3 VARIATION IN CHROMOSOME NUMBER & STRUCTURE

3.1 Chromosome Number in Different Species

In "higher" organisms (diploids), members of same species typically have identical numbers of chromosomes in each somatic cell. Diploid chromosome number (2n). Nearly all chromosomes will exist in pairs (identical wrt length and centromere placement) except the sex chromosomes. Members of pair are homologous chromosomes. Haploid number (n) is the number of chromosome pairs.

<table>
<thead>
<tr>
<th>Species</th>
<th>2n</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human</td>
<td>46</td>
<td>23</td>
</tr>
<tr>
<td>Horse</td>
<td>64</td>
<td>32</td>
</tr>
<tr>
<td>Cat</td>
<td>38</td>
<td>19</td>
</tr>
<tr>
<td>Geometrid moth</td>
<td>224</td>
<td>112</td>
</tr>
<tr>
<td>Tomato</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Pink bread mold</td>
<td>14</td>
<td>7</td>
</tr>
</tbody>
</table>

See other examples in text

3.2 Autosomal monosomy and trisomy

Occasionally, one finds an organism that has an extra copy of a particular chromosome. This is known as trisomy--because there are now 3 copies of an autosome. Some trisomies are viable in animals, but the condition usually has severe effects. These effects are presumably related to the fact that there are 3 copies of every gene on the trisomic chromosome, but only 2 copies of all the genes on the other chromosomes. We will see later, that organisms with three or more copies of all the chromosomes are often perfectly viable.

Trisomy of human chromosome 21 is the cause of the disorder known as Down syndrome. (Remember, humans have 23 pairs of chromosomes--the pairs are numbered 1 through 22,
plus the X and Y). It is characterized by multiple physical defects, including epicanthal fold, furrowed tongue, characteristic palm and finger print patterns, and lowered IQ. About 1 in 750 live births produces a child with this condition. It results from the non-disjunction of chromosome 21 during meiotic anaphase I or anaphase II, when the paired homologs (or paired chromatids) normally migrate to opposite poles of the cell.

**Nondisjunction:** The members of a chromosome pair (homologs) line up at the metaphase plate during meiotic metaphase I, then separate to opposite poles of the cell during anaphase I--review this material in Cambell or any introductory Genetics text if you are not thoroughly familiar with it!). If the pair fails to separate, and both migrate to the same pole, half of the resulting gametes will have two copies of chromosome 21, rather than one. When this gamete unites with a normal gamete (bearing one copy of chromosome 21) during fertilization, the resulting gamete has 3 copies of chromosome 21, rather than the normal 2. Non-disjunction of chromosome 21 seems to occur more often in the production of eggs than sperm, and the frequency increases with the age of the parent. Older individuals are often encouraged to test for trisomy 21 by amniocentesis at 15 to 16 weeks after conception. Non-disjunction can happen to other chromosomes in addition to chromosome 21. But human embryos that are trisomic for any other chromosome do not survive to birth.

It should be obvious that the other half of the gametes resulting from a non-disjunction event at anaphase 1 will have 0 copies of the chromosome. When a gamete with 0 copies of a chromosome unites with a normal gamete, the result is a zygote that has only one copy of that chromosome. This is monosomy. **Monosomy is not well tolerated in animals**--usually lethal. Some plants can survive (observed in maize, tomato, Oenothera, and Datura) but they have low viability and are usually sterile.

Nondisjunction can also occur at anaphase II, when sister chromatids fail to separate and migrate to opposite poles. Nondisjunction at anaphase one results in half the gametes being normal, and half being abnormal (see diagram in text).

If one surveys karyotypes of embryos that spontaneously abort, trisomies for all the autosomes are seen, and other forms of chromosomal abnormalities as well, but these conditions are apparently fatal early in development. **Normal embryonic development requires a precise diploid complement of chromosomes.**

![Chromosomal Abnormalities Occurring in Human Fetuses](image-url)
Exception to general lethality of monosomies and trisomies occurs if they involve mammalian sex chromosomes. These monosomies and trisomies are often viable because of **X-inactivation** and because the Y contains few genes. We will discuss X inactivation later in this course.

An extra X chromosome also has fewer deleterious effects than an extra autosome. This is because, in mammals, all X chromosomes except one are inactivated very early in embryonic development. If this were not the case, then females would have twice as many active X-linked genes as males, and would therefore have twice as much of all the protein products produced by these genes. The inactivation of one of the two X chromosomes in females equalizes the **gene dosage** of X-linked genes--**dosage compensation**. This topic will be covered in more detail in a later lecture.

### 3.3 Chromosomal Rearrangements:

We have so far considered only variation in chromosome number. Variations in chromosome structure also exist, and also cause characteristic genetic effects. We will consider deletions and duplications of parts of whole chromosomes, and inversions and translocations of sections of chromosomes.

#### 3.3.1 Deletions

Sometimes a chromosome will arise in which a segment is missing. These chromosomes are said to have **deletions**. Deletions are generally harmful, and typically, the larger the deletion, the more harmful it is. Small deletions are often viable if the deletion is heterozygous, because the other chromosome contains copies of the genes missing in the chromosome with the deletion. But even small deletions are usually lethal if they are homozygous. A deletion on one homologue can "unmask" recessive alleles on the other homologue--this effect is called pseudo-dominance.

```
  a
___________•________    _________•________  &  --- region lost at meiosis
```

**Heterozygote for deletion during Meiotic pairing of homologs:**

```
  a
___________•________ any recessive genes will be expressed (pseudodominance)
      _____•_______
```

"Unmatched" part of top chromosome forms a loop. **Deletion loop (see text).**

**Homozygotes for deletions often lethal.**

#### 3.3.2 Duplications

```
A B C D E       A B C B C D E
________________•____  __________________________•_____
```

3
Duplication often results in reduction of viability, but in general duplications are less severe in their effects than are deletions.

**Heterozygote for duplication during meiotic pairing of homologs:**

```
A    B    C    B    C    D    E
-----------------------------•----
A    B    C    D    E
```

"Unmatched" part of top chromosome forms a loop. **Duplication loop (see notes).**

**Heterozygotes and homozygotes for small duplications can be viable**, although often exhibit phenotypic effects (Bar eye in *Drosophila*).

Duplication may be important in generating multiple copies of genes that require very high levels of expression (**gene amplification**)--rDNA codes for genes producing RNA for construction of ribosomes. Also may be source of evolutionary origin and divergence of genes coding for similar (but not identical) proteins (**alpha and beta globin components of hemoglobin**)

### 3.3.3 Inversions

Chromosomes can sometimes break and rejoin in a different orientation. If this happens in a germ cell, the gametes will contain a **rearrangement or inversion**.

```
A    B    C    D    E
-----------------------------•----
A    D    C    B    E
```

**Inversion Heterozygotes:**

```
A    B    C    D    E
--------------------------•----

--------------------------•----
A    D    C    B    E
```

**Crossing-over within an inversion**

a) **Paracentric Inversion.** If the inversion does not includes the centromere, then the chromatids resulting from **crossing-over** may have no centromere (**acentric**) or two centromeres (**dicentric**).
b) **Pericentric Inversion.** If the inversion does include the centromere, then the chromatids resulting from crossing-over all have centromeres, but some will contain duplications or deletions for parts of the chromosome.

Inversions repress recombination (crossing over!)

Inversions and evolution: If loci inside an inversion affect a single trait (or suite of related traits), this means they'll be inherited together and allele combinations won't be broken up by recombination.

A suite of tightly bound loci which affect a single trait is collectively known as a **SUPERGENE**.

mimicry coloration in some species of butterflies
snail shell color pattern (some species)

**3.3.4 Translocations (Reciprocal)--Two nonhomologous chromosomes**
5% of people with Down Syndrome have one parent who is heterozygous for a translocation. Chromosome 14 is translocated onto chromosome 21. See text figure 4.29 (Overhead). Half the time, meiosis produces a normal set of balanced translocated chromosomes. But half the time, unbalanced chromosomes are produced, either a 14 w/out the translocated 21 segment or a translocated 14 with the attached 21 plus a normal 21.

### 3.4 Chromosome rearrangements in evolution

Chromosomal rearrangements are not just rare abnormalities. Many kinds of rearrangements have no deleterious effects, and some may be beneficial (e.g., duplications are the source of novel gene functions and allow evolutionary increase in gene number). Comparisons among species show that chromosomal rearrangements have occurred repeatedly throughout evolutionary history.

**SYNTENY** (from the Greek syn, "same" and tene, "thread"). Simply defined, SYNTENY is the presence in two different species of segments of DNA with the same gene sequences. Synteny provides evidence that multiple translocations and chromosomal rearrangements of originally similar chromosomes has been an important feature of evolutionary change.

Example: human vs. mouse genome:

![Diagram](image)

### 3.5 Other variations in numbers of chromosomes—Polyploidy

**POLYPLOIDY** results from having additional whole haploid sets of chromosomes. If a normal diploid individual is said to have 2n chromosomes, and a normal gamete is said to have n chromosomes, then polyploid individuals can be represented as: 3n, 4n, 6n, 8n, etc. Polyploidy is rare in many groups of animals, but we do observe it in fish, amphibians, and lizards.
Polyplody is much more common in plants (plants hybridize more easily than animals many are self-fertile). **Nearly half of all flowering plants (including many important crops) are polyploids!** Can result from nondisjunction of entire chromosomes sets, or from hybridization between different species with chromosomes that don’t “match up”.

<table>
<thead>
<tr>
<th>AUTOPOLYPLOID</th>
<th>ALLOPOLYPLOID</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sets of chromosomes from the same species. Diploid gamete fuses with normal haploid gamete.</td>
<td>Combos of chromosomes from different species. Hybridization between closely related species.</td>
</tr>
</tbody>
</table>

**Autotriploid.** Many domestic plants are autopolyploids. **Usually sterile.** Problems at meiosis if there are odd numbers of chromosome sets (3,5, etc.). Unbalanced gametes. Some "seedless" varieties of fruit are polyploid.

**Bananas** are triploid, produce unbalanced gametes, and are propagated by cuttings. Other crops are autotetraploid. Meiosis can proceed normally if there are even numbers of chromosome sets.

**Allotetraploid.** May produce new species! Non-homologous sets of chromosomes cannot synapse at meiosis. But if both sets are doubled (mitotic failure), all chromosomes now have a homolog to pair with, meiosis can take place normally.

**Wheat** (*Triticum aestivum*) descended from 3 diploid ancestors each of which contributed a diploid set of chromosomes *AABBCC*.

### 3.6 Polyploidy and Speciation

Some species are sufficiently closely related that their genes, when combined in a hybrid individual, provide the necessary information for a viable organism--but not for that organism to undergo normal meiosis.

Homo sapiens 2n - 46

Pan troglodytes 2n - 44

Hybrid between the two would be 2n = 45.
(BUT THIS HAS NOT HAPPENED, DESPITE WHAT THE WEEKLY WORLD NEWS WILL TELL YOU.)

In some cases, closely related species *can* hybridize, and if their chromosome sets differ in number, each chromosome in the hybrid is univalent (i.e., it has no homologous "mate"), and meiosis cannot proceed normally (no synapsis; no crossing over; random segregation of c'somes into forming gametes; inviable gametes)

Viable hybrids have been produced in the laboratory, and it's possible that they could occur in similar fashion in natural situations. Here's an example of an artificially produced new species.

*Brassica oleracea* (cabbage) x *Raphanus sativa* (radish)

Both species 2n = 18; n = 9

Breeding between the two species produces an allodiploid F1 generation in which 2n = 18 (but actually is 9 + 9, since the chromosomes are not homologous).

But if somatic doubling (i.e. nondisjunction) occurs in a meristematic cell. Result: 2n = 36. In effect, each parental chromosome set has "created" its own homologous set and migrated with it into a new cell.

The cell is said to be allotetraploid.

At this point, normal meiosis, complete with synapsis and crossing over can occur. Because these plants are usually self-fertile, they can produce offspring, even if there is only one such individual. This "new genus/species" was named Raphanobrassica.

Backtracking through natural matings of other species, one can see how new species may be produced via the non-finicky mating habits of some plant species.

Animals can also produce allopolyploids (e.g. horse x donkey yields a mule; lion x tiger yields a liger or tigon). In mammals, these crosses tend to be sterile, but many fish and reptile species are thought to have arisen as polyploids (e.g, trout, whip lizards).

Why is polyploidization more common in plants than in animals?

# animals have chromosomally determined sex, and polyploidy interferes with this.

# animals have multiple biological isolating mechanisms (geographic, temporal, behavioral etc.) which tend to prevent natural interbreeding between species.

# plants retain meristematic tissue throughout their lives and are self-fertile: these conditions are favorable for successful allopolyploidy.