FRST302: Forest Genetics

Lecture 1.1: Classical Genetics and its Molecular Mechanisms

Outline for Today

- Short history of genetics
- Mendel's laws
- Chromosomes

What is genetics?

What is genetics?

Genetics is the study of genes, of variation and heredity across all branches of the tree of life

What are the major questions in genetics?

History of Genetics

Humans have probably pondered inheritence for all history:

- For much of history, the mechanisms of inheritence were basically unknown
- The inheritance of acquired characteristics was widely accepted for much of history (from Hippocrates to Aristotal to Lamarck)

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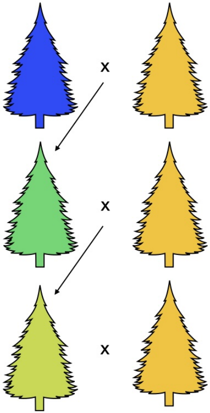
- *Early microscopists thought that they had seen small humans inhabiting sperm cells!*

1

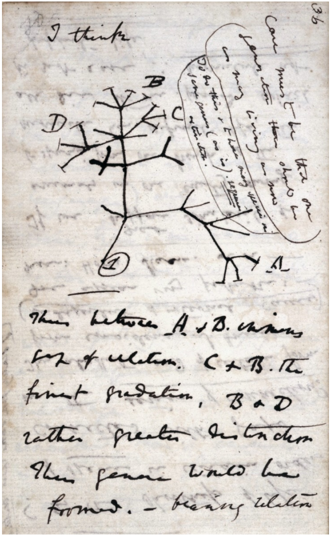
By the 19th Century, the dominant theory was **blending inheritance**

- The notion that an offspring's traits are simply the average of the parents' traits.
- This is intuitively appealing - continuously varying traits are often intermediate between their parents
- *There is one big problem with blending inheritance!*



What's the big problem with blending inheritance?

Darwin’s Thoughts on Inheritance



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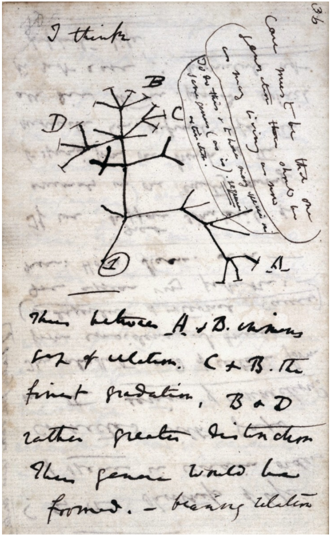
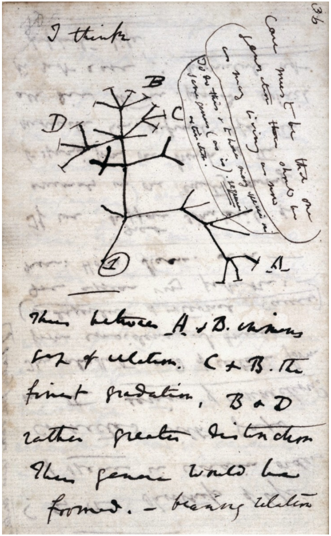


"'The laws governing inheritence are quite unknown; no one can say why the peculiarity in different individuals of the same species... is sometimes inherited and sometimes not so" [a]

Darwin's Thoughts on Inheritance



"'The laws governing inheritence are quite unknown; no one can say why the peculiarity in different individuals of the same species... is sometimes inherited and sometimes not so" [a]

But, Darwin clearly appreciated the limitations of blending and felt the need for an alternative:

"Each parent transmits it peculiarities, therefore if varieties allowed to cross... such varieties will be constantly demolished" [b]

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[a] *Ch. 1, The Origin of Species, C. Darwin 1859*

[b] *Foundations of the 'Origin of Species', F. Darwin 1909*

Trait Variation

Blending inheritence only really makes sense when you are thinking about continuously varying traits

But different modes of variation are common:

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- Continuous - traits measured on a numerical scale (e.g. height, diameter, chlorophyll fluorescence)
- Discrete - traits that exhibit categorical differences (e.g. different leaf forms, distinct flower colour)
- Ordinal - discrete traits with some informative order (e.g. high, medium and low shade tolerance)

Particulate Inheritance

Through careful experimentation analysing discrete traits in peas, Augustinian Friar Gregor Mendel found evidence supporting a model of particulate inheritence

Mmmmm...
Peas Peas Peas Peas Peas

Particulate Inheritance

Particulate Inheritance: traits are passed from parent to offspring via particles

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Blending Inheritance

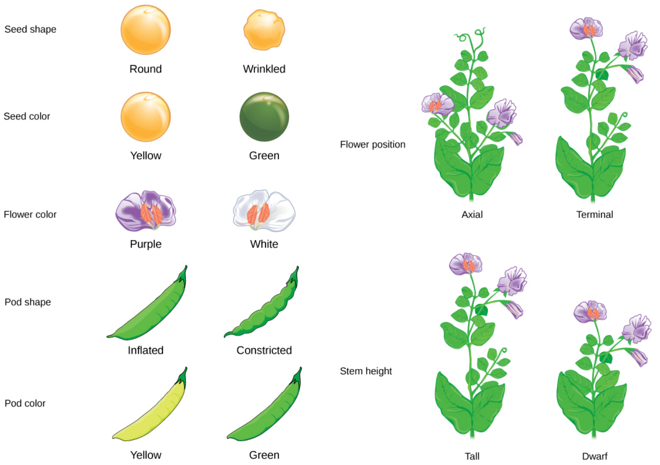
- Offspring exhibit averages of parental traits
- The "blended" traits are transmitted to offspring
- Variation is rapidly lost across generations

Particulate Inheritance

- Offspring exhibit *combinations* of parental traits
- Parental traits can manifest in offspring (or skip generations)
- Variation is maintained over time

Mendel's Crosses

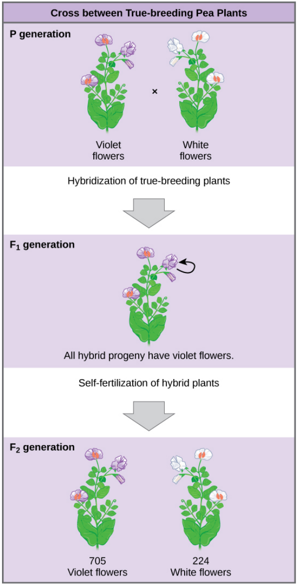
Mendel examined variation and inheritence of several discrete characteristics of pea plants



Mendel's Crosses

Garden peas are capable of self-fertilization, so Mendel was able to generate "true" lines of peas that exhibited a particular trait/phenotype

- Crossing lines produces an F1 generation
- The patterns of variation among the F2 generations were Mendel's focus



Mendel's Crosses

Note the 3:1 ratios of the two pea phenotypes in the F2

Mendel's Laws

The patterns of variation that Mendel observed led him to develop three laws of inheritance

- Law of Segregation
- Law of Dominance
- Law of Independent Assortment

The law of segregation: each individual possesses a pair of particles for any particular trait and each parent passes one of these randomly to its offspring

Mendel's Laws

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The law of independant assortment: when two individuals differ in more than two pairs of traits (e.g. smooth v. wrinkly and green v. yellow), the inheritance of one pair of traits is independent of another

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How does the image demonstrate **the law of segregation**?

Mendel's Laws

The law of segregation: each individual possesses a pair of particles for any particular trait and each parent passes one of these randomly to its offspring

How does the image demonstrate **the law of segregation**?

Answer: *Individuals (i.e. seeds) in the F2 generation exhibit a combination of seed colours and textures*

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How does the image demonstrate **the law of dominance**?

Mendel's Laws

The law of dominance: for some traits, the presence of one kind of particle masks the presence of another.

How does the image demonstrate **the law of dominance**?

Answer: *The uniformity of trait values in the F1 generation*

Mendel's Laws

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How does the image demonstrate **the law of independant assortment**?

Mendel's Laws

The law of independant assortment: when two individuals differ in more than two pairs of traits, the inheritance of one pair of traits is independent of another

How does the image demonstrate **the law of independant assortment**?

Answer: *The fact that wrinkly green peas and smooth yellow peas are seen in the F2 generation*

Mendel's Laws

I count 38 F2 seeds

13 Green : 25 Yellow
9 Wrinkly : 29 Smooth

Why do we see these ratios?

Mendelian Terminology

Remember, Mendel crossed "true" green (**G**) peas with "true" yellow (**Y**) peas.

The table below gives the results of the self-fertlization of the F1 generation

		GY	
		G	**Y**
YG	G	GG	**YG**
	Y	**YG**	**YY**

This table is an example of a Punnett square - Yellow phenotypes are shown in **bold**

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- Yellow is dominant to Green, so any offspring possessing a single Y particle will be yellow
- So $\frac{3}{4}$, (or 75% or 0.75)of the offspring are expected to be yellow
- With 38 F2 seeds, we would expect 28.5 seeds to be yellow, but **we would also expect variation around this number**

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	Y	YG	YY

- We use the term **homozygote** to refer to the offspring possessing the GG or the YY combinations
- We use the term **heterozygote** to refer to both YG and GY offspring as they are equivalent[a]

[a] but not always - see notes

Codominance

Codominance is a form of inheritance wherein both alleles in a heterozygote are equally expressed

As seen in this example from Sitka Spruce

 $\times$  $\rightarrow$

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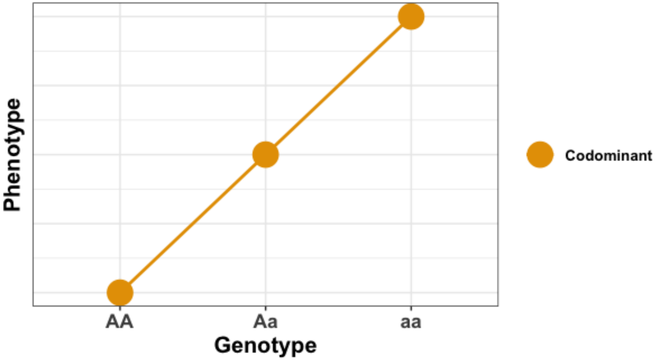
Codominance

Codominant and full dominance are just two domains on a continuous range

The degree of dominance can vary arbitrarily



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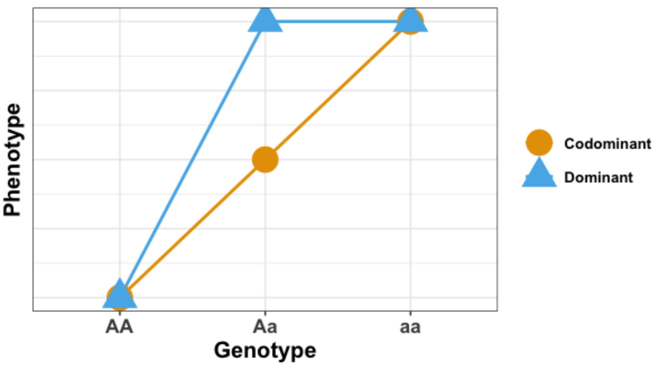

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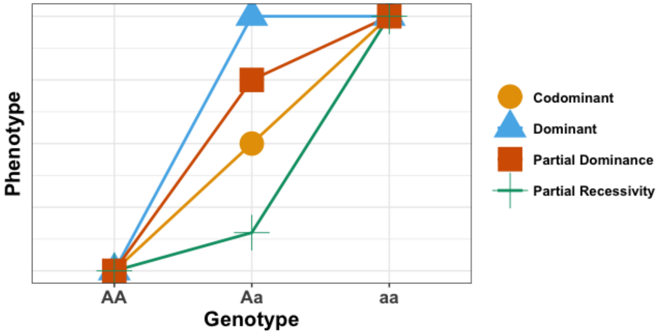

Crossing Experiments

Leaf phenotypes in European beech, *Fagus sylvatica*

$\times$

A leaf shape trait controlled by a single gene

Assuming the two individuals are homozygotes, how could you figure out if the allele for the cut leaf phenotype is dominant, recessive or codominant?

Test crosses are used to determine individual genotypes

In a test cross, individuals with unknown genotype (WW or Ww?) are crossed with individuals homozygous for a recessive trait (ww)

 × 

If any of the offspring exhibit the recessive phenotype, the unknown parent must be... ?

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In a test cross, individuals with unknown genotype (WW or Ww?) are crossed with individuals homozygous for a recessive trait (ww)

$\times$

If any of the offspring exhibit the recessive phenotype, the unknown parent must be... ? **Heterozygous**

Questions?

Questions?
Let's take a short break

Particulate Inheritance and Classical Genetics

- Proposed in 1865 and 1866
- 6-7 years after Darwin's Theory of Evolution
- As far as anyone knows, Darwin was totally unaware of Mendel *but see notes!*

- Represents the foundation of classical genetics
- **Classical genetics** refers to the study of genetic patterns observable from reproductive events

More peas please

Towards a Synthesis

Mendel's contributions were underappreciated in his time

Mendel's findings began to be appreciated early in the 1900s, largely thanks to the work of William Bateson and Edith Rebecca Saunders

Towards a Synthesis

The rediscovery of Mendel's laws kicked off a scientific feud

The Biometricians v. The Mendelians

Studying continuous variation	Studying discrete variation

Historians suggest that much of the debate was driven by personality rather than intellectual difference though

The rediscovery of Mendel's laws kicked off a scientific feud

The Biometricians v. The Mendelians

Studying continuous variation	Studying discrete variation

The debate boiled down to the following question:

How can the inheritence of discrete particles explain patterns of continuous variation?

Historians suggest that much of the debate was driven by personality rather than intellectual difference though

Reconciling the Mendelians and the Biometricians

Imagine a species of tree with a codominant trait we care about (let's say tree height) that is not affected by the environment

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In this species there is a single gene that controls height - with a pair of alleles (just like yellow v. smooth peas). The A allele does not affect height, but the a allele leads to a height of $+1$

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Pretend that we conducted a crossing experiment on these plants just like Mendel

What possible trait values could the F2 generation exhibit?

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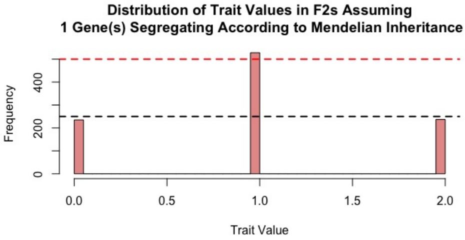
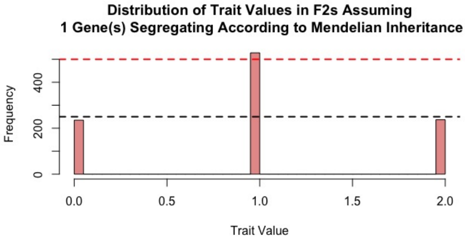


Reconciling the Mendelians and the Biometricians

Now let's say that our tree height trait is controlled by 100 genes, inherited according to the law of independant assortment

Instead of a $+1$ effect on height, each one has an effect of $+\frac{1}{100}$

What would the distribution of possible trait values look like now?



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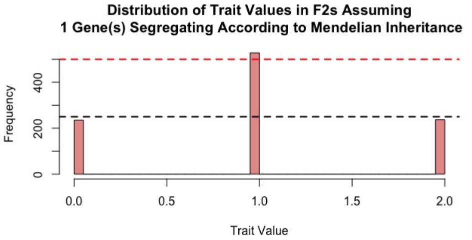
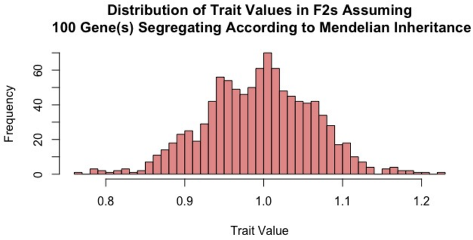




Reconciling the Mendelians and the Biometricians

Assuming Mendel's laws and that a large number of genes controls complex traits can reconcile the Mendelian and Biometrician's arguments

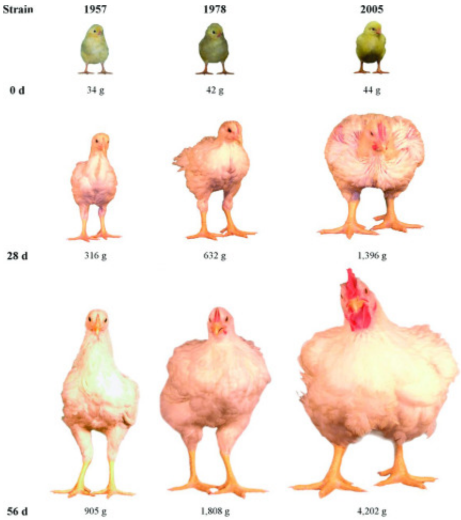
This model was first formalized in 1918[1], but even Mendel had an inkling that this may be the case

If we take this model to the limit of an infinite number of genes, each making an infinitely small contribution to a particular trait we get **the infinitesimal model** - the basis of quantitative genetics (more on that in Module 3)

[1] This idea, represents a major turning point in the history of genetics

How can we Apply a Model of Genetics?

Quantitative genetic models work and have been very effective in the last 100 years!



[a] Modified from Figure 1 - Zuidhof et al. 2014

Questions?

Questions?
Let's take a short break

The Units of Heredity

So a particulate theory of inheritance can explain discrete and continuous traits

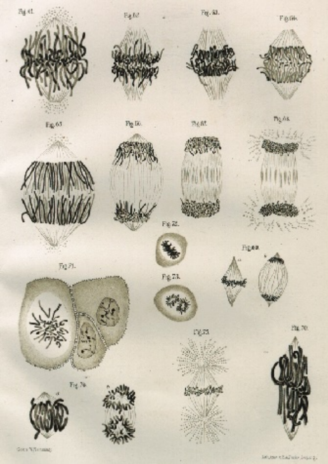
But what are the particles??

The Units of Heredity

So a particulate theory of inheritance can explain discrete and continuous traits

But what are the particles??
It should be obvious that we are talking about chromosomes and DNA

A Timeline of Some Discoveries



1865 Mendel postulates laws of inheritance

Drawing of mitosis by Walther Flemming 1882

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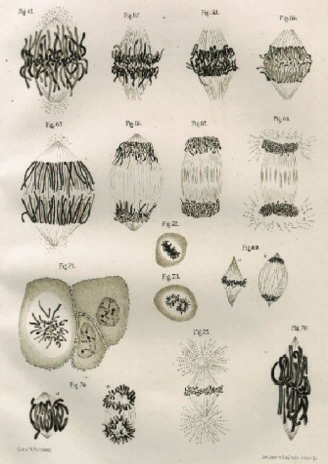

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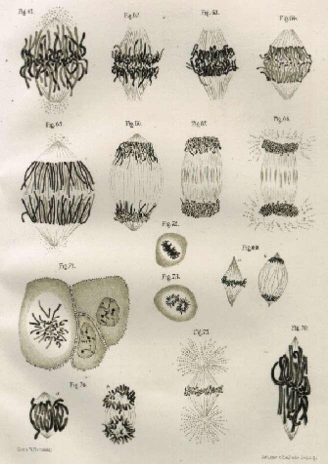

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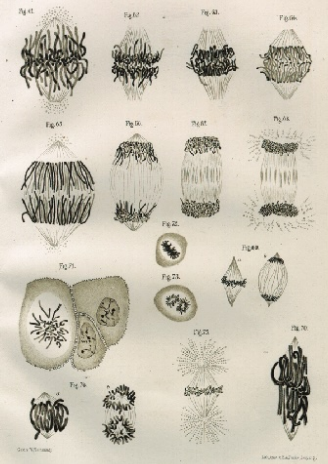

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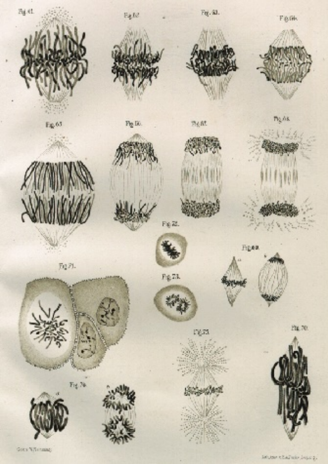

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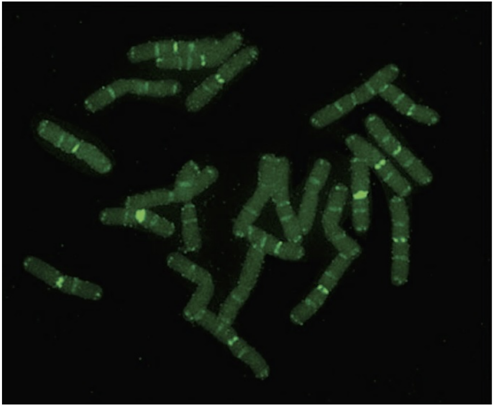
- **1882** Discovery of the fibrous network of "chromatin" (*stainable material*) and chromosomes within nuclei
- **1902-6** Sutton-Boveri chromosome theory - the segregation of chromosomes during meiosis matches the segregation pattern of Mendel's laws
- **1915** Morgan demonstrated that chromosomes carry genes, and also discovered genetic linkage[*won Nobel Prize in 1933*]

Drawing of mitosis by Walther Flemming 1882

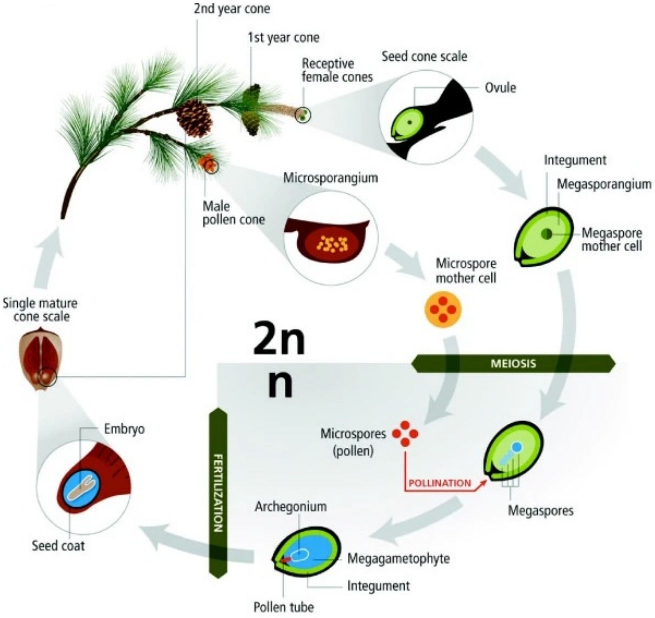
Chromosomes

- A chromosome is a string-like structure holding the genetic material of an organism
- The figure shows a micrograph of fluorescently stained loblolly pine chromosomes



We will only cover the inheritance of chromosomes here and leave detailed molecular features about DNA and chromosomes to next week

Conifer Life Cycle



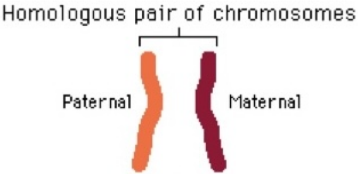
The specific stages of the lifecycles vary across taxa, the take home message here is that meiosis produces *haploid* gametes [a]

[a] Modified from Neale et al 2014 BMC Genomics

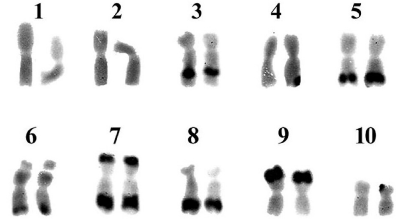
Homologous chromosomes

Chromosomes are in pairs except in gametes (pollen and ovules)

- Each pair of chromosomes are called homologous chromosomes, one is carried in the pollen, the other in the ovule
- Each member of a pair carries the same genes (except allelic variation)



Karyotype (chromosome configuration) of Maize [a]

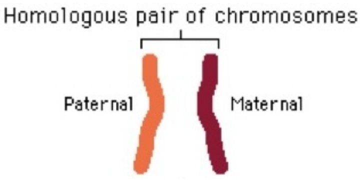


[a] Modified from Mondin et al 2014 Front. Plant Sci.

Confirming Mendel's First Law

The law of segregation:
each individual possesses a pair of ~~particles~~ homologous chromosomes and each parent passes one of these randomly to its offspring

The First Law helped to figure out the genetic features of chromosomes, while the discovery of chromosomes and how they are transmitted confirms the First Law



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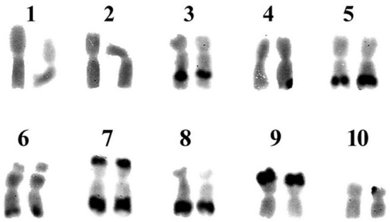

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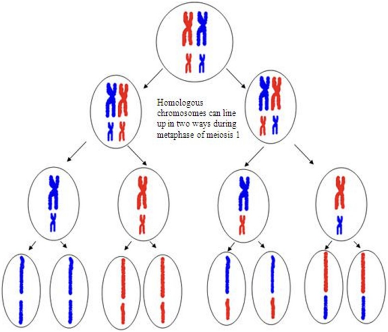
Confirming Mendel's Second Law

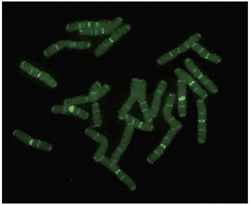
The law of independant assortment: traits are inherited independently of one another

During meiosis, different chromosome are replicated and segregate independently

If a pair of genes are located on different chromosomes, they obey the Second Law



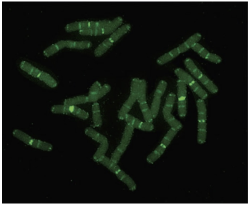
Chromosome Combinations



What is the probability that crossing two loblolly pines will result in two genetically identical offspring?

- 2 pairs of chromosomes = 4 combinations
- 12 pairs in loblolly pine, How many combinations?

Chromosome Combinations



What is the probability that crossing two loblolly pines will result in two genetically identical offspring?

- 2 pairs of chromosomes $= 4$ combinations
- 12 pairs in loblolly pine, How many combinations?
- $= 2^{12} = 4,096$ combinations
- So, very small chance for a particular cross to lead to 2 genetically identical offspring

Genetics is the study of genes, of variation and heredity across all branches of the tree of life

Branches of Genetics

- Behavioural genetics
- **Classical genetics**
- Developmental genetics
- **Conservation genetics**
- **Ecological genetics**
- **Evolutionary genetics**
- **Genecology**
- Genetic engineering
- Genomics
- Medical genetics
- Forensics
- Molecular genetics
- **Quantitative genetics**
- **Population genetics**
- Phylogenetics
- Statistical genetics
- Genetic epidemiology
- Archaeogenetics

A non-complete and *slightly* biased list

Terminology Check

We'll expand on each of these throughout the course...

- Gene - the unit of heredity
- Allele - a genetic variant
- Genotype - the configuration of genes possessed by an individual
- Homozygote - an individual possessing two identical alleles
- Heterozygote - an individual possessing two distinct alleles
- Any others... ?

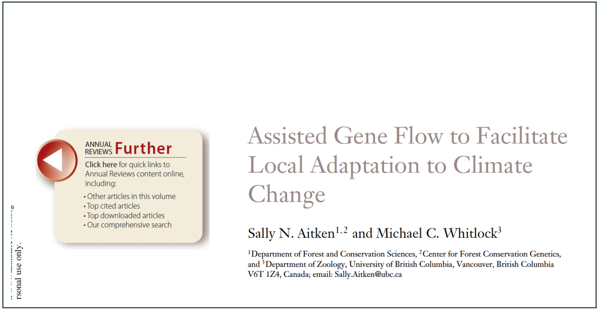
Learning Outcomes

- Basic definitions in genetics
- Basic principles and terms in classical genetics
- How Mendelian inheritence can lead to continuous trait variation
- Molecular mechanisms of Mendelian inheritence

A Question to Think About...

Albinism is caused by a recessive lethal allele
Seedlings with albinism have no chlorophyll, thus no photosynthesis
How come tree populations still carry this allele?

Assigned Reading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Assisted Gene Flow to Facilitate Local Adaptation to Climate Change

Sally N. Aitken[1,2] and Michael C. Whitlock[3]

[1]Department of Forest and Conservation Sciences, [2]Center for Forest Conservation Genetics, and [3]Department of Zoology, University of British Columbia, Vancouver, British Columbia V6T 1Z4, Canada; email: Sally.Aitken@ubc.ca

rsonal use only.

- Take the time you would spend in class next Tuesday to read this paper in depth
- Make a list of the terms and concepts you do not understand
- The contents of this paper istabular potentially examinable

- I will upload the PDF to Canvas after class

Below is the R code to make the figures on the infinitesimal model - feel free to play around with it

```
# Demonstrate the distribution of trait values for a quantitative trait
# Under Mendelian segregation for an arbitrary number of genes
# Assumes random mating, constant effect sizes, constant allele frequencies

nGenes = 100
alleleFrequency = 0.2
popSize = 5000
effectSize = 1

hist(
        replicate(popSize,
                sum(  1 * rbinom(nGenes, 2, alleleFrequency) ) ),
        col = "#e69b99",
        xlab=  "Trait Value",
        main= paste("Distribution of Trait Values in F2s Assuming\n",nGenes,
                "Genes Segregating According to Mendelian Inheritance"),
        breaks = 40)
```