Unit 3: Evolution, Genetics and Development

2. The Evolutionary Synthesis and Its Challengers

"Nothing in biology makes sense except in the light of evolution."
Dobzhansky, 1973, *American Biology Teacher*

The Impotency of Natural Selection

- Following Darwin, some skeptics argued that natural selection could not explain well-adapted traits
  - It can only eliminate variants—it cannot produce anything.
- Variants must arise from somewhere else—mutation, etc.
  - The source of variation is the true cause of evolution
- "We are now standing at the deathbed of Darwinism, making ready to send the friends of the patient a little money to insure a decent burial. . ." (E. Dennert, *At the Deathbed of Darwinism,* 1904)

The Mendelian Alternative to Darwin

- On the Mendelian account, factors/genes were responsible for traits
- It seemed plausible that a change in one of these factors would result in a fundamental change in a trait of an organism
  - Such a change might be large enough to itself yield transmutation
    - De Vries thought he had identified an instance in the Evening Primrose
- On this scenario, the origin of new species is due to mutation operating in one generation
  - Natural Selection, as a slow, gradual process, that got rid of the less fit but was claimed to play no role in the origin of species

Clicker Question

What fundamental change in conceptualization was required to bring Darwinian Natural Selection together with Mendelian Genetics

A. The recognition that genes reside on chromosomes
B. The recognition that many different genes could each produce small effects on a given trait
C. The recognition that each trait of an organism is governed by a different gene
D. The recognition that Natural Selection could only operate to eliminate variants

A Representational Tool: The Punnett Square

- The device for representing the genotypes that result from crosses in tables was developed by Reginald Punnett, a close collaborator of Bateson's at Cambridge
- A major contribution to making the theory intelligible

	R	**R**
R	RR	RR
r	Rr	Rr

	RY	**Ry**	**rY**	**ry**
RY	RRYY	RRYy	RrYY	RrYy
Ry	RRYy	RRyy	RrYy	Rryy
rY	RrYY	RrYy	rrYY	rrYy
ry	RrYy	Rryy	rrYy	rryy

Bringing Mathematics to Bear on Mendelism: Hardy-Weinberg Equilibrium

- Punnett felt unhappy with his attempt to explain why recessive phenotypes still exist, and asked his cricket partner and Cambridge mathematician Godfrey Harold Hardy (1877-1947)
  - Question: what happens to a Mendelian mutation?
- Hardy's approach: Assumed a 2-allele case: **A** and **a,** with starting f = **AA** = 0.49, **Aa** = 0.42 and **aa** = 0.09 This gives an allele frequency of **A** = 0.7, **a** = 0.3
- He demonstrated that this ratio would remain constant from generation to generation provided:
  - Population is large
  - Mating is random
  - No selection: All offspring combinations are equally successful
  - No migration in or out of the population
  - Mutation rate has reached equilibrium
- The same result was independently derived by Wilhelm Weinberg (1867-1937), pediatrician in Stuttgart

Pearson and Fisher

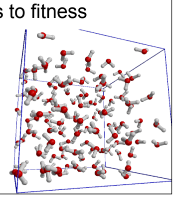
- The Biometricians (Galton, Pearson et al.—defenders of a Darwinian account based on gradual change through Natural Selection) had developed statistical tools to understand patterns of inheritance of traits such as height by assuming *continuous* distributions
  – But they did not have mathematical tools for dealing with discrete components such as Mendelian factors/genes
- These tools were developed by R.A. Fisher, who was initially snubbed by the Biometricians
  – "…Fisher…received an offer from Professor Pearson at the Galton Laboratory. Fisher's interests had always been in the very subjects that were of interest at the Galton Laboratory, and for five years he had been in communication with Pearson, yet during those years he had been rather consistently snubbed. Now Pearson made him an offer on terms which would constrain him to teach and to publish only what Pearson approved. It seems that the lover had at last been admitted to his lady's court—on condition that he first submit to castration. Fisher rejected the security and prestige of a post at the Galton Laboratory and took up the temporary job as sole statistician in a small agricultural research station [viz., Rothamsted Experimental Station] in the country." (Box, 1978, p. 61)

Ronald Aylmer Fisher and *Population* Genetics

- Analyzed populations in terms of the genes of its members and investigated mathematically how gene frequencies will change over generations if selection is applied
  – That is, add selection to Hardy-Weinberg
- 1918: Fisher's first paper: "The Correlation between Relatives on the Supposition of Mendelian Inheritance."
  – Argued that discrete Mendelian genes were the focus of selection
  – That if many genes contributed to a given trait, one could account for the continuous variation the Biometricians observed
  – Opposed Darwin's and Pearson's view of blending inheritance, and Galton's "Laws"—genes are inherited as unitary entities
- In developing this analysis, Fisher made major contributions to the development of statistics, including the analysis of variance (ANOVA)

Fisher's project of Population Genetics

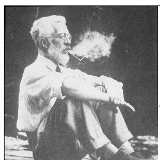
- Evolution occurs in large, virtually unlimited populations
- Variation and environmental change are random
- Selection produces a gradual shift in gene frequency
- Evolution leads inevitably to better adaptation
- Populations are simply collections of independent alleles combining and recombining every generation
  – These make independent contributions to fitness
- Aimed to make population genetics do for evolution what kinetic theory of gases did for temperature
  – Show how particles produce what appear to be continuous values for temperature



Discussion Question

By making Medelian genes the units on which natural selection occurred, what fundamental problem that Darwin had struggled with finally had an answer?

A. The evidence that the earth had not been around long enough for Natural Selection to have produced current species
B. The fact that the fossil record was so incomplete that one could not show that intermediate forms had existed
C. Fleming Jenkin's demonstration that Darwin's proposed account of blending inheritance was incompatible with evolution by Natural Selection
D. The problem of showing how varieties could ever generate independent species



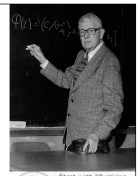
Genetical Theory of Natural Selection (1930)

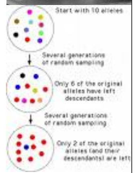
- First half of book involved developing Fisher's concepts of genetics at the population level:
  - Idea of a "gene pool"
  - Fitness of alleles
  - Role of selection
- Fundamental theorem of natural selection: *The rate of increase of fitness of any organism is equal to its additive genetic variance in fitness at that time.*
  - Importance of *additive* (contrast: interactive) *variance*
  - Downplayed but did not deny "genetic residue" – linkage, epistasis (interaction between genes at different loci)
- Second half applied these principles to human breeding as an argument for *eugenic control* of reproduction (eliminating the "unfit" and promoting the more fit by providing an allowance for children proportional to income)

Fisher's Fundamental Theorem

"It will be noticed that the fundamental theorem .... bears some remarkable resemblances to the second law of thermodynamics. Both are properties of populations, or aggregates, true irrespective of the nature of the units which compose them; both are statistical laws; each requires the constant increase in a measurable quantity, in the one case the entropy of the physical system and in the other the fitness .... of a biological population .... Professor Eddington has recently remarked that 'The law that entropy always increases - the second law of thermodynamics - holds, I think, the supreme position among the laws of nature'. It is not a little instructive that so similar a law should hold the supreme position among the biological sciences." (Fisher 1930 *The Genetical Theory of Natural Selection*).

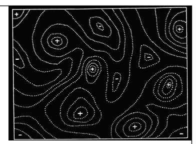
Sewall Wright's Alternative

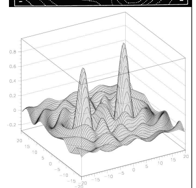




- Each in his carreer, Wright was involved in animal breeding
  - Breeders work with only a few animals
- Developed mathematical framework for analyzing artificial selection in a small population
- Argued that that small, inbreeding groups were the key to evolution—**Shifting balance theory**
  - Gene frequencies could more easily become fixed (reach 100%) by chance (genetic drift)
  - Inbreeding would promote homozygosity and hence expose genes more effectively to selection
  - Each population would become adapted to a micro-niche, or would become extinct
  - Genes often interact in production of traits (epistasis), and fortuitous combinations more likely in small groups
  - Some migration & interbreeding between groups

Adaptive landscapes





- The mathematical account Wright offered is much more complicated than that generated by Fisher
- Wright developed graphical ways of presenting his ideas
  - Peaks represent maximal adaptation
  - Valleys represent low adaptation
  - Sub-populations (demes) adapt by moving to a peak
  - If not at a peak, demes move to one or go extinct
  - Only small populations could move through valleys to new peaks—hence small populations were the key to evolution
  - Competition both between organisms and between groups
  - Adaptive landscapes constantly changing due to:
    - External conditions
    - Activity of the organisms themselves

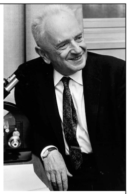
Fisher-Wright Dispute

- Fisher's and Wright's accounts make fundamentally different assumptions
  - Wright assumed that natural populations are sufficiently small, or divided into nearly isolated inbreeding groups
    - In such groups, genetic drift can be a critical factor
    - Natural selection one among several factors influencing evolution
  - Fisher assumed that natural populations are sufficiently large for Natural Selection to reliably promote the better adapted variants
    - Natural Selection is the overwhelming determiner of the course of evolution
- The conflict between Fisher and Wright turns on which mathematical model better describes our world
  - Each makes assumptions: the challenge is to determine which assumptions better fit the world
  - Settling this is not a job for theorists but researchers investigating natural populations

Field Studies of Evolution

- Russian tradition initiated by Chetverikov and continued by Dubinin studied large wild populations of *Drosophila melanogaster* collected in the Caucuses
  - Found large percentage (16%) of recessive lethals on 2nd chromosome
  - Natural populations are loaded with hidden genetic variability—population's *gene pool*
  - Since much of it is lethal, referred to as *genetic load*

From Theory to Field: Theodosius Dobzhansky



- Brought the Russian tradition to the US
- Unlike his more mathematically inspired predecessors, Dobzhansky's focus was the field (also true of Ernst Mayr and G. Ledyard Stebbins and of paleontologist G. G. Simpson)
- From the field he derived a very strong impression of both diversity and the adaptiveness of diverse forms to local circumstances
- Recognized the importance of variability:
  - ". . . the accumulation of germinal changes in the population of genotypes is . . . a necessity if the species is to preserve its evolutionary plasticity. . . . The environment is in a constant state of flux, and its changes...make the genotypes of the past generations no longer fit. . . . Hence the necessity for the species to possess at all times a store of concealed, potential, variability."

From Drift to Selection

- In 1937 (*Genetics and the Origin of Species)* Dobzhansky viewed much of the variability as non-adaptive and thus likely due to drift
  - Defined evolution as "a change in the frequency of an allele within a gene pool."
  - Emphasized isolating mechanisms for differentiating populations
- By 1951, he downplayed drift and emphasized selection
  - But a broadened conception of the power of selection not just in winnowing but in promoting particular traits
- Increased emphasis on selection referred to as the "hardening" of the synthesis
  - Favoring Fisher over Wright

Discussion Question

One of the questions confronting Darwin was how did Natural Selection results in new species. Has population genetics answered that question?

A. Yes. In large populations Natural Selection can drive populations to be sufficiently different that they no longer are parts of the same species
B. Yes. By allowing Natural Selection to remove some forms while promoting others, gaps emerge between populations that make them into different species
C. No. Natural selection in large populations will only lead to varieties, not new species. Something else is needed for generating species
D. Other

Geographic Isolation and Species

- From his field work with birds in New Guinea and the Solomon Islands, Ernst Mayr began to focus on geographical factors that separated populations
  - Within isolated individual populations, Natural Selection could promote different traits—resulting in isolating mechanisms that kept the new populations from interbreeding
- Emphasized the view that species should be view as populations of varying individuals
  - Separated when individuals are no longer able to reproduce

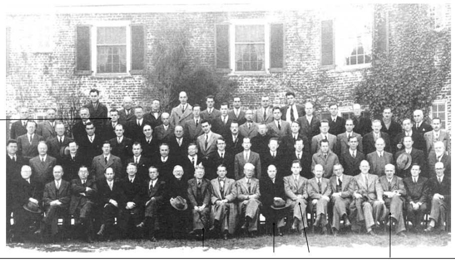
Dobzhansky's Isolating Mechanisms

1. Premating or prezygotic mechanisms.
   (a) Ecological or habitat Isolation.
   The populations concerned occur in different habitats in the same general region.
   (b) Seasonal or temporal Isolation.
   Mating or flowering times occur at different seasons.
   (c) Sexual or ethological Isolation.
   No attraction between the sexes of different species:
   (d) Mechanical Isolation.
   Physical non-correspondance of the genitalia of the flower parts prevents copulation or the transter of pollen.
   (e) Isolation by different pollinators.
   In flowering plants, related species maybe specialized to attract different insects as pollinators.
   (f) Gametic Isolation.
   Female and male gametes are not attracted to each other. In organisms with internal fertization, the gametes of one species may be invialble in other species sexual ducts.
2. Postmating or zygotic isolating mechanisms
   (g) Hybrid Inviablity.
   Hybrid zygotes have reduced viability.
   (h) Hybrid sterility.
   The F_1 hybrids of one sex or both sexes fail to produce functional gametes.
   (i) Hybrid break down.
   The F_2 or backcross hybrids have reduced viability.

The Synthetic Theory of Evolution

- Selection results in the promotion of genes, resulting in the different features of species
  - New species typically require some interruption in gene flow, allowing selection to promote different traits in different species

Dobzhansky



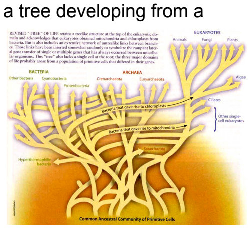
International Conference on Genetics, Paleontology, and Evolution, Princeton, 2-4 January, 1947

The Prokaryote Challenge

- In the late 19th century Weismann argued for the sharp distinction between germ cells that could figure in generating offspring and somatic cells that did not affect offspring
  - Mutations in somatic cells would not be passed on
  - Germ cells are, and they give rise to a vertical path from parents to offspring
- There is no germ/soma distinction in prokaryotes—they reproduce by dividing
  - Any change to genes will be passed on
- Moreover, prokaryotes are capable of acquiring DNA from other organisms—horizontal gene transfer
- As a result, a given prokaryote can get its DNA from many sources
  - If one bacterium has a mutation that helps deal with a challenge (a new drug we devise)
    - Other bacteria can borrow the solution
    - And even store it offline until they need it and move it to a place where it will be transcribed and translated into proteins

Problems for the Tree of Life

- It is common to view evolution as a tree developing from a single root
- But lateral gene transfer allows for passing material between lineages
- It also appears likely that eukaryotic cells (cells with internal organelles such as a nucleus and mitochondria) resulted from the combining of two prokaryotes (one becoming the mitochondrion or the chloroplast)
- These raise serious problems for understanding evolution as creating a tree of life



Drift and Neutral Evolution

- Following Wright, some evolutionists focused on what happens in relatively small populations
  - Alleles can change without selection
    - can even become the sole allele in a population (they become *fixed*)
- At the gene level, the possibility of amino acid change without selection arises if two genes don't differ in their effects
  - And at the molecular level, nucleic acids can change without effect if they code for the same amino acid
- There can be a great deal of variability that is outside the reach of natural selection
- How much of evolutionary change is actually due to selection?