Cooperation and construction

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Evolution of cooperation – simplified PD

$$\begin{array}{c} \\ \textit{Cooperator} \\ \textit{Defector} \end{array} \begin{array}{c} \begin{array}{cc} \textit{Cooperator} & \textit{Defector} \end{array} \\ \begin{pmatrix} \mathbb{b} - \mathbb{c} & -\mathbb{c} \\ \mathbb{b} & 0 \end{pmatrix} \end{array}$$

where $\mathbb{b} > \mathbb{c} > 0$.

Mechanisms for the evolution of cooperation

- Direct reciprocity
- Indirect reciprocity
- Structure
- Kin recognition
- Multi-level selection

The origin of eusociality

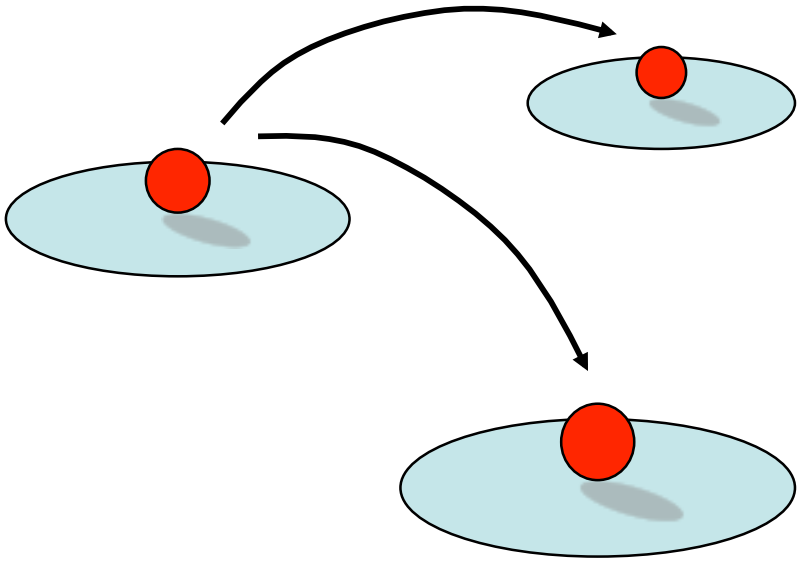
Different origins of eusociality

Eusociality is characterized by

- overlapping generations
- division of labor
- division of reproduction

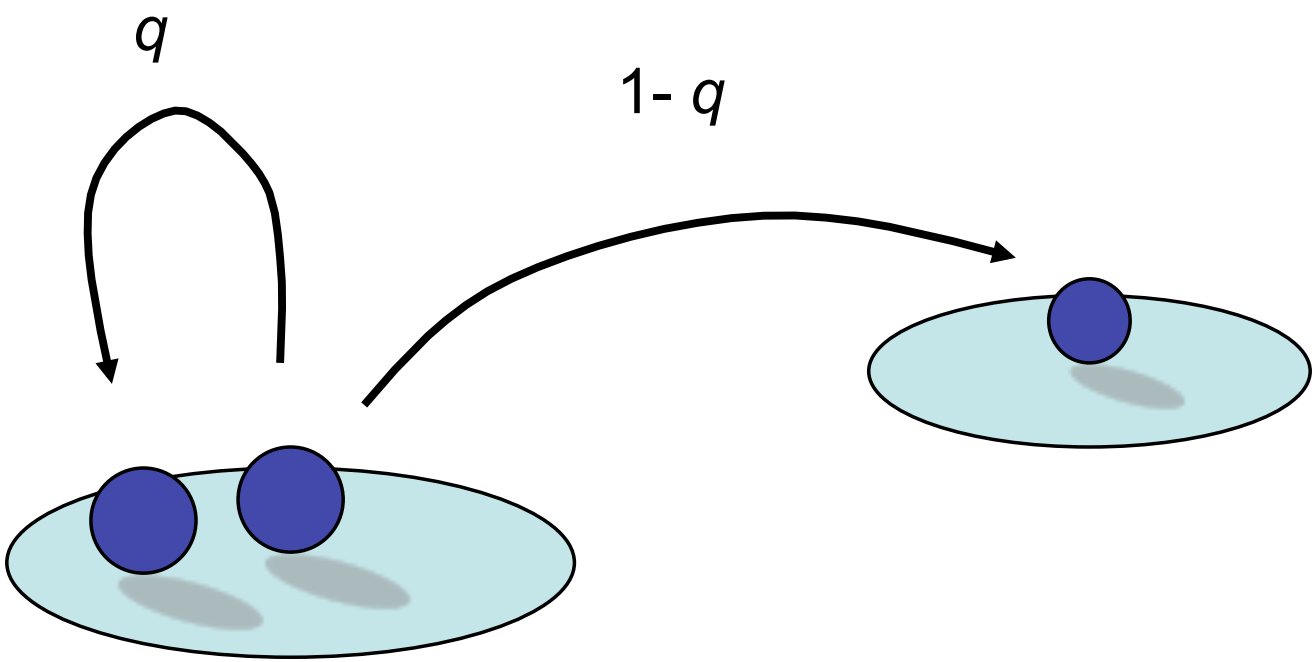
- Ants
- Termites
- Wasps
- Bees
- Australian ambrosia beetle
- Aphids
- Thrips
- Snapping shrimp
- Naked mole rats

Precursor state: “solitary"



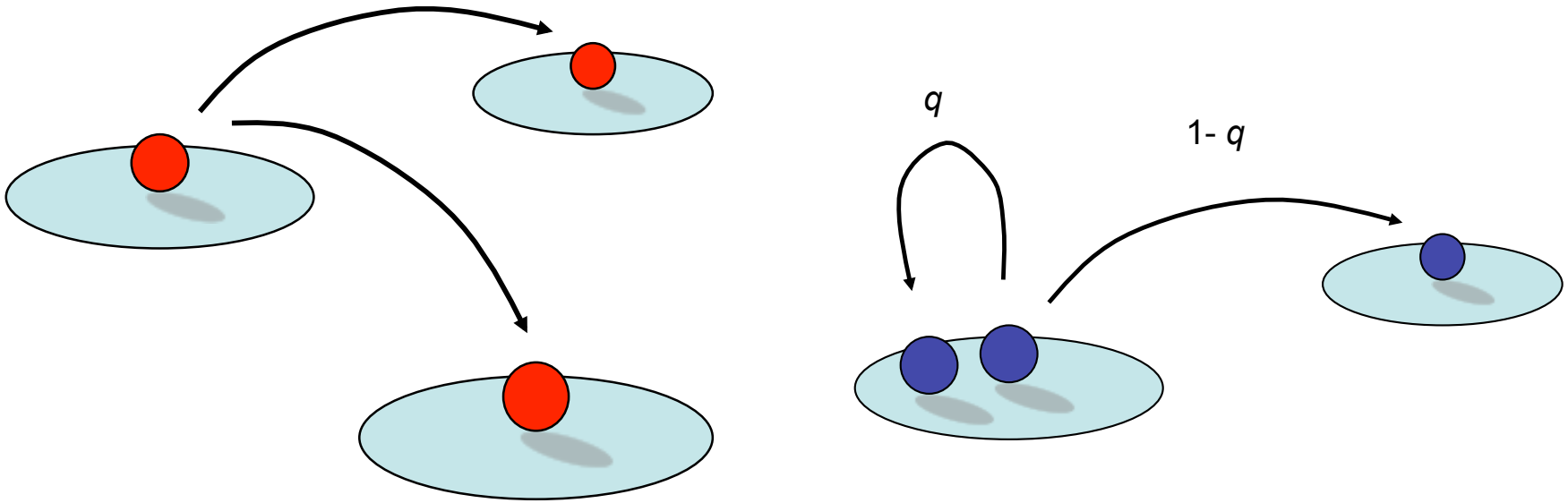
- valuable and defensible nest
- dependable food source within foraging distance
- progressive provisioning = fertilized female builds nest, gathers food, feeds young. The young then leave.

Eusocial



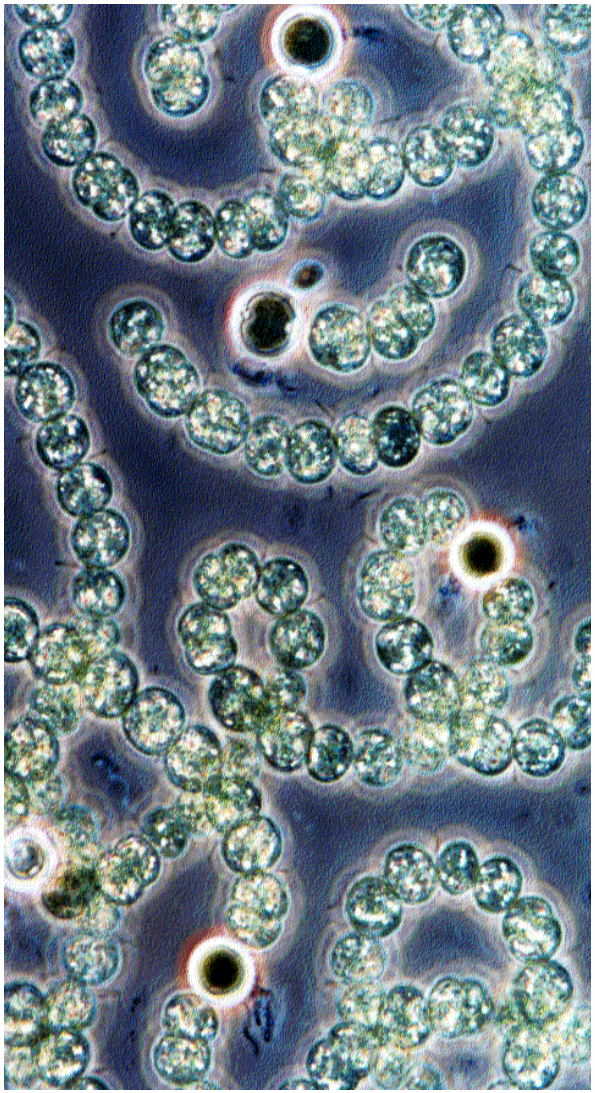
$q \cdots$ probability that daughter stays with the nest

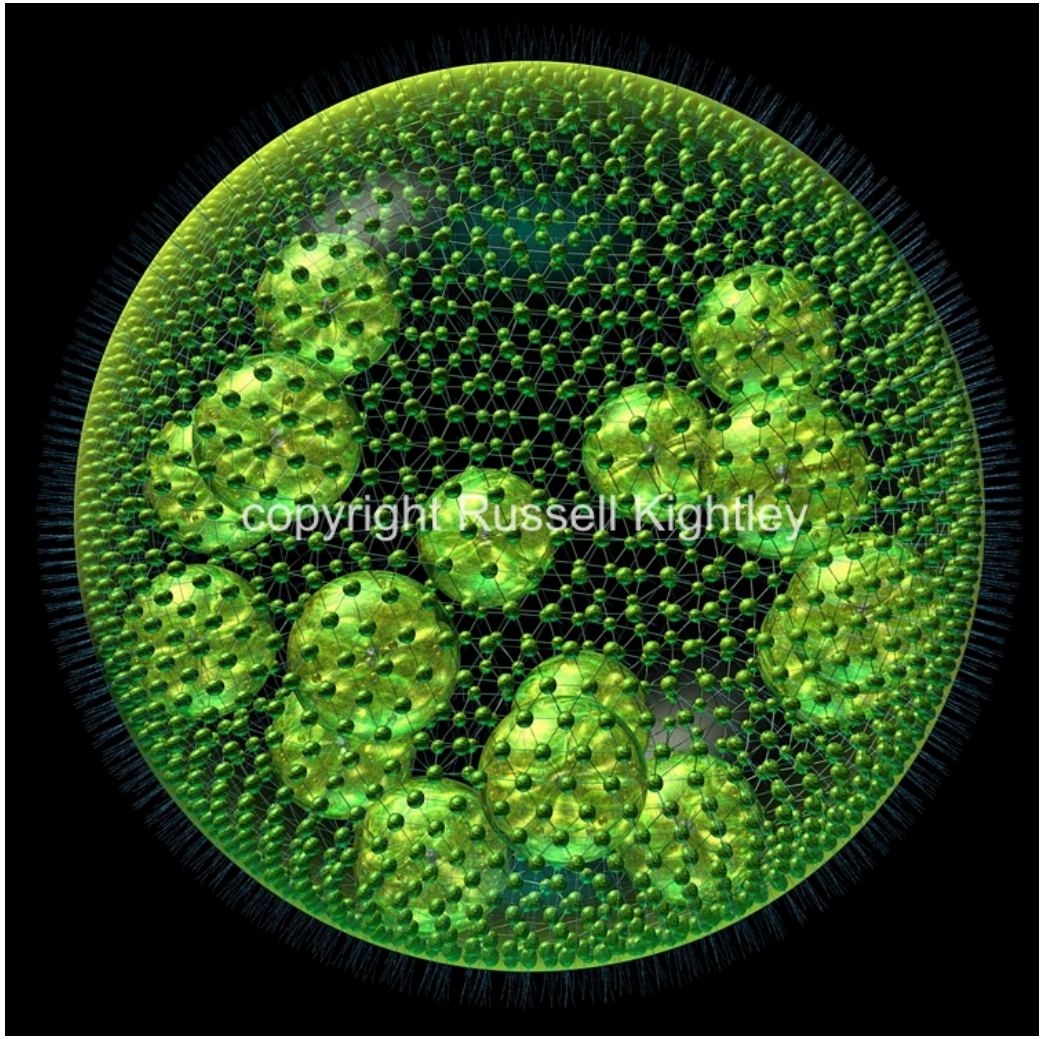
Solitary versus eusocial



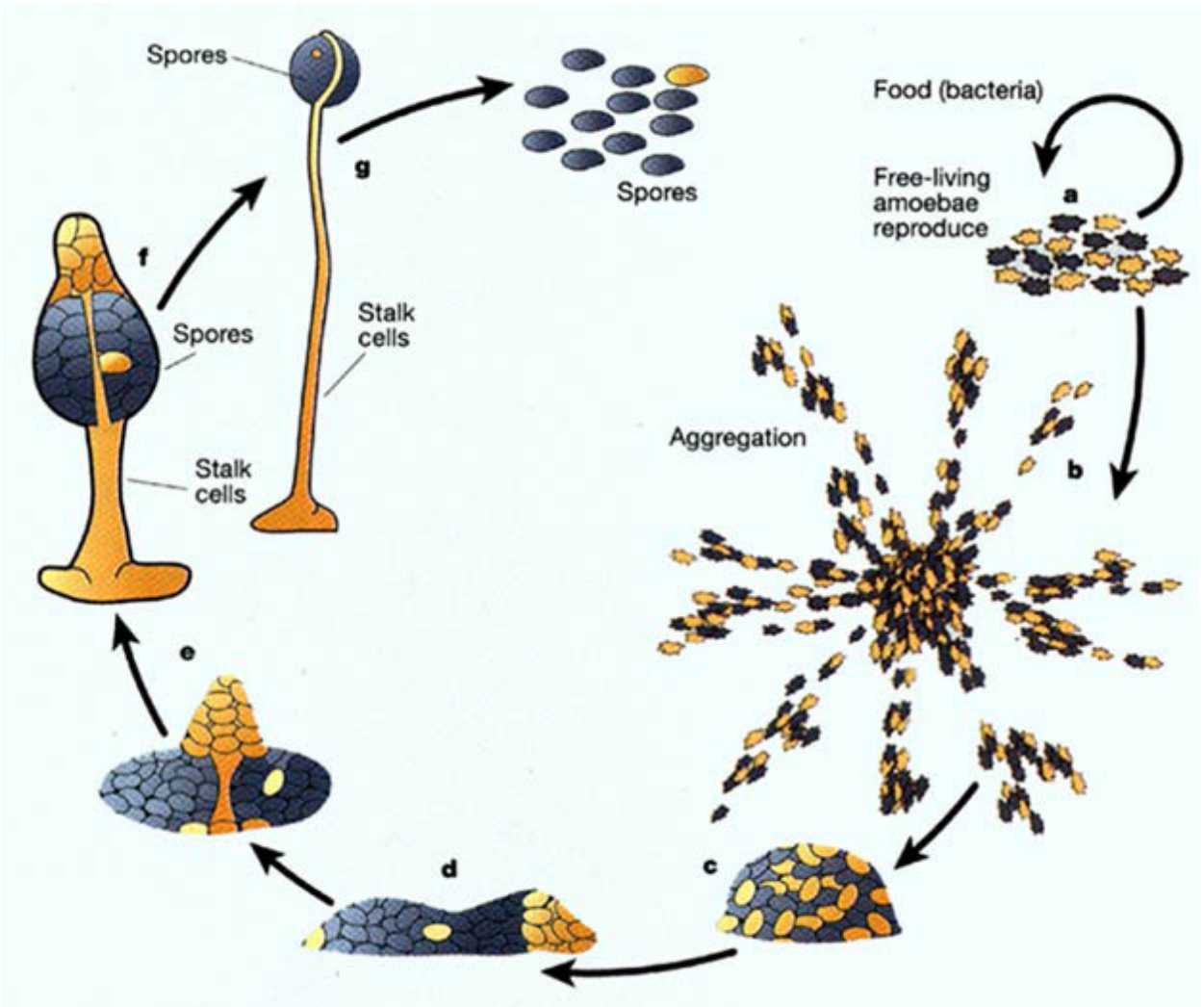
Eusociality represents a different form of cooperation.

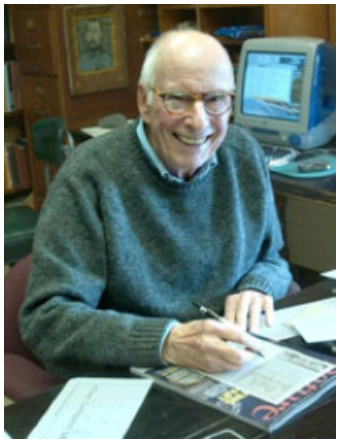
Multicellularity



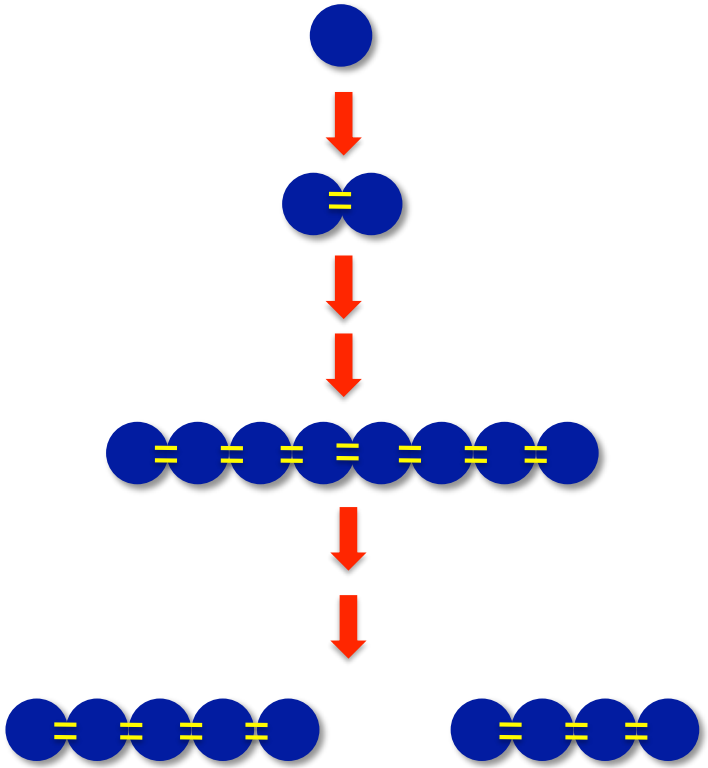


Another way to construct - Aggregation

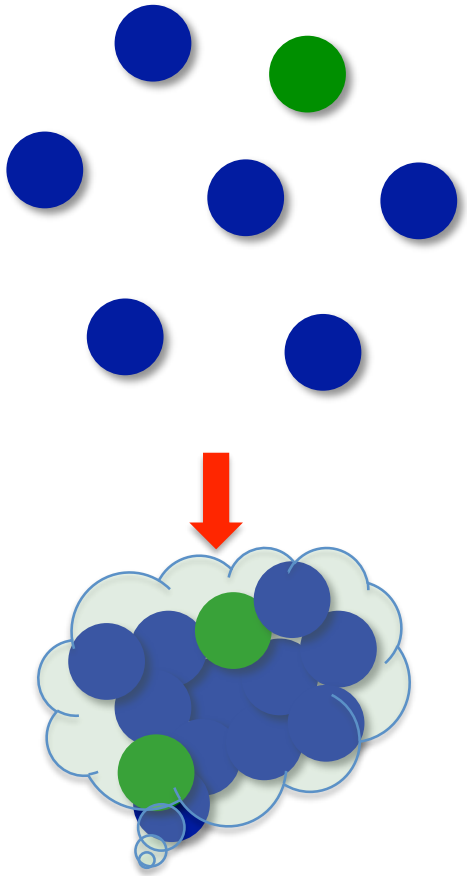




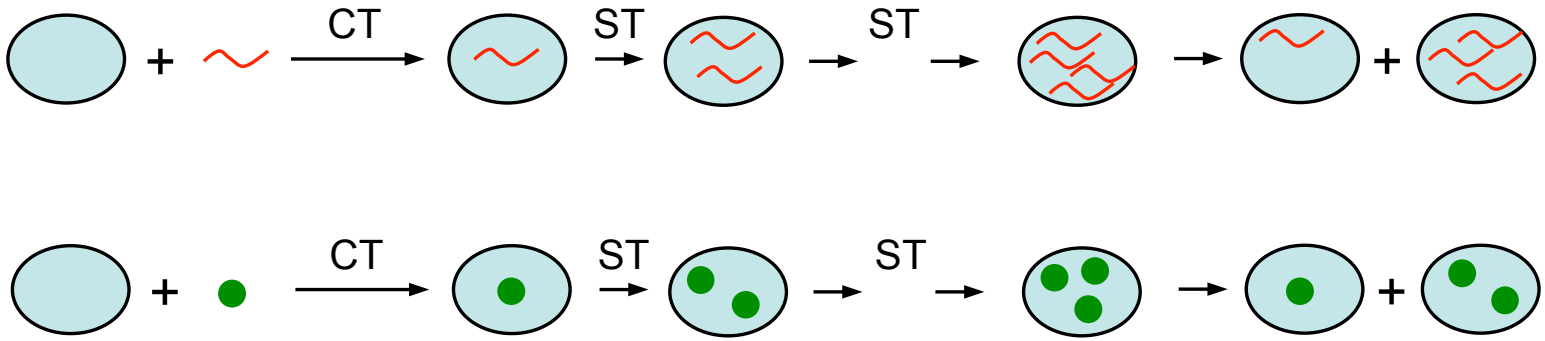
Staying together



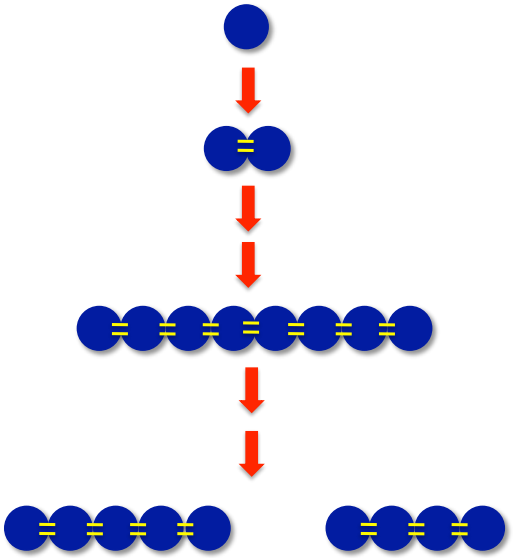
Aggregation



Protocells, Endosymbiosis, Eusociality and Sociality



Staying together



$$A_i \xrightarrow{a_i q} A_{i+1}$$

$$A_i \xrightarrow{a_i(1-q)} A_i + A$$

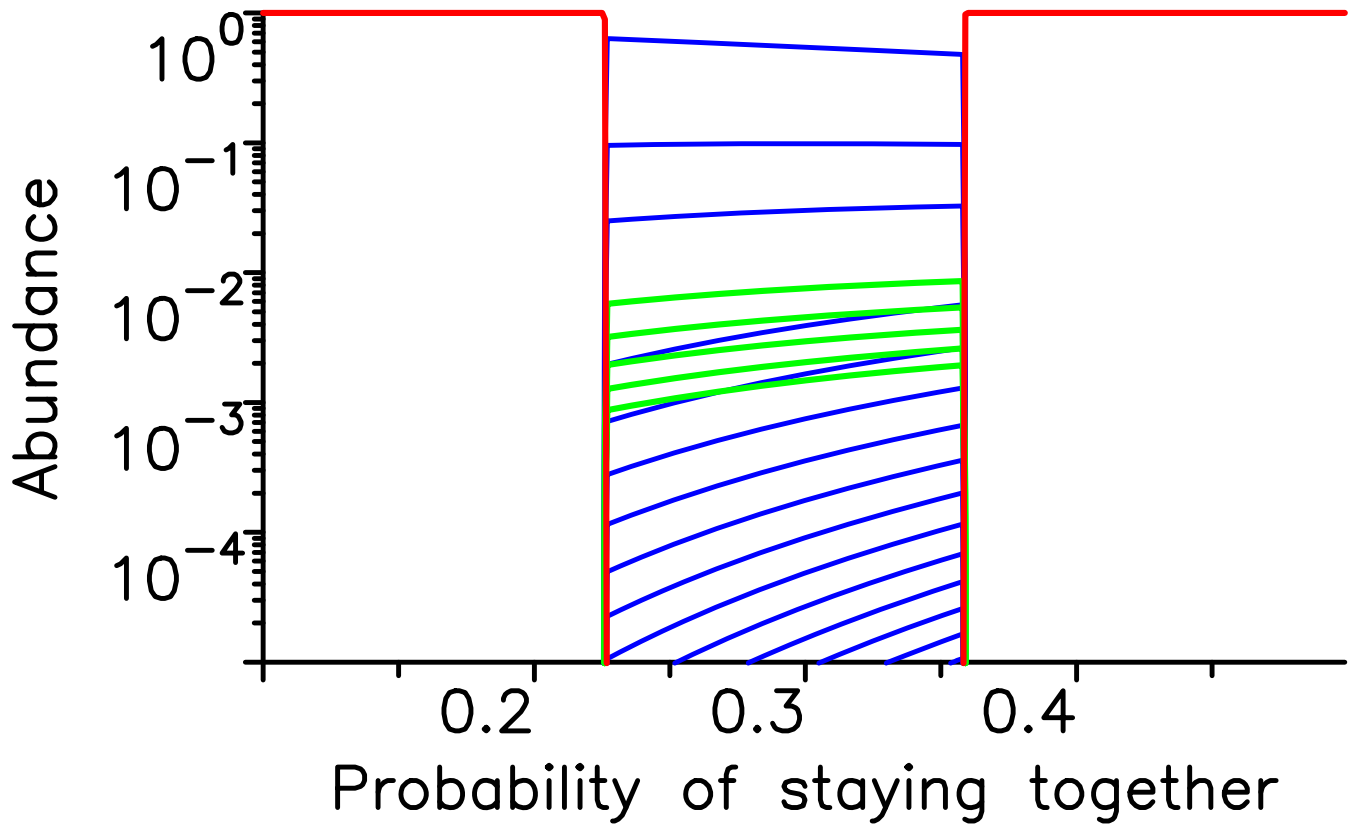
$$B \xrightarrow{b} B + B$$

$$\dot{x}_1 = (1-q)\sum_i a_i x_i - q a_1 x_1 - \phi x_1$$

$$\dot{x}_i = q(a_{i-1}x_{i-1} - a_i x_i) - \phi x_i \quad i = 2, 3, \ldots$$

$$\dot{y} = by - \phi y$$

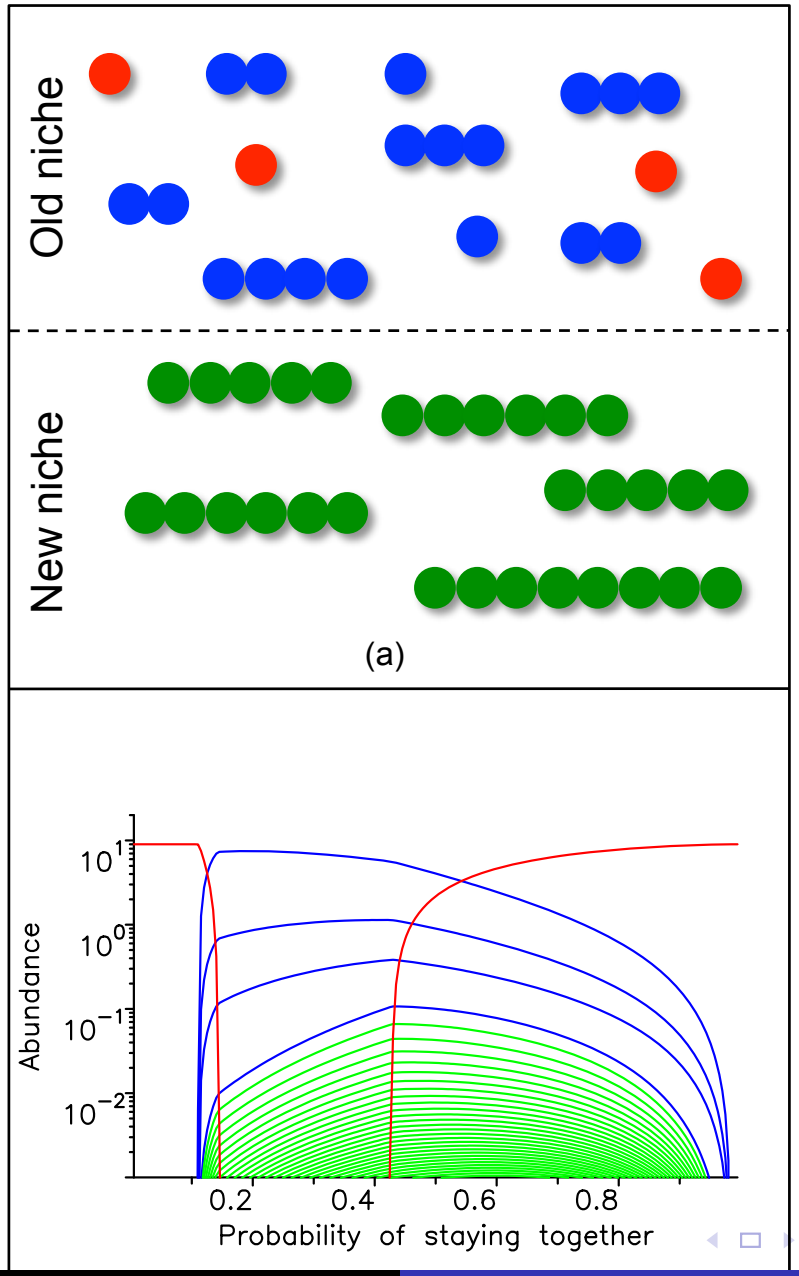
Staying together



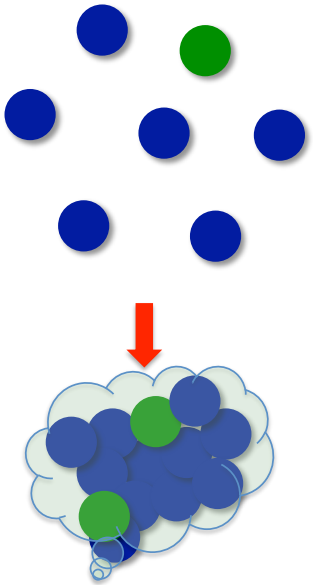
$a_i = b \cdot 0.95i$ for $i = 1, 2, 3$; $a_i = b \cdot 2i$ for $i = 4, .., 8$

$a_i = b \cdot 0.3i$ for all $i \geq 9$.

Complexes find a new niche



Coming together (aggregation)



$$A_i + A \xrightarrow{\beta} A_{i+1}$$

$$A_i \xrightarrow{a_i} A_i + A$$

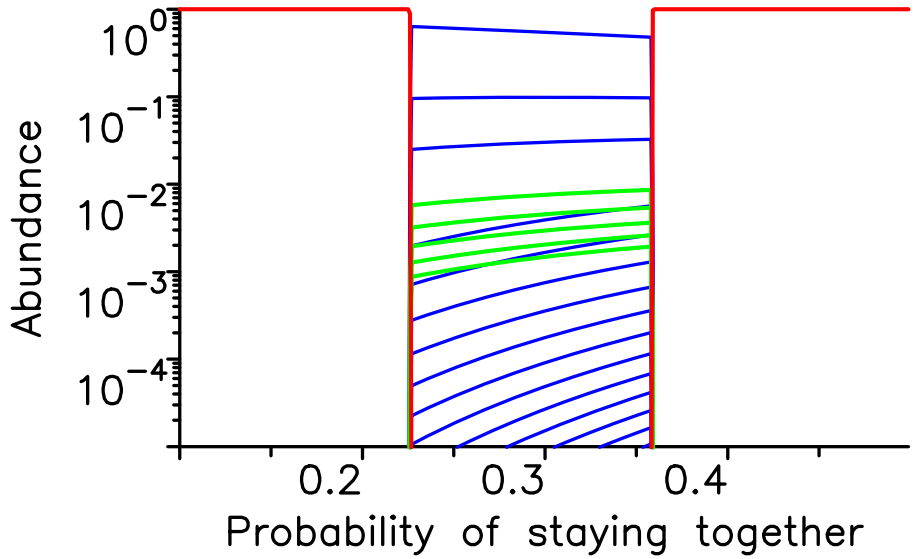
$$B \xrightarrow{b} B + B$$

$$\dot{x}_1 = \sum_i a_i x_i - \beta x_1 \sum_i x_i - \beta x_1^2 - \phi x_1$$

$$\dot{x}_i = \beta x_1 (x_{i-1} - x_i) - \phi x_i \quad i = 2, 3, \ldots$$

$$\dot{y} = by - \phi y$$

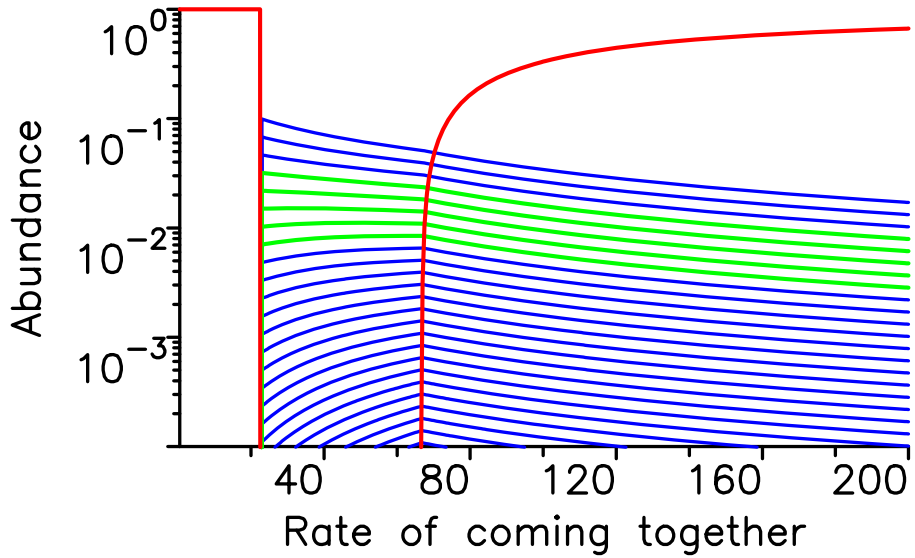
Staying together vs. Coming together



$$A_i \xrightarrow{a_i q} A_{i+1}$$

$$A_i \xrightarrow{a_i(1-q)} A_i + A$$

$$B \xrightarrow{b} B + B$$



$$A_i + A \xrightarrow{\beta} A_{i+1}$$

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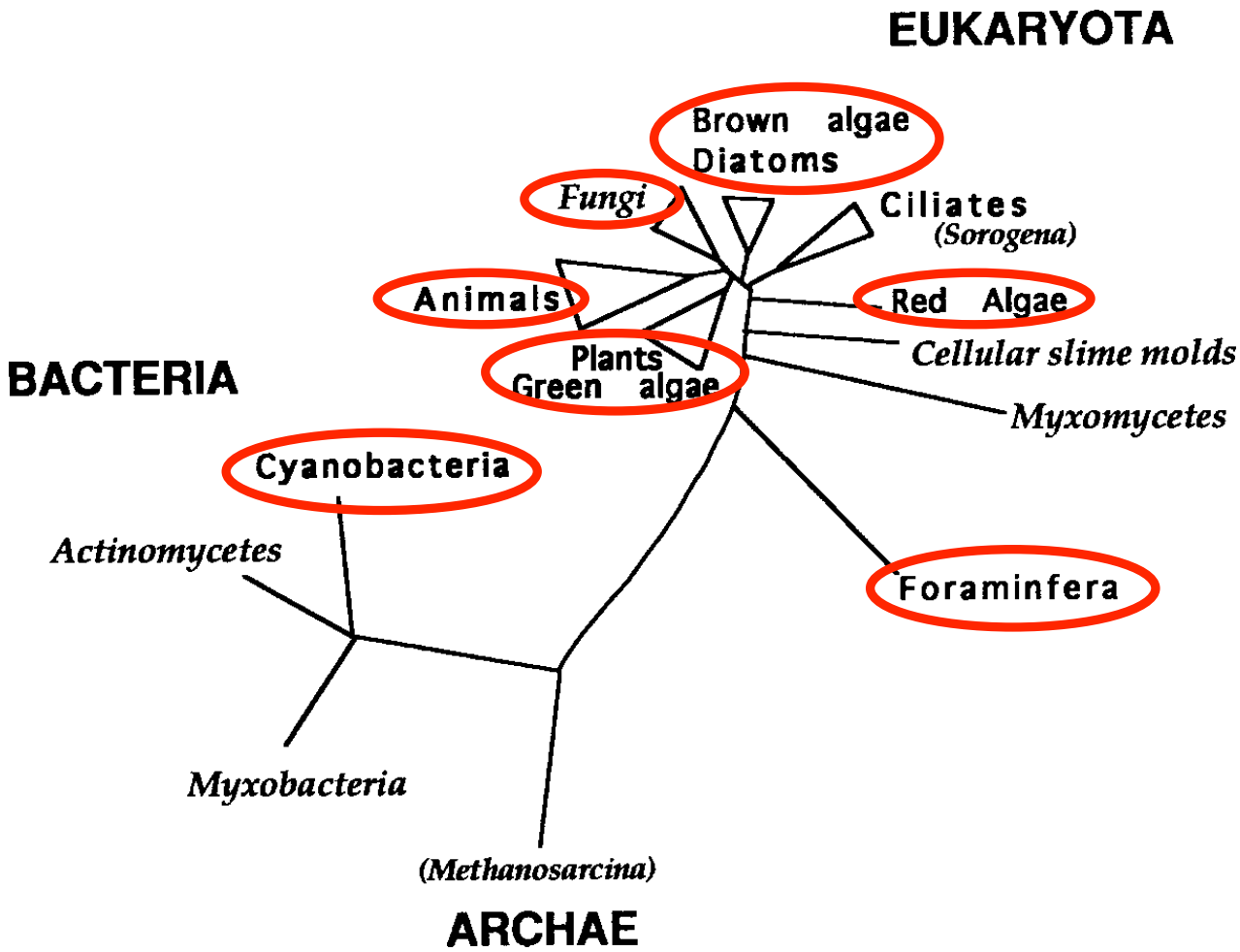
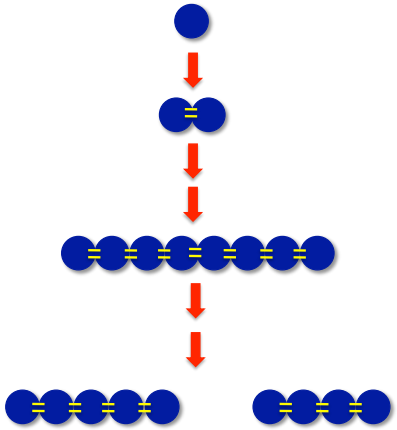
Staying together vs Coming together



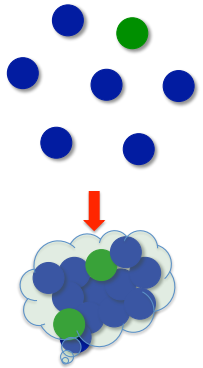
(Bonner JT, *Integr. Biol. 1998*)

Staying together



- aquatic
- successful in fitness landscapes where there is a cost to form complexes

Aggregation



- terrestrial
- successful in fitness landscapes where only large complexes provide fitness advantages

Staying together and aggregation are two building blocks used for biological construction on every scale.

It is important to understand their differences and similarities before developing a general theory of cooperation and construction.

What is cooperation?

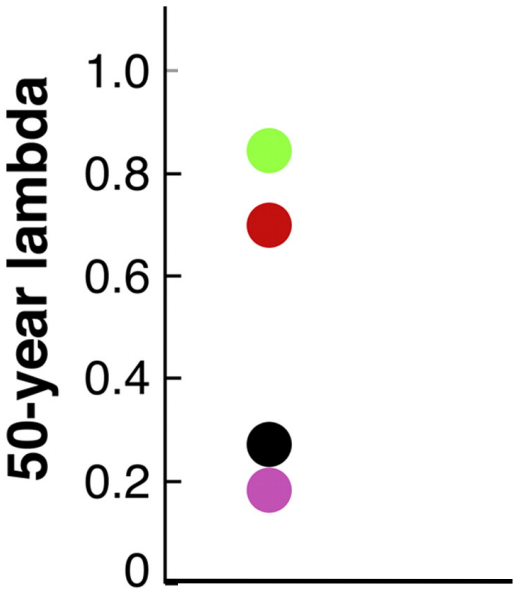
- On what time scale are we measuring cooperation?
  - immediate observable effect
  - effect on life-time fitness
  - evolutionary time
- Are maybe cheaters not so bad (or not even cheaters) depending on time scale?

Problem

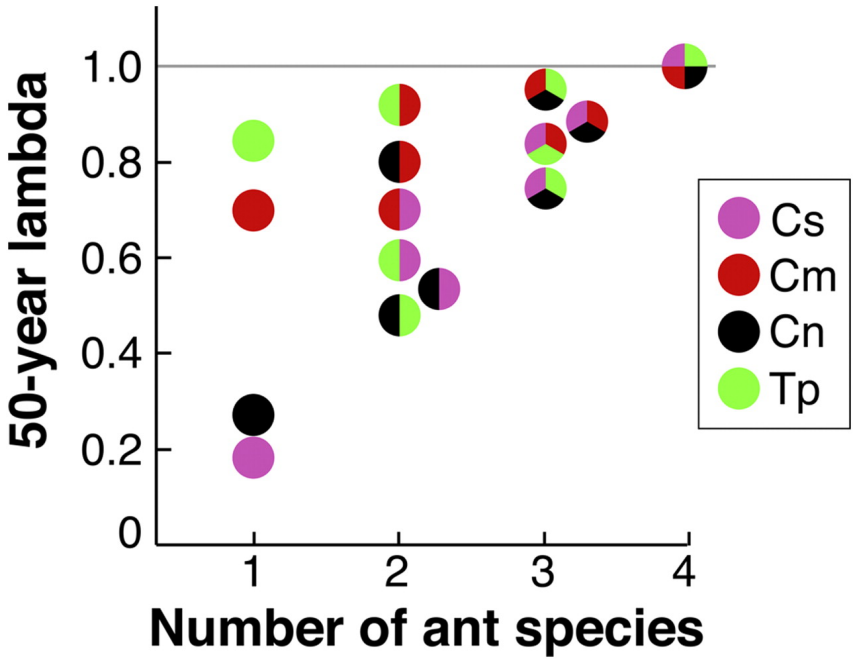
Solution

Ants and plants

- *T.penzigi* – effective partner
- *C.mimosae* – effective partner
- *C.nigriceps* – “parasite”: defends BUT sterilizes
- *C.sjostedti* – “parasite”: increases mortality



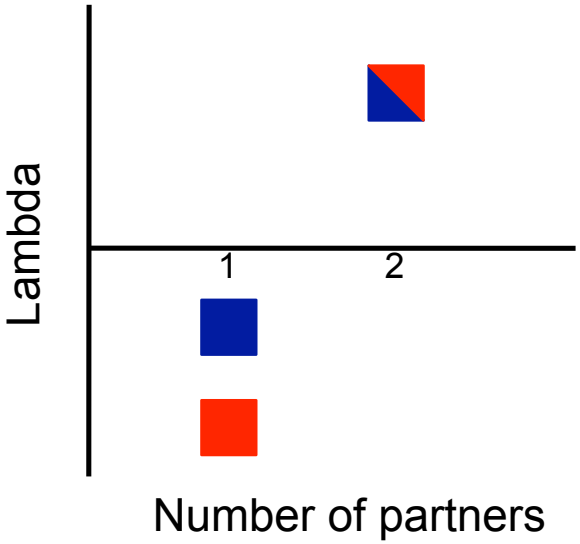
Synergy of multiple partners



Palmer T M et al. PNAS
2010;107:17234-17239

Fig 1. Long-term Acacia population growth rates (λ50) for simulated communities consisting of one, two, three, or four ant species. Cs = C. sjostedi, Cm = C. mimosae, Cn = C. nigriceps, Tp = T. penzigi.

What, then, is mutualism?



Scenario	λ
Host	$\cdot$
Host + M_1	$\searrow$
Host + M_2	$\searrow$
Host + M_1 + M_2	$\nearrow$

Thank you!

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