Introducing Myself

- Postdoc in Genetics and Bioinformatics at NC State
- PhD in Genetics from University of Georgia (2006)
- BS Genetics and AB Latin (UGA, 2000)
- Computational evolutionary geneticist
- My current research involves developing, implementing, and applying models of molecular evolution to study mammalian evolution.
- I am also active in several pro-science citizens organizations
- And was involved with the Cobb County (GA) Disclaimer case and the Dover Area (PA) Intelligent Design case.
Evolution

Theodosius Dobzhansky, 1973

Nothing in Biology Makes Sense Except in the Light of Evolution.

- The study of life’s variation is the central focus of modern biology.
  - Why do different species look different?
  - Why do different individuals of the same species look different?
  - Why do different parts of individuals look different?
- Evolution explains the variation and diversity of life.

Brief History of Evolutionary Biology

- pre-1850s: Many attempts by early philosophers, authors, and naturalists to apply evolution-like ideas to biology.
- 1859: Darwin’s *On the Origin of the Species* is first published.
- 1860s-1920s: Evolution accepted by the scientific community, but doubts about natural selection abound.
- 1866: Mendel publishes his laws of inheritance, rediscovered in 1900.
- 1920s-1940s: Modern synthesis of genetics and evolution, firmly establishing importance of natural selection.
- 1953: Watson and Crick solve the structure of DNA; molecular biology is born.
- 1968: Kimura develops the neutral theory of molecular evolution.
- 1972: Gould and Eldredge develop punctuated equilibrium, applying concepts from evolution and ecology to paleontology.
- 1982: Kingman develops coalescent theory.
- 1990s: Genomics and bioinformatics start providing data faster than we can study it.
What is Evolution?

**Definition: Evolution**
Change in the heritable characteristics of a population over time.

- Populations evolve, not individuals. Think “Descent with Modification”.

**Definition: Microevolution**
Evolution apparent between individuals in the same species.

**Definition: Macroevolution**
Evolution apparent between individuals in different species.

- Microevolution and macroevolution are the same process, evolution.
- They differ by the degree of change typically observed.

Four Examples of Evolution

- **Peppered Moths** as an example from population genetics
- **Whales** as an example from paleontology
- **Humans** as another example from paleontology
- **HIV** as an example from molecular biology
Example: Peppered Moth, *Biston betularia*

Fall of the *carbonaria* form

Figure 1. Change in frequency of the *carbonaria* form of the peppered moth *Biston betularia* (L.) in the Manchester area since 1950. Data are from Bishop et al. (1976a), Cook et al. (1980) and Table 1. Vertical lines show standard error, horizontal lines range of years included. The curve is the theoretical prediction from the model of May (1982, 1990) with modified fitness.

Figure 2. Change in frequency of *carbonaria* form in northwest Kent in records published by R. K. West. The curve is the theoretical prediction from the model of May (1982, 1990). Other details as for figure 1.

Example: Hominins

- A. Pan troglodytes, chimpanzee, modern
- B,C. Australopithecus africanus, 2.6, 2.5 My
- D,E. Homo habilis, 1.9, 1.8 My
- F. Homo rudolfensis, 1.8 My
- G. Homo erectus, 1.75 My
- H. Homo ergaster, 1.75 My
- I. Homo heidelbergensis, 300-125 Ky
- J,K,L. Homo sapiens neanderthalensis, 70, 60, 45 Ky
- M. Homo sapiens sapiens, Cro-Magnon I, 30 Ky
- N. Homo sapiens sapiens, modern

Source: Nick Matzke (NCSE)

http://www.talkorigins.org/faqs/condesc/hominids.html

Dr. Reed A. Cartwright (NCSU)   Evolutionary Biology in 30 Minutes   2/6/07  9 / 41
### Partial sequence of the C2-V5 region of HIV-1 env protein.

- Subset of samples taken from a single patient during a nine year period.

What is Evolution Not?

- Directional—Evolution has no inherent direction. Species can evolve “downwards” as well as “upwards”. There is no such thing as “devolution”.
- Universal—The theory of evolution explains the origin of the diversity of life on Earth. It does not attempt to explain the origin of the universe, or of the Earth, or of life itself.
- Anti-theistic—Evolution, like meteorology or gravity, is an explanation of natural events. It is not part of some atheistic campaign to eliminate religion. Mainstream denominations like United Methodists, Catholics, Episcopalians, Presbyterians (USA), Lutherans, Baptist Joint Committee, etc. have all said that evolution is not in conflict with their faith.

Mechanisms of Evolution

- There are five main evolutionary forces.
  - The Generating Force: Mutation—including recombination, gene duplication, etc.
  - The Choosey Force: Selection
  - The Random Force: Genetic Drift
  - The Uniting Force: Gene Flow—including isolation.
  - The Genotypic Force: Nonrandom Mating
A population is a group of interbreeding individuals, like a species or subspecies.

Population genetics studies the frequencies of alleles and genotypes in a population.

Variation: Foundation of Evolution

- Phenotypic variation is due to the interaction of genotypic variation and environmental variation.
  - Example: Two people can have different heights because they have different genes and/or different diets.
  - Evolution affects genotypic variation and not environmental variation.
    - Unless there is a relationship between the two.
  - If there is no genotypic variation, then there can be no evolution.
  - Where does genotypic variation come from?
Evolutionary Force: Mutation
The Generating Force

- Genes are copied in order to pass them to offspring.
- This process is inexact, causing random changes—mutations—to the genes to occur.
- Mutation is the foundation of evolution because it generates the variation that evolution requires.
- In fact, any species that could reproduce itself flawlessly would go extinct because it would be unable to evolve in response to a changing environment.

Evolutionary Force: Natural Selection

Definition: Natural Selection
Variation in average reproductive success among phenotypes.

- If a population has a) variation in a trait and b) a consistent relationship between the trait and reproductive success,
- Then some variants will consistently have more offspring than other variants.

Definition: Evolution by Natural Selection
Change in the heritable characteristics of a population due to selection.

- If the population has c) a heritable component to the trait variation,
- Then the variants with more offspring will likely become more common in the population in the next generation.
Natural Selection is Not Random

- Natural selection is the creative force of evolution.
- By filtering natural variation, selection is able to extract a “signal” from the “noise”.
- Produces complex adaptations by sequential addition and modification of parts.
- Natural selection is not random. The fitness of a phenotype is a product of the environment and is not determined randomly.

Selection Example
Components of Fitness

- Zygotes
- Adults
- Parents
- Gametes
- Viability
- Sexuality
- Fecundity
- Gametic Compatibility

Adaptation Example

- Why do we vomit? How is it adaptive?
- Why do we vomit when we get dizzy?
- Why do we vomit after other people vomit?
How Evolution Makes Complex Things
Mullerian Interlocking Structures

Over many generations evolution can produce surprisingly complex adaptations.

H. J. Muller, 1918

Most present-day animals are the result of a long process of evolution, in which at least thousands of mutations must have taken place. Each new mutant in turn must have derived its survival value from the effect which it produced upon the “reaction system” that had been brought into being by the many previously formed factors in cooperation; thus a complicated machine was gradually built up whose effective working was dependent upon the interlocking action of very numerous different elementary parts or factors, and many of the characters and factors which, when new, were originally merely an asset finally became necessary because other necessary characters and factors had subsequently become changed so as to be dependent on the former. It must result, in consequence, that a dropping out of, or even a slight change in any one of these parts is very likely to disturb fatally the whole machinery; for this reason we should expect very many, if not most, mutations to result in lethal factors, and of the rest, the majority should be “semi-lethal” or at least disadvantageous in the struggle for life, and likely to set wrong any delicately balanced system, such as the reproductive system.

Evolutionary Force: Genetic Drift
The Random Force

Definition: Genetic Drift
The random fluctuation of alleles due to sampling error.
Evolutionary Force: Genetic Drift

Definition: Genetic Drift

The random fluctuation of alleles due to sampling error.

- Drift is the result of reproduction: all offspring contain a sample of the parents’ genes.
- It is statistically unlikely that offspring will have the same allele frequencies as their parents.
- Drift occurs in every finite population, i.e. every real population.
- Drift is stronger in small populations than in large populations.
- Because of drift, even favored alleles can be lost from a population.
- Drift is the basis of molecular evolution’s neutral theory.
Interaction of Selection and Drift

- Evolution is the most mathematical of all the life sciences.
- It is possible to use math to make predictions about the relative strengths of selection and drift.

**Probability that a New, Neutral Allele is Fixed.**

\[ P(\text{fixation}) = \frac{1}{2N_e} \]

**Probability that a New, Selected Allele is Fixed**

\[ P(\text{fixation}) = \frac{1 - e^{-s}}{1 - e^{-2N_e s}} \approx s \]

Using these equations it is possible to determine how the strengths of selection and drift compare.

**Selection is Stronger than Drift**

\[ s \gg \frac{1}{2N_e} \]

**Selection is Weaker than Drift**

\[ s \ll \frac{1}{2N_e} \]
Evolutionary Forces: Gene Flow and Nonrandom Mating

**Definition: Gene Flow**
The migration of alleles from one population to another.

- Lack of gene flow (isolation) allows populations to evolve independently of one another.

**Definition: Nonrandom Mating**
A mating system where partners are not chosen independent of their genotypes, either directly or indirectly.

- Changes genotype frequencies not allele frequencies.

Origin of New Genes
Duplication and Divergence

- Sections of a chromosome can be duplicated (a type of mutation) if non-homologous recombination occurs.
- If a gene happens to be in this duplication, then the organism will have two copies of the same gene.
- Thus, there is redundancy of function, allowing the duplicated genes to evolve new functions while maintaining the old.
- Gene families like the globins (hemoglobin, myoglobin, etc.) are examples of duplication and divergence.
Why Evolution is Important

- In the culture wars, pundits often regard evolution as unimportant or harmful for our society.
- Among developed countries, only Turkey has a lower acceptance of evolution than the US.
- Attacks on the central concept of modern biology have serious consequences, if we want a society that values reality over superstition.
- A prime example is the case of the Tripoli Six.
Why Evolution is Important: The Tripoli Six

- The Tripoli Six are a group of foreign medical workers that worked at Al-Fateh Hospital in Benghazi, Libya.
- In 1998 they were charged with deliberately spreading HIV and hepatitis to children at the hospital.
- They've been tortured, raped, and sentenced to death (twice) by the Libyan government.
- The Libyan government has mostly ignored the pleas of foreign governments to release the Tripoli Six.
- Libya is using these medical workers to extort money from Europe and to retaliate for the conviction of Libyans in the Lockerbie-Pan-Am-103 bombing.

What Can Evolution Say?
The Tripoli Six

Two months ago a team of evolutionary biologists published an analysis of the HIV and hepatitis infections which exonerated the Tripoli Six.

- Using evolution, the scientists were able to demonstrate that the HIV infections were inconsistent with the accusations.
- Instead, the infections are consistent with an outbreak caused by bad practices at the hospital before the doctors arrived.
The HIV-1 sequences from the hospital form a well-supported monophyletic cluster within the CRF02_AG clade, indicating that the outbreak arose from one CRF02_AG lineage. The cluster is closest to three west African reference sequences (Fig. 1a), the basal location of which suggests that the Al-Fateh Hospital lineage arrived in Libya from there. The branch length leading to the Al-Fateh Hospital cluster is perfectly typical; hence the Al-Fateh Hospital strain is not unusually divergent.

a–c, Estimated maximum-likelihood phylogenies for HIV-1 CRF02_AG (a), HCV genotype 4 (b) and HCV genotype 1 (c). Source of sequences used for analysis: AFH, red; Egypt, green; Cameroon, blue. Black circles mark the common ancestor of HCV subtype 4a and 1a; numbers above AFH lineages give clade support values using bootstrap and Bayesian methods, respectively. Scale bar units are nucleotide substitutions per site. For visual clarity, AFH clusters are represented by triangles and some non-informative reference strains are excluded.
We found that, irrespective of which model was used, the estimated date of the most common recent ancestor for each cluster pre-dated March 1998, sometimes by many years (Fig. 2).

In most analyses, the probability that the clusters from the Al-Fateh Hospital originated after that time was almost zero (for details, supplementary information). For the three HCV clusters, the percentage of lineages already present before March 1998 was about 70%; the equivalent percentage for the HIV-1 cluster was estimated at about 40%.

Results obtained by using different evolutionary models. Vertical lines show the 95% highest posterior density intervals. Red line shows time of arrival of the foreign staff in March 1998. For further details, see supplementary information. 'Const', constant size; 'Expo', exponential growth.
de Oliveira et al.

Our results support the existing nosocomial transmission scenario and suggest that Al-Fateh Hospital had a long-standing infection-control problem. The earlier origin and greater number of HCV clusters than HIV-1 clusters reflect the higher transmissibility of HCV compared with HIV-1 by such routes. Crucially, we have shown that the HIV-1 and HCV strains responsible were being spread and transmitted among individuals attending the hospital before March 1998, indicating that many of the transmissions giving rise to the infection clusters must have already occurred before the foreign medical staff arrived.

What’s Next for the Tripoli Six

The work of de Oliveira et al. could not have been done without our understanding of HIV evolution.

No “intelligent design” or “biblical creation” approach could have even tackled the question.

Sadly, the Tripoli Six, although proven innocent by this research, are still on death row.

It is unclear whether Libya will even listen to this scientific evidence; they’ve ignored earlier scientific testimony by the defense.
Thanks