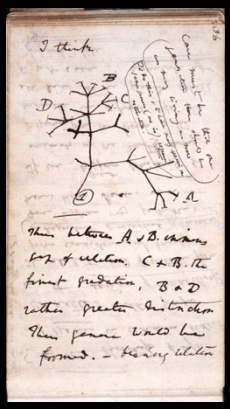
The history of evolutionary theory & natural selection



1

When you see such a title…

- Who, or what works, first come to mind?
- Why do you think that is so?

2

Where do initial ideas about natural history come from?

- Every culture has their origin/creation stories
- Mythological/religious cosmologies
- e.g., Vedic Sanskrit texts describe a heliocentric system – further developed by Indian astronomers Yajnavalkya (9-8 century BC), Aryabhata (476-550 CE) and Bhaskara (1114– 1185 CE)

3

Early Western ideas about natural history

- "The great chain of being" (*Scala naturae*)
  - Aristotle, 4th c BC
  - The idea that all organisms exist in a hierarchical ladder with humans on the top rung

Didacus Valades, *Rhetorica Christiana* (1579)

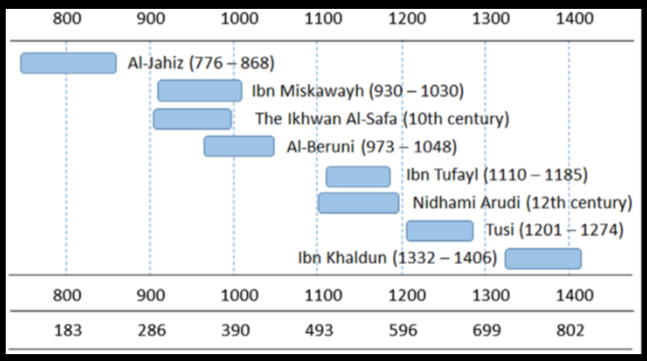
4

Early Western ideas about natural history

- Fixity of species
  - Every species was created in the past exactly as it appears today.
  - No new species can be created or go extinct.
  - Species diversity (variation) is just 'noise' in the system around an 'ideal type'.
  - Part of religious doctrine from the Western Middle Ages – naturalists were trying to seek God's purpose, rather than natural mechanisms.

5

Muslim scholars (8th-14th c)



Malik et al. (2017)

- Many ideas foreshadowing key points of modern evolutionary theory!
  - kingdoms of life; common descent (esp. w/ monkeys); struggle for existence; change over time

6

Biblical literalism

- Archbishop James Ussher, 1581-1656
- Natural theologian
- Counted up descendants of Adam & Eve in the Bible & determined the world began on Oct 23, 4004 BC
  – young Earth (6,000 years old)

7

Impediments to the development of the theory of evolution

- Concept of fixity of species
- Concept of the great chain of being
- A short geological time scale

8

European Renaissance (14-16 c)

- Emphasized reason, science & rationality
- Colonization of "new" lands and circumnavigation of the globe – discovering new (to them) species
- New technology developed with which to study the natural world (microscopes & telescopes)
- Advances in anatomy and biology (e.g., da Vinci)
- Scientists working in paleontology, geology & astronomy made it clear that the universe had been & continues to be EVER CHANGING, not fixed.

9

European Renaissance

- ASTRONOMY: The Copernican revolution showed the Earth is not the center of the universe. The heavens are not immutable, but rather change.
- PALEONTOLOGY: Scientists began to see how structures in fossilized organisms changed through time.
- GEOLOGY: It was determined that the Earth was much older than 6 000 years, thus allowing time for evolution to occur.

10

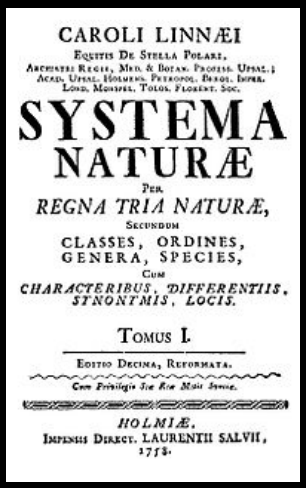
European Rennaisance

- social change – no more social stagnation that marked the Middle Ages
- with the advent of capitalism, society is not as rigidly stratified or hierarchical as it once was
- it is possible to move up (and down) the social ladder
- world view is no longer of a fixed, unchanging world

11

Classification of the living world

- Carl Linnaeus (1707-1778): *Systema Naturae* (Systems of Nature)
- Classification of plants & animals using binomial nomenclature
- Genus & species names - e.g., *Homo sapiens* for human beings
- Placed humans within the animal kingdom, but still believed in fixity of species.


CAROLI LINNÆI

SYSTEMA NATURÆ

PER

REGNA TRIA NATURÆ,

SECUNDUM

CLASSES, ORDINES, GENERA, SPECIES,

CUM

CHARACTERIBUS, DIFFERENTIIS, SYNONYMIS, LOCIS.

TOMUS I.

EDITIO DECIMA, REFORMATA.

HOLMIÆ,

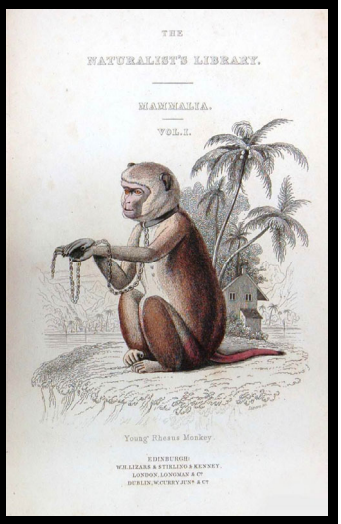
IMPENSIS DIRECT. LAURENTII SALVII,

1758.

12

Ideas about adaptation

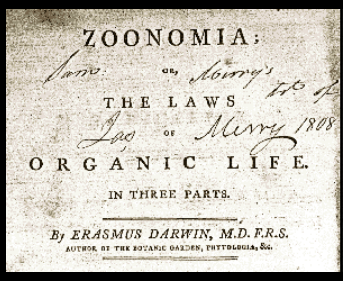
- Count George-Louis Leclerc de Buffon: *Natural History* in 1749
- Emphasized importance of a changing universe & changing nature of species
- Outlined ideas using comparative anatomy, geology, biogeography…
- STILL DID NOT believe that one species could evolve into another.
- BUT, did understand that species can change by adapting to their environment.



13

Precursors to the theory of evolution: Erasmus Darwin (1731-1802)

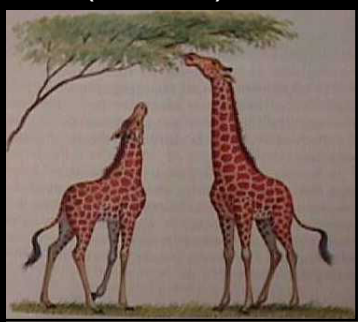
- Charles Darwin's grandfather
- Early supporter of evolution & idea of change in a species through time
- Believed that life originated in the seas & that all species are descended from a common ancestor
- Ideas were not widely accepted because he did not provide a MECHANISM by which evolution occurs



14

Inheritance of acquired characteristics

- Jean-Baptiste Lamarck (1744-1829)
- The first to try to explain HOW evolution works - tried to get at the mechanism behind evolution
- The key factor was the environment (correct)
- Species changed due to environmental influences
- Coined term "biology"



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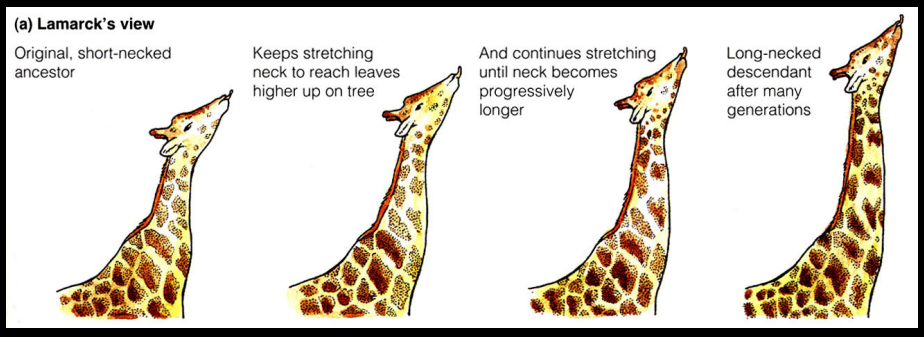
Lamarck's theory of the inheritance of acquired characteristics

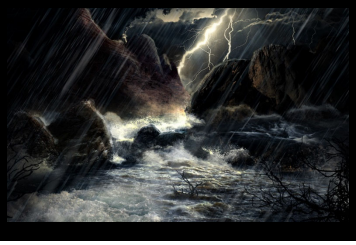


Activity changes to accommodate a new environment. Certain body parts may be used more than others. As a result, the structure is modified. As the change provides a benefit to the organism, the new trait is passed down to its descendants – "Lamarckian evolution"

16

Catastrophism

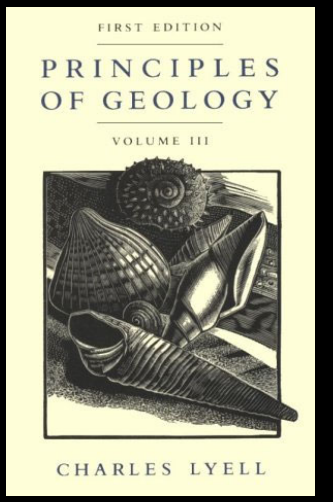
- Georges Cuvier proposed the idea of EXTINCTION to explain the disappearance of animals represented only by fossils
- Worldwide catastrophic events responsible for the Earth's geological features
- Once extinction occurs, new & more advanced forms colonized the region. These new forms are the result of more recent creation events.



17

Uniformitarianism: "The present is key to the past"

- The Earth looks the way it does today as the result of LONG-TERM processes that operated in the past and continue to operate today (unlike catastrophism)
- James Hutton, Charles Lyell
- Implied the Earth is MUCH OLDER – many millions of years old, not a few thousand
- Darwin read it on the *HMS Beagle*



18

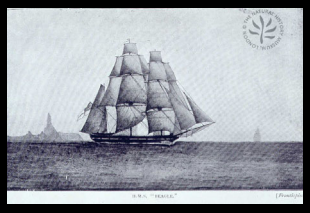
Struggle for existence

- Thomas Malthus (1766-1834) *Essay on the Principle of Population*
- Populations have a limitless potential for reproduction unless they are kept in check by limited food supplies.
- In nature, population growth is controlled by resource availability - this leads to a struggle for existence
- both Darwin and Wallace read it

19

Charles Darwin (1809-1882)

- Studied medicine at Edinburgh University, dropped out after two years! Most of his professors were supporters of Lamarck. Learned taxidermy from John Edmonstone.
- Studied theology at Christ's College in Cambridge. Immersed himself in botany & geology.
- After graduation (in 1831) he took an offer to sail for 5 years on the HMS Beagle as part of a scientific expedition as a "gentleman's companion" to Captain R. Fitzroy



20

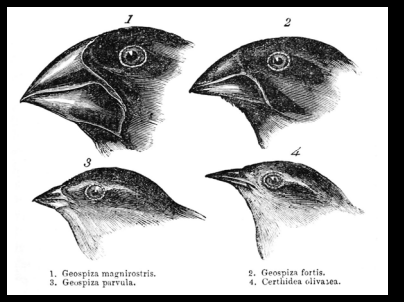
The HMS Beagle (1831-1836)

- Lyell's *Principles of Geology*
- Evidence that Earth had deep time scale - fossils similar to living species
- Ocean-living fossils on top of mountains
- Animals from different regions slightly different from each other

21

Darwin's Galápagos finches

- Island plants & animals similar to mainland, but not identical
- 12 different types of finches - different sized & shaped beaks
- 1 type on mainland = founding population
- Variation in Galápagos' finches due to different island habitats & diets
- How do we get from 1 species to 12?



22

The origins of *natural selection*

- Based on concept of 'selective breeding' - select those animals that possess certain traits so they will be emphasized in offspring
- All domestic dogs (*Canis lupus familiaris*) share a common ancestor (wolf) - variation in dog breeds seen today is the result of artificial selection imposed by humans

- When 'natural' species develop, nature does the selecting - hence NATURAL SELECTION

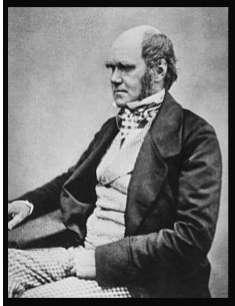
23

The origins of *natural selection*

- In 1838 Darwin read Malthus and realized that:
  - Populations increase at a faster rate than do resources.
  - As a result, there is a constant struggle for existence.
- He put the following ideas together:
  - more offspring are born than survive to adulthood
  - there is competition for resources
  - there is variation within species

24

About that struggle for existence…



I should premise that I use the term Struggle for Existence in a large and Metaphorical Sense, including dependence of one being on another, and including (which is more important) success in leaving progeny.

(Charles Darwin)

25

Darwin's theory of natural selection

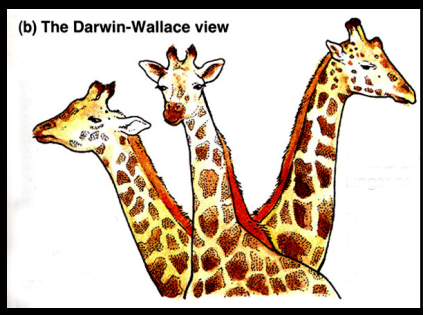
" It at once struck me that under these circumstances favourable variations would tend to be preserved, and unfavourable ones to be destroyed. The result of this would be the formation of a new species."

Charles Darwin

26

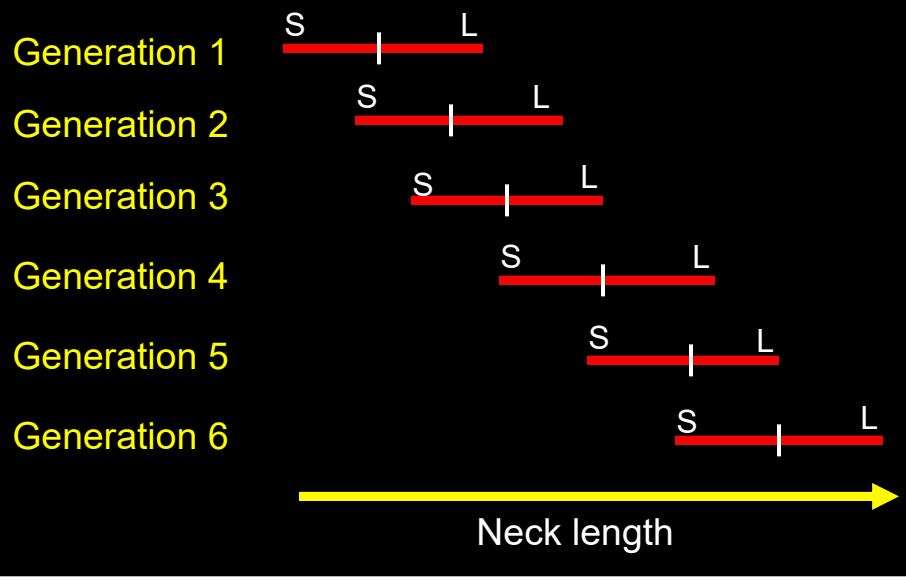
Darwin's theory of natural selection

- Original group exhibits variation in neck length
- Natural selection favors longer necks (e.g., to reach food)
- More long-necked giraffes survive to reproduce than short-necked giraffes
- After many generations, the group still varies in neck-length, BUT there is a general increase in average neck length



27

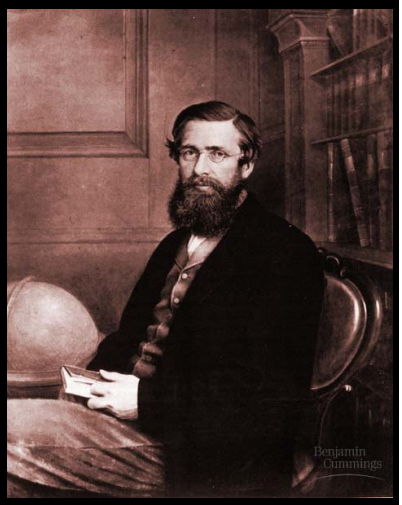
Natural selection



28

Alfred Russell Wallace (1823 - 1913)

- From 1846 spent time in the Amazon & Malaysia collecting birds & insects
- 1855: published a paper suggesting species descended from other species
- Darwin still resisted publication.
- 1858: Wallace sent Darwin another paper describing evolution as a process driven by competition & natural selection
- Prompted Darwin to publish



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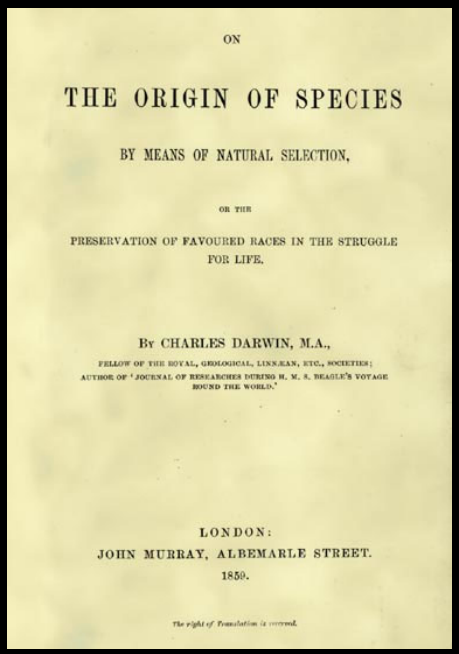
"As many more individuals of each species are born than can possibly survive… it follows that any being, if it vary however slightly in any manner profitable to itself… will have a better chance of surviving, and thus be naturally selected."



ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNEAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

30

The theory of evolution by means of natural selection

- All organisms are capable of producing offspring at a faster rate than food supplies can sustain.
- Because of limited resources, there is competition between individuals for access to these resources.
- Organisms vary & this variation is heritable.
- Individuals who possess favorable phenotypic traits (speed, disease resistance, etc.) have an advantage in competition for resources over those that do not. These individuals will survive & reproduce more.
- Which traits are advantageous depends on the particular environment at a given time.

31

Darwin: *The Origin of Species*

"There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been, and are being, evolved."

32

Evidence for evolution in the 19th century

- Artificial selection (domestication)
- Biogeography (geographic distribution)
- Paleontology & archaeology
- Comparative anatomy
- Embryology

33

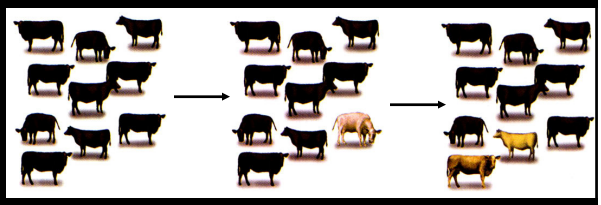
Remaining questions

- Where did variation come from?
- How did inheritance work?

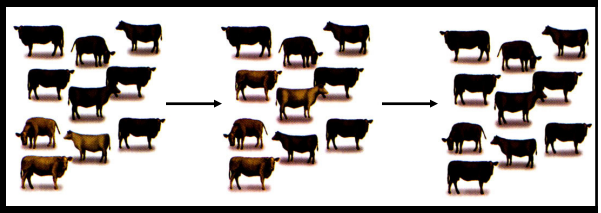
34

19th century: Blending inheritance

- Each parent contributes equally to offspring
- Contributions are halved at each successive generation
- PROBLEM for natural selection: any advantageous trait is "diluted" in each generation!



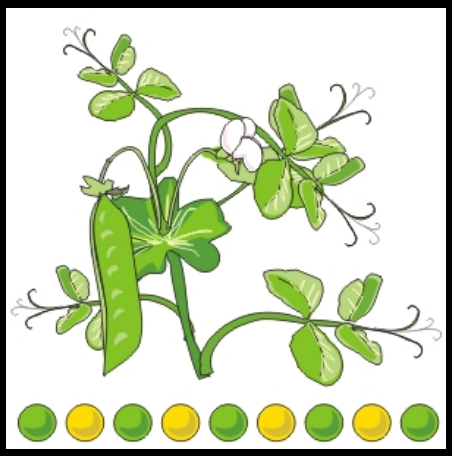
Herd of animals Mutants with increased fitness appear



Feature is 'blended out' with each passing generation

35

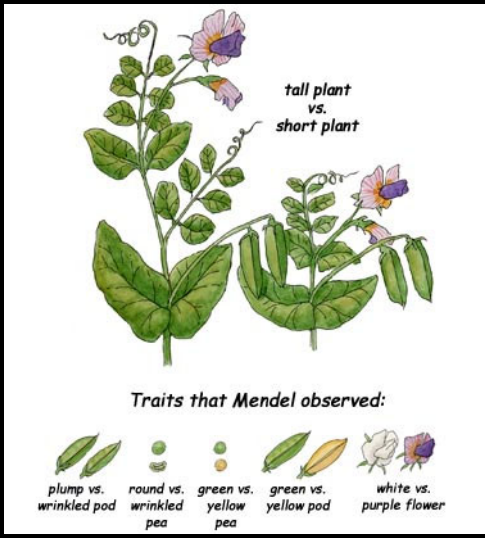
Gregor Mendel (1822-1884)



Pisum sativa

36

Mendel's pea experiments



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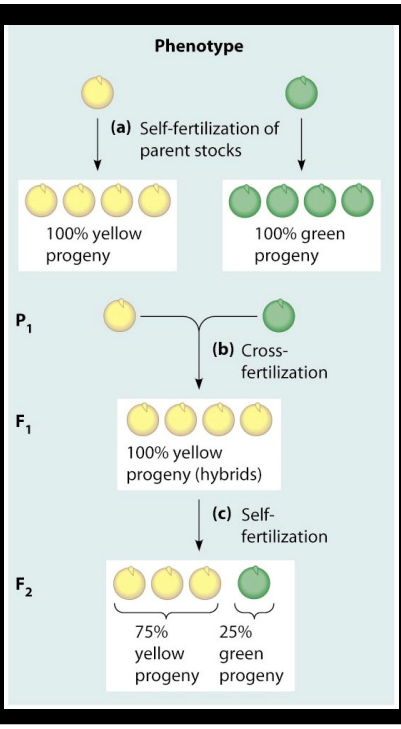


Mendel's Principle of segregation

- Expression of each trait controlled by discrete units (aka genes)
- Units occur in pairs
- Each offspring inherits one unit from each parent
  - a sex cell from a parent contains only 1 unit
  - upon fertilization, sex cells unite and the 2 units make a pair

38

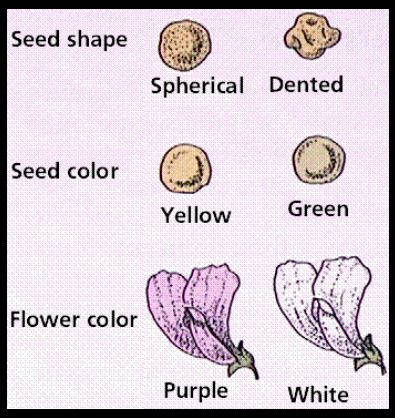
Mendel's Principle of segregation

- During the formation of gametes (meiosis), the paired chromosomes separate, or segregate, randomly so that each sex cell receives one or the other with equal likelihood.
- So, offspring may inherit either version of either parent's chromosome 1 & chromosome 2 etc… with 50% chance of each. (Parents inherited their different versions from their parents etc.)

39

Mendel's Law of independent assortment

- Dihybrid crosses - looked at simultaneous transmission of two traits (e.g., seed color & flower color)
- The genes controlling different traits are inherited independently of one another.
- Results from the chance distribution of chromosomes to daughter cells during meiosis.



40

Mendel's "unit" = GENE

- Basic unit of inheritance
- Segment of DNA that controls one or more traits (i.e., codes for a protein)

41

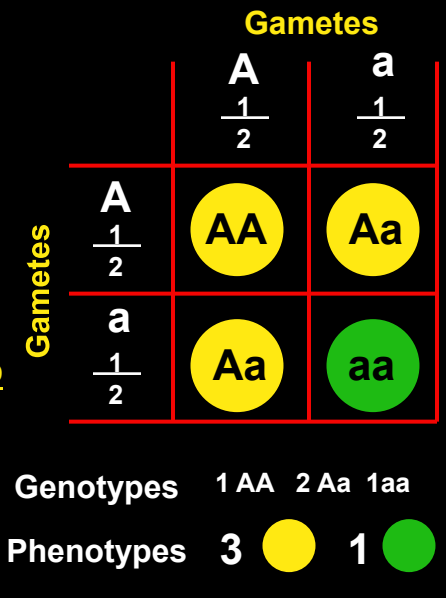
Genes & alleles

- Different versions of a gene are called **alleles**
- Example, gene locus Z
  - A allele
  - a allele
- For most genes you will have two alleles, one 'version' from each biological parent
- Example, gene locus Z, three possible genotypes:
  - AA (homozygous A)
  - Aa (heterozygous)
  - aa (homozygous a)

42

Dominant vs. recessive (alleles)

- Punnett square of F1 gametes and resulting F2 genotypes & phenotypes
- The dominant allele, if present, is always expressed.
- The recessive allele is only expressed in the phenotype if there are two copies - one on each homologous chromosome (otherwise it is masked)



43

Mendelian traits

- Controlled by alleles at only one genetic locus.
- Examples include ABO blood type & genetic disorders such as sickle-cell anemia & Tay-Sachs disease
- In contrast to polygenic traits - phenotypic traits that result from the combined action of more than one gene (most complex traits are polygenic!)

44

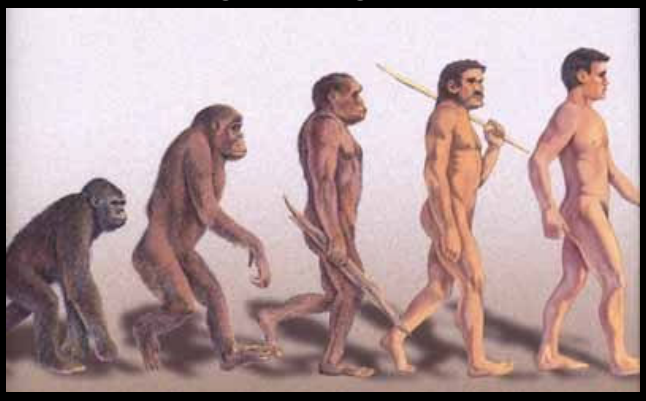
The Modern Synthesis (1930s)

- Early proponents of Mendelism opposed Darwin's theory of natural selection.
- In the 1930s, various evolutionary biologists worked out the details of how natural selection could work with Mendelian genetics.
- Evolution by natural selection now possessed a well tested theory of heredity.

45

Evolution (common usage)

Connotations of progress or hierarchy towards a long-term goal



46

Evolution (in biology)

- Evolution in biology is simply *change over time*.
- There is no connotation of progress.
- There is, however, an implication that the past is connected to the present.

47

Evolution: modern definition

- Evolution is a change in allele/gene frequencies over time.
- Gene frequency is a measure of the relative frequency of a gene at a particular genetic locus (an allele) in a population (%).
  - A population is a community of individuals within a species where mates are usually found.

48

What is *allele frequency*?

- The allele frequency is simply the frequency of an allele at a particular locus in a population.
- Example, Population Y (8 individuals) at Locus Z
  - AA, Aa, aa, aa, AA, Aa, AA, Aa
- Example, Population Y at Locus Z (genotype frequencies)
  - AA 3/8 0.375 (37.5 % of the population is AA)
  - Aa 3/8 0.375 (37.5 % of the population is Aa)
  - aa 2/8 0.250 (25.0 % of the population is aa)
- Example, Population Y at Locus Z (allele frequencies)
  - Frequency of A 9/16 0.5625 (~ 56 %)
  - Frequency of a 7/16 0.4375 (~ 44 %)

49

Remember!

- Allele frequencies refer only to populations - not individuals.
- Therefore, only a *population* can *evolve* over time - individuals cannot!

50

Extended Evolutionary Synthesis

- First proposed in 2007; controversial

"It builds upon traditional evolutionary explanations by recognizing a broader set of causes. Understanding how organisms develop, grow, and interact with their environment is central to the EES, and may help us to account for the diversity of life and the process of adaptation. ..."

51

Extended Evolutionary Synthesis

...We are particularly interested in the idea that the way organisms develop shapes the direction and rate of their evolution, and that inheritance occurs not just through the transmission of genes, but through many additional means including the developmental conditions that parents construct for their offspring…

52

Extended Evolutionary Synthesis

… The EES emphasizes the importance of topics such as developmental bias and constraint, developmental plasticity, inclusive inheritance and niche construction and their role in driving the evolutionary process."

53

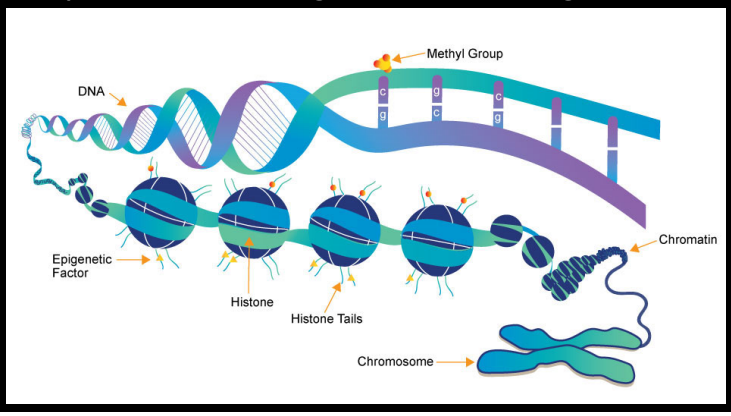
Epigenetics

- Heritable changes in gene expression – how, when, and for how long genes are "switched" on or off (e.g. differentiation of cells)
- Changes in phenotype WITHOUT changes in genotype!
- Reversible!

54

Epigenetic mechanisms

- DNA methylation, histone modification, chromatin remodeling, non-coding RNA (ncRNA)-associated gene silencing etc.



55

Epigenetics

- Changes often induced by environment
- Can be transgenerational
- ≠ Lamarckian evolution!
  - Often non-adaptive
  - reversible
- But… a way for effects of environment—natural, social etc.—to be embodied (Thayer & Non, 2015)

56