Statistical Models in Evolutionary Biology
An Introductory Discussion

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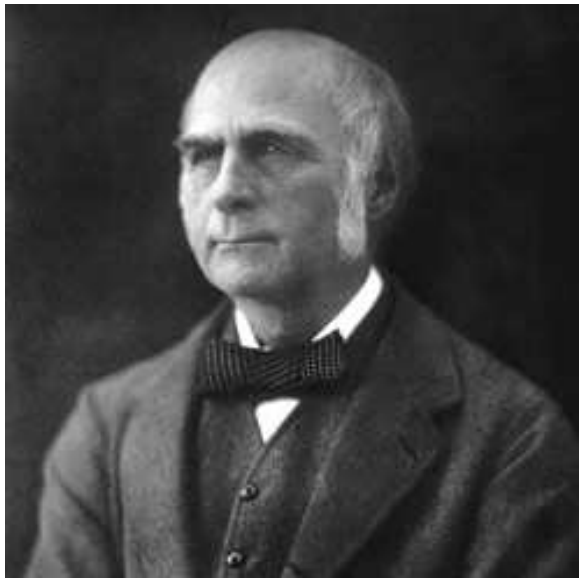
Early Connections



Galton

Fisher

What is Biological Evolution?

Darwin's phrase is apt: "Descent with modification".

A Working Definition:

> Cross-generational change in a population of organisms that involves changes in gene frequency.

Key points:

1. Evolution acts on populations; individuals do not evolve.
2. Evolution requires heritable variation in the population.
3. Evolution does not only occur over long periods of time.
4. Evolution does not always lead to "improvement."

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What we call the "theory of evolution" actually encompasses several different components.

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1. The Fact of Evolution
2. Theory of Common Descent
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

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1. The Fact of Evolution

   Cross-generational change occurs in both gene frequencies and phenotypes.

   This is observed directly. Examples:

   - antibiotic resistant bacteria, influenza, HIV
   - Fish stocks

   The Fact of Evolution does not describe *how* evolution occurs or explain how it produces the diversity of life.

2. Theory of Common Descent
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

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1. The Fact of Evolution
2. Theory of Common Descent

   All organisms alive on earth are descendants of one (or at most a few) common ancestor(s).

   As evolutionary changes accrue over time, new forms of life are generated as lineages split, a process called *speciation*.
3. Theories of Evolutionary Mechanisms
4. Theories of Speciation

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   Explain *how* evolutionary change occurs.

   - Natural Selection
   - Genetic Drift
   - Sexual Selection
   - Developmental Plasticity

   Current thinking: Most evolutionary change is driven by natural selection.

4. Theories of Speciation

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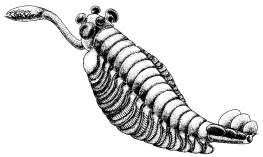
4. Theories of Speciation

   Explain how population-level changes in gene and phenotype distributions produce new species.

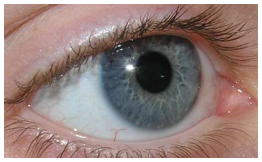
   Central Idea: Reproductive isolation.

   Modes of speciation: Allopatric, Parapatric, and Sympatric

What "The Theory" Must (And Does) Explain



The diversity of life.



The origins of complex adaptations.

Features that do not benefit individual organisms.

Cooperation and Social Behavior.

Coordination and Signalling

Extinction

...

What is Natural Selection?

- *Natural Selection* is a mechanism first proposed by Charles Darwin and Alfred Russel Wallace to explain life's diversity and remarkable adaptation.
- Darwin and Wallace were guided by several observations:
  - There is a struggle for existence in nature.

    Organisms typically produce many more offspring than survive. Limitation of resources and competition prevent exponential growth in populations.
  - Offspring tend to resemble their parents.
  - There is substantial variation in traits within natural populations.
  - An organism's traits can confer advantage (or disadvantage) for survival and reproduction.

Natural Selection (cont'd)

If the following are present in a population:

- Reproduction,
- Heredity,
- Variation in heritable characters,
- Differential reproductive successive across different types.

Then individuals with greater reproductive success

(i) will produce more offspring,

(ii) who will tend to resemble them in those characters that confer reproductive advantage, and

(iii) who will thus tend to propagate.

Natural Selection (cont'd)

> As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be naturally selected. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.
>
> — Charles Darwin, *On the Origin of Species* (1859)

Darwinian Fitness

Fitness quantifies an individual's *relative* contribution to the gene pool of the next generation – that is, reproductive success.

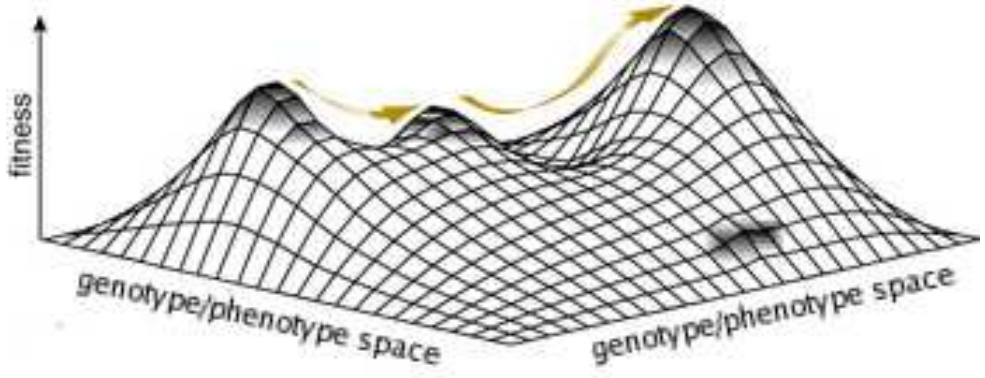
Natural selection will propagate genotypes with a high fitness in a given environment.

Fitness is a function of both genotype and environment

Comparisons must be made in proper context.

Fitness can only be indirectly measured in practice.

Walks on fitness landscapes as a metaphor for evolution



Statistics and Evolutionary Bio: A Bright Future

Why Statisticians Might Be Interested:

- Evolutionary processes are fundamentally stochastic.
- Observed changes across few generations are small and noisy.
- Strong connections to decision theory, statistical inference, prediction, and information theory.

What Statisticians Can Contribute:

- Stochastic and mathematical modeling.
- Complex data analysis (examples: Darwin's finches, phylogenetics, microarrays)
- Statistical inference: phylogenetics, gene networks, development

Today's Speakers

Sergey Gavrilets

Professor of Ecology, Evolutionary Biology, and Mathematics
University of Tennessee

- Mathematical models of speciation
- Fitness landscapes
- Sexual conflict
- Book: *Fitness Landscapes and the Origin of Species*

Carl Bergstrom

Assistant Professor of Biology
University of Washington

- Strategic aspects of communication (signaling, deception, language)
- Information in Biological Systems
- Evolution of infectious diseases