Meiosis & Sexual Reproduction (Ch. 11)
Cell division / Asexual reproduction

• Mitosis
  – produce cells with same information
    • identical daughter cells
    – exact copies
    • clones
  – same DNA

Aaaargh! I'm seeing double!
Asexual reproduction

- Single-celled eukaryotes
  - yeast (fungi)
  - Protists
    - *Paramecium*
    - *Amoeba*
- Simple **multicellular** eukaryotes
  - *Hydra*

What are the disadvantages of asexual reproduction?

What are the advantages?
How about the rest of us?

• What if a complex multicellular organism (like us) wants to reproduce?
  – joining of egg + sperm

• Do we make egg & sperm by mitosis?

![Diagram: Egg (46) + Sperm (46) → Zygote (92) with red crosses indicating "No!"

Doesn’t work!}
Human female karyotype

46 chromosomes
23 pairs
Human male karyotype

46 chromosomes
23 pairs
Homologous chromosomes

• Paired chromosomes
  – both chromosomes of a pair carry “matching” genes
  • control same inherited characters
  • homologous = same information
How do we make sperm & eggs?

• Must reduce 46 chromosomes → 23
  – must reduce the number of chromosomes by half

46 (meiosis) → 23 (egg) → 23 (fertilization) → 46

zgote
Meiosis: production of gametes

- Meiosis
  - chromosome number must be reduced
    - *diploid* → *haploid*
    - (*2n* → *n*)
      - humans: 46 → 23
  - makes *gametes*
    - *fertilization* restores chromosome number
      - *haploid* → *diploid*
      - *n* → 2*n*
Sexual reproduction lifecycle

- 1 copy
- haploid
- 1n

- 2 copies
- diploid
- 2n

- 1 copy
- haploid
- 1n

- 2 copies
- diploid
- 2n

In the next generation...
We're mixing things up here!
A good thing?
Meiosis

• **Reduction Division**
  – special cell division for sexual reproduction
  – reduce $2n \rightarrow 1n$
  – diploid $\rightarrow$ haploid
  • “two” $\rightarrow$ “half”
  – makes gametes
    • sperm, eggs

**Warning:** meiosis evolved from mitosis, so stages & “machinery” are similar but the processes are radically different. Do not confuse the two!
Overview of meiosis

Interphase 1

Prophase 1

Metaphase 1

Anaphase 1

Telophase 1

Prophase 2

Metaphase 2

Anaphase 2

Telophase 2

2n = 4

n = 2

n = 2
Double division of meiosis

DNA replication

1st division of meiosis separates homologous pairs

2nd division of meiosis separates sister chromatids
Meiosis 1

- 1st division of meiosis separates homologous pairs

- **synapsis**

- **tetrad**

- **prophase 1**

- **metaphase 1**

- **telophase 1**

- 2n = 4 single stranded

- 2n = 4 double stranded

- 1n = 2 double stranded

- **reduction**
Meiosis 2

- 2nd division of meiosis separates sister chromatids

What does this division look like?
Meiosis 1 & 2

Prophase I

Metaphase I

Anaphase I

Metaphase II

Anaphase II

Telophase II
Trading pieces of DNA

- **Crossing over**
  - during **Prophase 1**, sister chromatids intertwine
    - homologous pairs swap pieces of chromosome
      - DNA breaks & re-attaches
Crossing over

- 3 steps
  - cross over
  - breakage of DNA
  - re-fusing of DNA

- **New combinations of traits**

What are the advantages of **crossing over** in sexual reproduction?
Mitosis vs. Meiosis

**Mitosis**

- **Prophase**
  - Duplicated chromosome (two sister chromatids)
  - Chromosome replication

- **Metaphase**
  - Chromosomes align at the metaphase plate

- **Anaphase Telophase**
  - Sister chromatids separate during anaphase
  - Daughter cells of mitosis: 2n

**Meiosis**

- **Prophase I**
  - Chiasma (site of crossing over)
  - Tetrad formed by synopsis of homologous chromosomes

- **Metaphase I**
  - Tetrads align at the metaphase plate

- **Anaphase Telophase I**
  - Homologous chromosomes separate during anaphase I; sister chromatids remain together
  - Daughter cells of meiosis I: 2n

- **Meiosis II**
  - Daughter cells of meiosis II: n
  - No further chromosomal replication; sister chromatids separate during anaphase II
Mitosis vs. Meiosis

• **Mitosis**
  - 1 division
  - daughter cells genetically **identical** to parent cell
  - produces **2 cells**
  - $2n \rightarrow 2n$
  - produces **cells for growth & repair**
  - no crossing over

• **Meiosis**
  - 2 divisions
  - daughter cells genetically **different** from parent
  - produces **4 cells**
  - $2n \rightarrow 1n$
  - produces **gametes**
  - crossing over
Putting it all together...

meiosis → fertilization → mitosis + development
The value of sexual reproduction

• **Sexual reproduction introduces genetic variation**
  – genetic recombination
  • **independent assortment** of chromosomes
    – random alignment of homologous chromosomes in Metaphase 1
  – **crossing over**
    • mixing of alleles across homologous chromosomes
  – **random fertilization**
    • which sperm fertilizes which egg?

– providing variation for natural selection
Variation from genetic recombination

- Independent assortment of chromosomes
  - meiosis introduces genetic variation
  - gametes of offspring do not have the same combination of genes as gametes from parents
- Random assortment in humans produces $2^{23} (8,388,608)$ different combinations in gametes
Variation from **crossing over**

- Crossing over creates completely new combinations of traits on each chromosome
  - creates an infinite variety in gametes
Variation from random fertilization

• Sperm + Egg = ?

– any 2 parents will produce a zygote with over 70 trillion ($2^{23} \times 2^{23}$) possible diploid combinations (not even counting crossing over!!!!!!!!!!)
Sexual reproduction creates variability

Sexual reproduction allows us to maintain both genetic similarity & differences.
Sperm production

- **Spermatogenesis**
  - continuous & prolific process
  - each ejaculation = 100-600 million sperm
Egg production

- **Oogenesis**
  - eggs in ovaries halted at Metaphase 1
  - Meiosis 1 completed during maturation
  - Meiosis 2 completed after fertilization
  - 1 egg + 2 polar bodies

What is the advantage of this development system?

Meiosis 1 completed during egg maturation

Meiosis 2 completed triggered by fertilization

Unequal divisions
Oogenesis

MEIOSIS I
- first polar body

MEIOSIS II
- after fertilization
  - secondary oocyte (haploid)
  - ovum (haploid)

- germinal cell (diploid)

- fertilization

- primary follicles
- fallopian tube
- primary follicle with secondary oocyte
- developing follicle
- mature follicle with secondary oocyte
- ruptured follicle (ovulation)
- corpus luteum

Putting all your egg in one basket!
Differences across kingdoms

- Not all organisms use haploid & diploid stages in the same way
  - which one is dominant (2n or n) differs
  - but still alternate between haploid & diploid
- *must* for sexual reproduction
What are the **DIS**advantages of sexual reproduction?

Eggs are Precious, Sperm is Cheap. Any Questions??

What are the **DIS**advantages of sexual reproduction?
Review Questions
1. How do cells at the completion of meiosis compare with cells that have replicated their DNA and are just about to begin meiosis?

A. They have twice the amount of cytoplasm and half the amount of DNA.

B. They have half the number of chromosomes and half the amount of DNA.

C. They have the same number of chromosomes and half the amount of DNA.

D. They have half the number of chromosomes and one-fourth the amount of DNA.

E. They have half the amount of cytoplasm and twice the amount of DNA.
2. Which number represents $G_2$? *

A. I  
B. II  
C. III  
D. IV  
E. V
3. Which number represents the DNA content of a sperm cell?
A. I
B. II
C. III
D. IV
E. V

Diagram:
- DNA content/cell
  - 4X
  - 3X
  - 2X
  - 1X

Time
4. Which of the following would not be considered a haploid cell?
   A. daughter cell after meiosis II
   B. gamete
   C. daughter cell after mitosis in gametophyte generation of a plant
   D. cell in prophase I
   E. cell in prophase II
5. A cell in G₂ before meiosis compared with one of the four cells produced by that meiotic division has

A. twice as much DNA and twice as many chromosomes.
B. four times as much DNA and twice as many chromosomes.
C. four times as much DNA and four times as many chromosomes.
D. half as much DNA but the same number of chromosomes.
E. half as much DNA and half as many chromosomes.