Challenges in multicellularity solvable with studies of social amoebae

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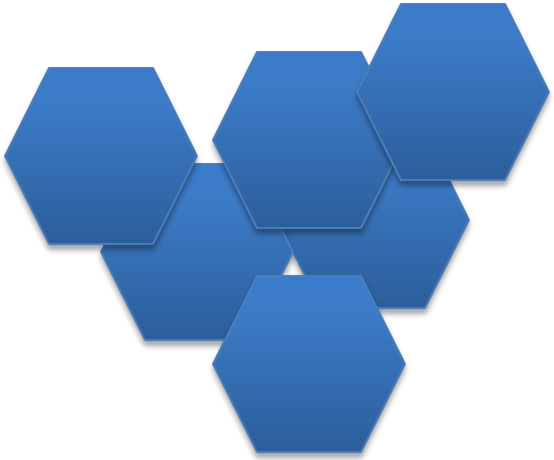
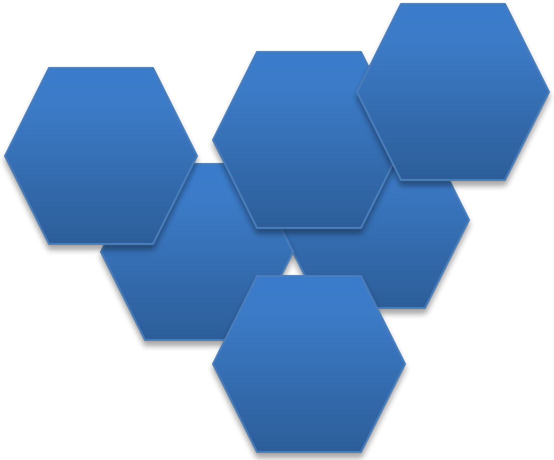
sociobiology.wordpress.com

What are the challenges in multicellularity?

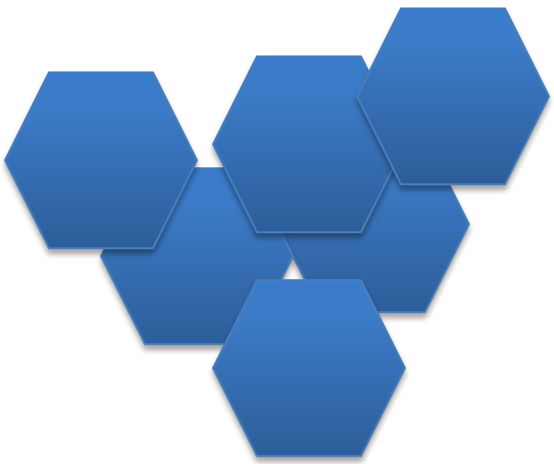


1. What is multicellularity?

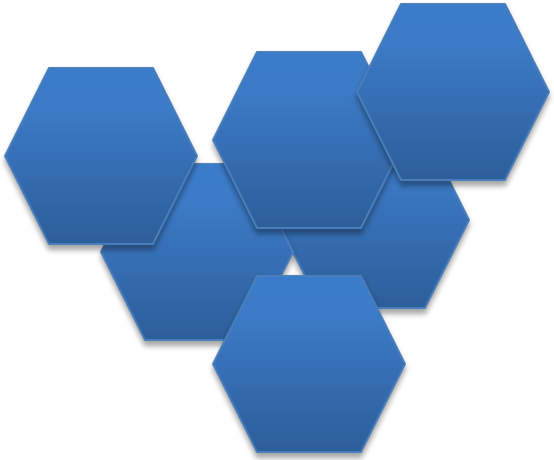


1. What is multicellularity?

A multicellular organism is made up of multiple cells.

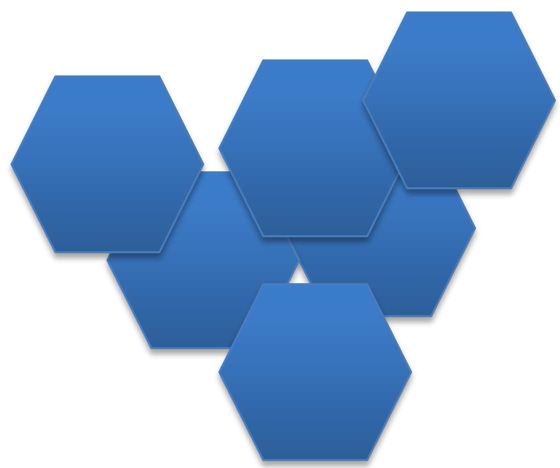


2. What characterizes the cells in a multicellular organism?

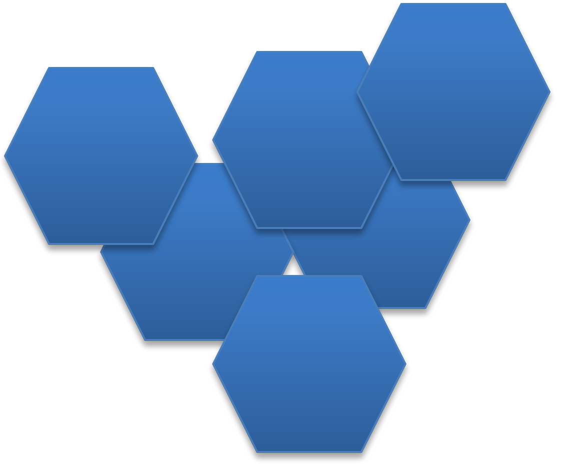


2. What characterizes the cells in a multicellular organism?

The cells are alike, at least originally, from the same species, typically the same genetic individual.

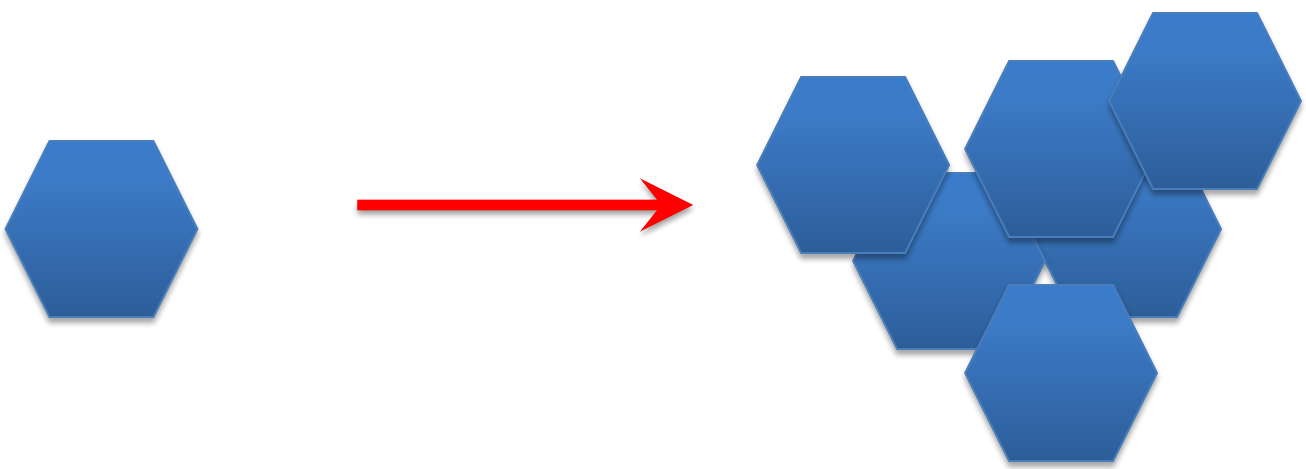


3. How did multicellularity arise?



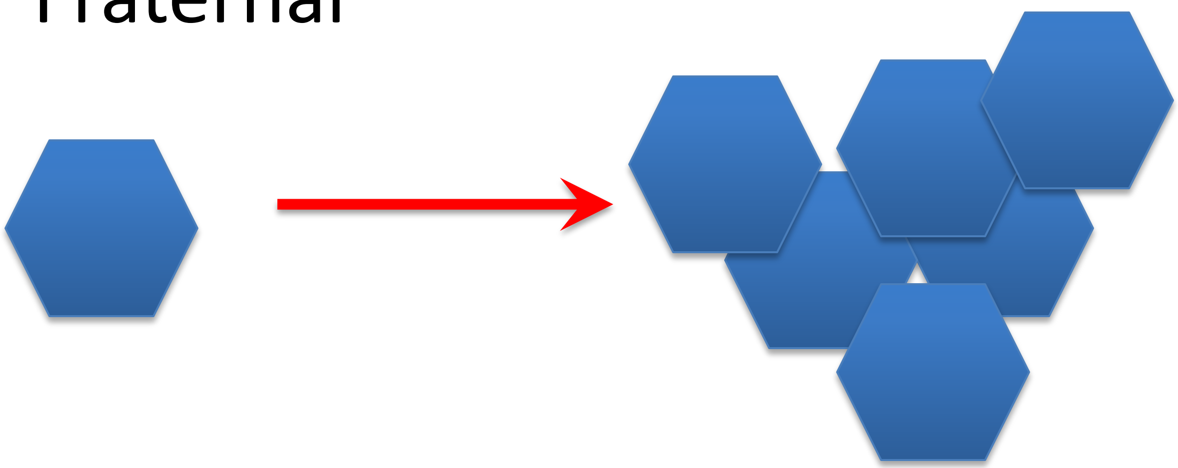
3. How did multicellularity arise?

Usually from a single cell, as a fraternal major transition (Queller 1997).



3. What are the two kinds of major transitions?

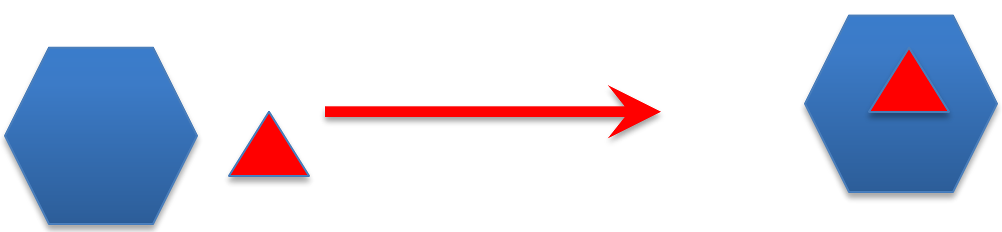
- Fraternal



Units:

Like, fungible

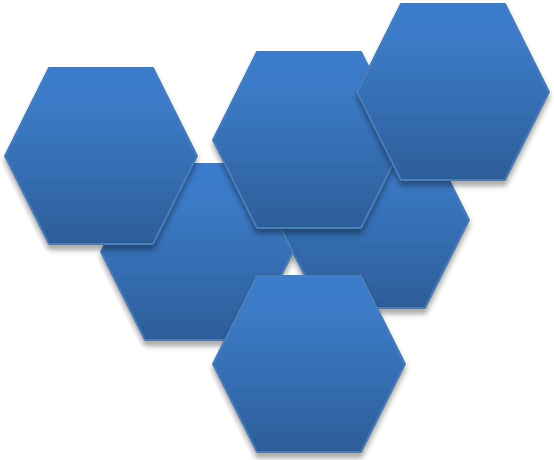
- Egalitarian



Unlike, non-fungible

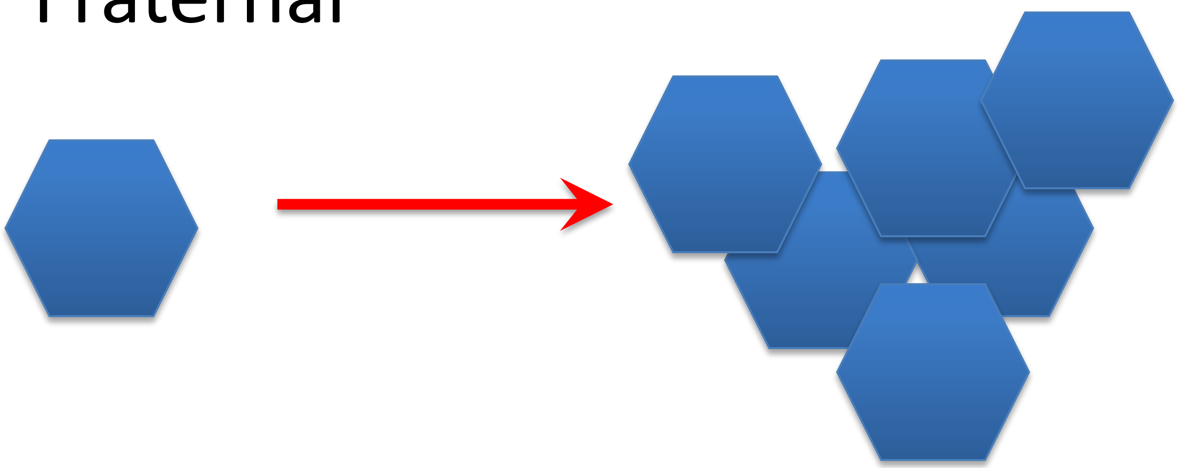
Queller 1997, *Quarterly Rev. Biol. 72:184 – 188*

4. Why did multicellularity arise?



4. What are the advantages to the two kinds of major transitions?

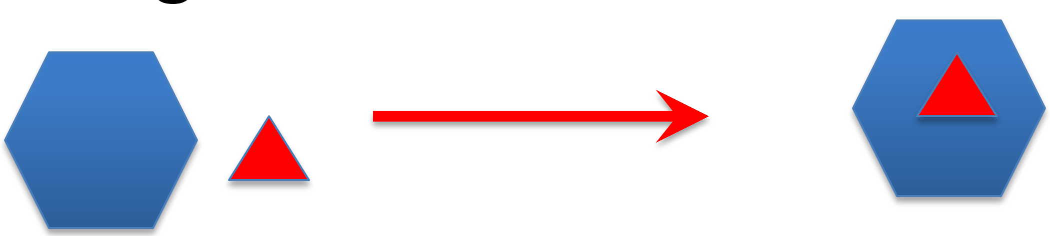
- Fraternal



Initial advantage:

Size, economy of scale; later division of labor

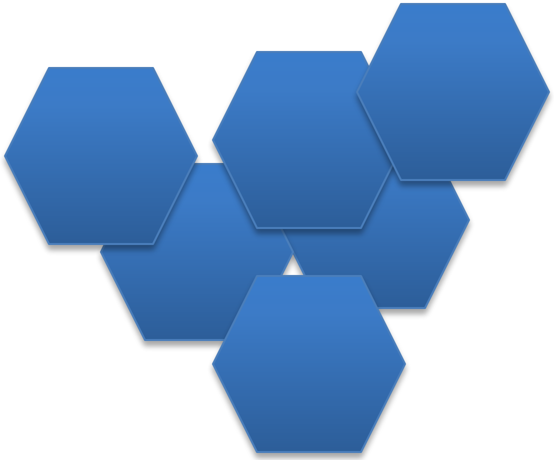
- Egalitarian



Division of labor; combination of function

Queller 1997, *Quarterly Rev. Biol. 72:184 – 188*

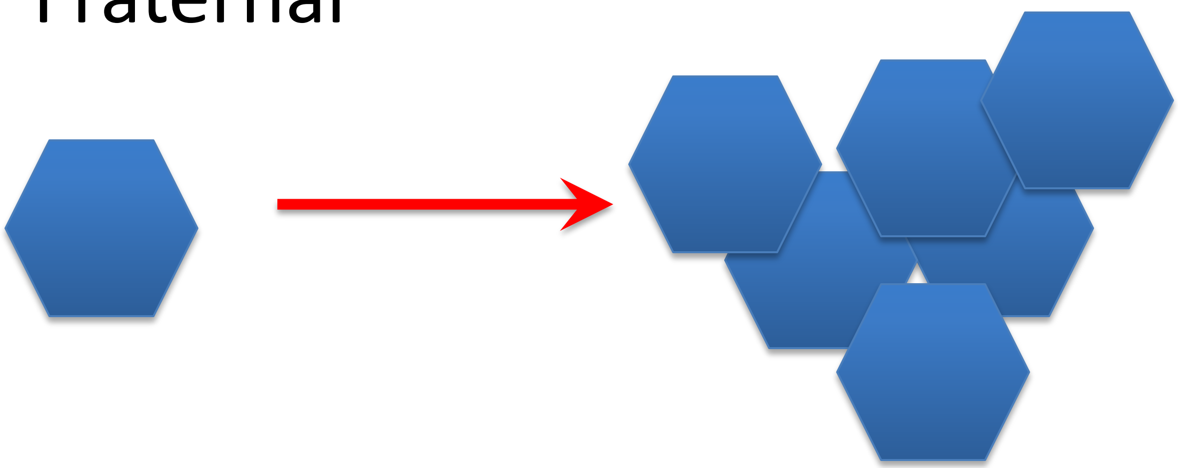
5. How are conflicts within a multicellular organism controlled?



5. How are conflicts controlled in the the two kinds of major transitions?

Control of conflict:

- Fraternal



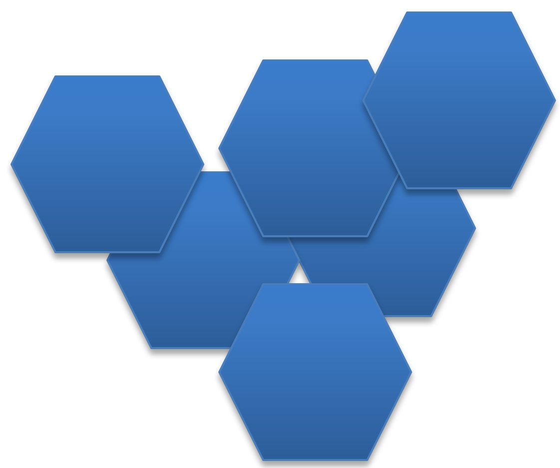
kinship

- Egalitarian

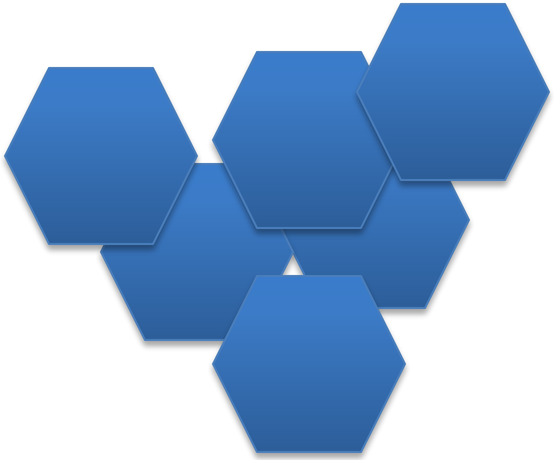
Reproductive fairness
Mutual dependence

Queller 1997, *Quarterly Rev. Biol. 72:184 – 188*

6. How do the larger bodies that result from multicellularity manange nutrient transfer, waste removal, defense, reproduction, etc.?



What is NOT a multicellular organism?



What is NOT a multicellular organism?

Most biofilms

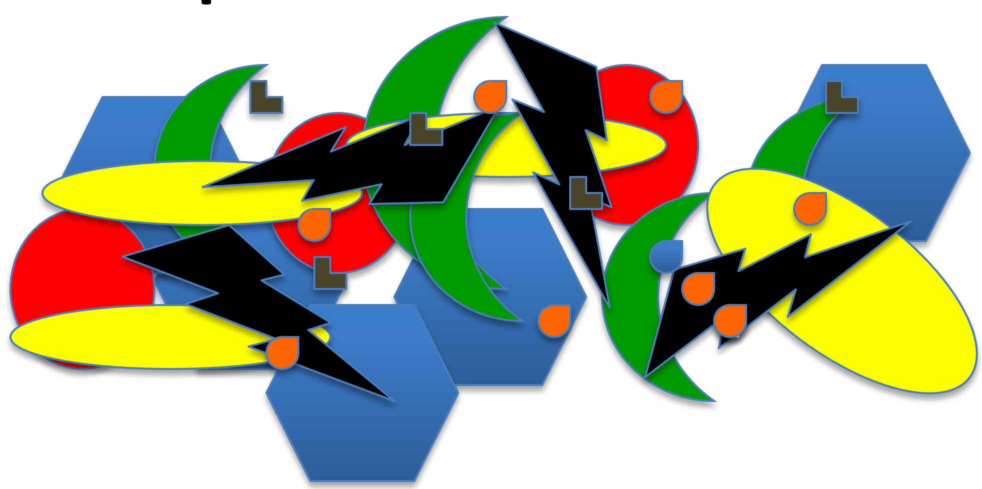
Why not?

Made up of multiple species

Not inherited together

No shared interests

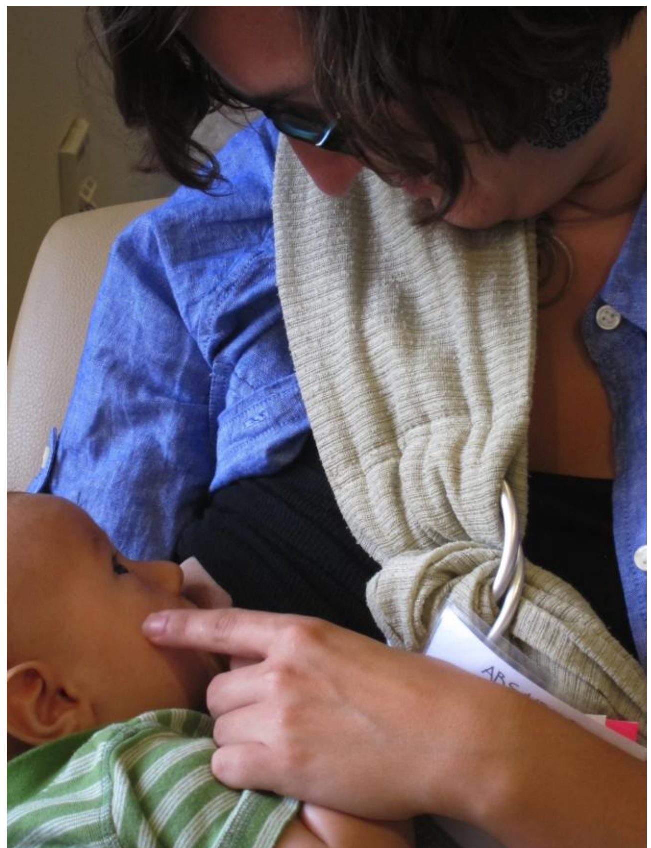
No cooperative evolution



What if biofilms were vertebrate communities?

Photo credit: Chin Tintin:CC Copyright, Wikimedia

Are interactions like a mother nursing her child?



Are interactions like two male springbok fighting?

Photo credit: Siedepiem, Wikimedia

Are interactions like a farmer and his herd?

Photo credit: Julio Postigo

Are interactions like a lioness killing water buffalo?

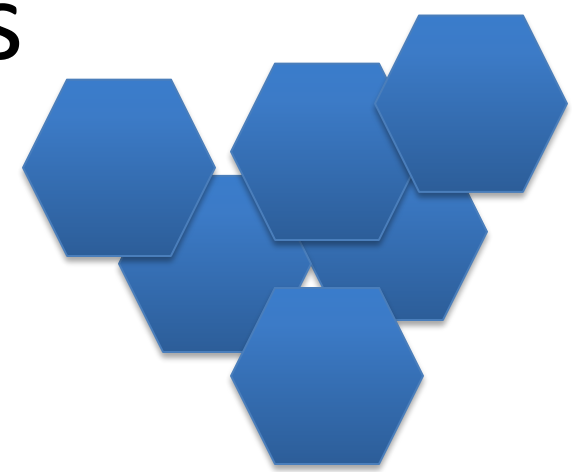
Photo credit: Corinata, Wikimedia

Before we can understand microbial communities, we need to distinguish these and many other kinds of interactions, for they are very different, and are certainly not multicellular organisms.

Photo credit: Corinata, Wikimedia

What is the best group of organisms for studying multicellularity?

What are the challenges in multicellularity?



1. Multiple cells
2. Like cells
3. High relatedness
4. Advantages of size, division of labor
5. Conflict is controlled
6. Physiological, developmental issues

What is the best group of organisms for studying multicellularity?

- Volvocine algae if you are interested in division of labor and multiple cell types.

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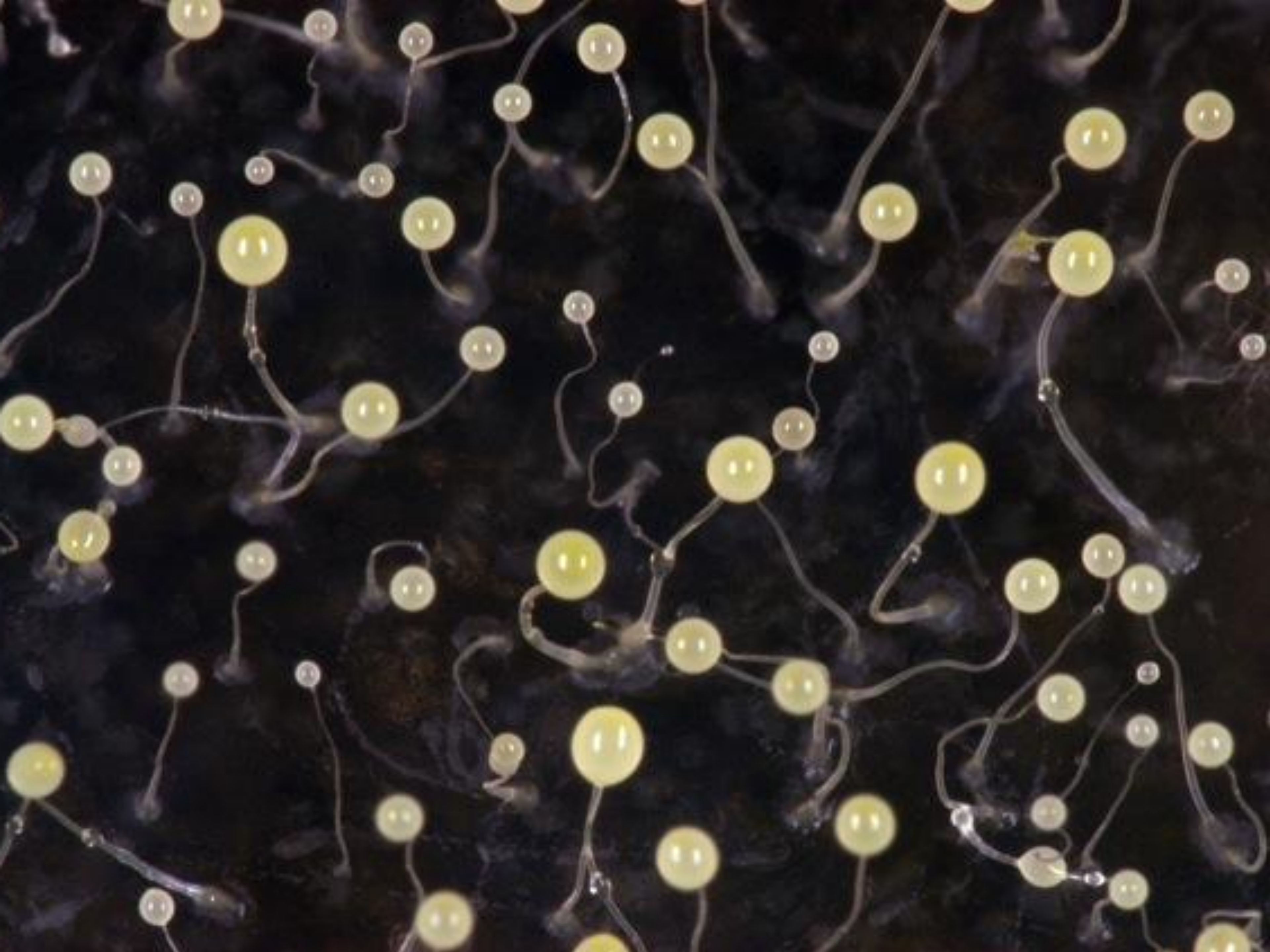
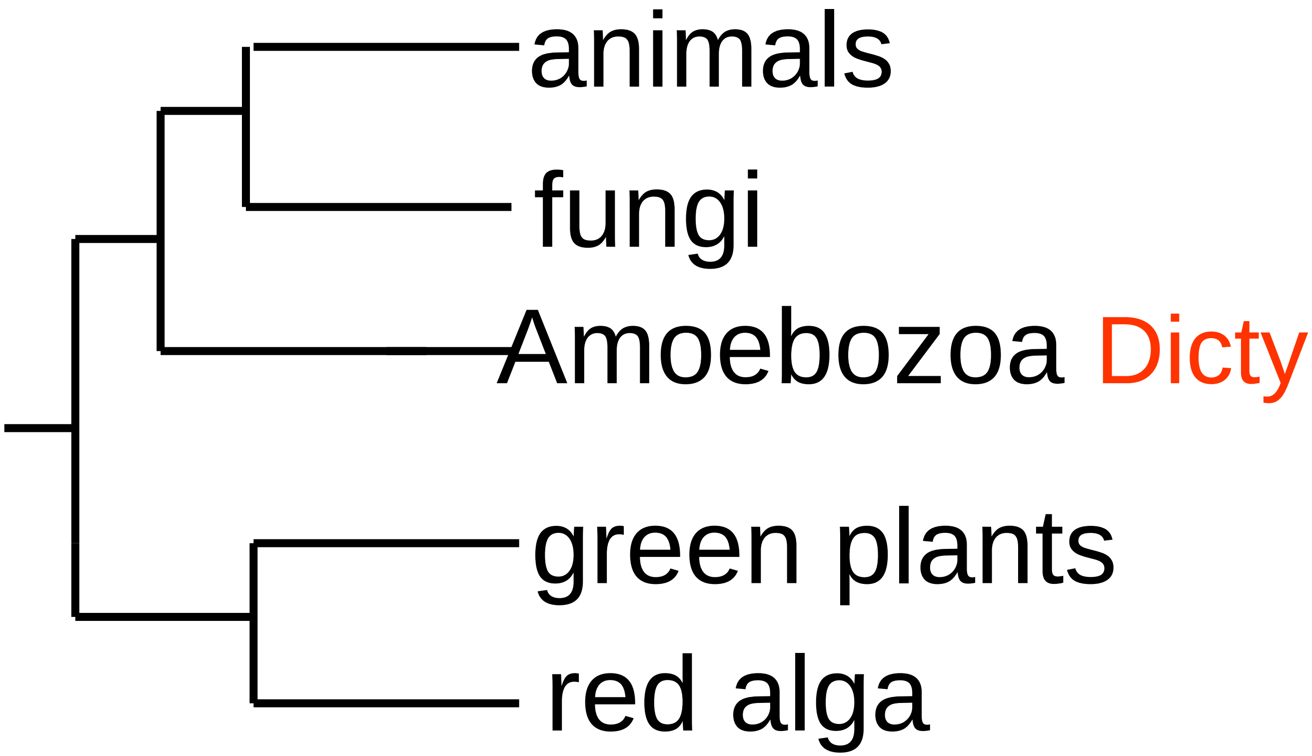
- Dictyostelid social amoebae if you are interested in conflict and the path not taken, lacking a single cell bottleneck.

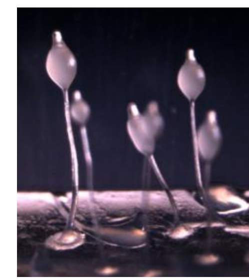
What is the best group of organisms for studying multicellularity?

- Volvocine algae if you are interested in division of labor and multiple cell types.
- Dictyostilid social amoebae if you are interested in conflict and the path not taken, lacking a single cell bottleneck.
- Your favorite organism…but say why it's good.



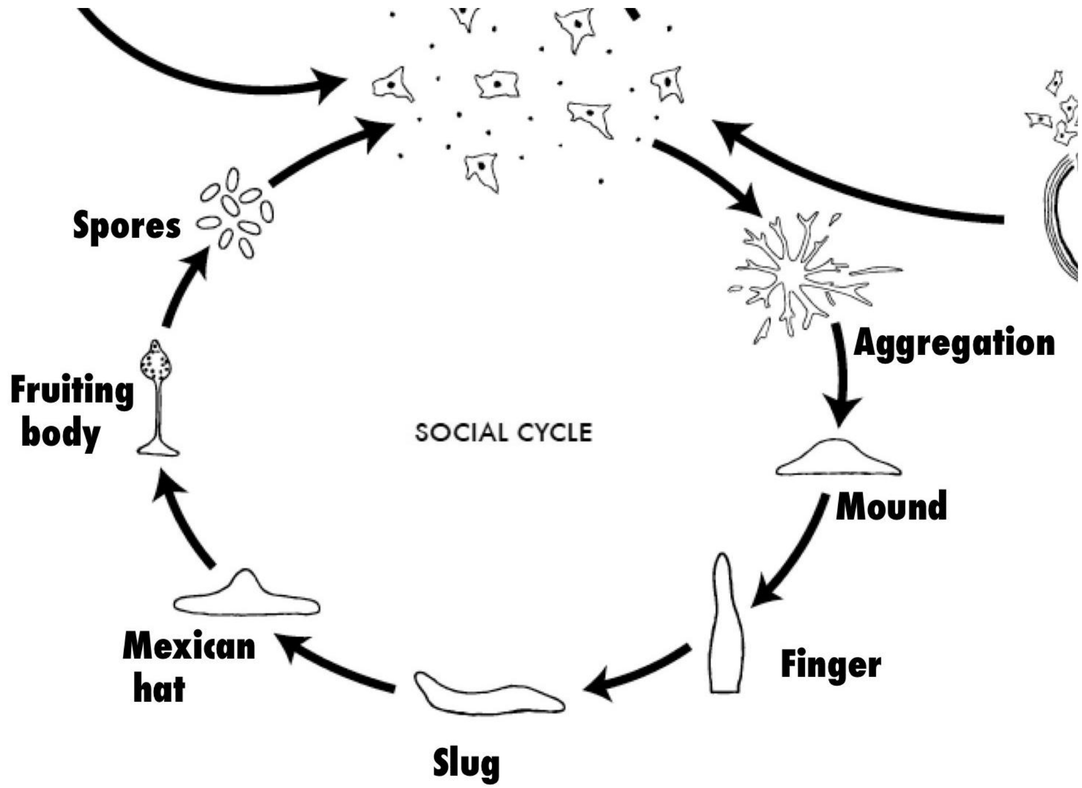
What are these social amoebae?



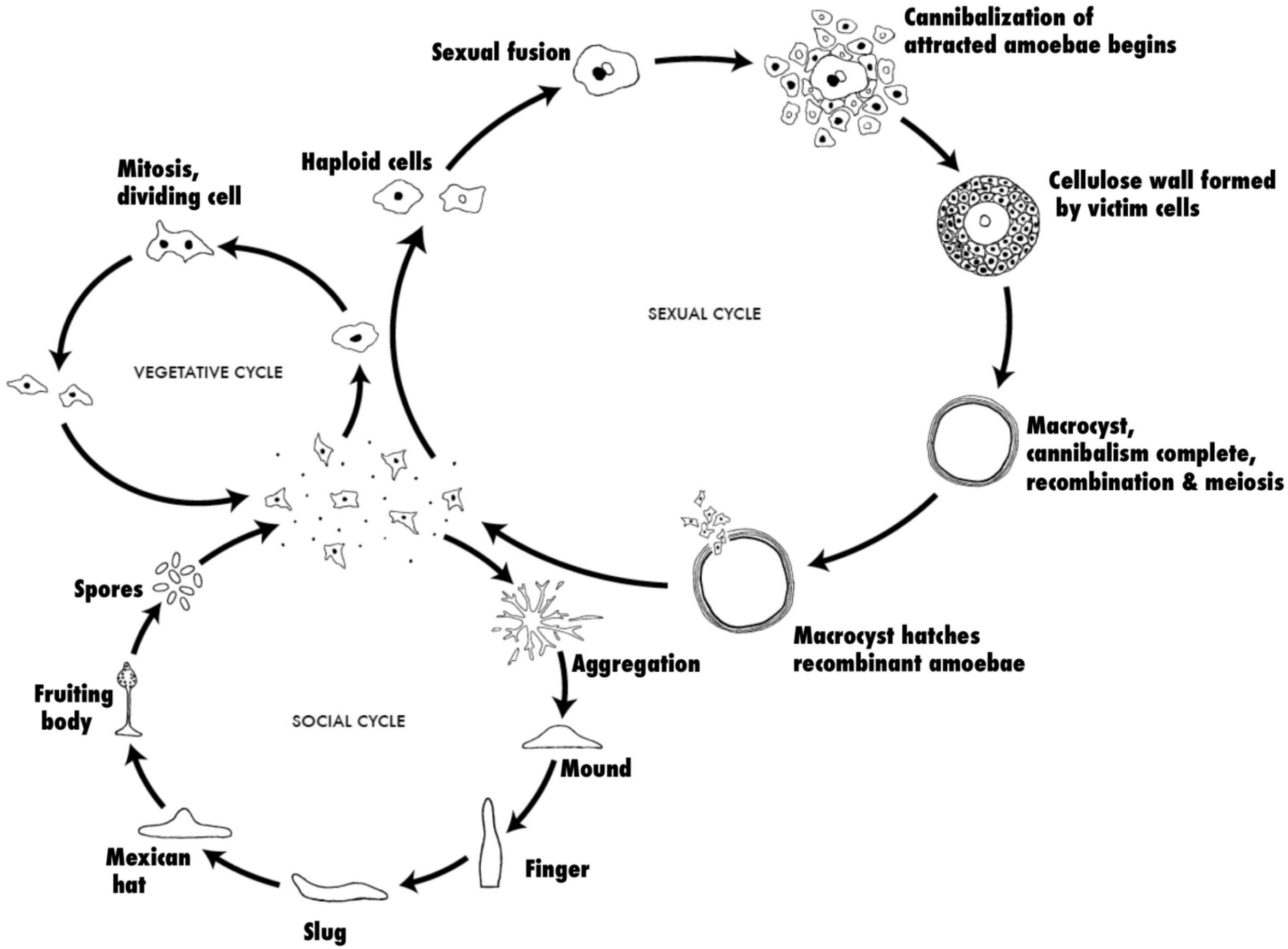


Phylogeny based on EF-1alpha, also supported by actin, beta-tubulin and other sequences (Baldauf et al. 2000)

In the social life cycle of *D. discoideum,* the haploid cells form a motile aggregation, then a fruiting body, with no or little change in cell number. About 20% of cells die to lift the spores.



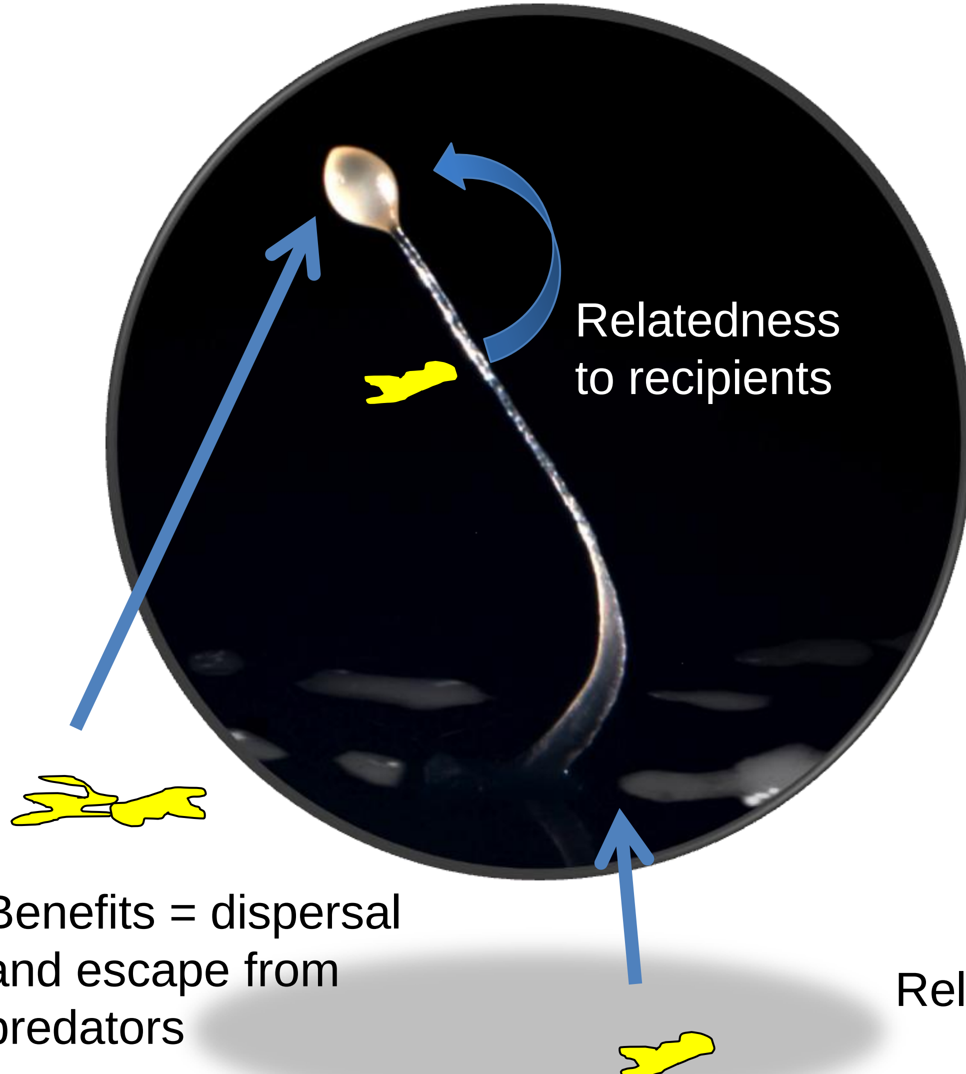
The life cycles of *Dictyostelium discoideum*



Kin selection

- Hamilton's Rule:
- rb - c > 0
- b is fitness benefit,
- c is fitness cost
- r is relatedness to beneficiary

Altruism can be maintained when:



Benefits = dispersal and escape from predators

Cost to actor = death

$$R\ B > C$$

Relatedness to recipient(s)

Benefit to recipient(s)

Cost to actor

Hamilton (1964) J. Theor. Bio.

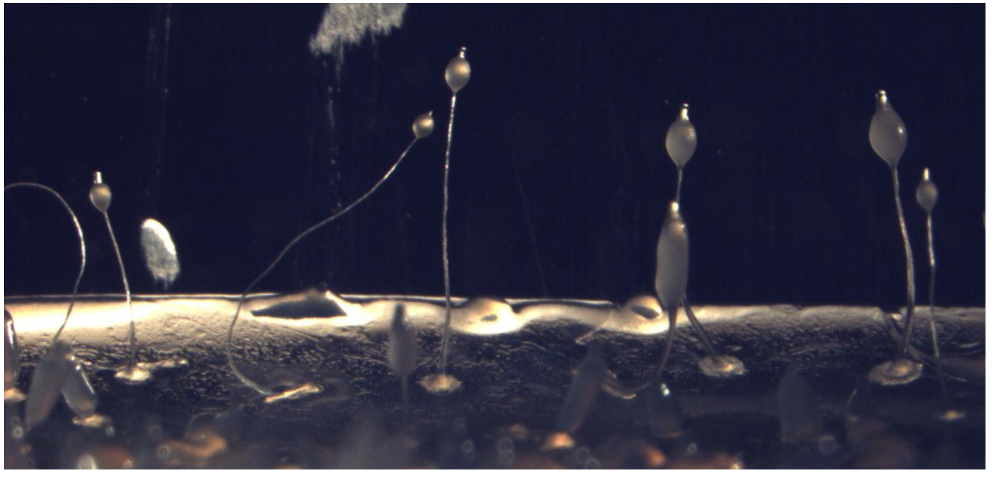
Fitness benefits R **B** > C

a. Rise above soil, facilitating dispersal

b. Migrate farther (Foster et al. 2002)

c. Seed new resources (Kuzdzal-Fick et al. 2007)

d. Make better spores



R B > C

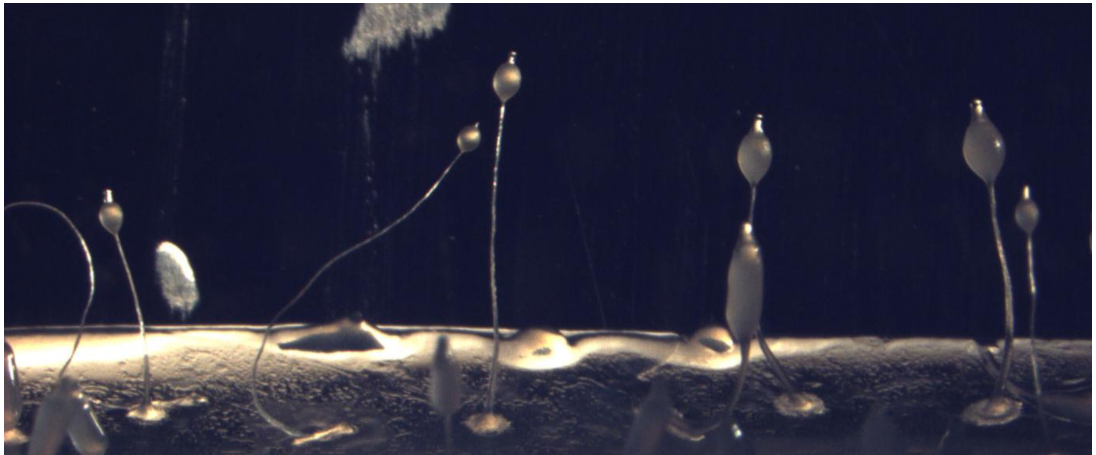
Fitness costs

a. Death in stalk (Strassmann et al. 2000)

b. Conflict in chimeras because group initiators become spore (Kuzdzal-Fick et al. 2010)

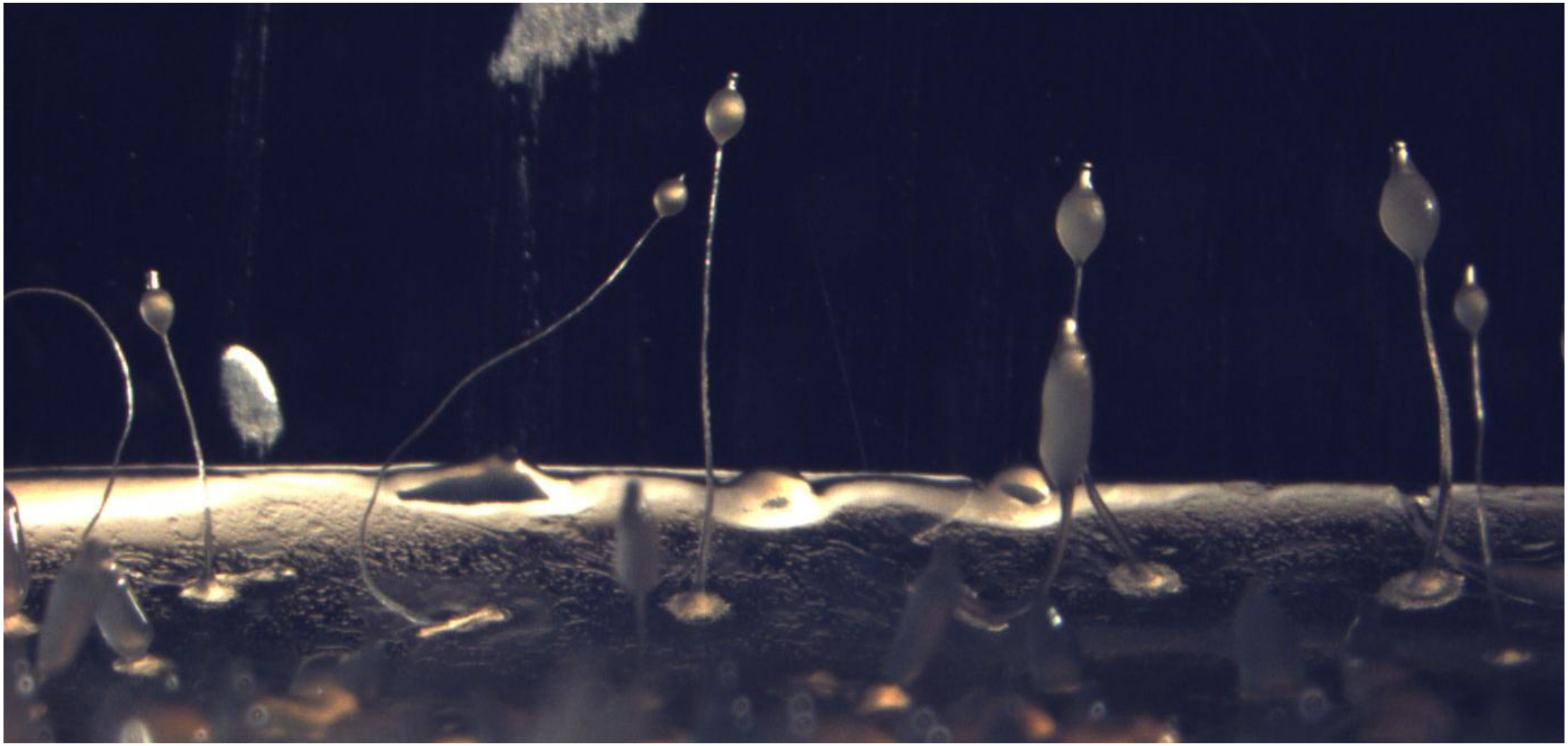
c. Conflict in chimeras inhibits mobility (Foster et al. 2002)

d. Chimeras make shorter stalks (Buttery et al. 2009).

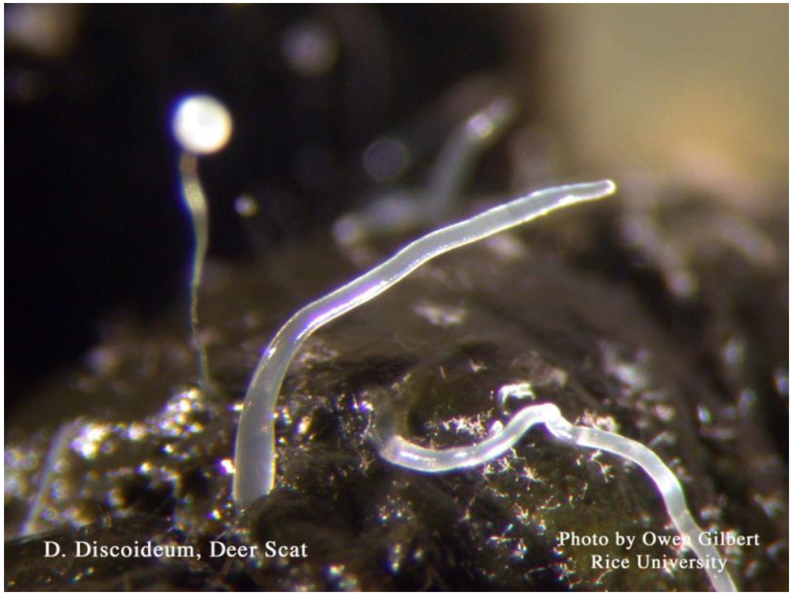


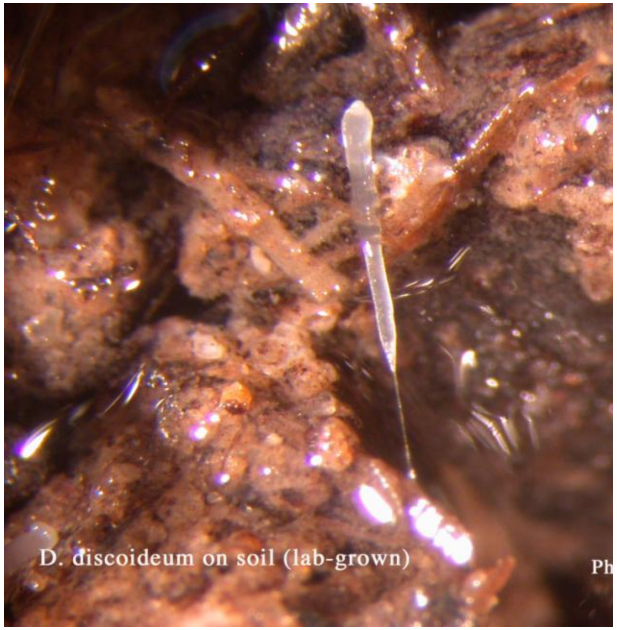
What is relatedness within social groups?

R B > C



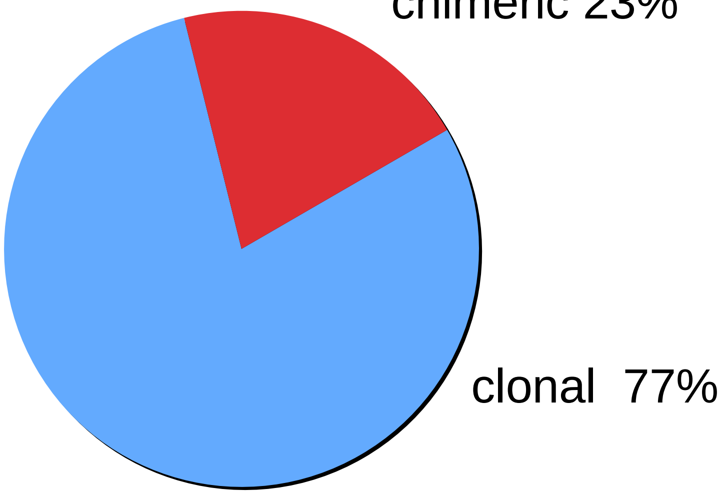
2. What is relatedness in wild fruiting bodies?





Relatedness in wild fruiting bodies is high, but they are not always clonal, so we predict conflict to become spore, not stalk

n = 88 fruiting bodies from 25 dung piles

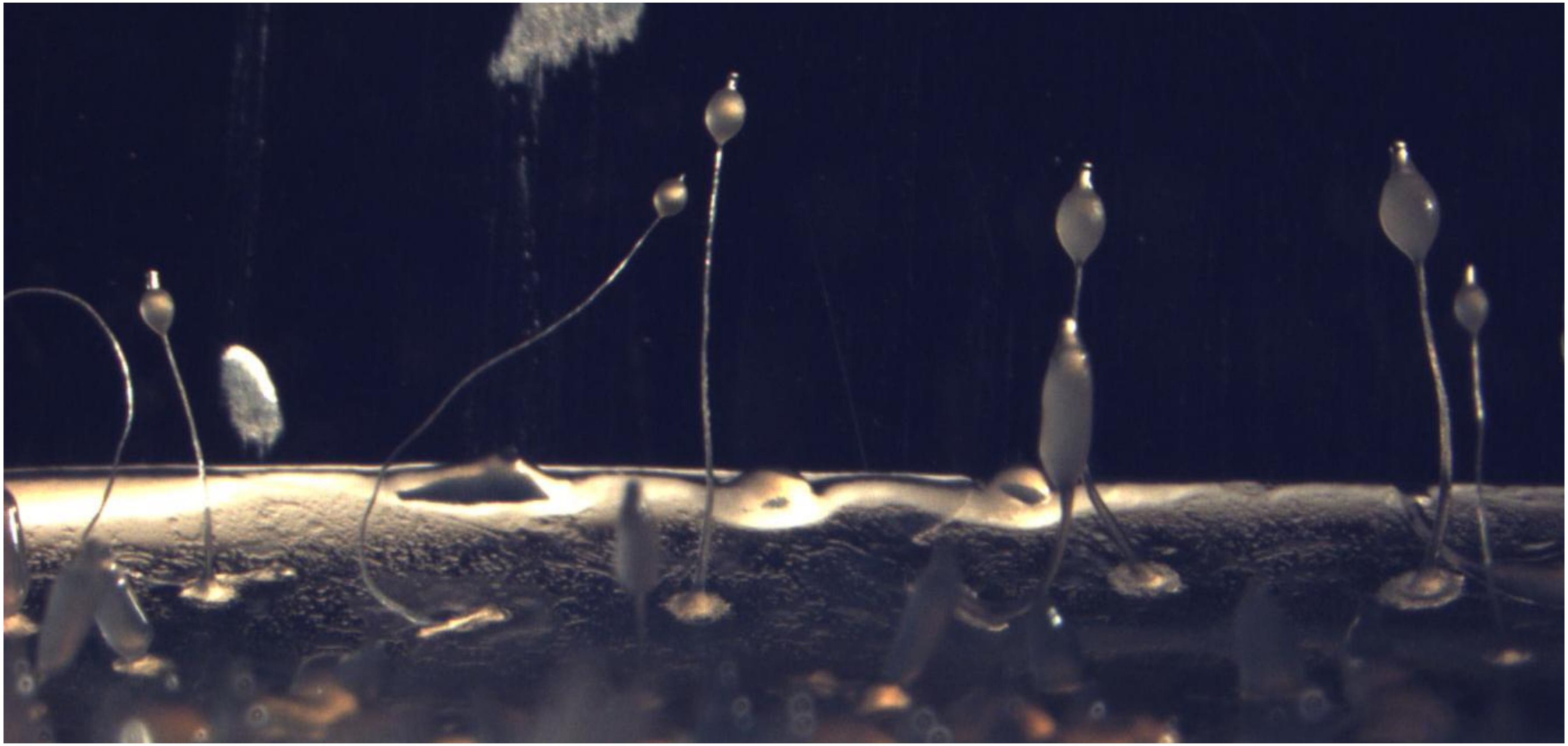


r > 0.86

Gilbert et al. PNAS 2007

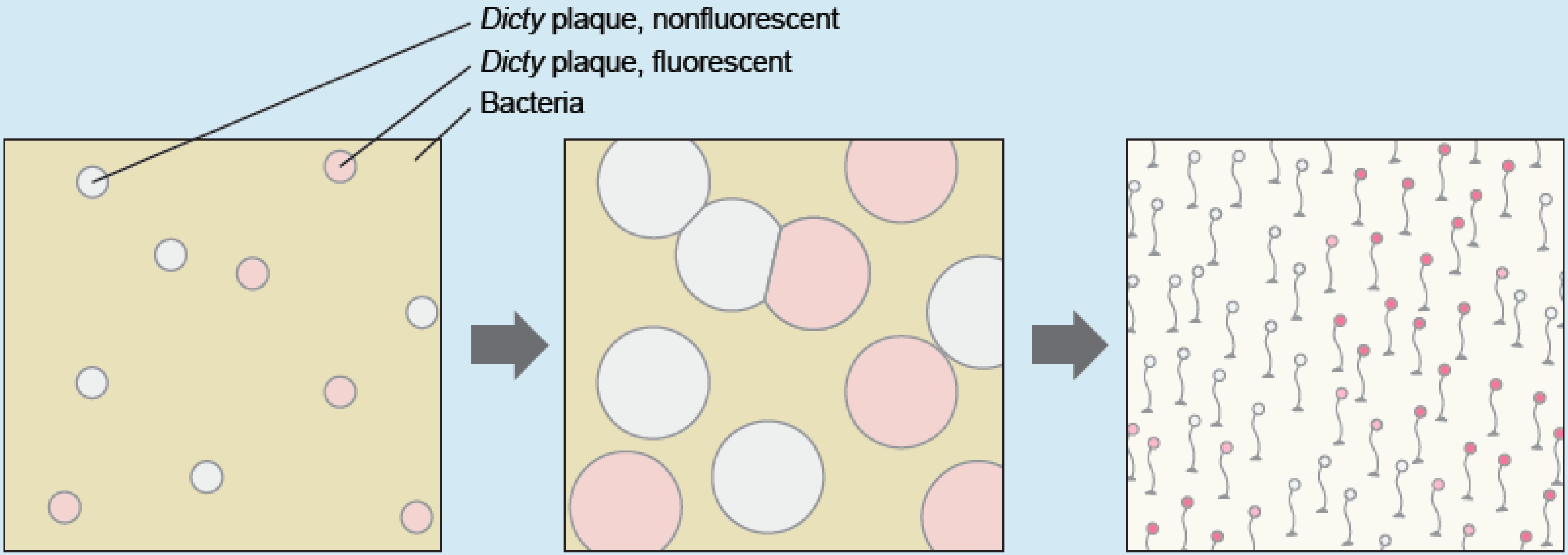
How do we get high relatedness?

R B > C

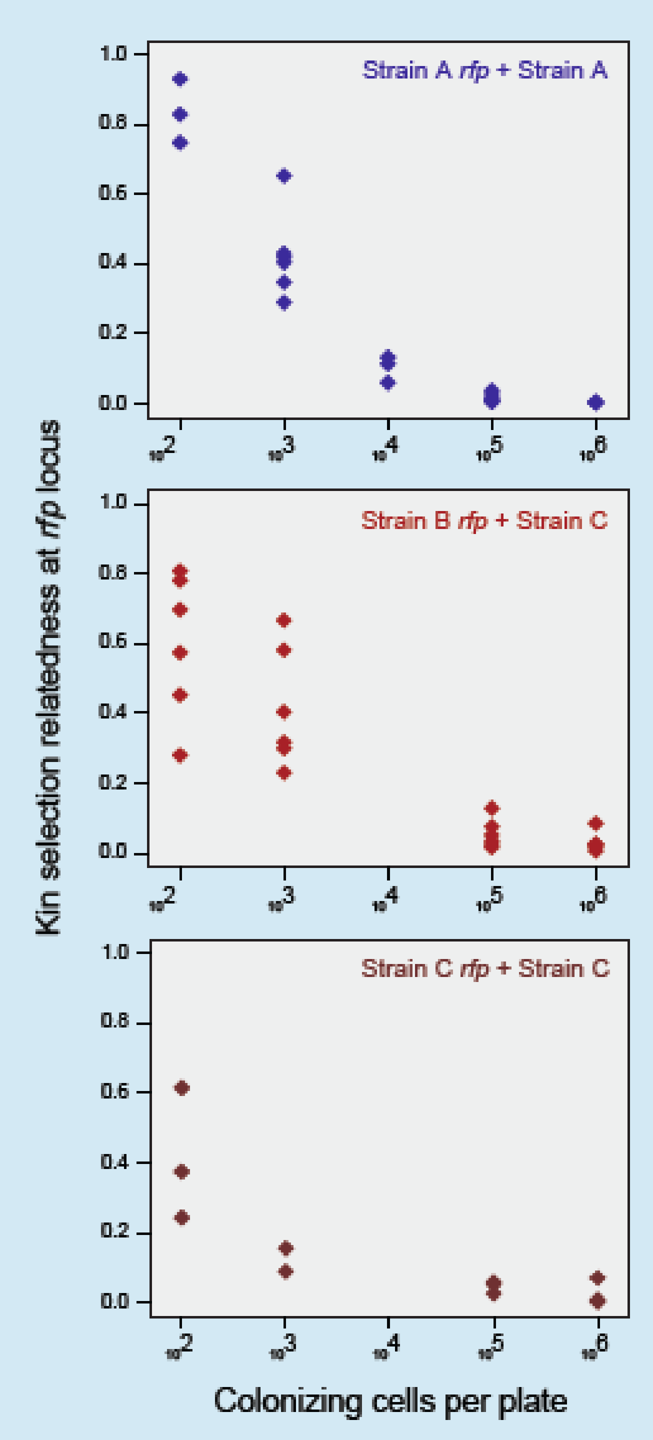


1. Increased relatedness with sparse density.

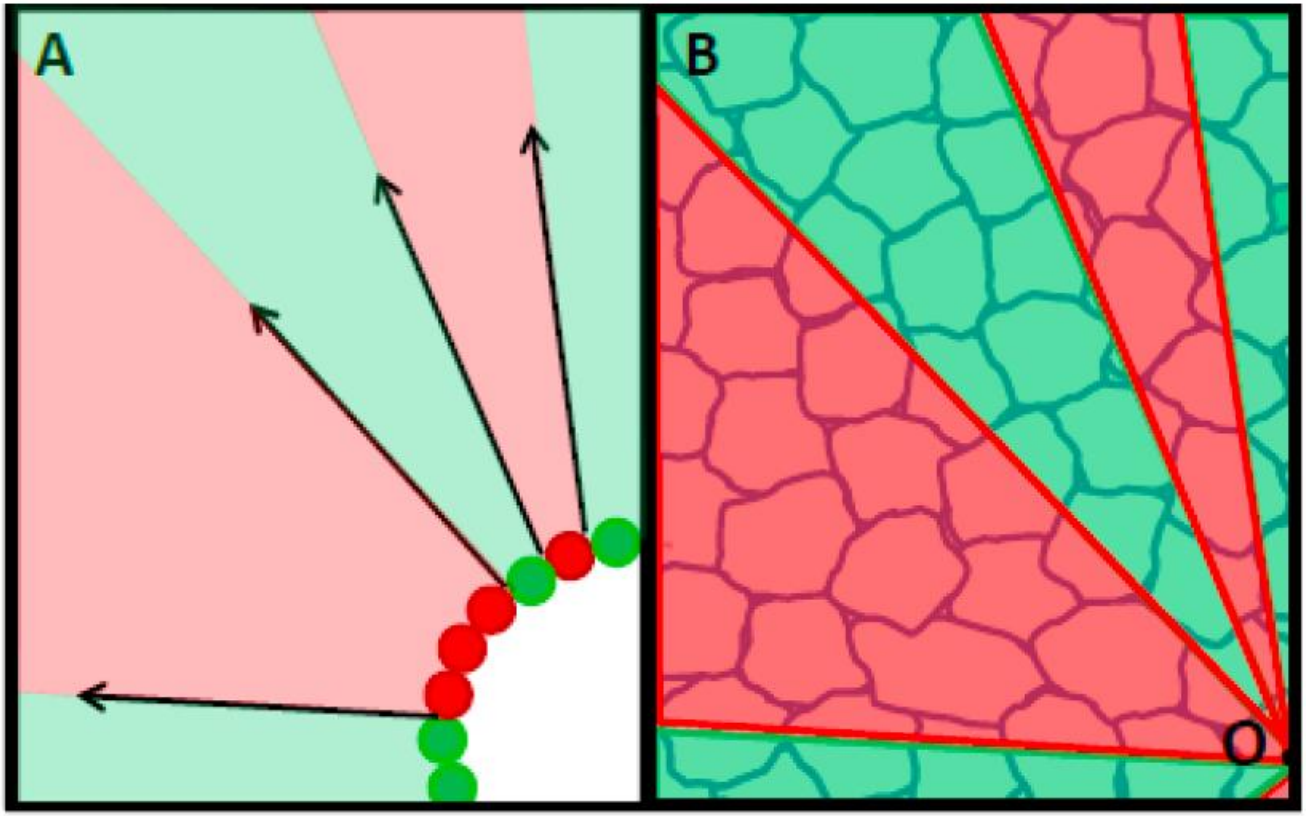
jeff smith



Elevated relatedness if density is low

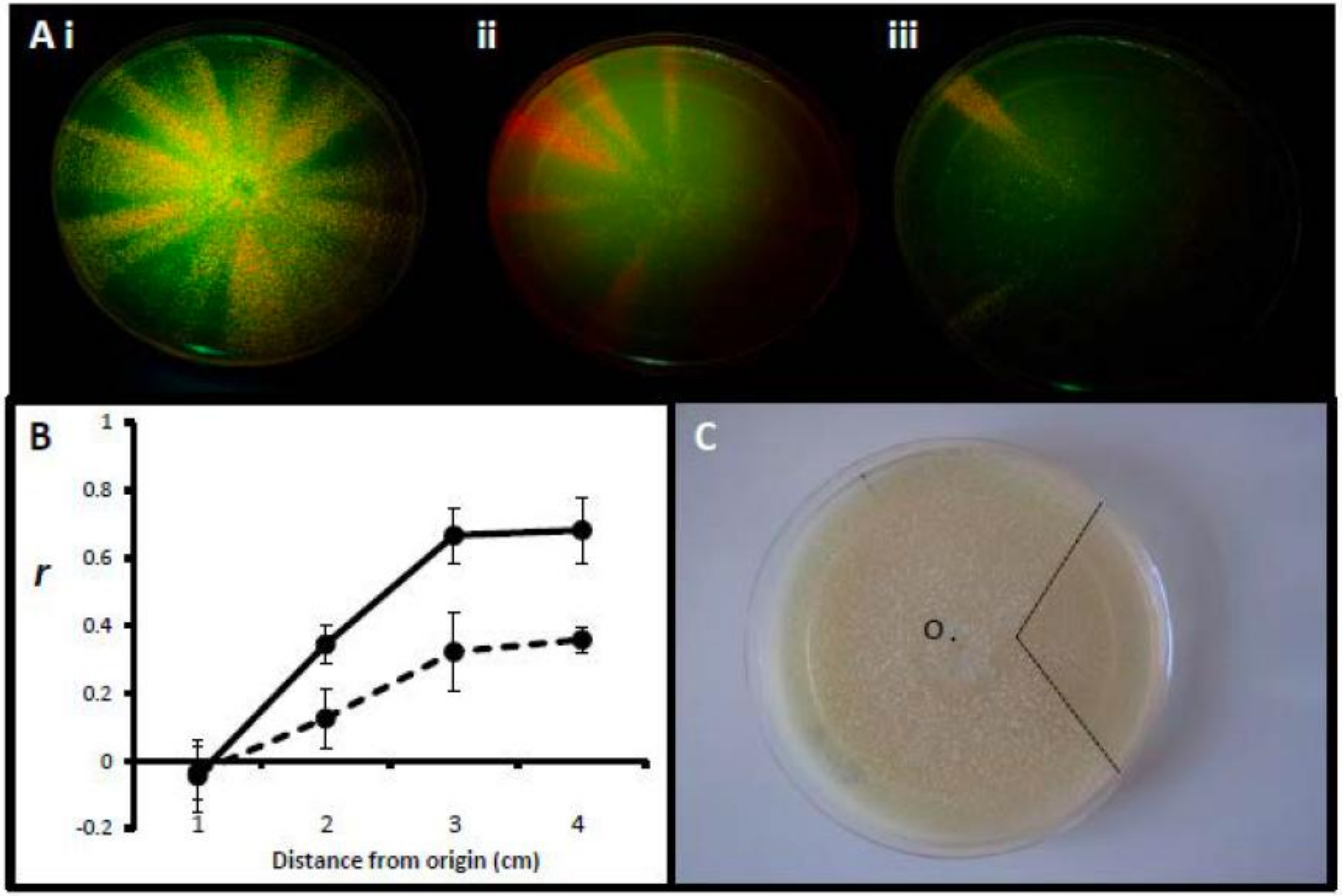


2. Increased relatedness from drift through growth.



Buttery et al. *Biology Letters* 2012

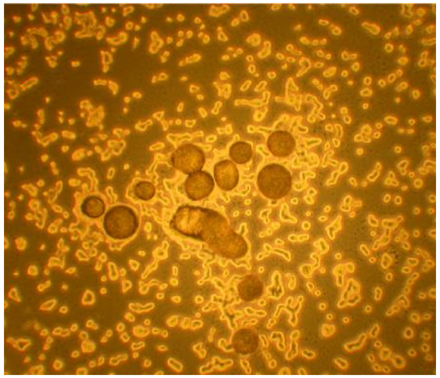
Relatedness increases away from center

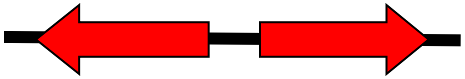


Buttery et al. 2012

3. Increased relatedness through kin recognition, based on *tgrC, tgrB*

- Plasma membrane localization
- Multiple Ig-fold domains
- tgrC knockout: cells come together, then fall apart
- Co-expression in development with tgrB





Adam Kuspa

Gad Shaulsky

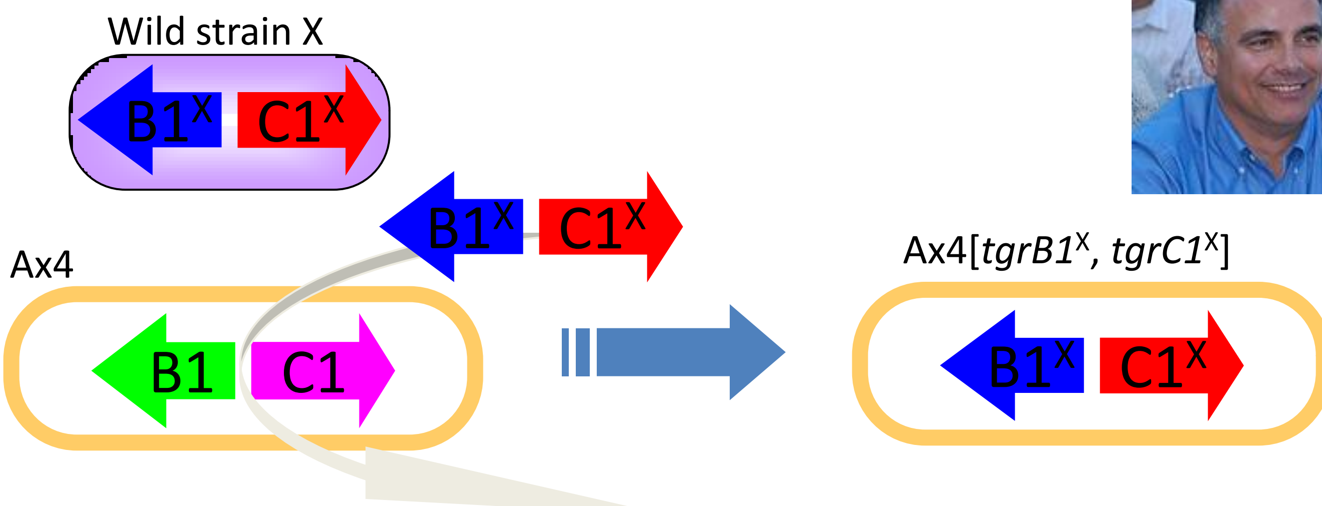
Benabentos et al., 2009 Current Biol. 19(7):567-72.

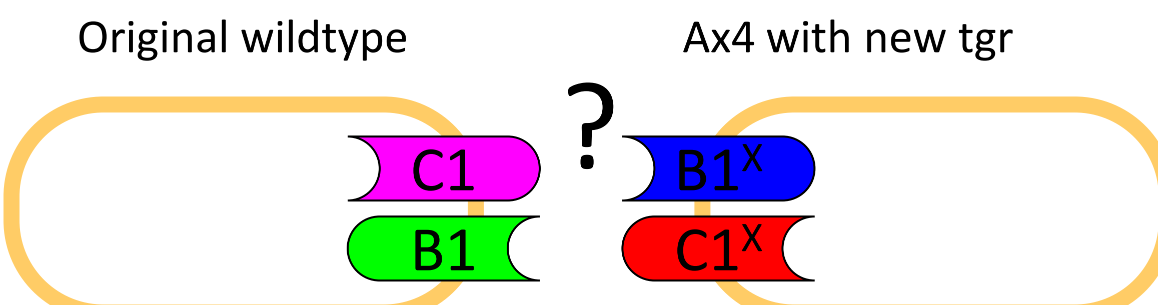
Gene replacements show power of tiger genes

Generate *tgr* gene replacement strains in a common genetic background.
If one of the strains recognize parental Ax4 as non-self. The gene(s) is(are) the recognition molecule(s).

Adam Kuspa

Gad Shaulsky



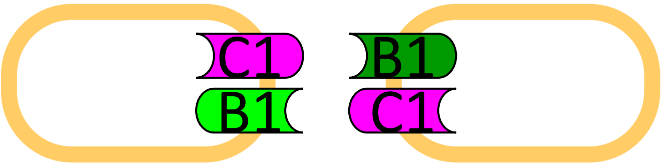


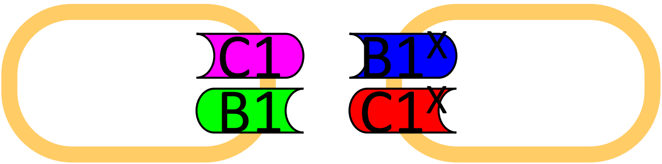
Shigenori et al.
Science, 2011

Red and green the same clone

Red differs from green only at *tgrB and tgrC*

- Video shows sorting with *tgrB* and *tgrC* differences only.

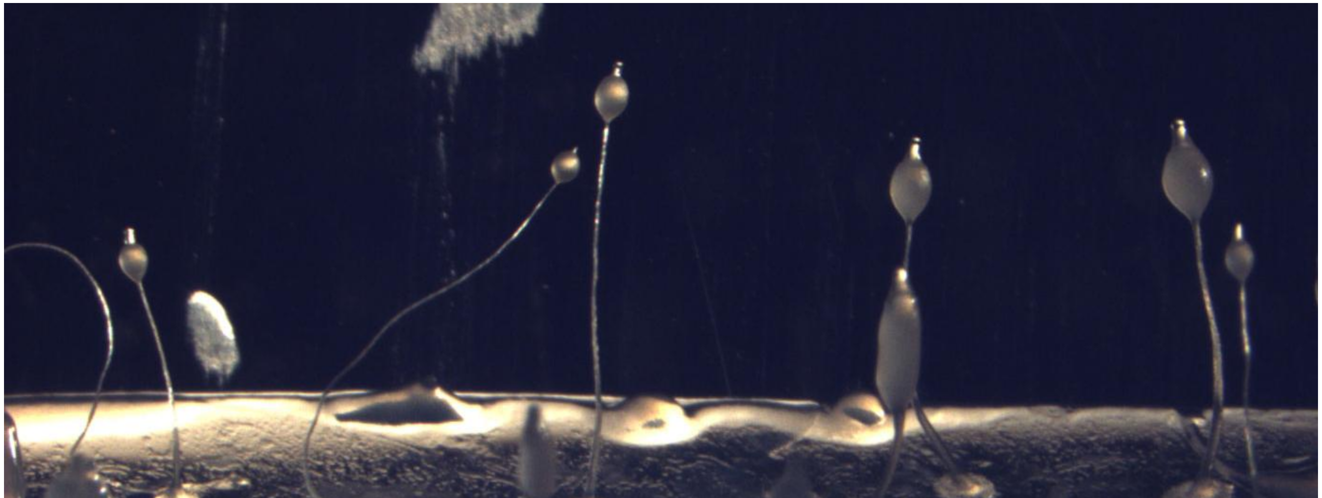




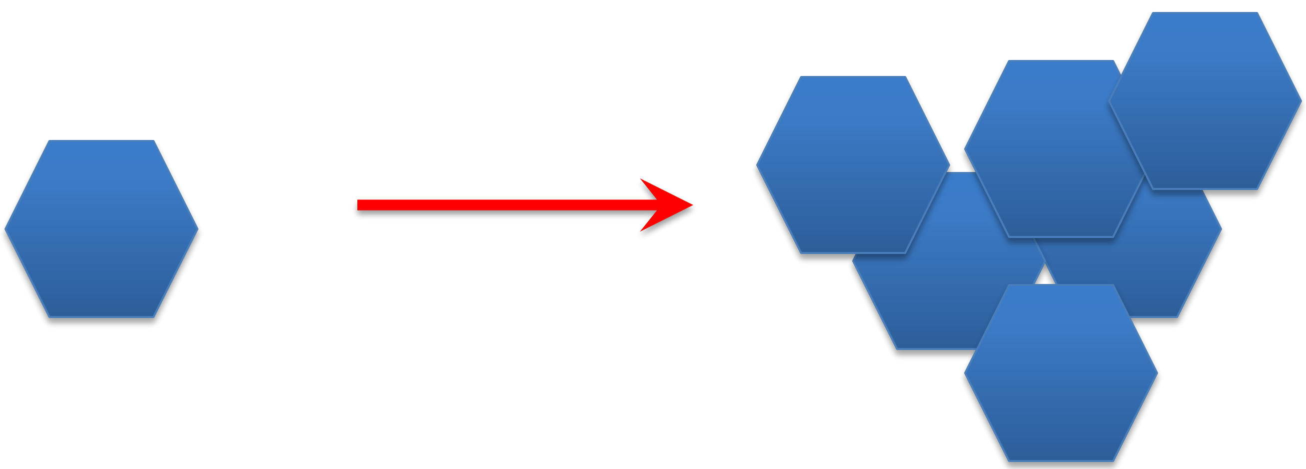
R B > C

Causes of elevated relatedness

1. Sparse occurrence
2. Drift during proliferation
3. Kin recognition

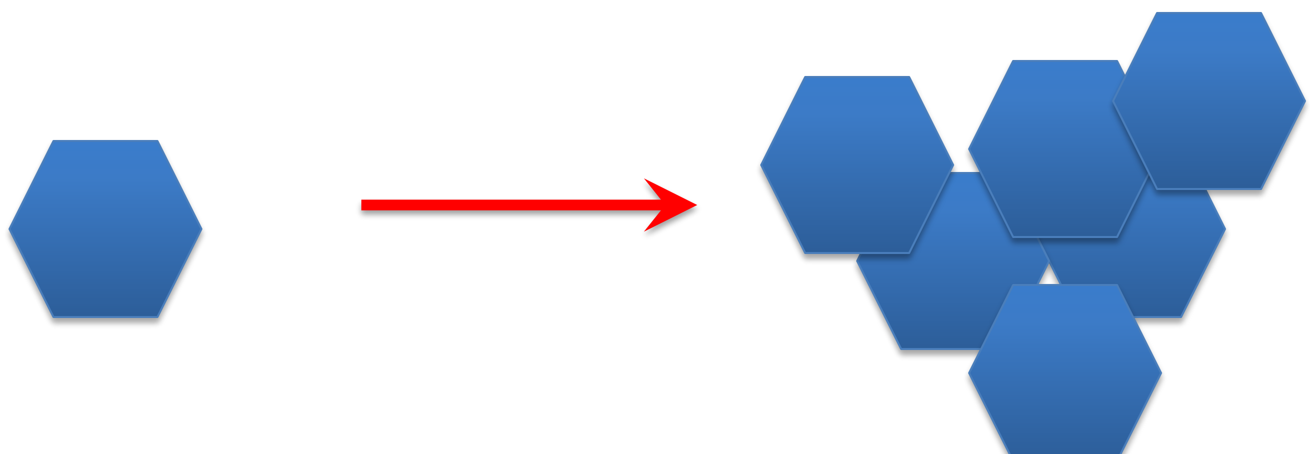


Relatedness is high, but not as high as if they went through a single cell bottleneck the way most multicellular organisms did.

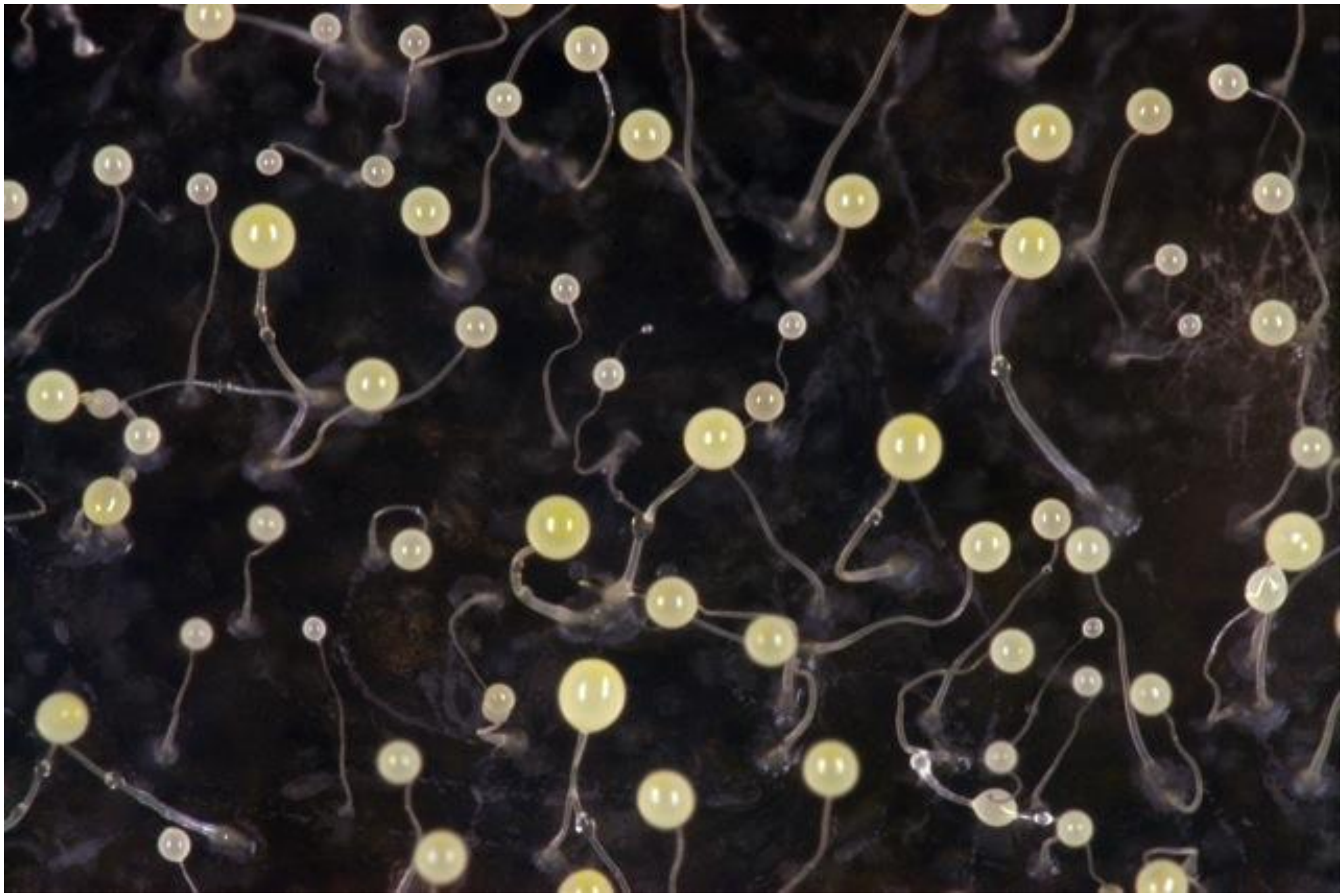


Relatedness is high, but not as high as if they went through a single cell bottleneck the way most multicellular organisms did.

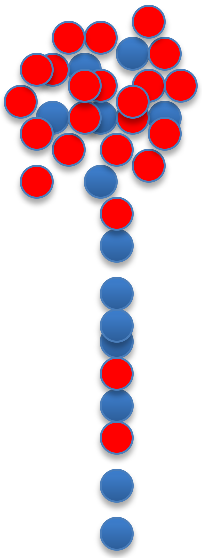
Morphological innovation may therefore be constrained.



We've shown relatedness in the social stage is high, and we have shown how they achieve high relatedness. But is high relatedness in the social stage really so important?



Will low relatedness select for increased cheating?

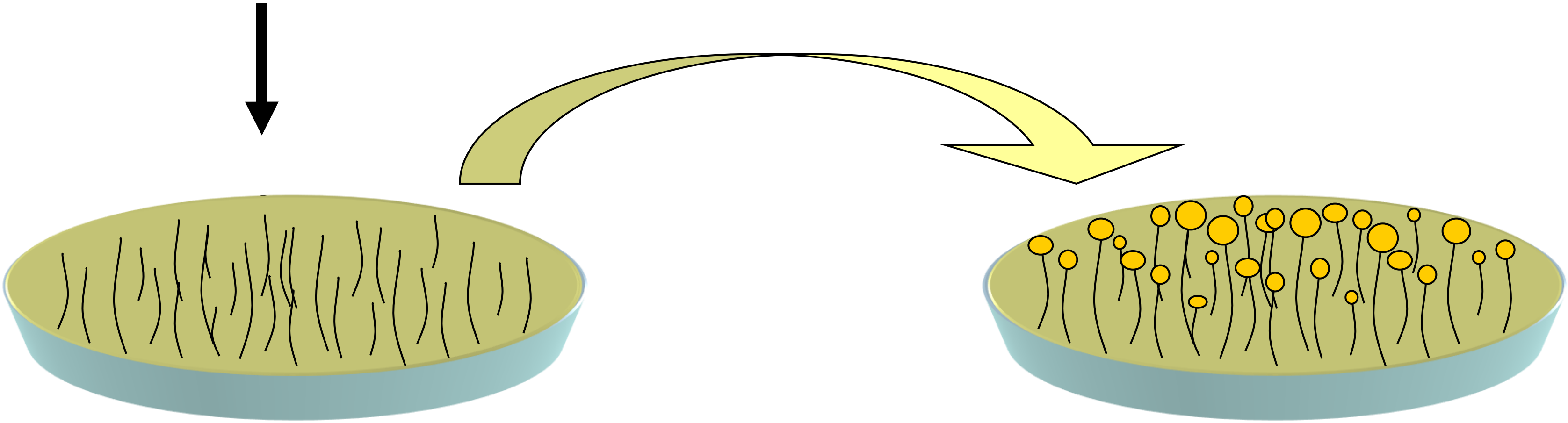


Jennie Kuzdzal-Fick

Perils of low relatedness: Experimental evolution beginning from a single cell

Jennie Kuzdzal-Fick

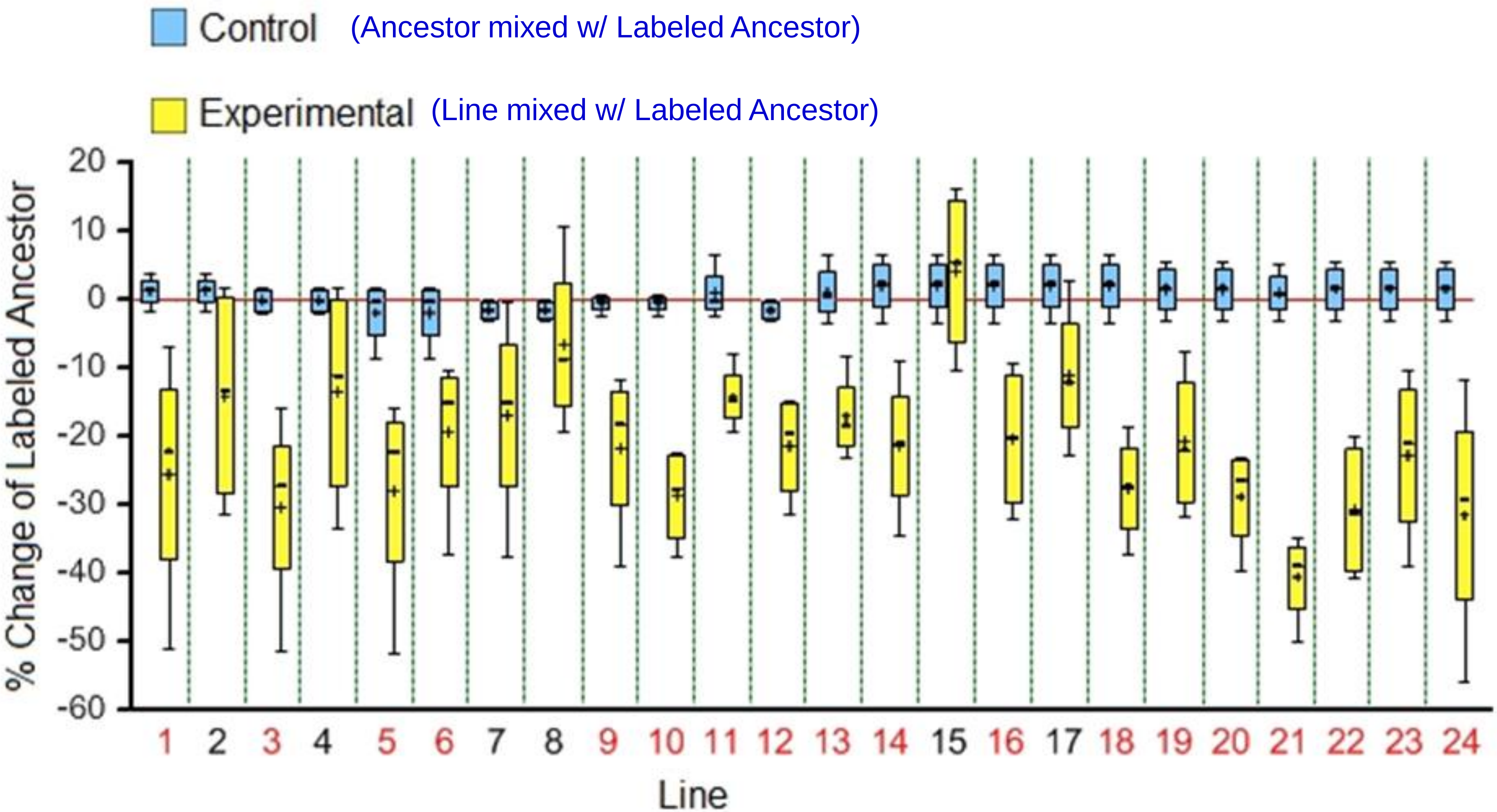
Low relatedness – plate 10^6 spores 1 round



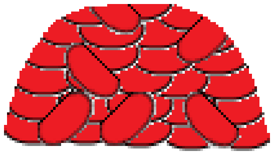
SM plate SM plate

Kuzdzal-Fick et al. *Science* 2011

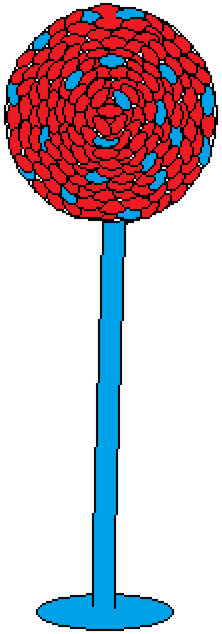
18 out of 24 evolved lines showed significant evidence of cheating the ancestor



Many clonal isolates did not form fruiting bodies or spores when alone

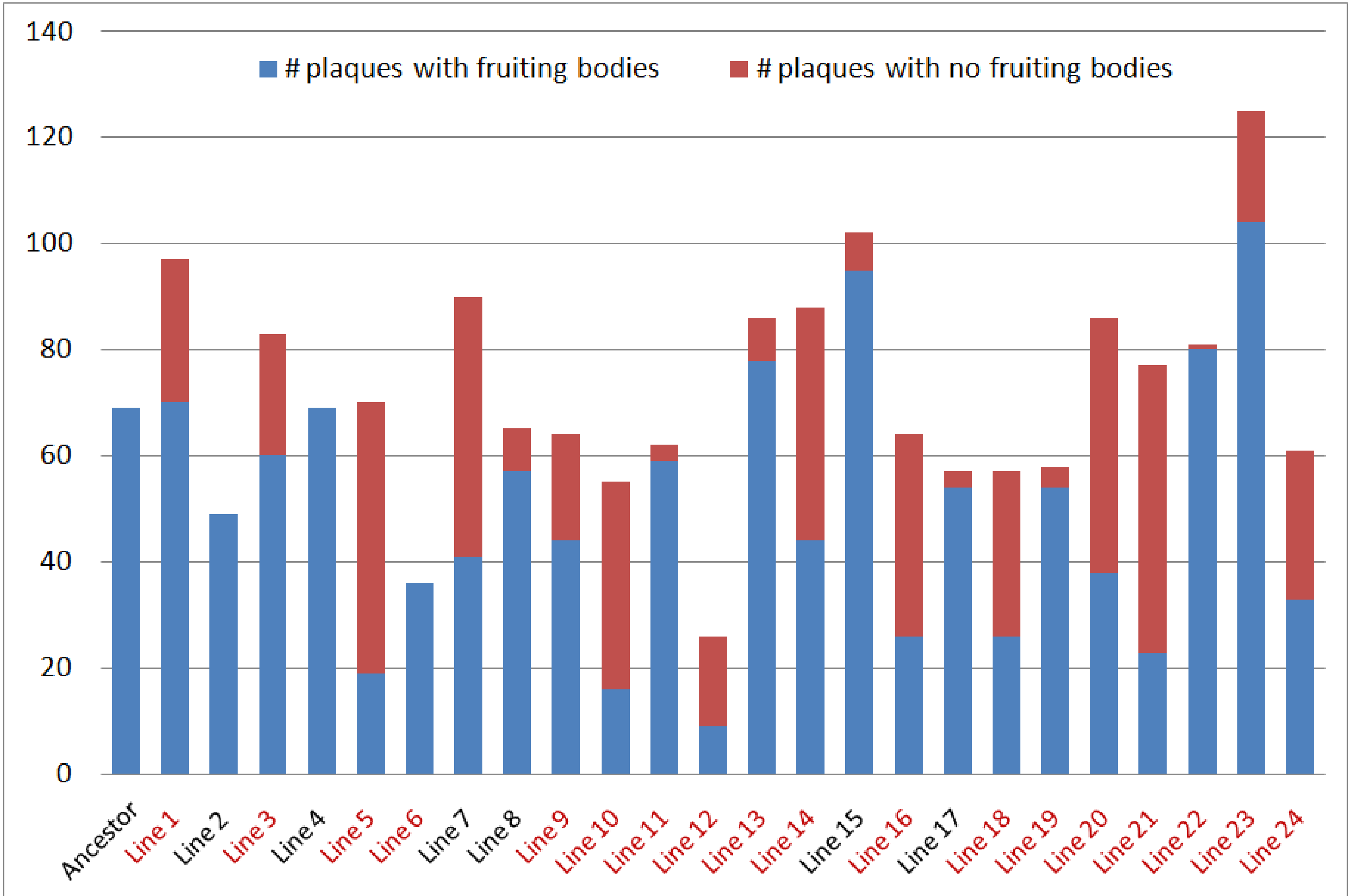


non-fruiting clone alone

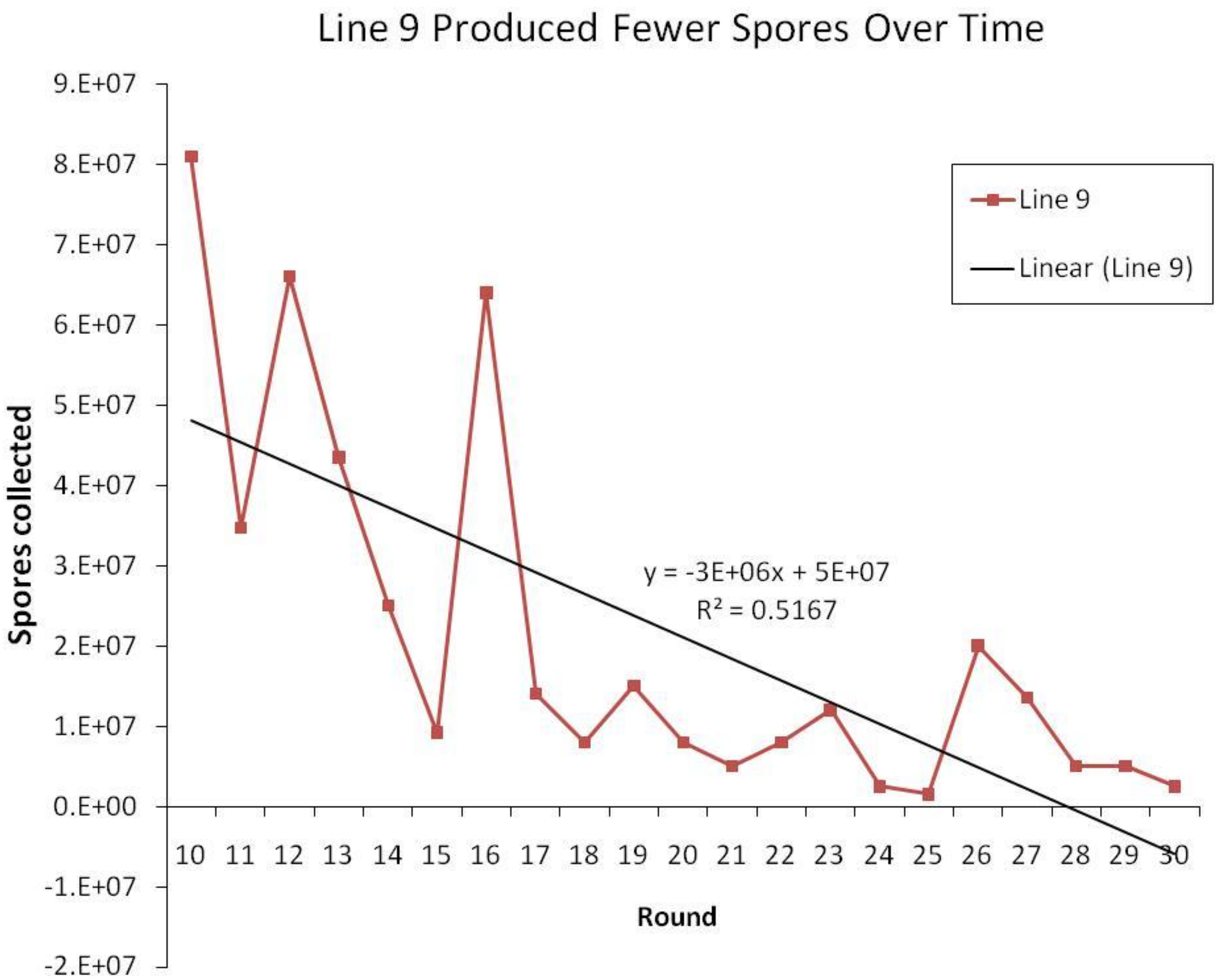


non-fruiting clone in chimera

Many clonal isolates don't form fruiting bodies or spores

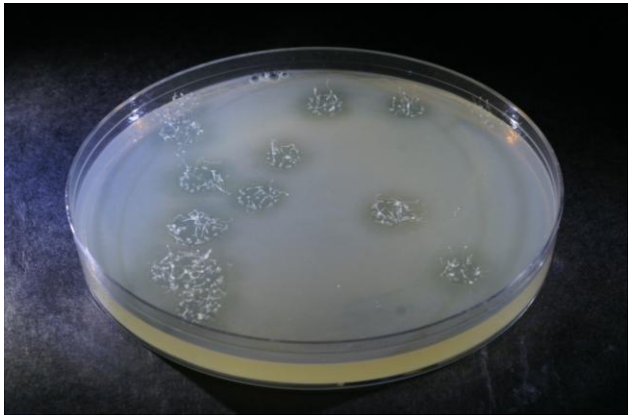


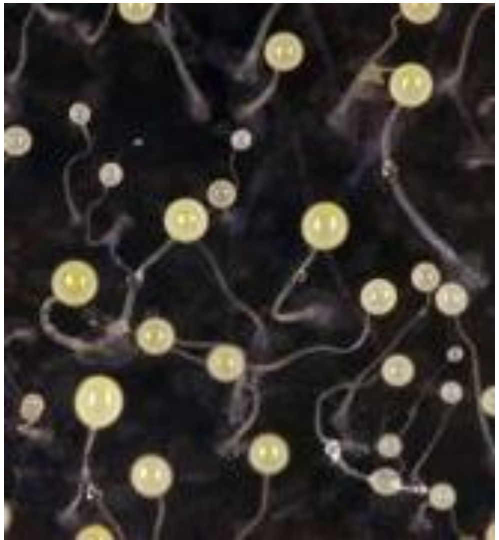
Non-fruiting cheaters may take over the lines



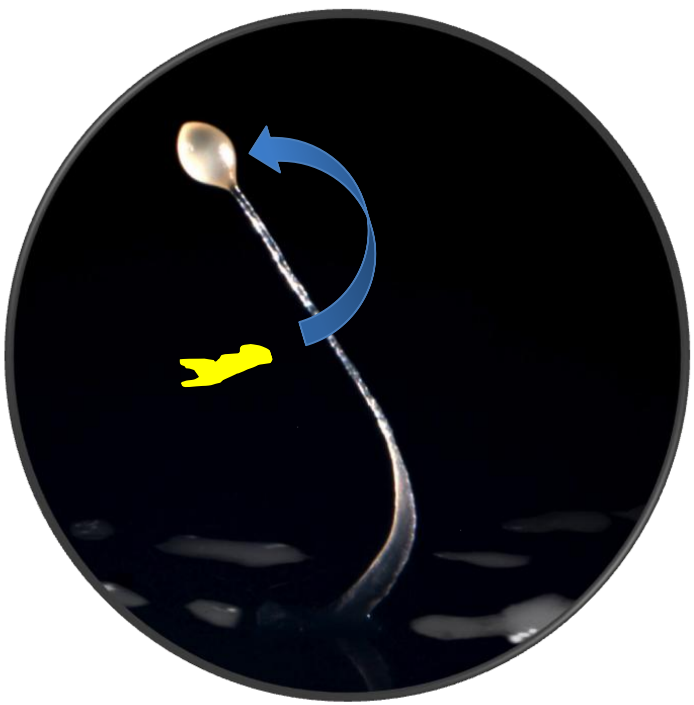
High relatedness is necessary and sufficient for maintaining the altruistic trait of stalk formation.

Low relatedness results in widespread loss of stalks over 30 social generations, while 70 social generations of mutation accumulation resulted in no stalkless mutants.





Benefits of grouping involve dispersal.
Costs to grouping come from death in stalk.
Control of costs come largely from relatedness elevation.



$$R\ B > C$$

Cost to actor

Benefit to recipient(s)

Relatedness to recipient(s)

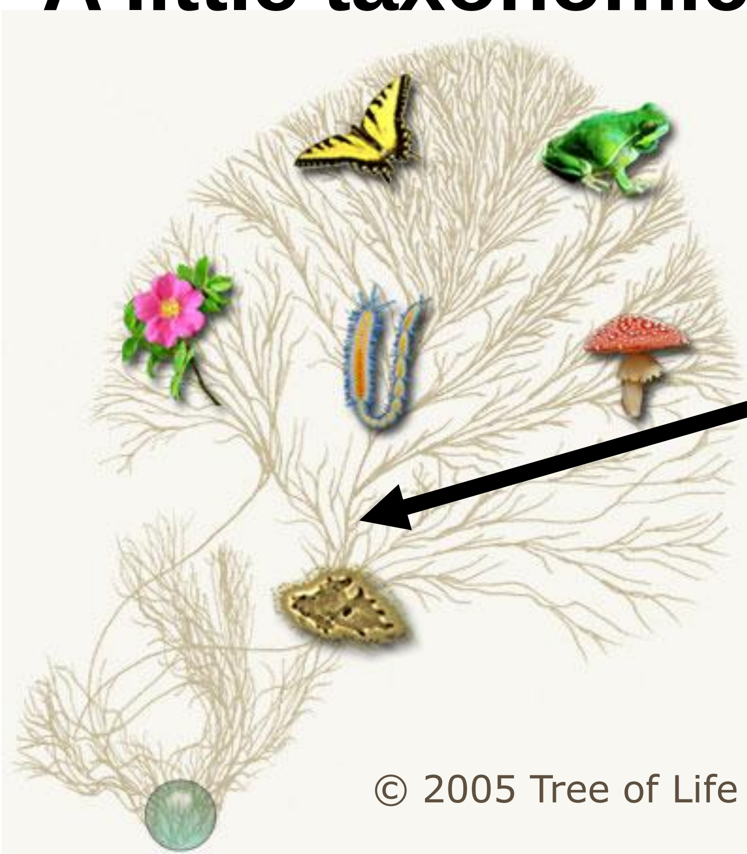
Dictyostelia are as old as Animalia but have diverged morphologically far less.

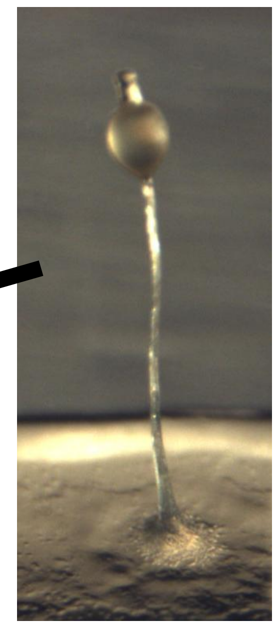
Photo by Alex Wild

Dictyostelia are as old as Animalia but have diverged morphologically far less.

- Is it because of conflicts since they do not go through a single cell bottleneck?

A little taxonomic adventurousness is fun!





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