No area of evolutionary biology offers ... a more fascinating mixture of strange phenomena ... than the evolution of sex...

(Stearns, 1987)
Sex

• Refers to union (SYNGAMY) of two genomes
  - usually carried by gametes
  - followed later by reduction (meiosis)

• Individuals need not have distinct sexes
  - defined as differences in size or structure of gamete
Sexual Dimorphism

- sexual dimorphism occurred late in evolution of life
  - major onset with the development of eukaryotes
  - feature of most vertebrates
Isogamous Organisms

- Isogamous - gametes are not distinct in size or shape
  - Many fungi (yeasts)
  - Algae
- Same size gametes unite if different mating type (+ or -)
Anisogamous Organisms

• **Anisogamous** - large (egg) and small (sperm) gametes
  - **GONOCHORISTIC** - individual can only be male or female
  - **HERMAPHRODITIC** - individual can be male and female
    • sequential
    • simultaneous
Gonochoristic

- Sexual phenotype is determined early in the life history of these animals
- Once established it persists throughout adult life
- Most common pattern of sex allocation
Sequential hermaphroditism

- producing both male or female gametes sequentially
  - not at same time

- Undergo sex reversal
  - Protoandry: male first
  - Protogyny: female first

- East Asian swamp eel
  - Presently invading Florida wetlands (protogyn)
  - Also observed in hagfish, reef fishes
Simultaneously hermaphroditic

- Simultaneously male and female
  - Not common
- Possess an *ovotestis* containing oogenic and spermatogenic tissue
- Most are not self fertilizing
- -2x the chance of meeting a potential mate
  - important in low density populations

*Rivulus marmoratus*
Acquired 'hermaphroditism'

- Deep sea ceratioid angler fish
- Male fish fuses body with female fish
  - shares blood supply and all his organs degenerate (except male reproductive organs)
Two parts to the evolution of sex

• 1) the origin of sexual reproduction (cellular evolution)
• 2) the evolution and maintenance of sexual reproduction and recombination

• Recombination
  - like sex in that it re-assorts genetic material
Advantages with Sex

- Recombination increases rate of adaptive evolution
  - Does sex increase the rate of evolution?
  - Does this explain the origin versus persistence of sex?
Problems with Sex

- Even if rate of evolution increased - two problems
  - 1) Recombination destroys adaptive combinations of genes
  - 2) cost of sex
    - Half of the offspring are males!
    - “cost of males”
Cost of Anisogamy

- Male contributes only the genome of the sperm
- Female ovum provides
  - Nuclear genes
  - Mitochondrial genes
  - Cellular environment necessary for embryonic development

Females invest more energy per viable gamete than males
Cost of meiosis

• Loss of genetic information
• Gametes contain $\frac{1}{2}$ of the parental genotype
  - Clonally reproducing form passes 100% of its genetic material on to offspring
  - Sexually reproducing form must produce 2 fit offspring to pass on the same amount of genetic material to the next generation
Cost of genetic recombination

- Genetic recombination dismantles two successful genotypes and recombines them into a novel combination in the next generation
- Adaptive allele combinations may be lost
- Recombined genome may not be as successful
  - May contain deleterious recessive alleles
Cost of mating

• Energetic costs of mating are associated with sexual dimorphisms and mating behaviors
• Increased risk of predation?
Immortality versus Mortality

- individual protozoans are potentially immortal
- multicellularity has a heavy price - individuals become mortal
Sex Must Be An Advantage

- Sexual reproduction persists in many, many populations
- Must be great enough to offset 2X disadvantage
Sexual Reproduction

• 1: can bring together beneficial mutations
  - aids in the spread of advantageous traits
• 2: can bring together deleterious mutations
  - severely unfit individuals eliminated
  - removal of deleterious genes
• 3: creates new gene combinations
  - maybe more fit than existing ones
Immediate Benefit Hypothesis

- Immediate benefit hypothesis
  - (Bernstein and Bernstein, 1991)
    - Molecular recombination facilitates DNA repair
      - Breaks/lesions in DNA molecule can be repaired by copying homologous chromosome
    - Formation of new gene combinations are a by-product of DNA repair
      - not reason for evolution of recombination/sex
Problem?

- DNA repair does not require meiosis or syngamy (fertilization)
- Permanent diploid species exist - thus can repair DNA without the above
- Origin of recombination could have been a response driven by need for DNA repair
  - but what about meiosis & syngamy?
DNA Repair

Healthy cell

rate of DNA damage = rate of repair

Diseased cell

rate of DNA damage > rate of repair

DNA replication

Damage

Metabolism

Exogenous damage

Endogenous damage

Repair

Nuclear DNA

Mitochondrial DNA

Unrepaired

Pathology

Cancer

Senescence

Apoptosis
Why Sex?

- **The Red Queen Theory**
  - "It takes all the running you can do, to keep in the same place." Red Queen - ‘Alice in Wonderland’

- **Parasite-host interactions**
  - Sexual reproduction persists because it enables species to rapidly evolve new genetic defenses against parasites
    - Guppy and snail species exhibit sexual reproduction when higher level of parasitism
      - (Dybdahl and Lively 1995; Howard and Lively 1994).
Additional Hypotheses

- Many
  - Fixation of rare beneficial mutations
  - Heterogeneous habitats
  - Deleterious mutations removed
    - Muller’s ratchet
Muller’s Ratchet

• Herman Muller (1964)
  - Nobel Prize for mutagenic effects of radiation

• Back mutation from deleterious to wild-type alleles is extremely rare
  - In asexual population mutations accumulate over time
  - Can’t be removed
  - Zero mutation genomes become rare, then extinct
Muller’s Ratchet

- Frequency of asexual individuals with different numbers of mutations at three time periods.
Evolution of Sexes

- **Anisogamy** evolved from **isogamy**
  - evolution of large versus small gametes

- **If:**
  - Large size enhances survival of offspring
    - Movement difficult
  - Selection for 'transport' of second gamete
**Sex vs. Gender**

**Sex:** either of the two major forms of individuals that occur in many species and that are distinguished respectively as female or male

- based on type of gonad/gamete produced

**Gender:** the behavioral, cultural, or psychological traits typically associated with one sex

Merriam-Webster online
Evolution of Gender

• Anisogamy gives rise to different mating types
  - (+ / -) (female/male)

• Recognition of opposite type has advantages
  - chemical (pheromones)
  - visual signals
    • secondary sex characters
      - coloration, horns, behavioral display