Plan of my lectures

- Cooperation and conflict in evolution
  - Monday
    - Molecules to societies
    - Multicellularity
  - Sunday
    - Teaching of biology (10:30am)
      - NSF high school teacher internship in our lab
    - Sex & immortality of life (4:30pm)

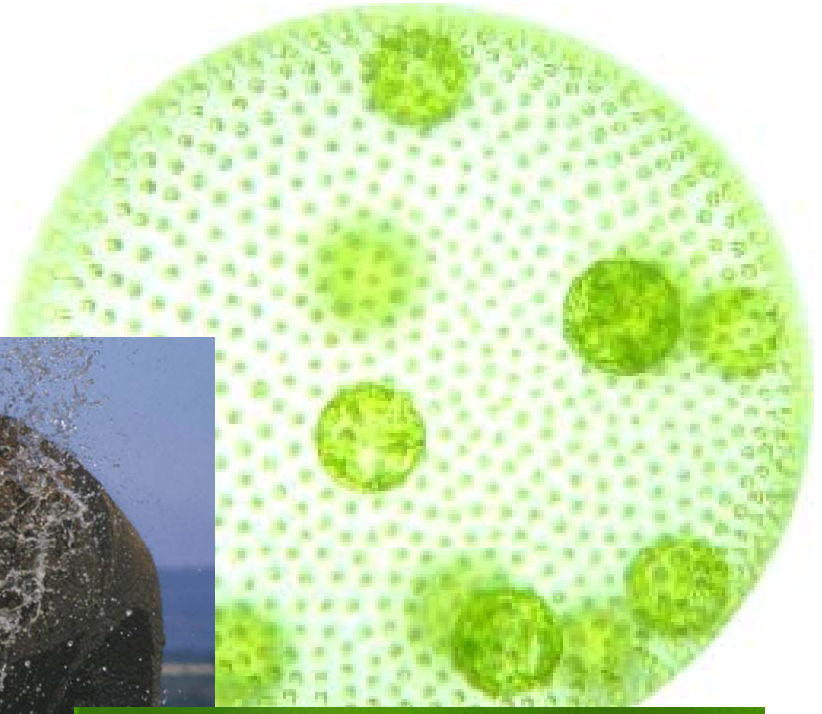
Cooperation and conflict from molecules to societies

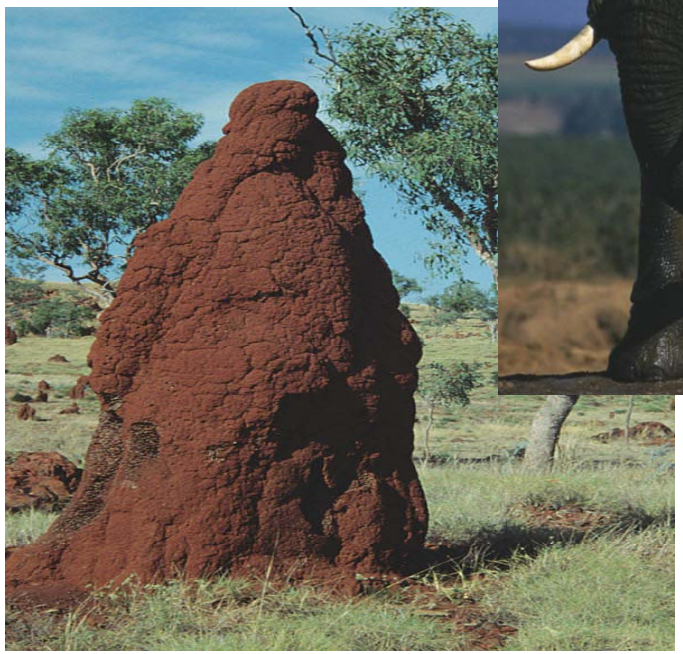
Evolutionary transitions in Individuality (ETIs)

Plan of talk

- Basic Points:
  - The world is a very social place, what we call individuals are really societies
  - Cooperation underlies complexity and drives the emergence of new kinds of individuals
  - Cooperation just doesn't happen.
    There is often a short term temptation to cheat.
  - Cycle of cooperation-conflict-conflict mediation
  - This cycle underlies the hierarchy of life
- Two examples: Sex and Multicellularity
- Cooperation and Human Nature

Societies of the world





Living Ant Bridge

Cooperation & Conflict in Bee Societies

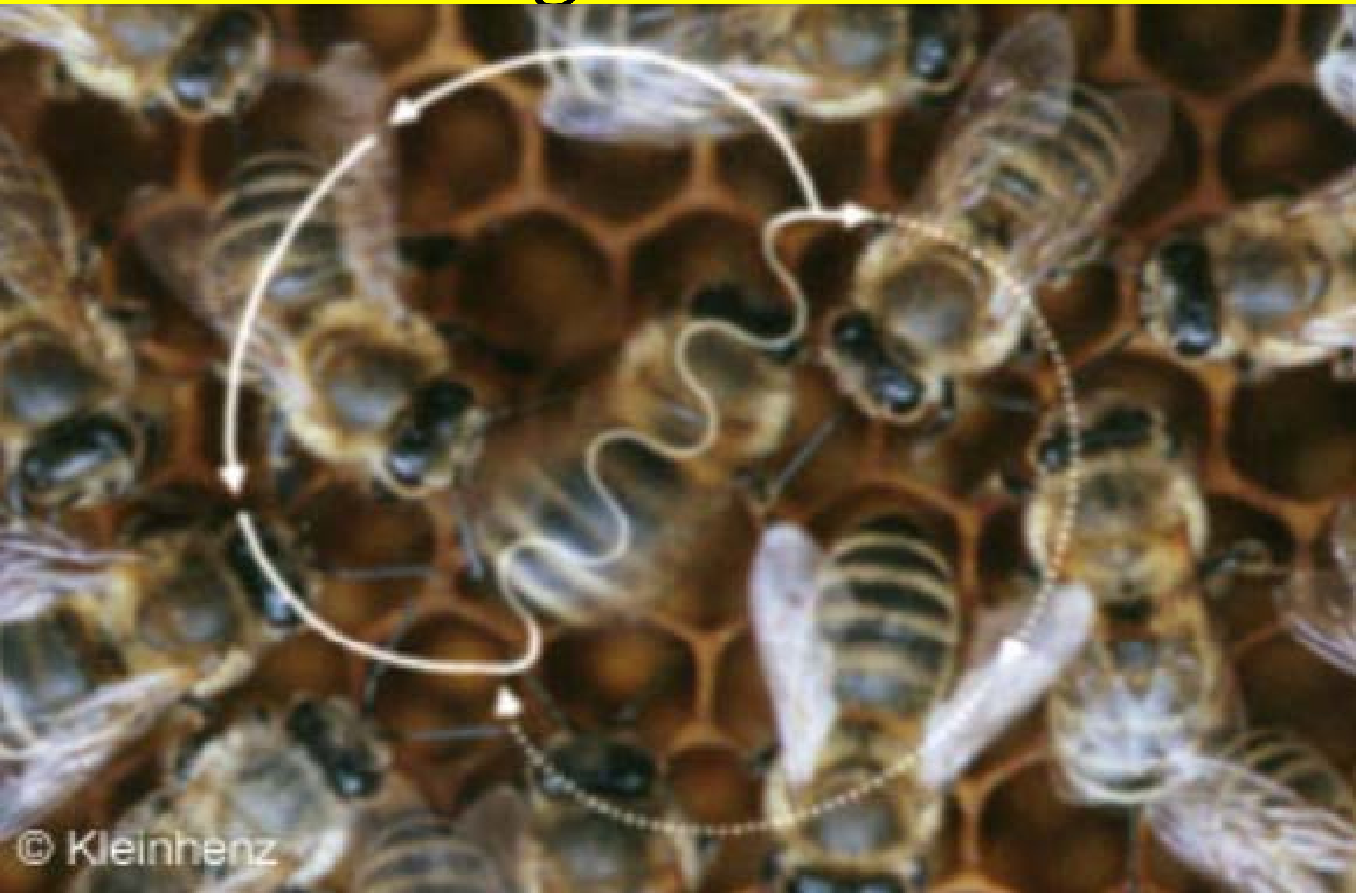
Worker foraging

Self-sacrifice

Keeping House

Sharing Food

Sharing Information



Air Conditioning

Tending To The Dead

Queen Laying An Egg

The Police Force

Credit: F. Ratnieks

Guilty and Punished!

Nature’s harmony is illusionary

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plants produce no f

s not ge

ys both partners to cooperate

Credit: J. Bronstein

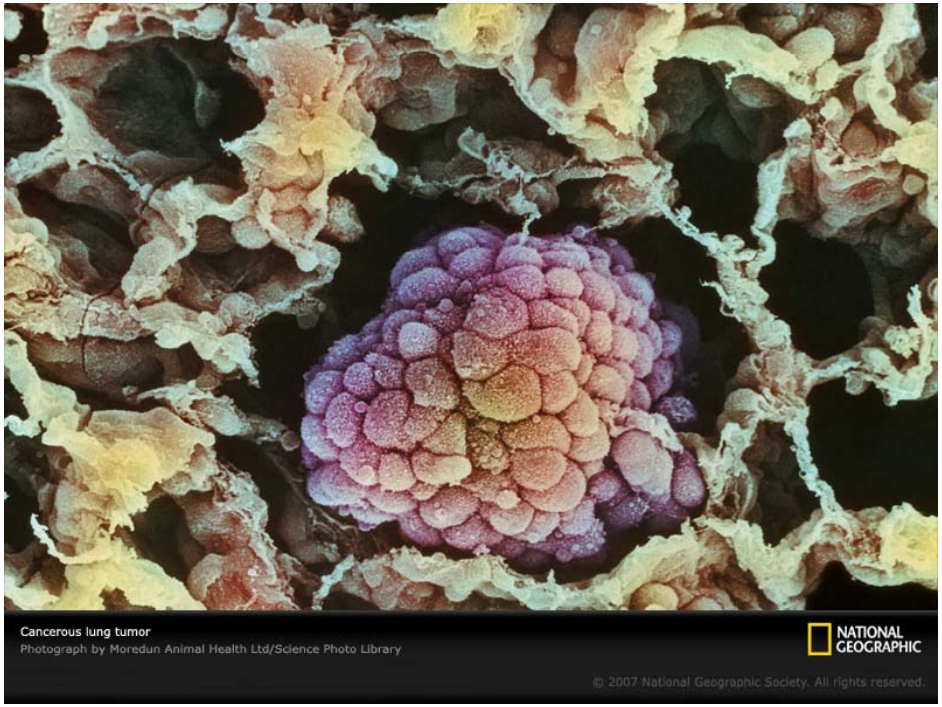
Tragedy of the commons

Credit: The Rusty Muffler Oracle

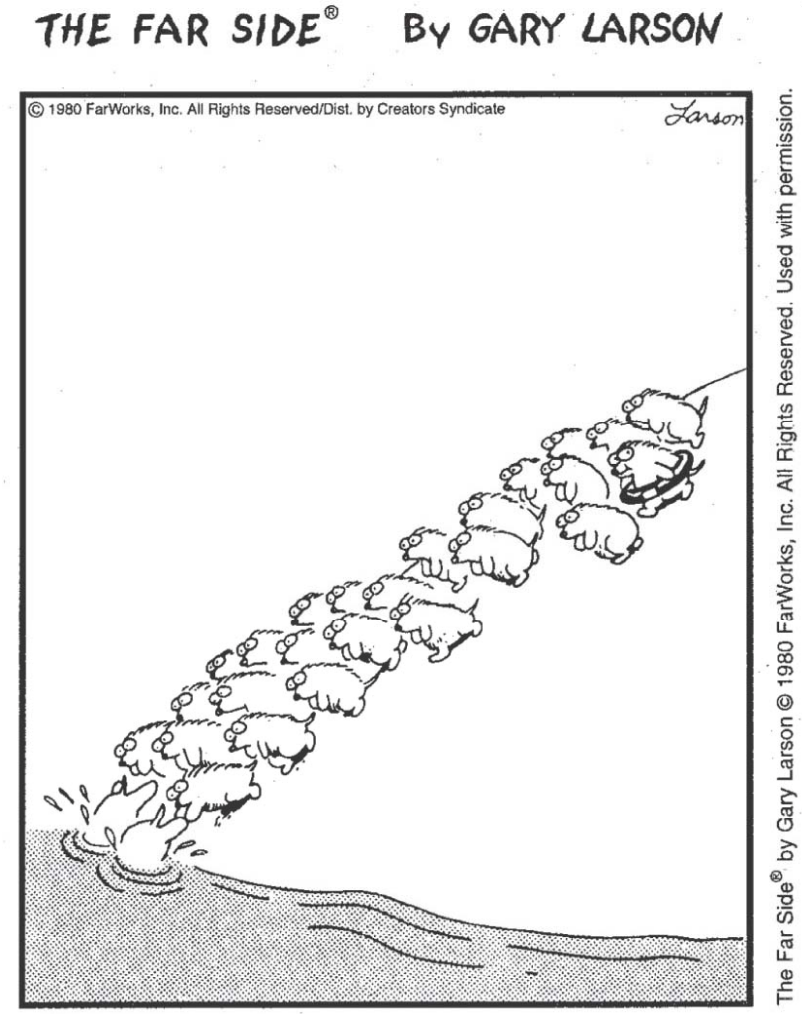
Puccini's Tragedy in *Tosca*

- Heroine: Tosca
- Her lover Cavaradossi is condemned to death by the police chief Scarpia
- Scarpia offers Tosca a deal—sleep with me and I will put blanks in the guns of the firing squad and Cavaradossi will live

Cheating

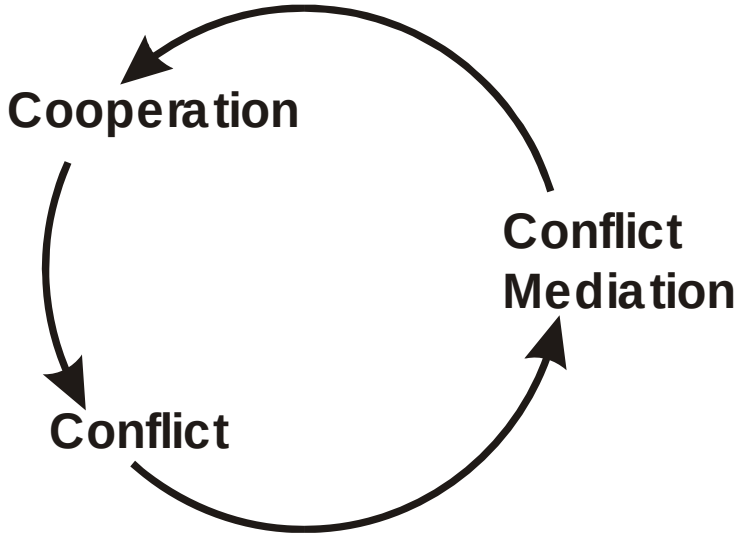


cancerous tumor within a human lung



Cooperation, conflict, mediation

- A society is a group of cooperating individuals
- The individuals can be genes, cells, organisms
- Cooperation benefits the group, costs the individual
- Cheating benefits the individual, costs the group
- The temptation to cheat may be mediated
- The group may become a new individual



Cooperation drives complexity

Social Organisms

Sex reinvented — Multicellular Organisms

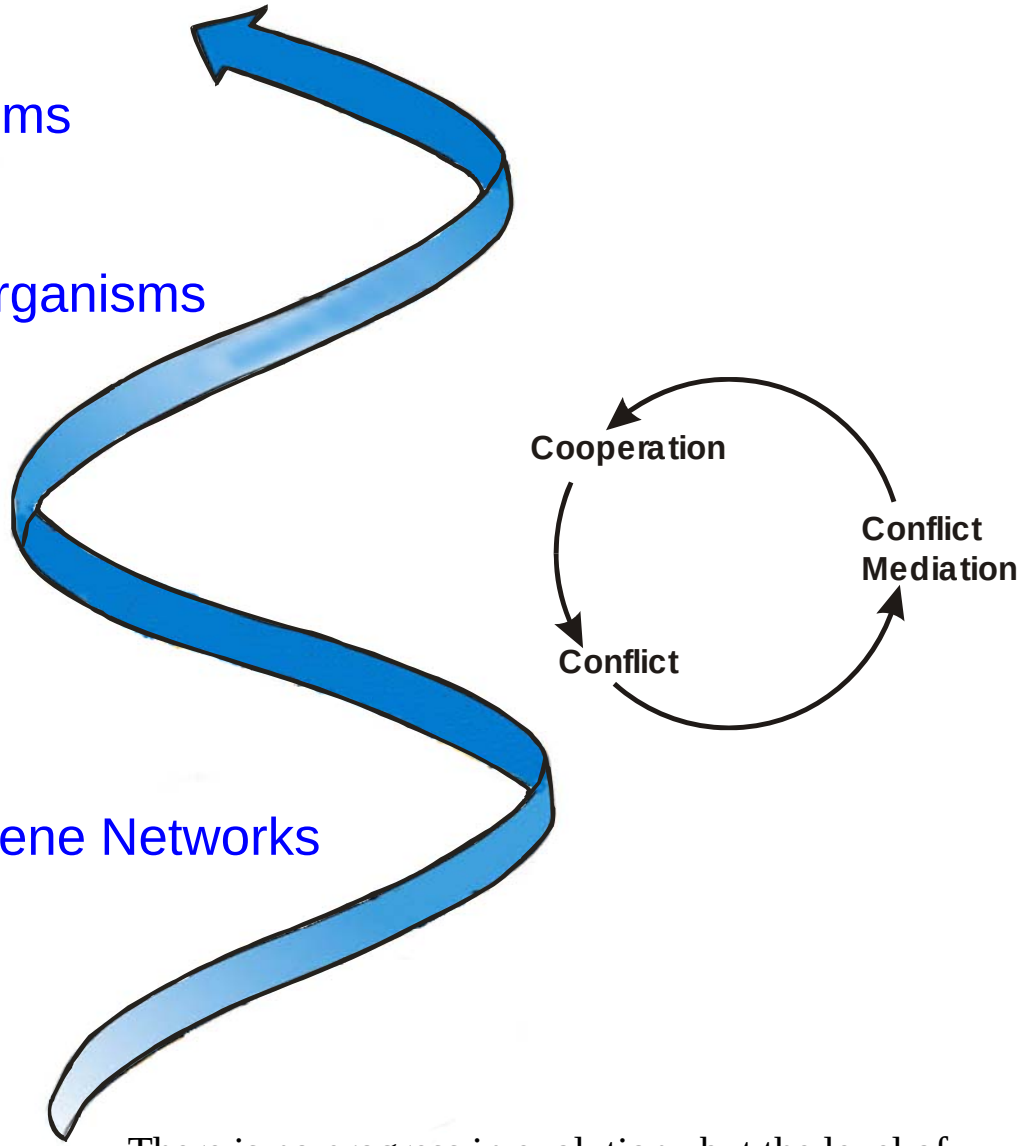
Sex reinvented — Cells in cells

Sex reinvented — Cells

Sex happened — Cooperative Gene Networks

Genes

Molecules

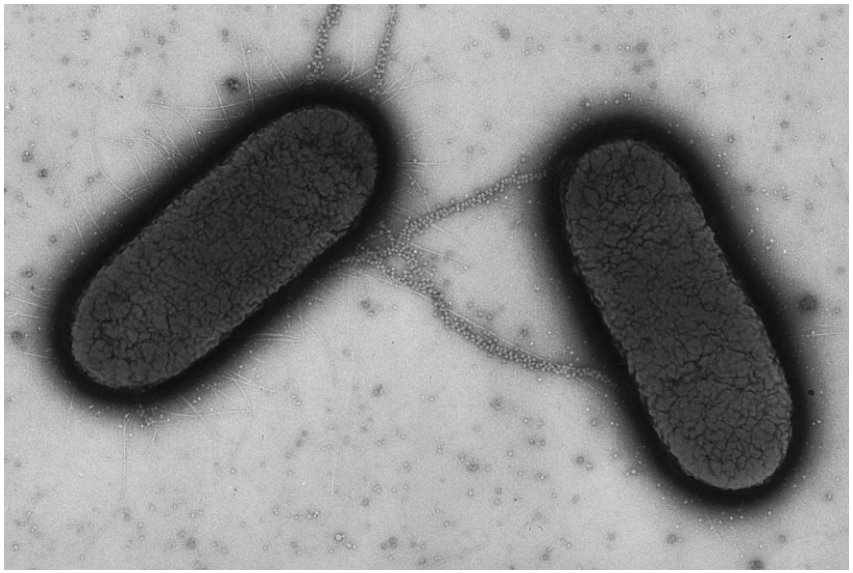


There is no progress in evolution, but the level of complexity can increase under certain conditions

A sensual world because of sex

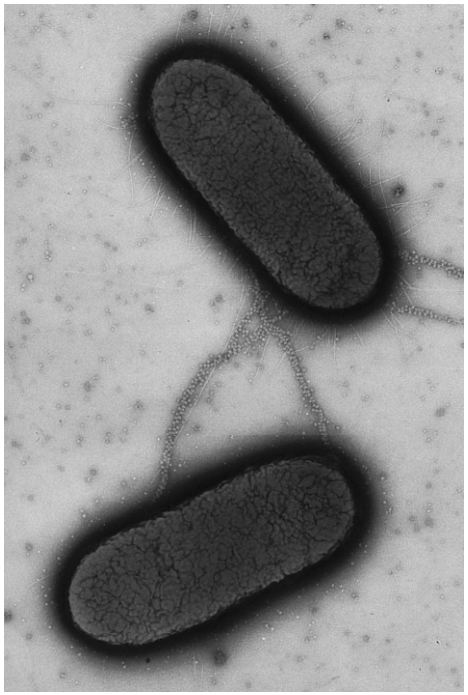
What is sex?

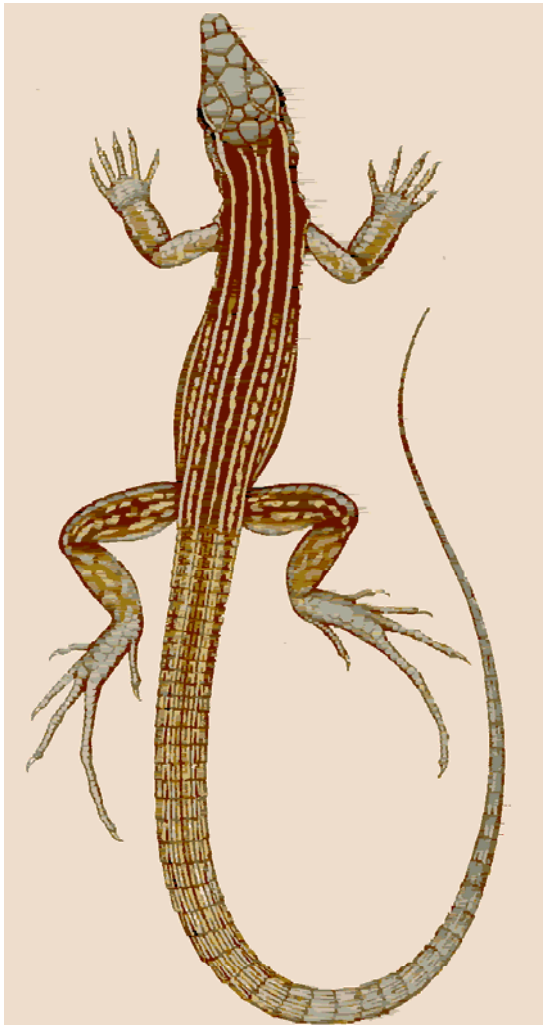
- Universal definition
  - Recombination and outcrossing (mating)
  - Mixing of genes
  - Reproduction?



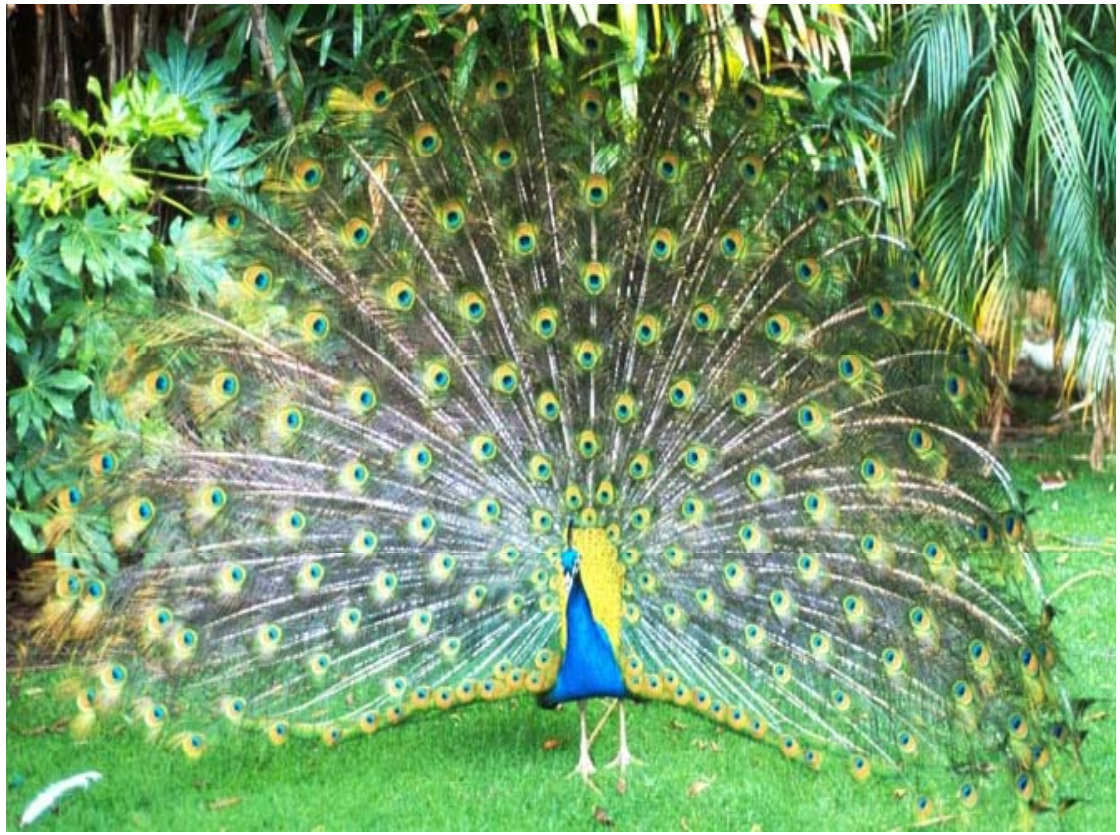
Sex and reproduction may be decoupled

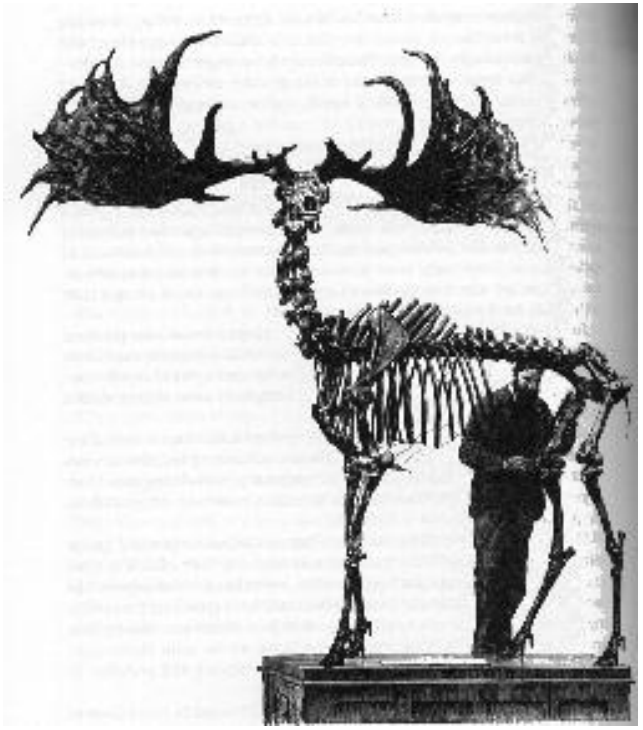
- Reproduction without sex
- Sex without reproduction





Sex is costly

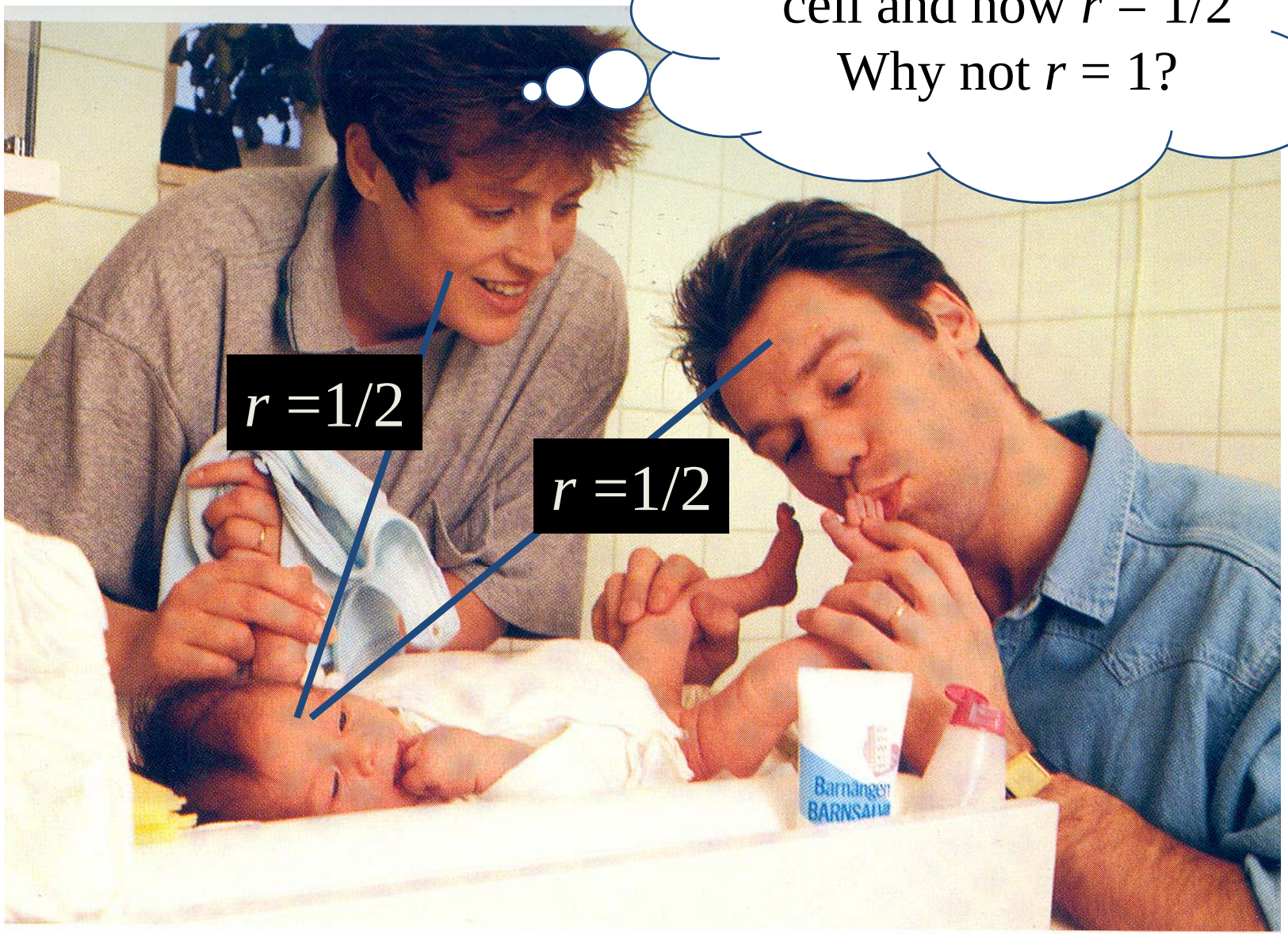




Parasites are a cost of sex

- Sexually Transmitted Diseases
  - Syphilis
  - Gonorrhea
  - Chlamydia
  - Genital herpes
  - Genital warts
  - Hepatitis B
  - AIDS
- Unfortunately, this makes perfect sense to the parasite

Genetic costs



Cost of males

		Adults time = t		Eggs		Adults time = $t+1$
Asexual	♀ ♀	n	→	kn	→	skn
Sexual	♀ ♀	N	→	$\frac{1}{2}kN$	→	$\frac{1}{2}skN$
	♂ ♂	N	→	$\frac{1}{2}kN$	→	$\frac{1}{2}skN$

Frequency Asexual: $\frac{n}{2N+n} \longrightarrow \frac{n}{N+n}$

What are the benefits of sex?

- Sex not necessary for reproduction
- Variation
- Rejuvenation
- Evolutionary biologists disagree
- The benefits are unclear
- Sex induced by stress

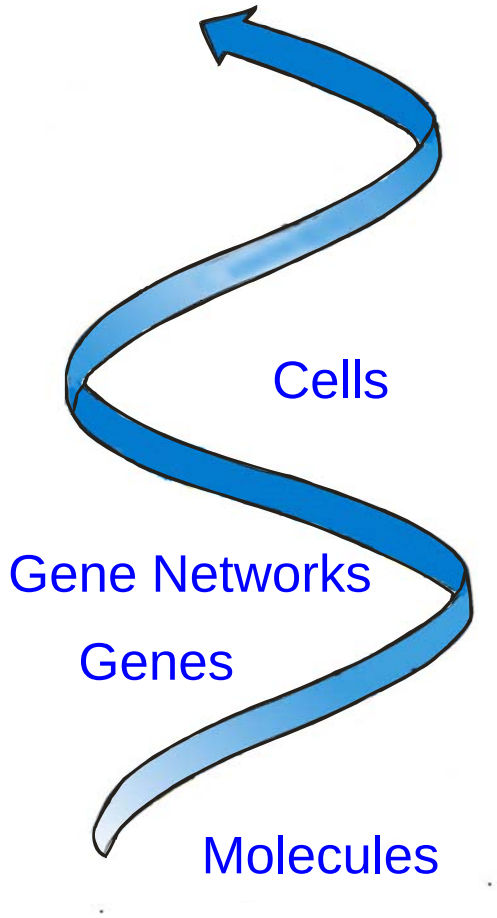
Paradox of sex

- Sex is costly
- Benefits are small or unclear
- Sex is common

Why is there sex?

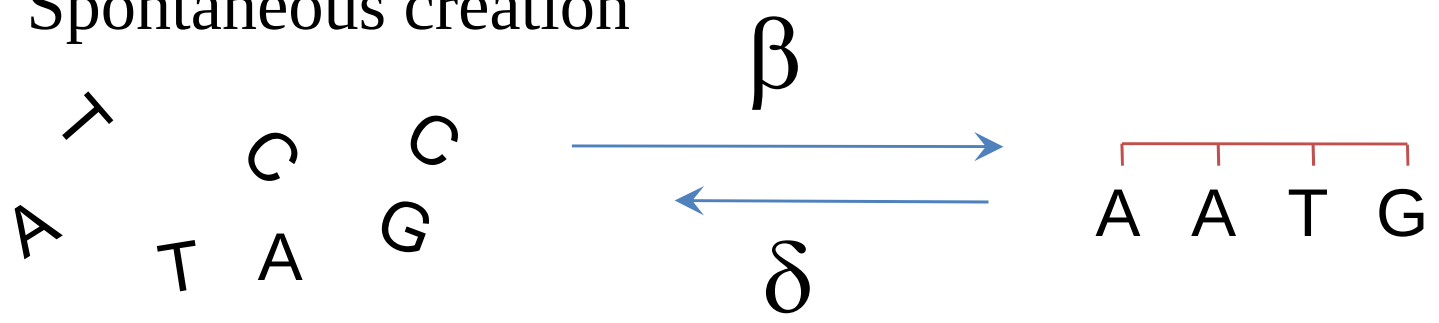
The first individuals were…

- Molecular Replicators
- Cooperative Groups of Replicators
- The First Cell

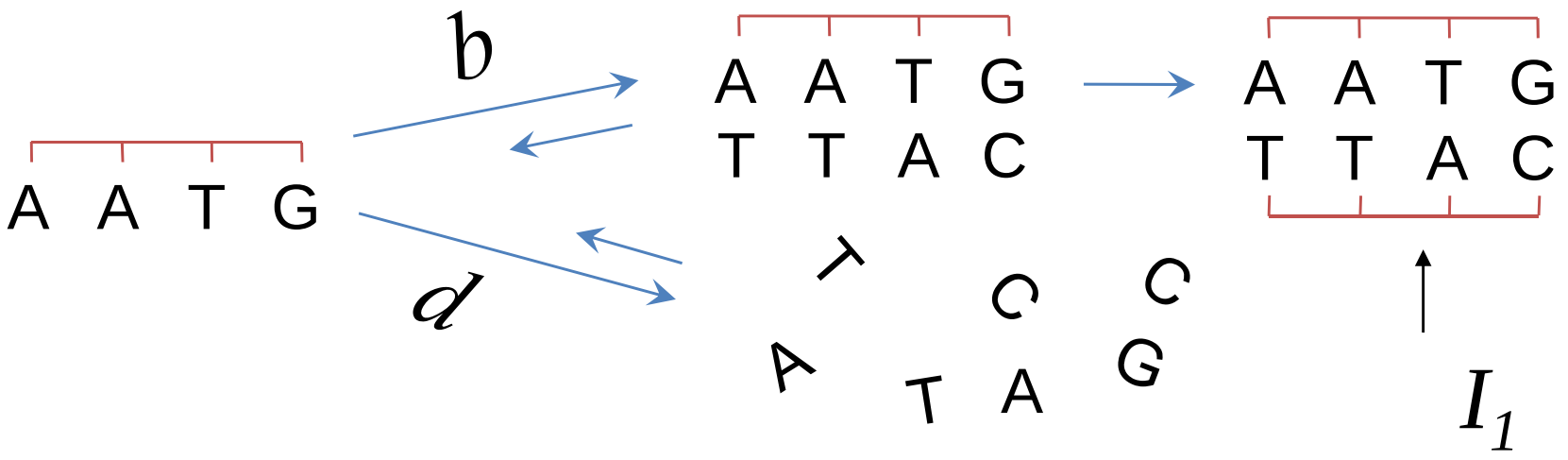


In the beginning …

Spontaneous creation

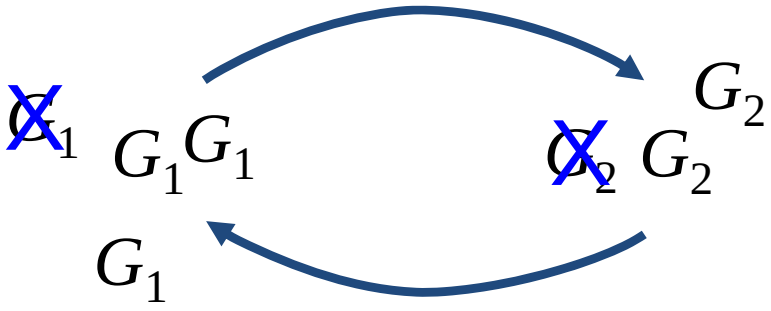


Replication



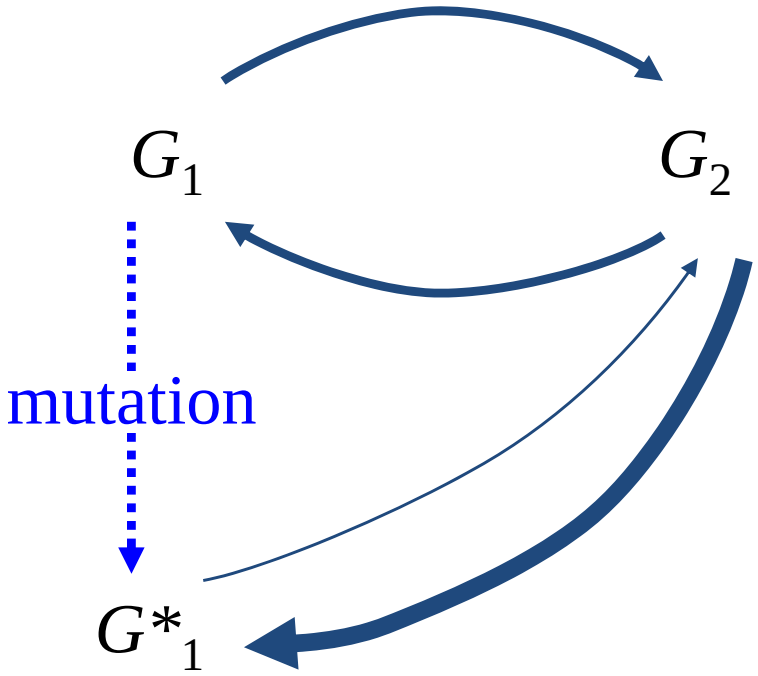
(*I* = informational molecule or gene used in next two slides)

Sex among genes



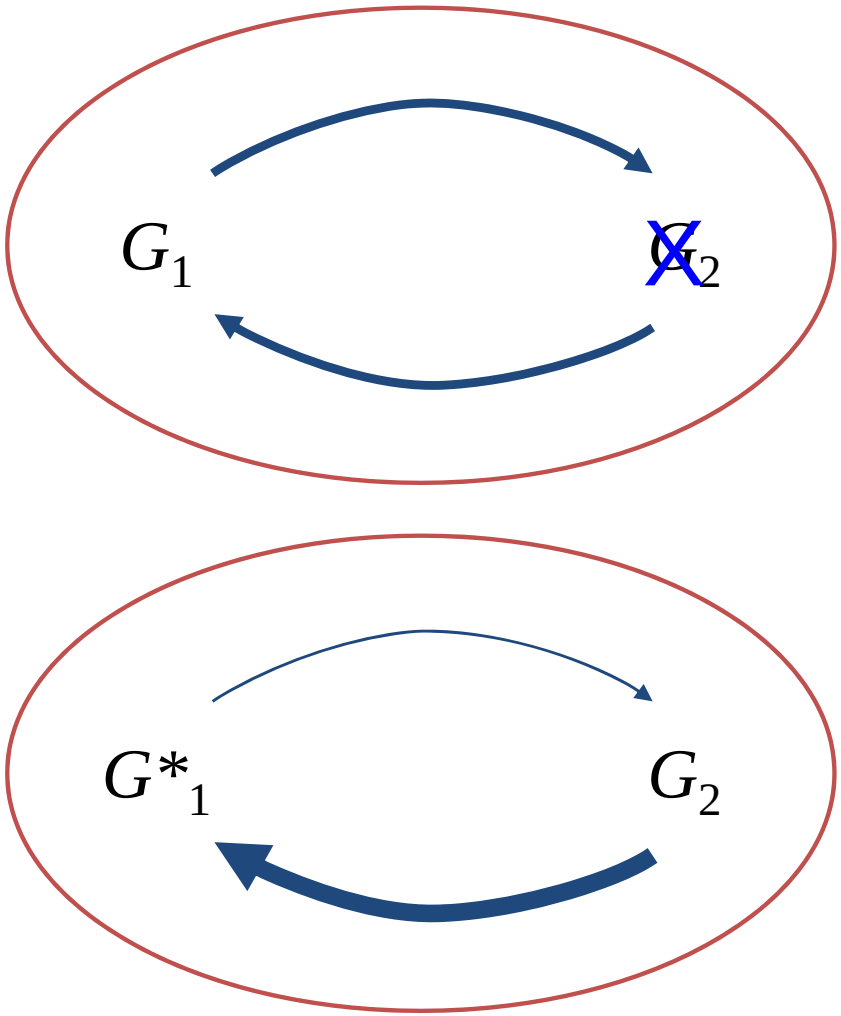
- Life is based on cooperative interactions among genes
- Living world born sexual
  - Advantage of mixing and gene repair
- Little individuality
  - Prone to cheating

Cheating in gene networks



- Selfish mutant: takes more, gives less
- Need for conflict mediation

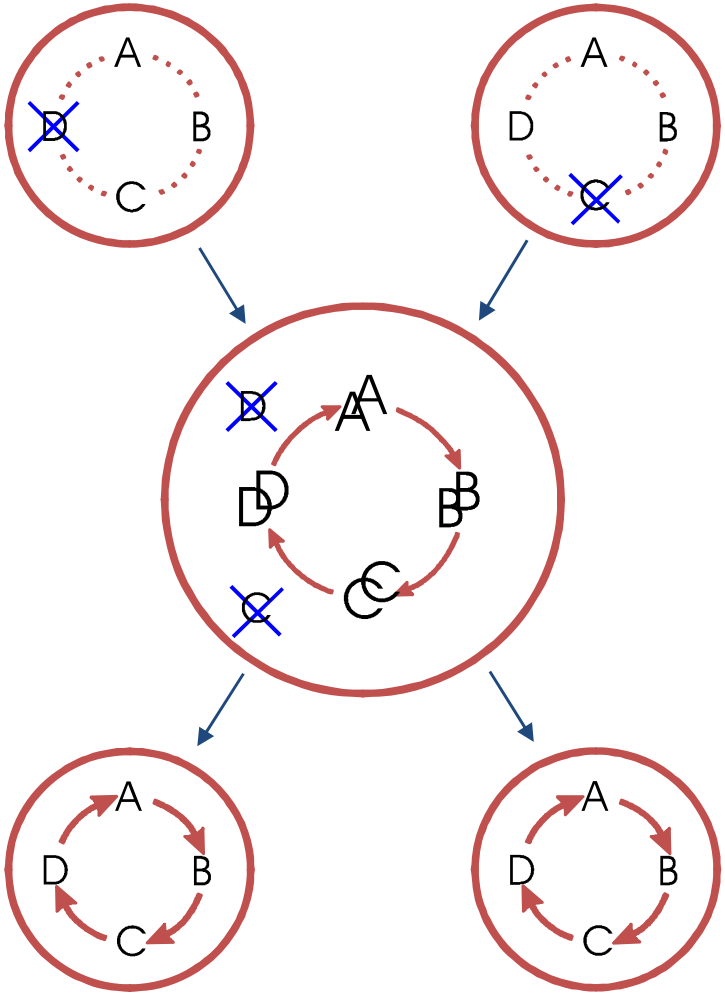
Cell evolved to mediate conflict



- Why is life cellular?
  - The cell aligns the interests of its members
  - Cells with selfish mutants do worse than cells with cooperative genes
- New problem
  - Errors trapped on the inside
- Re-invent sex among cells

Sex among cells

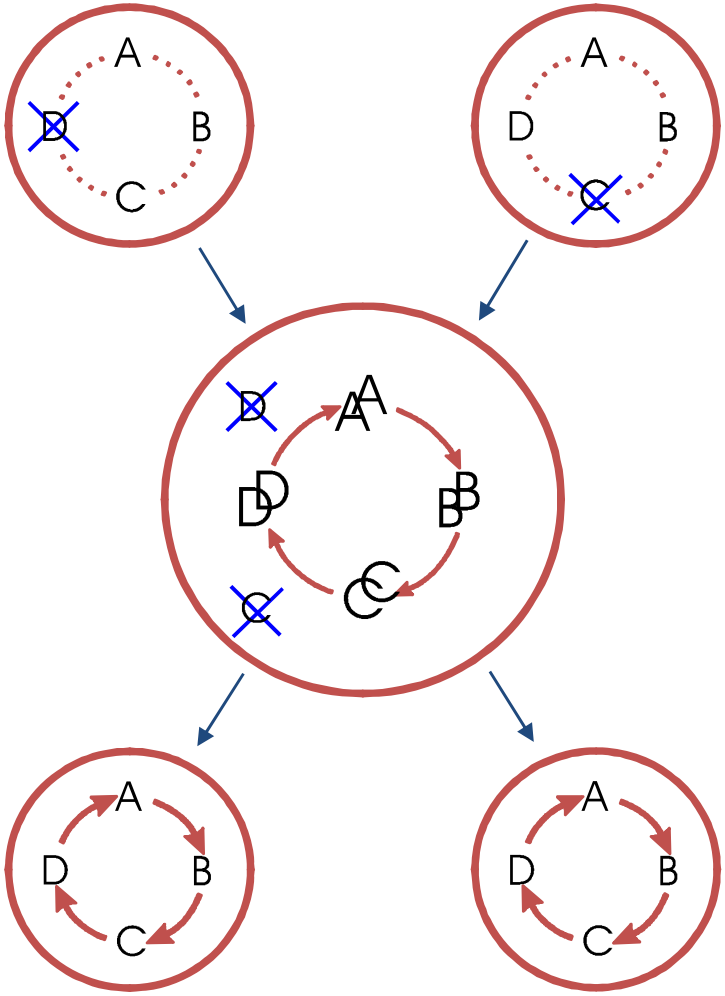
- Sex repairs error
- Keeps genes healthy
- Rejuvenates life



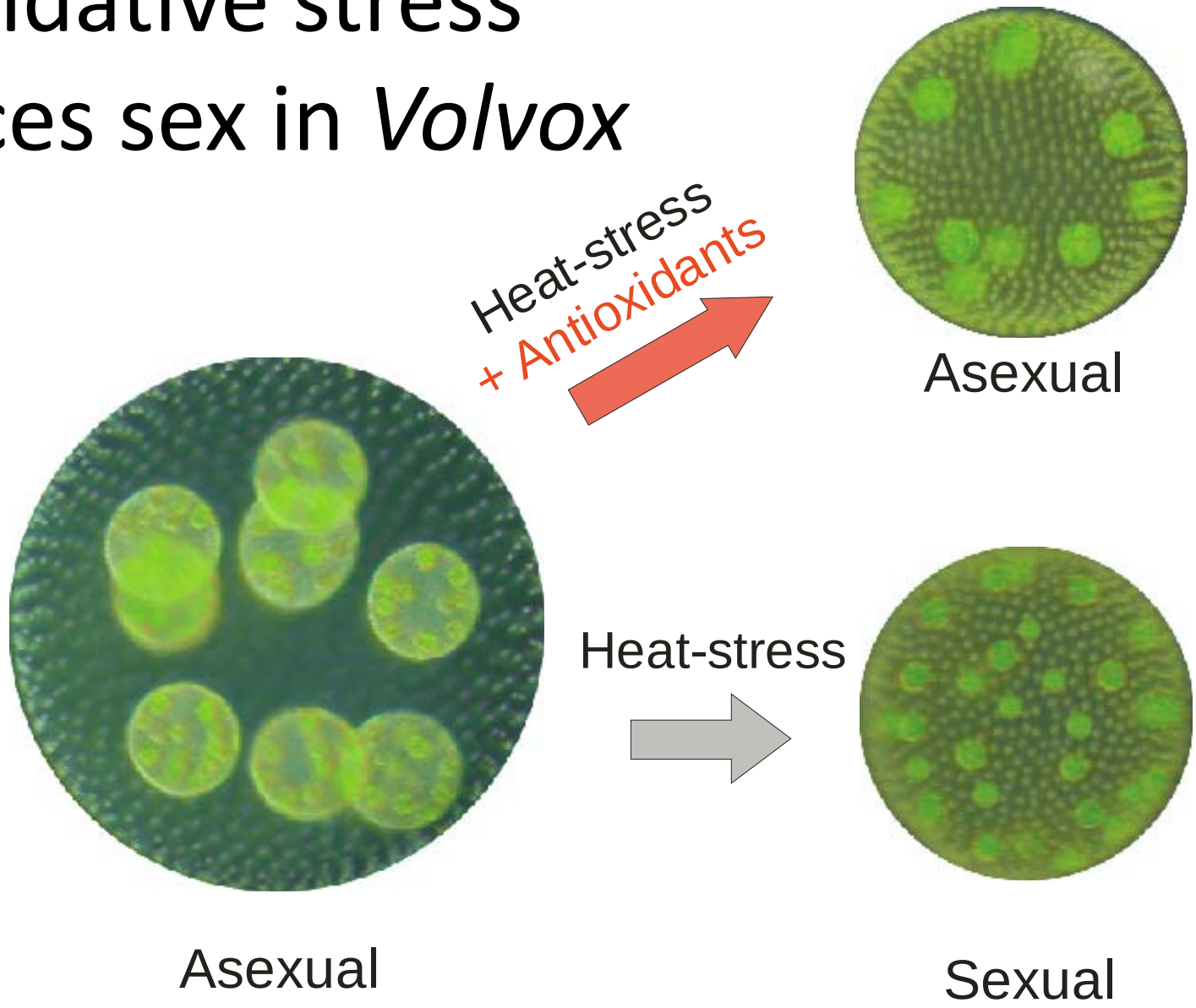
Why sex & stress?

- Life requires balance (redox balance)
- Stress upsets redox balance
- Stress creates oxidative compounds (= “ROS”)
- ROS are damaging to DNA
- Sex repairs damages and copes with mutation
- Immortality of life
- Prediction:

  Primary signal for sex is ROS and ROS-induced DNA damage

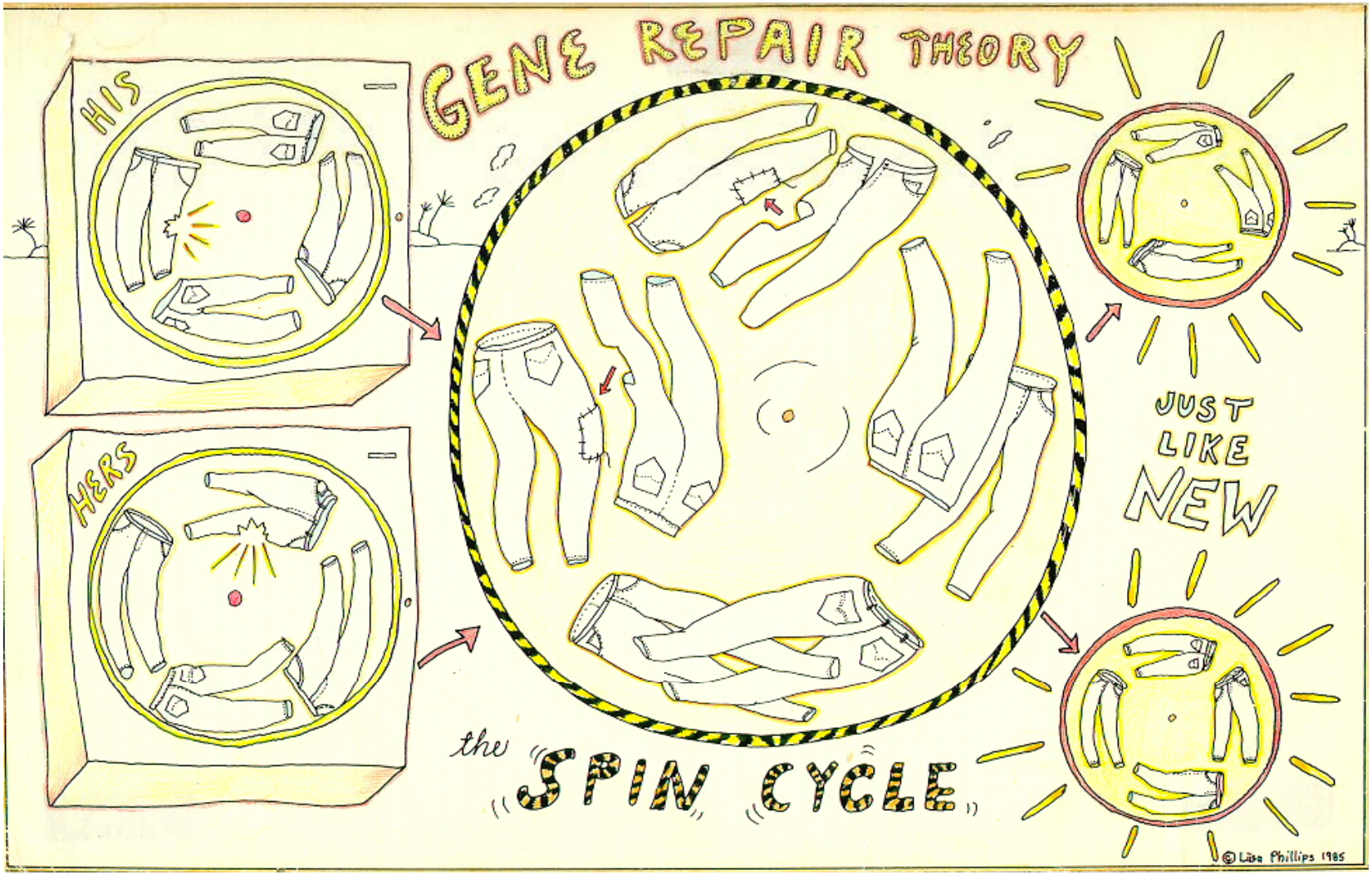


Oxidative stress induces sex in *Volvox*

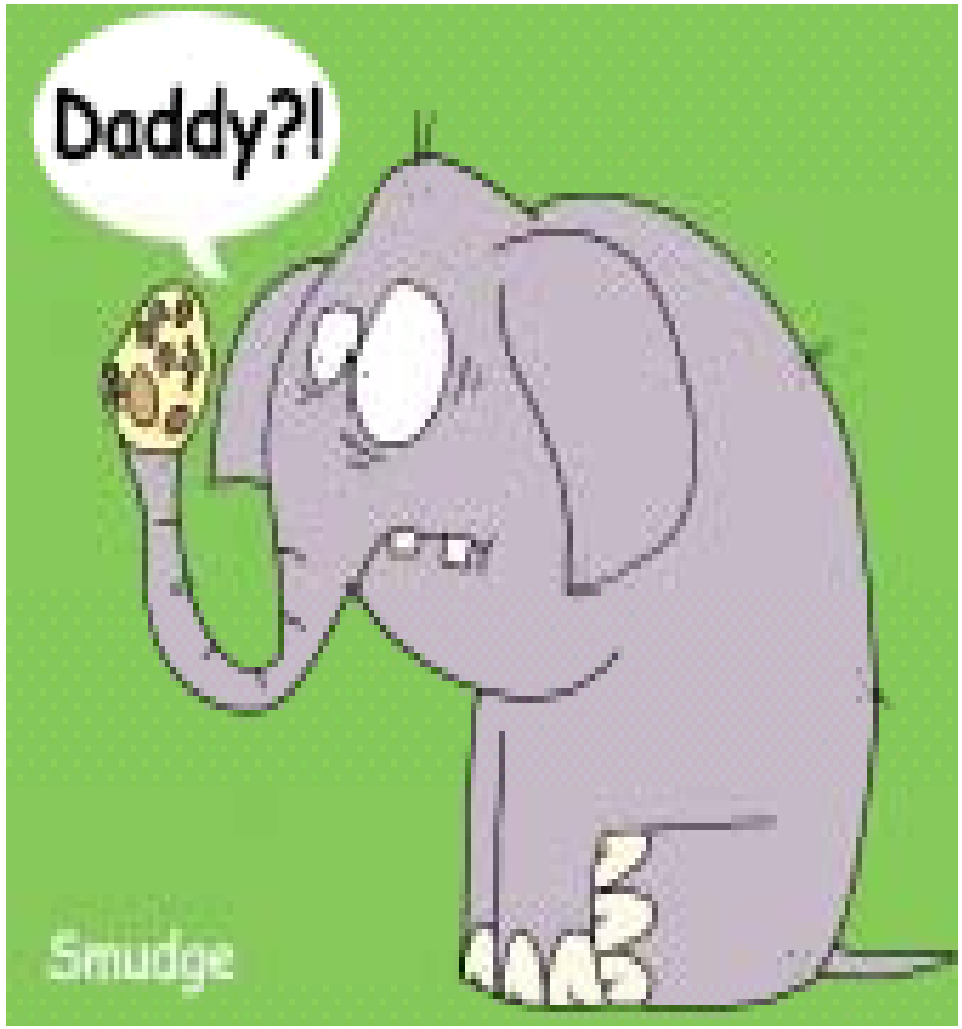


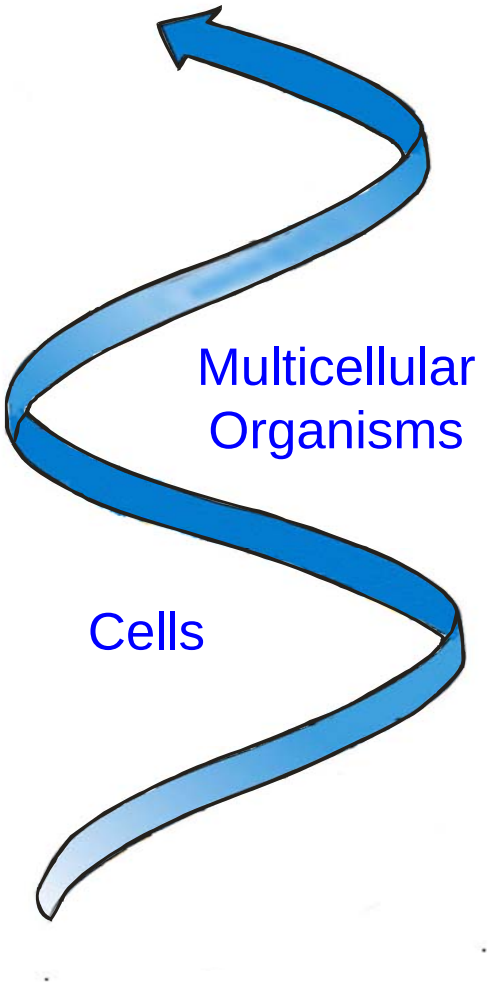
Credit: A. Nedelcu

Sex the “The Spin Cycle” keeps genes clean



Origin of multicellularity

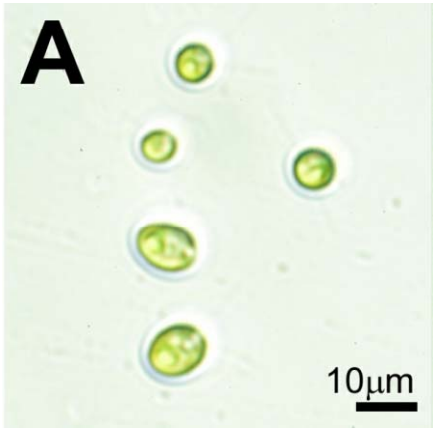


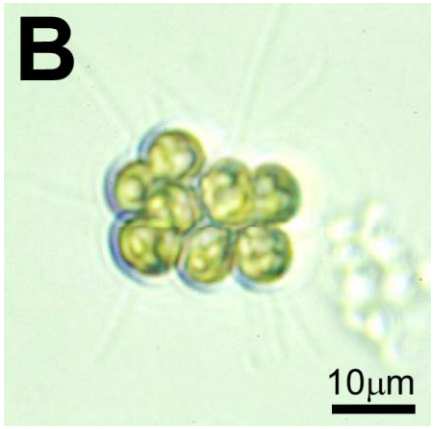


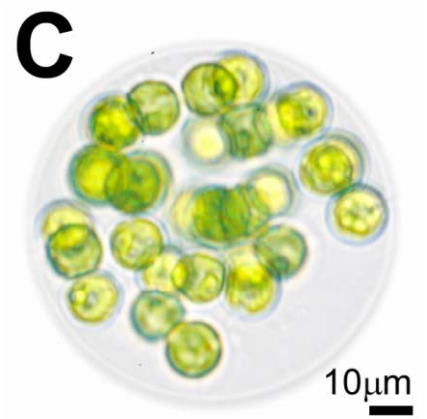
Multicellularity is a complex trait

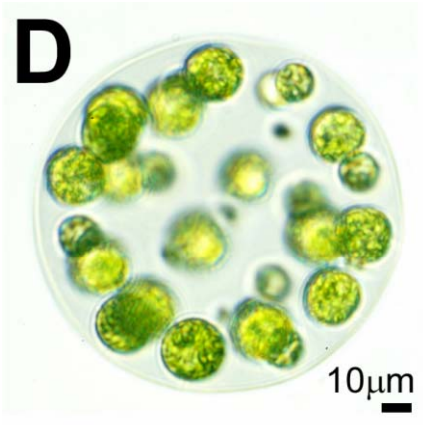
- Reduce this complexity to a set of steps each advantageous in itself
  - Group formation (why? how?)
  - Groups increase in size
  - Cells within groups cooperate and specialize
  - Conflict mediation so cheating is less likely
  - Group becomes indivisible and hence an individual

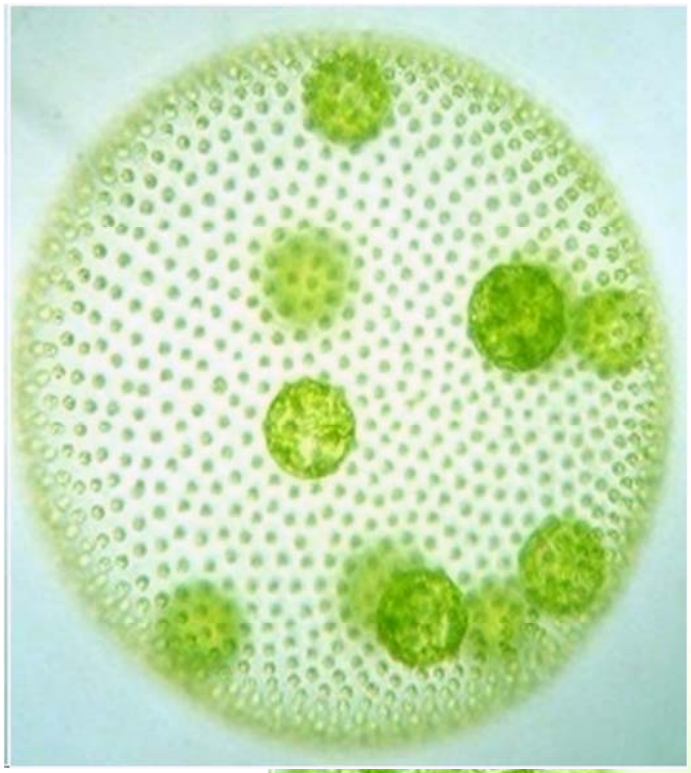
Volvocine algae illustrate these steps to multicellularity

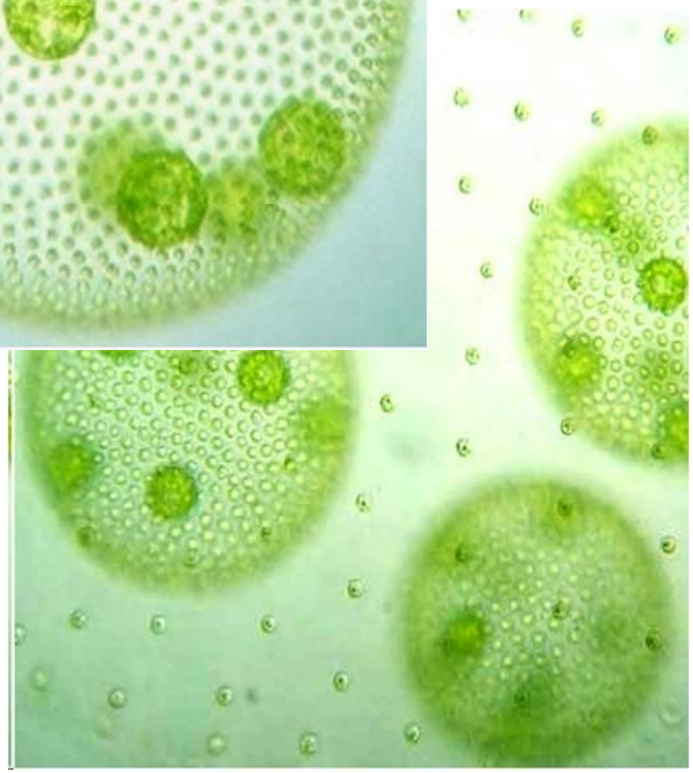








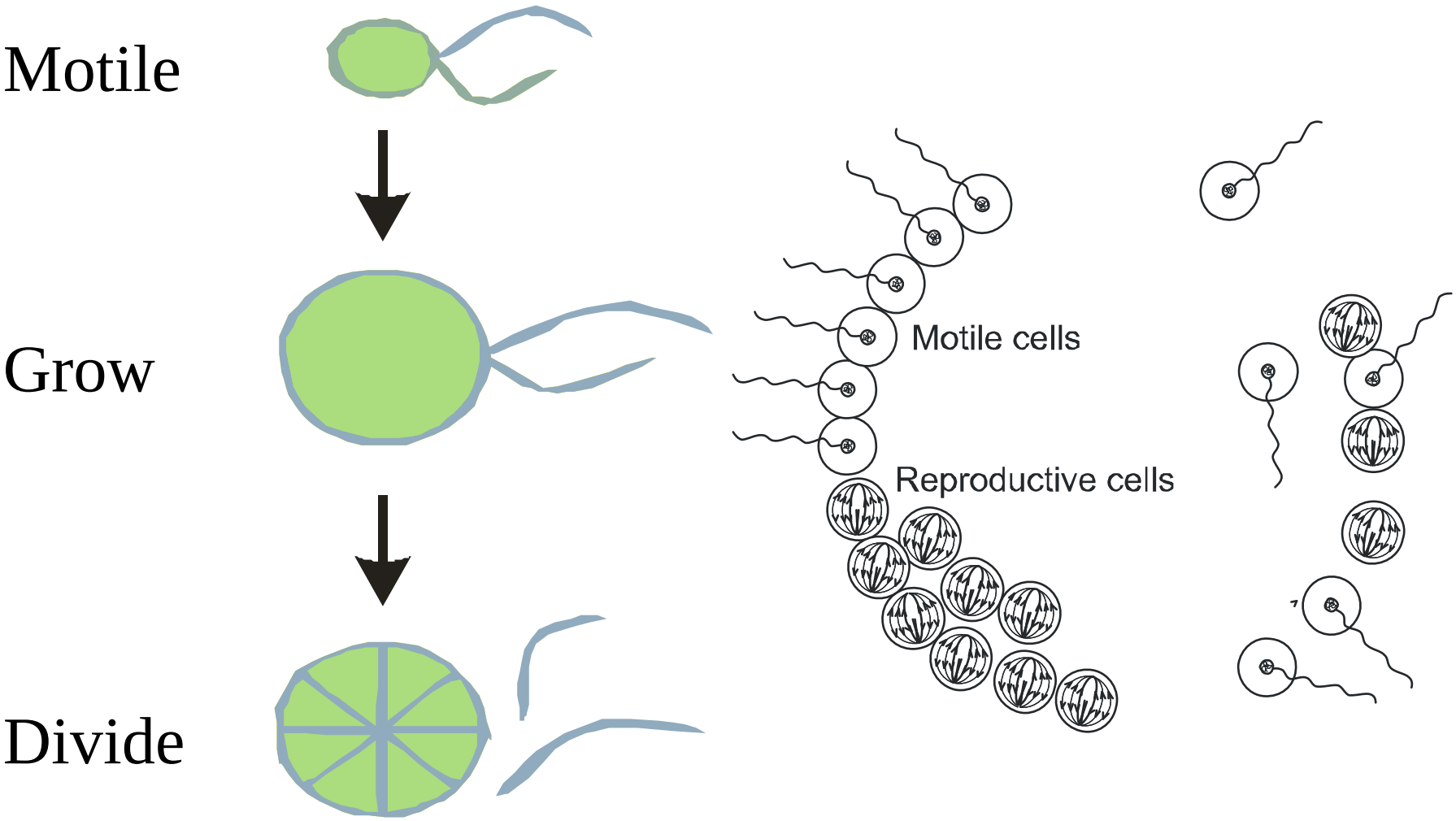




Why form groups?

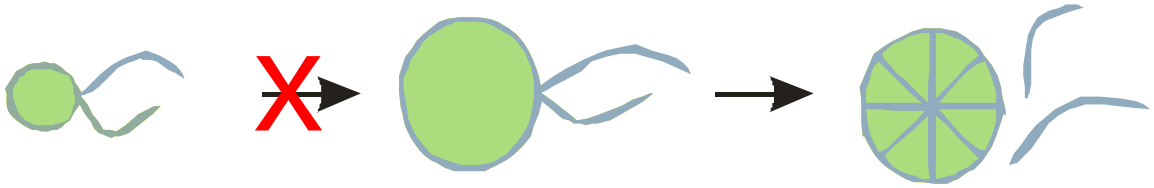
Multicellularity in real time

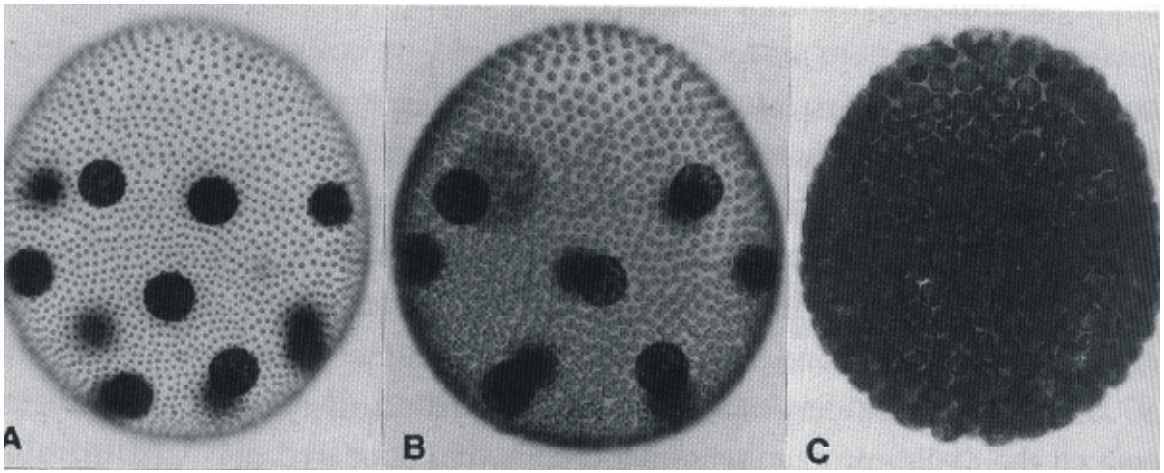
Cooperation in a mindless world



Altruism & cheating & cancer in *Volvox*

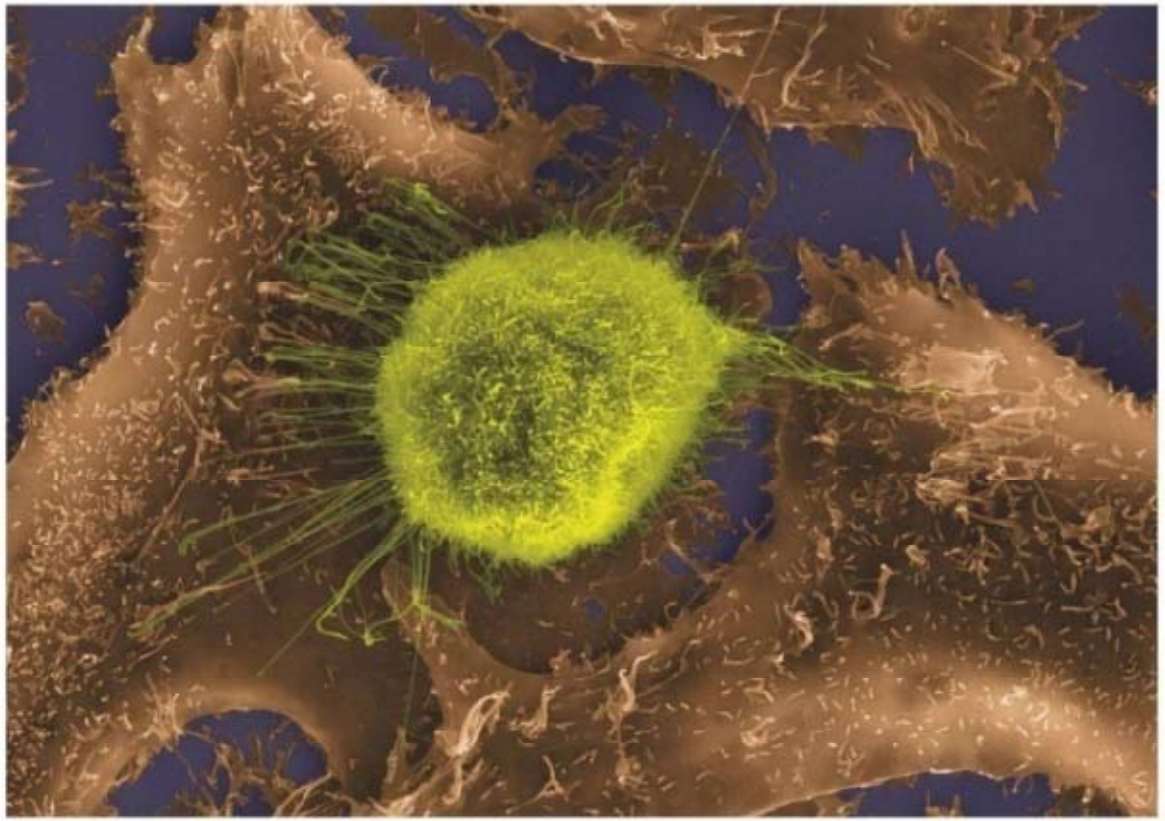
- *regA*
  - RegA represses chloroplasts
  - Keeps somatic cells small by starving them
  - Altruistic gene
  - Selfish mutants
- Origin of *regA*?





Kirk, D. 1998

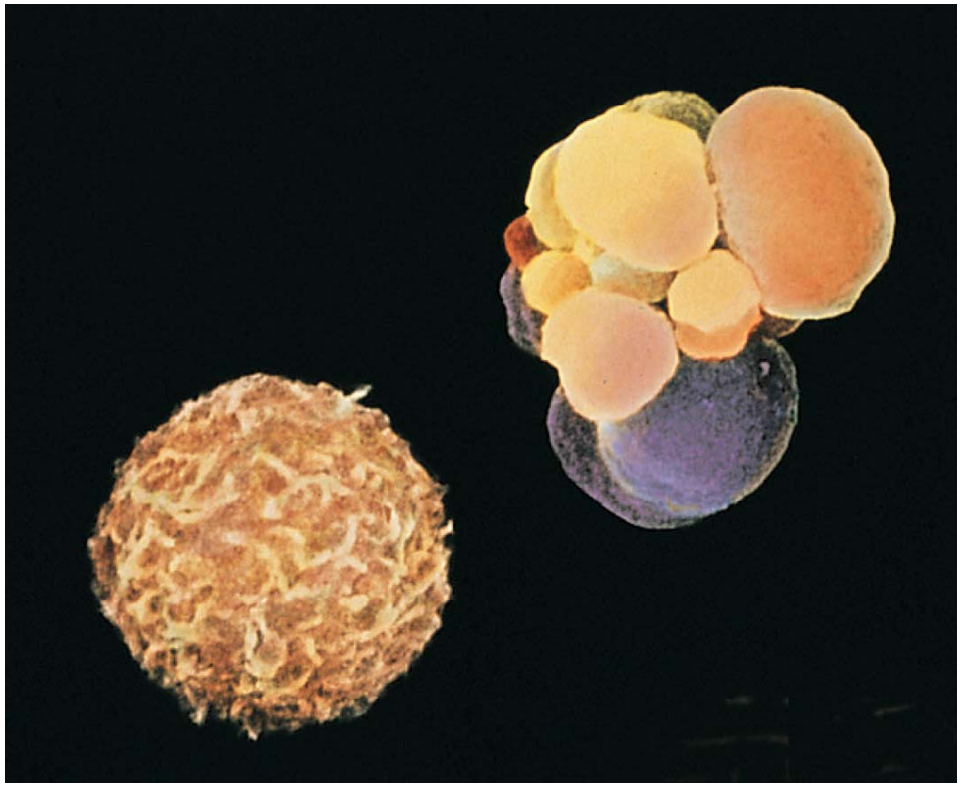
Cancer & conflict among cells



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 17.13 *A Cancer Cell with Its Normal Neighbors*

Conflict mediation inside humans: Cell suicide and immune system

Cell suicide of cheater (right) Normal cell (left)



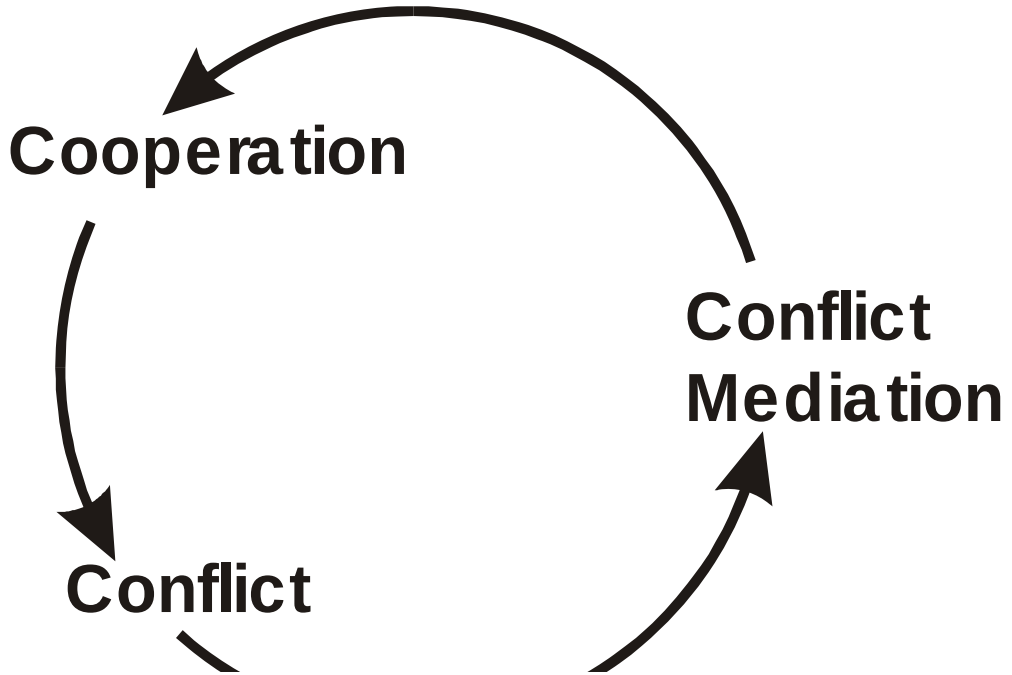
Police force. Immune system cells (orange) attack cheaters (purple)

Video of attack on cancer cell

CONCLUSIONS & IMPLICATIONS

Kinds of cooperation and conflict

ECM
Soma
Transfer of fitness to new level
Sex

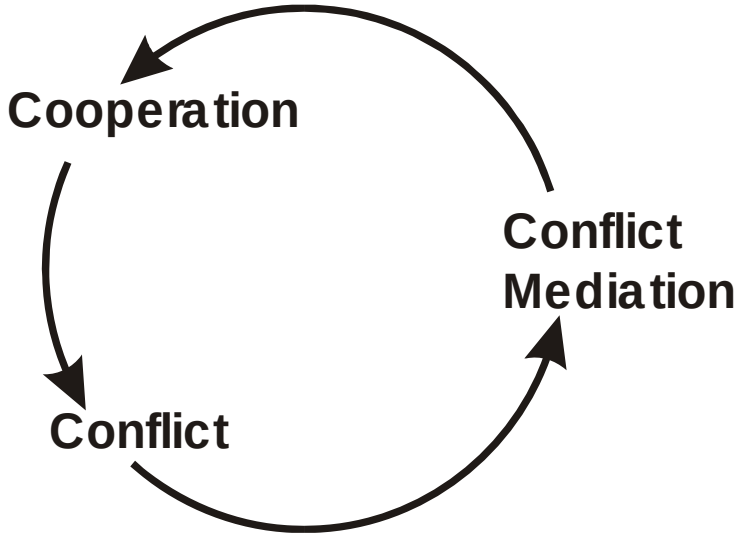


Fitness trade-offs
Selection levels
Stress
Genetic error
Manipulation
Sex

Individuality
Determinate growth
Sex
Germ/soma
Group living
Kinship
PCD
Development

Theme of talk

- *Basic properties of the living world emerge out of cooperation and conflict*
- Properties of life
  - Hierarchical Structure
  - Sociality
  - Individuality
  - Sex
  - Immortality
  - Aspects of human nature



Social Organisms

Sex reinvented — Multicellular Organisms

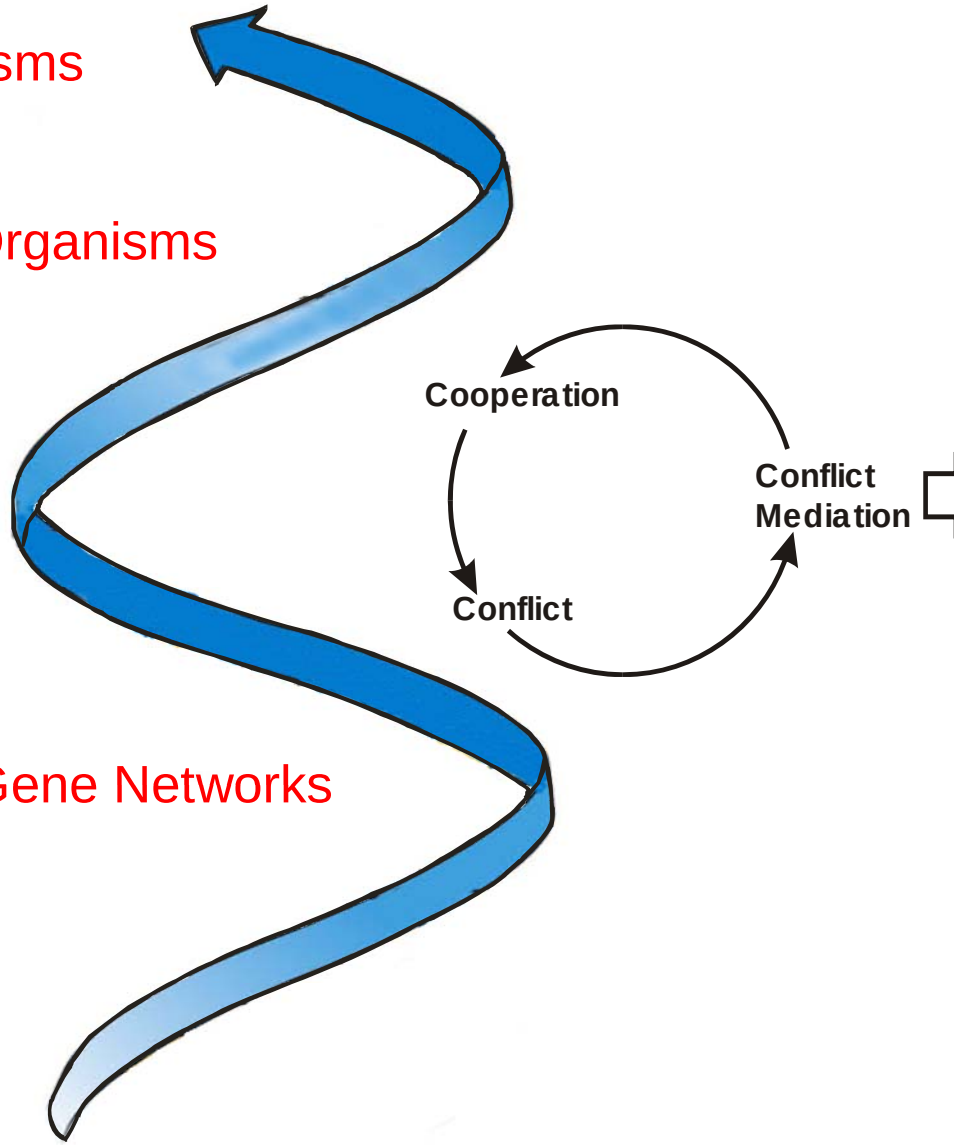
Sex reinvented — Cells in cells

Sex reinvented — Cells

Sex happened — Cooperative Gene Networks

Genes

Molecules



There is no progress in evolution, but the level of complexity can increase under certain conditions

Sex and individuality are in conflict

- Individuality
  - Requires closure
    - Mediates conflict
  - Facilitates adaptation
- Sex
  - Requires openness
    - Creates conflict
  - Promises a better future
    - Variation for new environments
    - Coping with genetic error
  - Rejuvenates life
  - Immortality of life

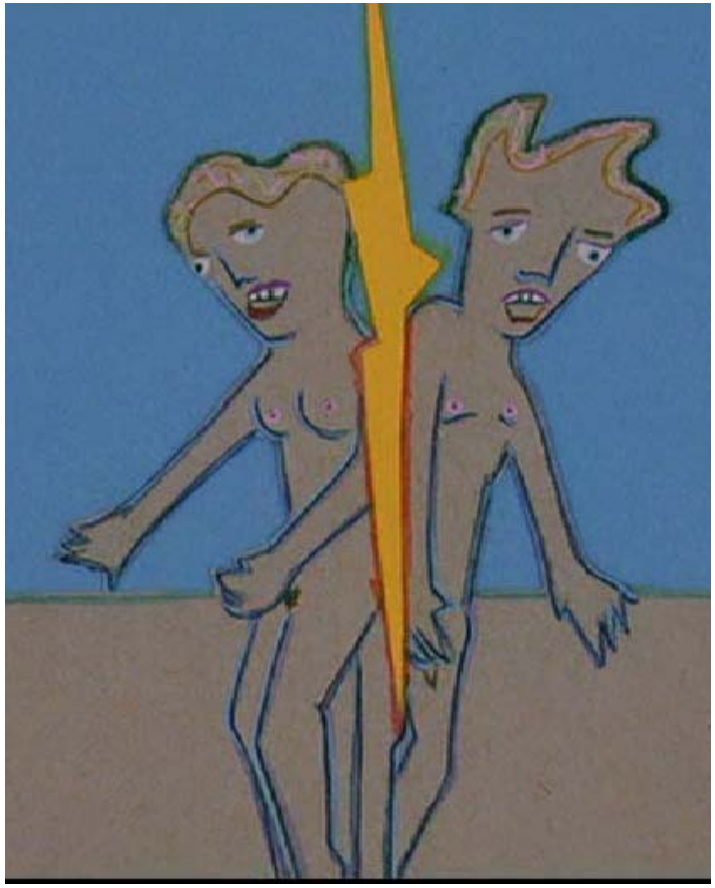
Both are necessary for life

Immortality of life

- Life arose once 3-4 billion years ago
- Life is passed on like a family hierloom (not created anew every generation)
- The cells in our body are mortal
- The cells in the germ line are immortal
- How does this come about?
  - Sex rejuvenates genes

Love is the pursuit of the whole

- Love and desire for immortality in Plato's *The Symposium*
- Aristophanes story…



Credit: Hedwig and the Angry Inch

Plato on love and immortality

- "...It is in this way that everything mortal is preserved, not by remaining for ever the same, which is the prerogative of divinity, but by undergoing a process in which the *losses caused by age* are *repaired* by *new acquisitio*[illegible] of a *similar kind*...it is in order t[illegible]ecure imm[illegible]tality th[illegible] each individual is haunt[illegible] by this *ea*[illegible] *desire a*[illegible]*d love*"

Genes in mate

Genetic error

Partner from same species

Are Humans the apex of cooperation?

- Social insects are routinely completely altruistic, but they comprise simple family groups
- Humans are unique in the extent of collective action involving diverse and extended networks
- Humans are prone to trust and cooperate
  - Resource sharing
  - Cooperative production
  - Aid-giving
  - Coalition based conflict (cooperate to compete)

Cooperation & conflict and human nature

- Humans are social animals
- We evolved in small closely knit groups in which individual survival depended on group survival
- Cooperation was key
- If our genes are selfish, they have built us to be cooperative, social & trustworthy
- Cooperation provides meaning and fulfillment to our lives
- Love keep us whole
- Cooperation feels good
- Enjoy!