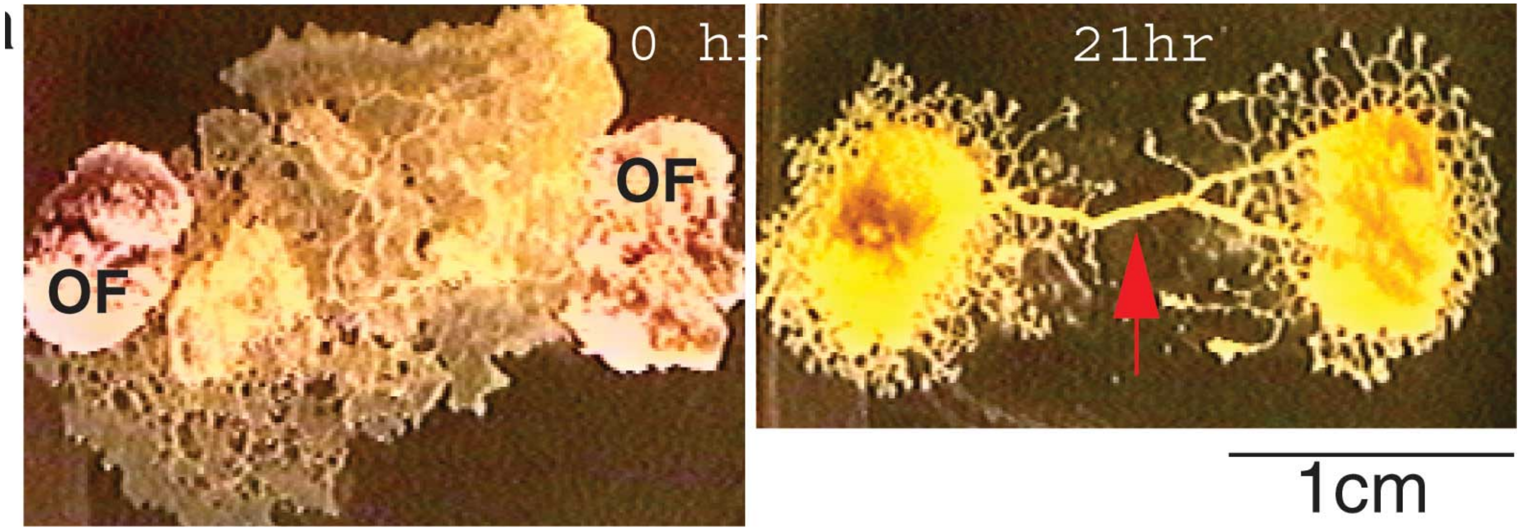
orientation of actomyosin filament in the tube

How finish a survival task ?

A nasty trick:
Presenting each small food at multiple locations

Physiological requirements:
* absorption of nutrient as possible
* maintenance of one large system

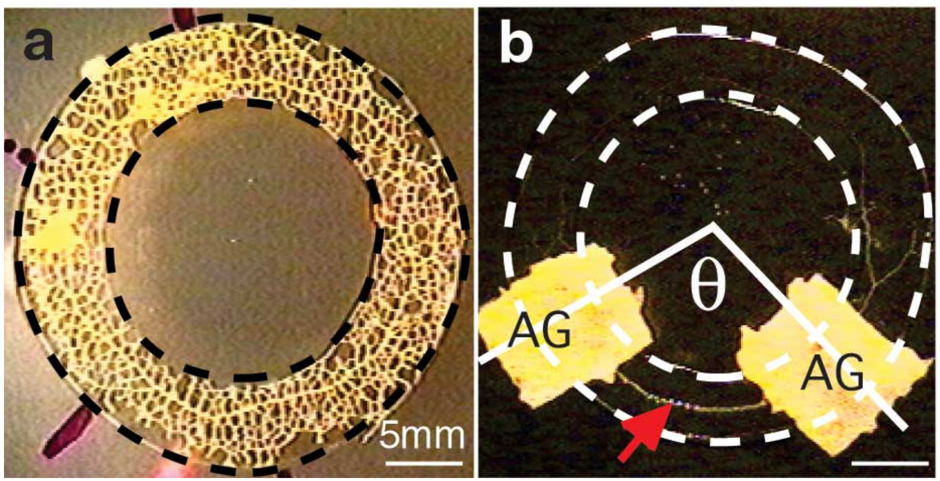
A thick tube connecting two FSs



This shortest connection enables that…

* Almost all part of the organism stays on food-sources,
working for fast absorption of nutrient as possible.
* Exchange of chemical signals between two main parts is effective
through the thick shortest tube, because
Poisuelle flow increases in thicker and shorter tube.

Selection of shorter tube

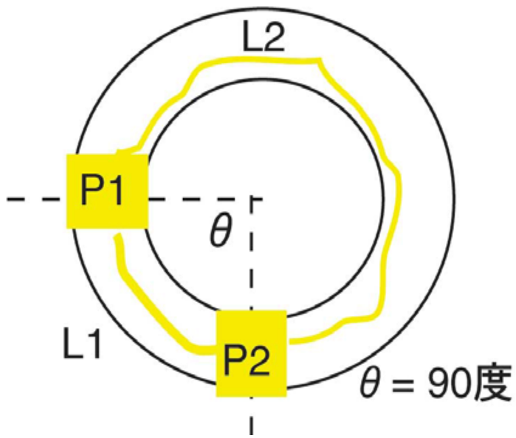


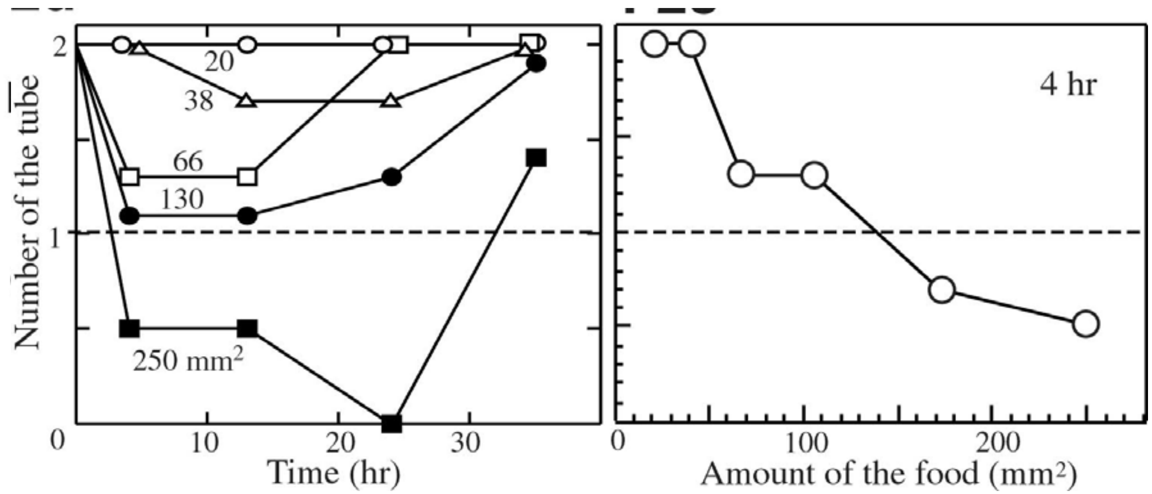
c

# of tubes \ θ°		90	135	160	180
0		1	0	0	10
1	short	17	9	8	5
	long	0	0	1	
2		1	1	5	7
		19	10	14	22

Effect of food amount on tube path

--- Changes in body mass under a fixed amount of food ---





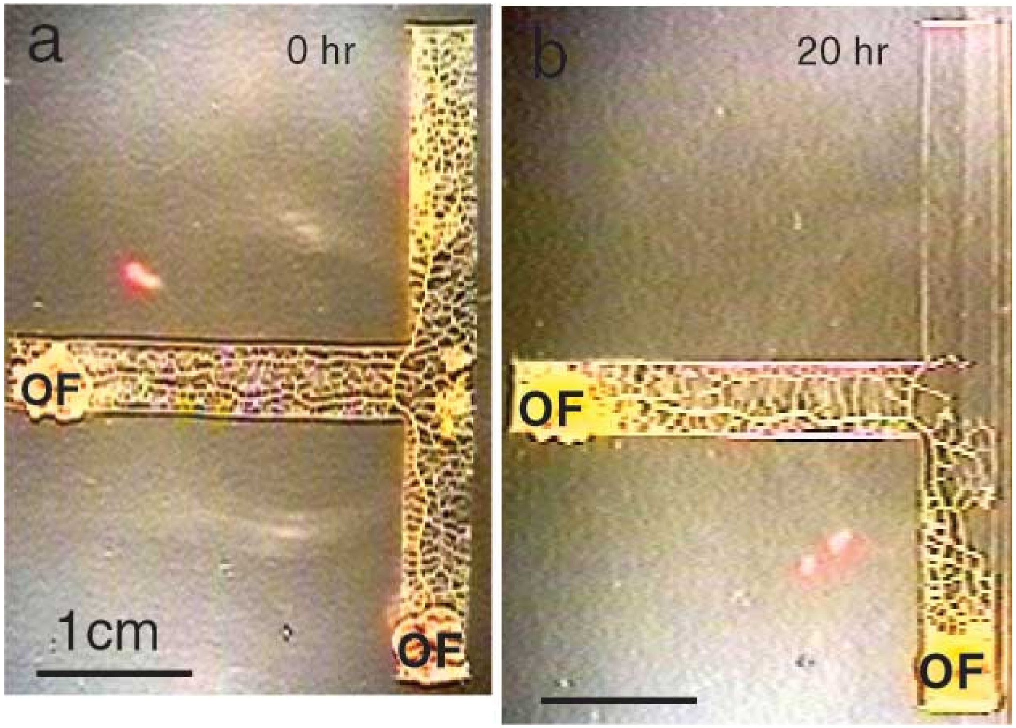
＊for the shorter tube to always disappear after another

＊flexible giant system:

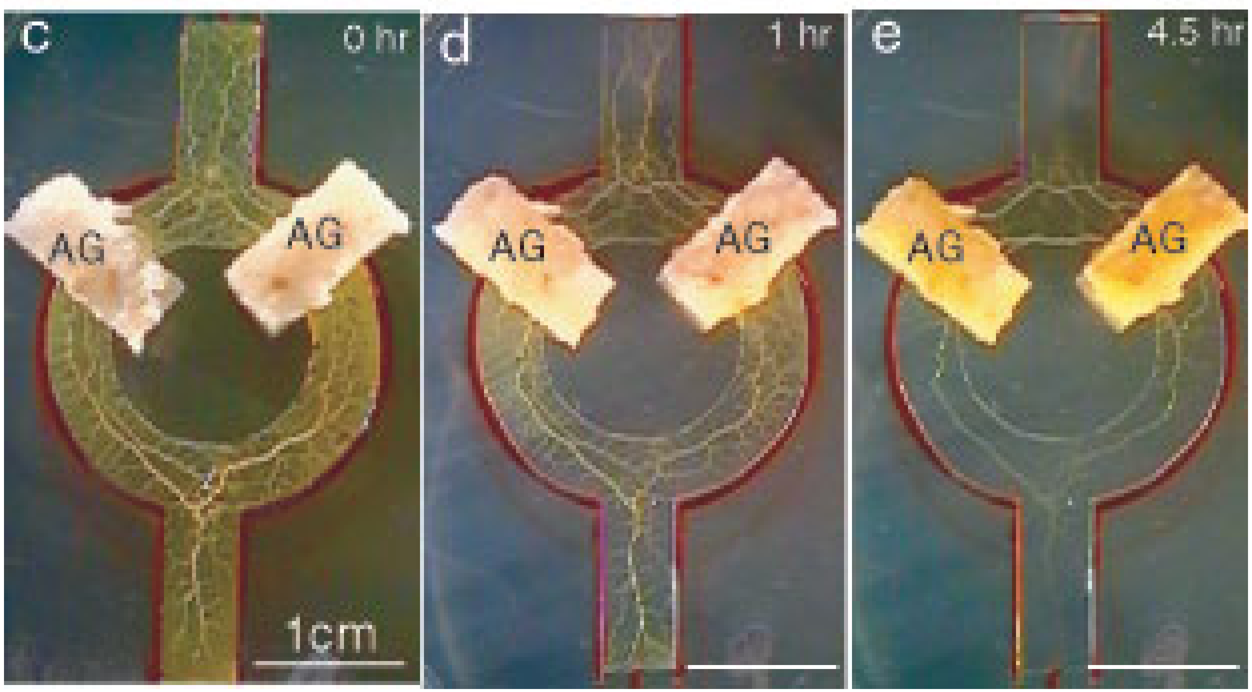
no problem if dividing to two parts

but keep in touch as lasting as possible

Shrinking from dead end space

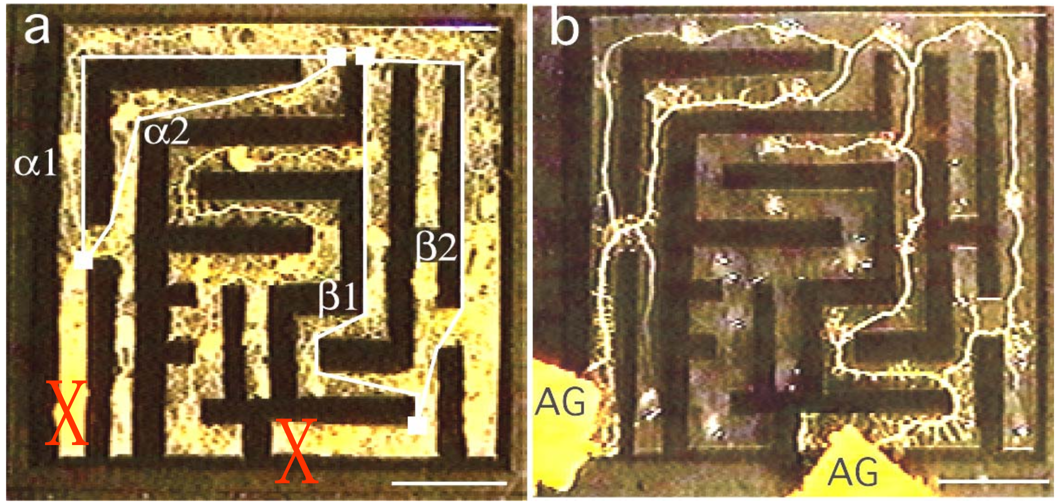


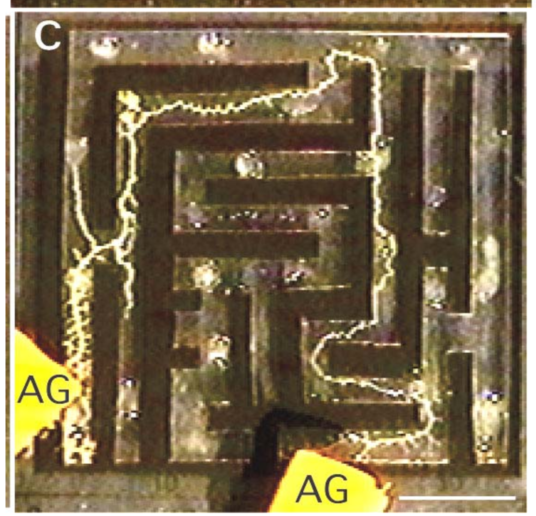
What happens in combination of dead ends and multiple connections ?



Order of disappearing: from dead-ends to long connection.
Is it really an empirical rule ?

Amazing tube in a maze





d

		β			
		none	β1	β2	β1, β2
α	none	2	0	0	0
	α1	0	0	0	0
	α2	0	5	6	3
	α1, α2	0	0	0	3

Physiological benefits of the shortest connection in the maze

physiological requirements:

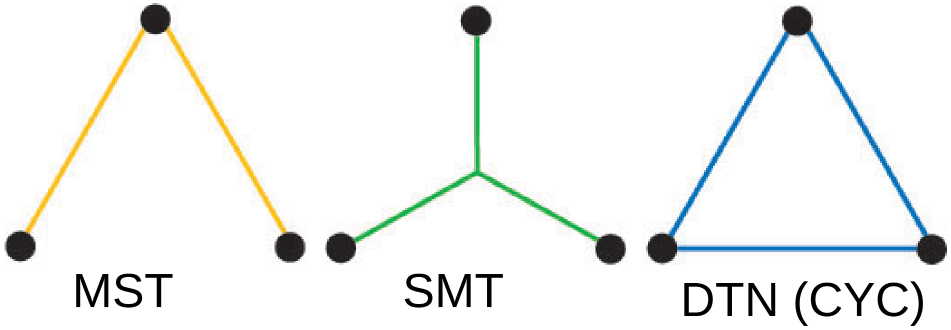
* absorption of nutrients from food-sources
* maintenance of individual system of large amoeba
* given amount of protoplasm

The shortest connection enables that…

* Almost all part of the organism stays on food-sources, working for absorption of nutrients.
* Intracellular communication of two separating parts is close and effective through the thick shortest tube.

It is possible even in a maze, so his behavior is smart !

Three and more food-sites



Steiner's Minimum Tree ?

Measuring a physiological requirement

--- compensation for disconnection ---

- ref : S.H. Strogatz, Nature 410, 268-276 (2001) -

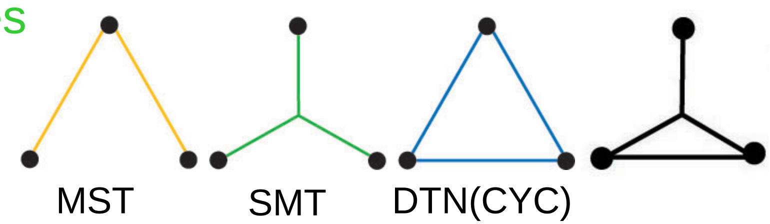
Ratio of Fault Tolerance and Total Length, FT_N/TL :

TL--- total length of tubes, normalized to SMT, (dimensionless)

FT_N--- the probability of occurrence of the event where the organism is not broken into two pieces if N times accidental disconnections happen at a random position on tubes.
Disconnection probability of each tube is proportional to the ratio of its length to total length.

FT becomes higher as network is robust with redundant connections at the cost of TL.

Examples



	MST	SMT	DTN(CYC)	
FT_1	0.00	0.00	1.00	0.79
FT_2	0.00	0.00	0.33	0.23
TL	1.15	1.00	1.72	1.58
FT_1 /TL	0.00	0.00	0.58	0.50

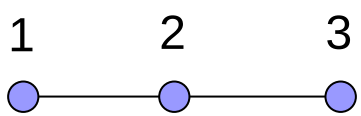
Definition of averaged separation

- ref : S.H. Strogatz, Nature 410, 268-276 (2001) -

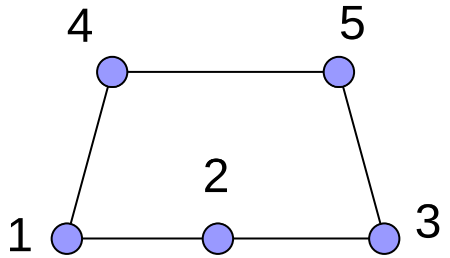
Averaged degree of separation, AS:

Degree of separation between two food-sources, I and j (DS_{ij}), is the number of transit food-sources through the shortest path. AS is degree of separation averaged over all pairs of food-sources. Then AS becomes lower as food-sources are coupled more closely.

$DS_{12} = 0$

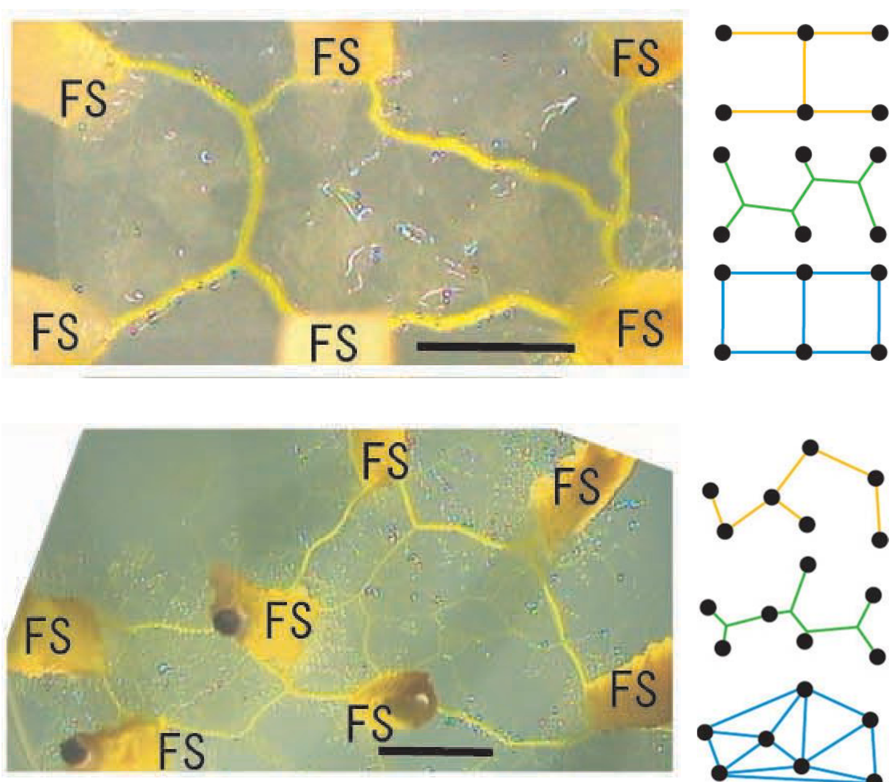


$DS_{13} = 1$

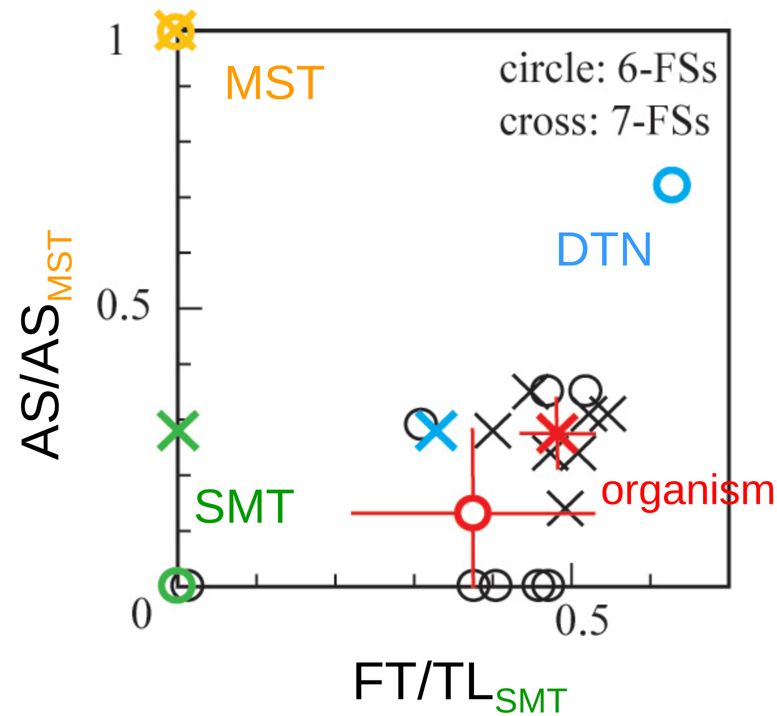


$DS_{13} = 1$

Close communication among major parts of body on the food-sources

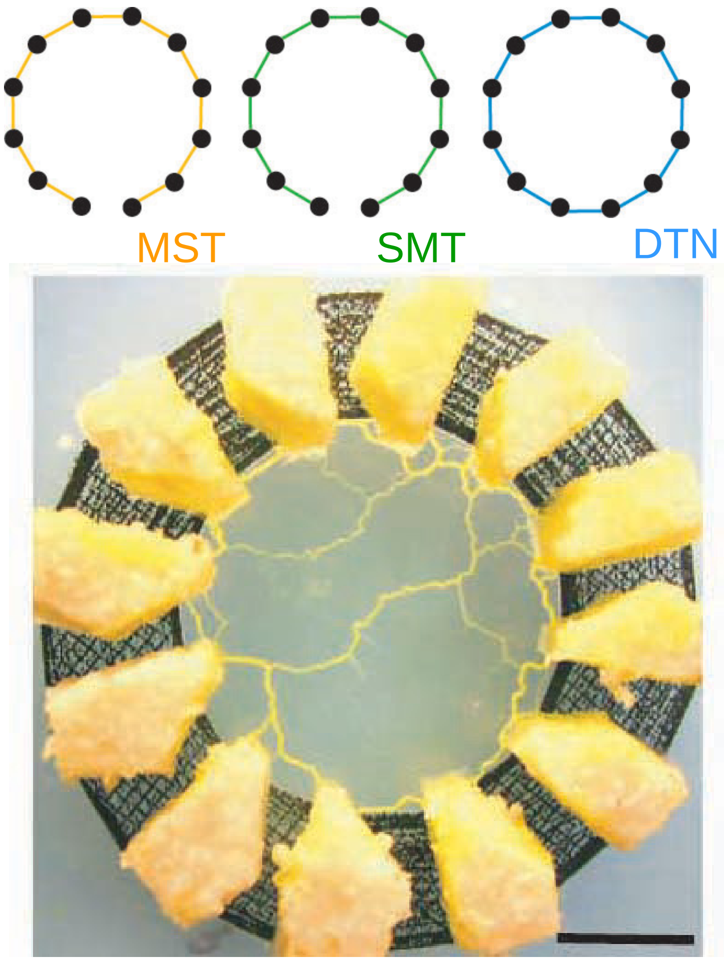


Scale bar: 1 cm



Good values in both measures

Network shape in 12 and 64 FSs



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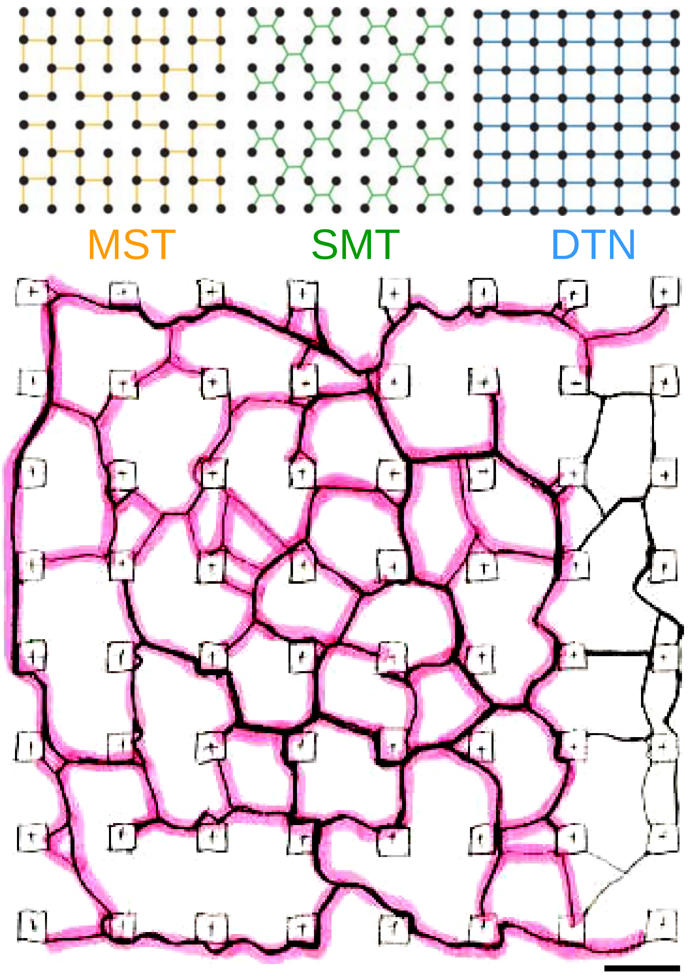


Cellular computation by body shapes

The plasmodium has ability of fighting against environments in which it is difficult to optimize the survival task.

Information processing: transformation from input to output

Environments: input or problem to be solved

Behaviors or body shape: output or solution

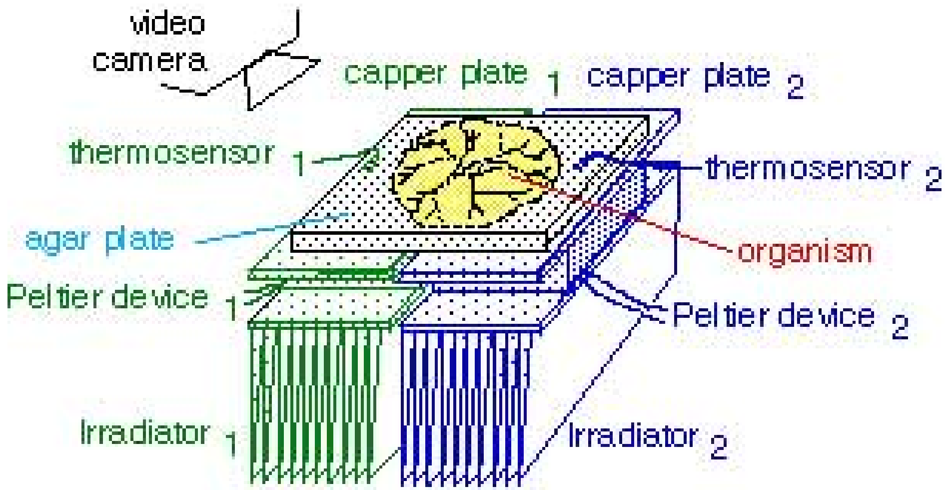
We can observe the way of information processing if evaluating smartness of body shape in complicated environments.

* How smart is the organism's solution ?
* How does the organism obtain the solution ?

Dynamic Morphogenesis of Tube

Modulation of tube formation by controlling contraction patterns

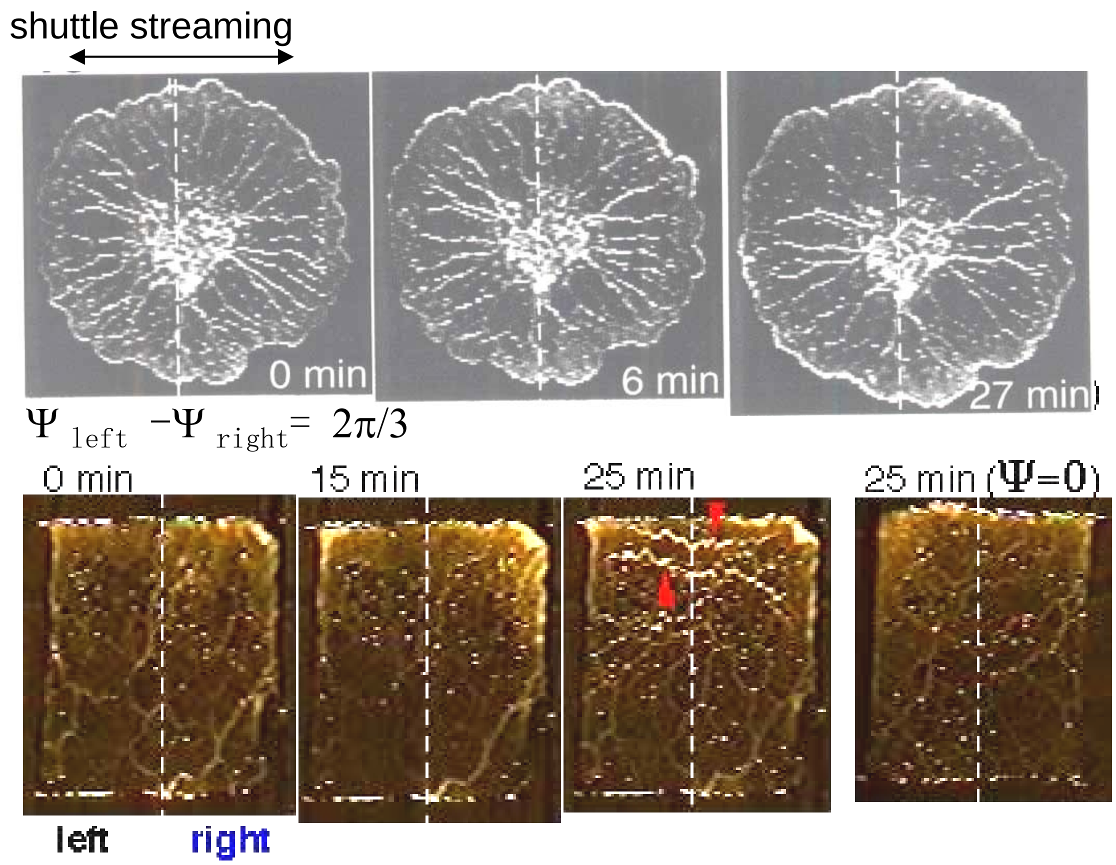
-entrainment of contraction rhythms to external oscillation of temperature-



Schematic illustration for experimental setup

* artificial induction of phase difference between two halves
* protoplasmic shuttle streaming between two halves

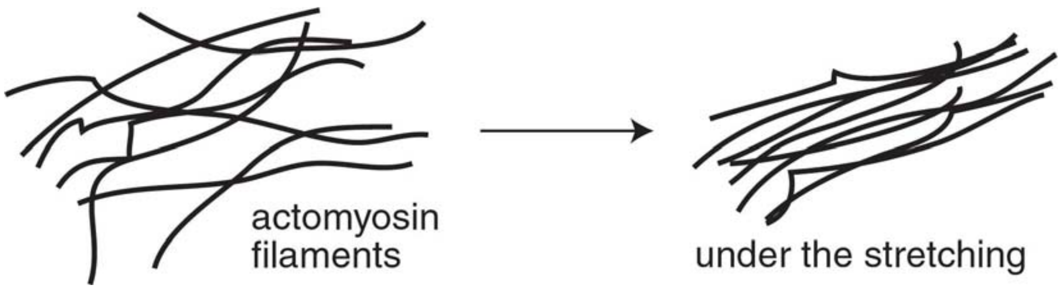
Modulation of tube structure by controlling rhythmic contraction



* The shuttle flow induces the tubular structure along the flow direction

Possible effects of shuttle flow on tubes

* skeleton of tubular structure: regular orientation of actomyosin filaments
(longitudinal orientation in young tube, hoop-like in old tube)
* stretch activation effects:
induction of filament orientation by artificial stretching



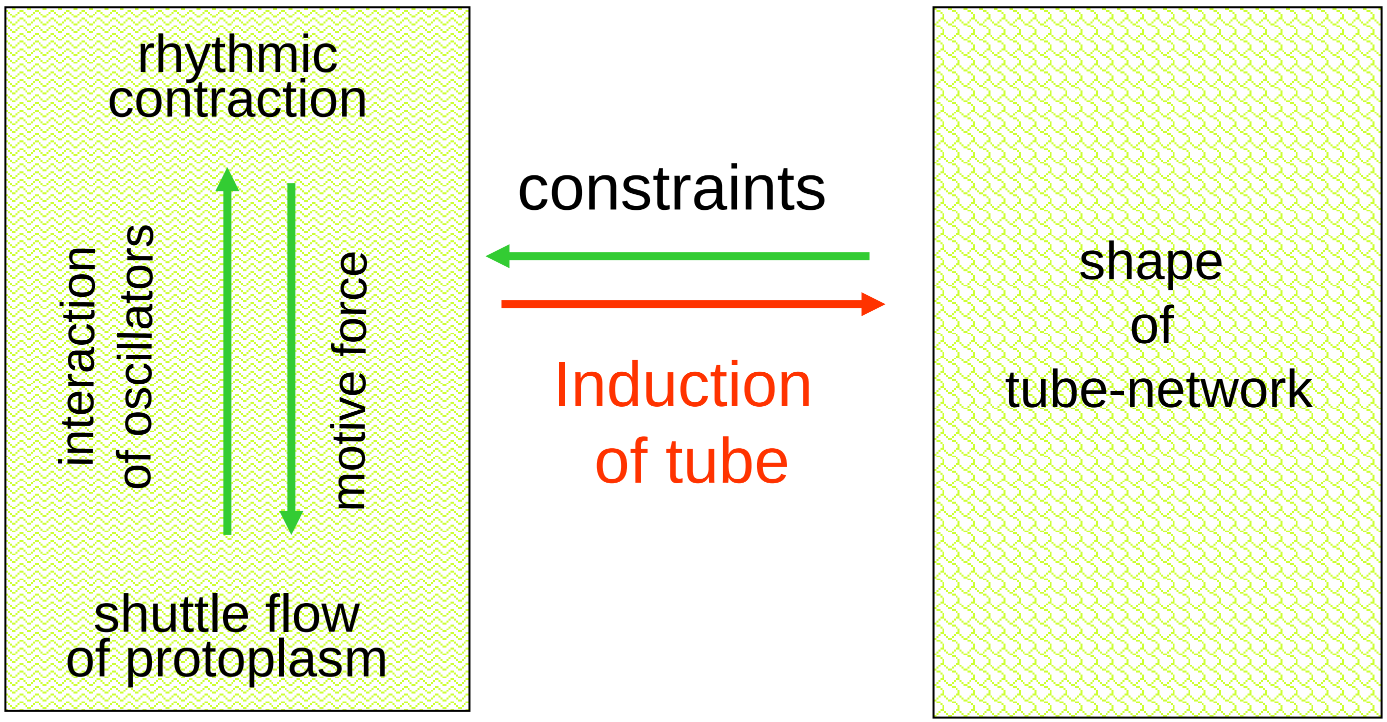
Is this stretching force inside the organism ?

* shear stress of viscous flow at tube wall : longitudinal orientation
* expansion of tube wall by internal pressure : hoop-like orientation

protoplasmic shuttle streaming → stretching effects →
orientation of filaments → tubular structure

Outline of tube formation viewed from contraction pattern

Plasmodium: collection of biochemical oscillators



Food stimulation: local changes in oscillation frequency and stiffness of cell elasticity

Mathematical modeling for pattern of shuttle flow

There are different two lines of understanding
the cell behaviors, based on:

* interaction by visco-elastic property of sol-gel fluid
* oscillatory biochemical reaction with active flow

Required task is to combine these two lines.

DRY model & WET model:
Coupled oscillator model with
mass conservation and visco-elastic interaction

Conclusion

The thick tube is smart !