Origins 103: Addendum – Mutation Rate Illustration

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Illustrating the Numbers: Probability and Time

Introduction

- Last week we began to introduce factors A through H in order to determine whether mutation was capable of resulting in speciation rates fast enough to accomplish all the genetic diversity of life that has ever existed.
- Tonight we will continue that calculation using a more realistic example to illustrate factors A through H.
- To illustrate the impact of factors A through H, we will consider the hypothetical example in which a gene that creates scales in reptiles undergoes a series of mutations that transform scales into the first feathers.

1) This is one of the current evolutionary theories regarding the origin of a feather (and the evolution of birds from reptiles).

   "**feather** – feather, the component structure of the outer covering and flight surfaces of all modern birds. Unique to birds, **feathers apparently evolved from the scales of birds' reptilian ancestors.**" – http://www.britannica.com/EBchecked/topic/203162/feather

2) Notice that the morphological changes (i.e. changes in physical form) are a "series," which means multiple steps.

   "Historical-narrative evolutionary explanations for **the origin and further evolution of avian feathers involve two steps.** The first phase reconstructs **a series of probable morphological changes from a reptilian scale to the primitive feather.** The second deduces possible functions and biological roles of the features and feasible selective demands on these features at all stages in its evolution." – Explanatory History of the Origin of Feathers1, by Walter J. Bock, Department of Biological Sciences, Columbia University, 1200 Amsterdam Avenue, Mail Box 5521, New York, 10027-7004, http://m.icb.oxfordjournals.org/content/40/4/478.full

3) Notice that evidence suggests the feather "evolved only once" in history. This further underscores the scenario in which these mutations compound over multiple generations of a single population.

“The complex structure of avian feathers, including all information from fossilized feathers such as those present in Archaeopteryx, **suggests strongly that feathers evolved only once in the history of the Vertebrata**.” – Explanatory History of the Origin of Feathers1, by Walter J. Bock, Department of Biological Sciences, Columbia University, 1200 Amsterdam Avenue, Mail Box 5521, New York, 10027-7004, http://m.icb.oxfordjournals.org/content/40/4/478.full

4) Notice that feathers “might have depended on a simple switch in the wiring of the genetic commands…causing their cells to grow vertically through the skin rather than horizontally” and that they are essentially “using the same genetic instruments.” This means we’re not talking about adding genes, we’re talking about changes to an existing gene.

   “If they were **early feathers, how had they evolved from flat scales?** Fortunately, there are theropods with threadlike feathers alive today: baby birds. All the feathers on a developing chick begin as bristles rising up from its skin; only later do they split open into more complex shapes. **In the bird embryo** these bristles erupt from **tiny patches of skin cells called placodes**. A ring of fast-growing cells on the top of the placode builds a cylindrical wall that becomes a bristle. **Reptiles have placodes too.** But in a reptile embryo each placode switches on genes that cause only the skin cells on the back edge of the placode to grow, eventually forming scales. In the late 1990s Richard Prum of Yale University and Alan Brush of the University of Connecticut developed the idea that **the transition from scales to feathers** might have depended on **a simple switch in the wiring of the genetic commands** inside placodes, **causing their cells to grow vertically through the skin rather than horizontally**. In other words, feathers were not merely a variation on a theme: They were **using the same genetic instruments** to play a whole new kind of music.” – Evolution of Feathers, The Long Curious Extravagant Evolution of Feathers, By Carl Zimmer, Published: February 2011, http://ngm.nationalgeographic.com/print/2011/02/feathers/zimmer-text

   a. (The placode is a platelike thickening in an embryo, which for animals produces the outermost layer of skin or covering.)

      “**placode** - a **platelike thickening** of embryonic **ectoderm** from which **a definitive structure develops**.” - http://www.merriam-webster.com/medical/placode

      "**ectoderm** - 1: the outer cellular membrane of a diploblastic animal (as a jellyfish) **2a: the outermost of the three primary germ layers of an embryo that is the source of various tissues and structures** (as the **epidermis**, the nervous system, and the eyes and ears)." - http://www.merriam-webster.com/dictionary/ectoderm

> “**epidermis** – **medical: the outer layer of skin. 1a: the outer epithelial layer of the external integument of the animal body** that is derived from the embryonic epiblast; specifically: the outer **nonsensitive and nonvascular layer of the skin of a vertebrate that overlies the dermis** b: any of various animal integuments. – http://www.merriam-webster.com/dictionary/epidermis
>
> “**integument** – **something that covers or encloses**; especially: an enveloping layer (as a skin, membrane, or **cuticle**) of an organism or one of its parts.” - http://www.merriam-webster.com/dictionary/integuments

5) For illustrative purposes, we can imagine a few of these basic steps, or changes, to the scale – each change or step would be caused by a mutation.
    a. Scale gets longer.
    b. Scale splits forming a kind of webbing.

    Feather, Evolution – **Theories of the scale-based origins of feathers suggest that the planar scale structure was modified for development into feathers by splitting to form the webbing**. – http://en.m.wikipedia.org/wiki/Feather

    “**Both scales and feathers are flat.** So **perhaps the scales of the birds' ancestors had stretched out, generation after generation. Later their edges could have frayed and split,** turning them into the first true feathers.” – Evolution of Feathers, The Long Curious Extravagant Evolution of Feathers, By Carl Zimmer, Published: February 2011, http://ngm.nationalgeographic.com/print/2011/02/feathers/zimmer-text

6) (Of course, we are oversimplifying and abbreviating for the sake of illustration. Many other mutations or steps would have occurred to transform a scale into the feathers we see today.)

    “Once the first filaments had evolved, only **minor modifications would have been required to produce increasingly elaborate feathers**.” – Evolution of Feathers, The Long Curious Extravagant Evolution of Feathers, By Carl Zimmer, Published: February 2011, http://ngm.nationalgeographic.com/print/2011/02/feathers/zimmer-text

Now we can plug these pieces into factors A-H, using as our example a population of small, ground-running dinosaurs known generally as theropods.

> “This feathers-led-to-flight notion began to unravel in the 1970s, when Yale University paleontologist John Ostrom noted striking **similarities between the skeletons of birds and terrestrial dinosaurs called theropods**, a group that includes marquee monsters like *Tyrannosaurus rex* and *Velociraptor*. Clearly, Ostrom argued, **birds were the living descendants of theropods**. Still, many known theropods had big legs, short arms, and stout, long tails—hardly the anatomy one would expect on a creature leaping from trees. Other paleontologists argued that birds did

not evolve from dinosaurs—rather, their similarities derived from a shared common ancestor deeper in the past. In 1996 Chinese paleontologists delivered startling support for Ostrom's hypothesis. It was **the fossil of a small, short-armed** 125-million-year-old **theropod**, *Sinosauropteryx*, which had one extraordinary feature: a layer of thin, hollow filaments covering its back and tail. At last there was **evidence of truly primitive feathers**—found on **a ground-running theropod**." – Evolution of Feathers, The Long Curious Extravagant Evolution of Feathers, By Carl Zimmer, Published: February 2011, http://ngm.nationalgeographic.com/print/2011/02/feathers/zimmer-text

Factor A – Base Number of Generations

We are measuring how many generations it will take for a particular mutation to spontaneously occur in 1% of a population.

Imagine a group of theropods with 3 different alleles (gene variations) for their scales.

1) 50% of the population has the gene for a MEDIUM-sized scale.
2) 10% has the gene for a slightly BIGGER scale.
3) 40% has the gene for a SHORTER scale.

We are assigning these percentages in order to correspond to the 50% and 10% starting points used in Britannica below.

(Like human eye color, let's say for simplicity that these variations themselves don't impact survival ability and these percentages are fixed over generations.)

"**Evolution, Dynamics of genetic change, Processes of gene frequency change**
Mutation – The allelic variations that make evolution possible are generated by the process of mutation; but new mutations change gene frequencies very slowly, since mutation rates are low. Assume that **the gene allele A 1 mutates to allele A 2** at a rate m per generation, and that at a given time the frequency of A 1 is p**…If the mutation rate is 10 [to a power of -5] (1 in 100,000) per gene per generation, about 2,000 generations will be required to change the frequency of A 1 from 0.50 to 0.49 and about 10,000 generations to change it from 0.10 to 0.09."** – Encyclopaedia Britannica 2004 Deluxe Edition

According to Britannica, what happens if this gene that controls scale shape mutates to create a significantly longer scale?

1) Let's imagine the mutation occurs on the **MEDIUM** gene, which is in **50%** of the population. It will take **2,000 generations** for **MEDIUM** gene to mutate into the **LONG** gene.

2) Let’s imagine the mutation occurs on the **<u>BIG</u>** gene,which is in **<u>10%</u>** of the population. It will take **<u>10,000 generations</u>** for **<u>BIG</u>** gene to mutate into the **<u>LONG</u>** gene.

After either 2,000 or 10,000 generations, the mutant LONG gene **<u>will be in only 1% of the population</u>**.

Why use 1%?
1% isn’t necessarily significant or an established threshold for a new species to arrive, but it serves as a reasonably small starting point for the emergence of a new species.

- After all, one member of a population with a new gene is not a new species.
- This amount is an attempt to reasonably represent a self-sustaining portion of the population.

Now, imagine what happens when this gene mutates to SPLIT the scale into webbing.

1) What happens if the SPLIT mutation happens in the 99% of the theropod population that does not have the mutant LONG gene? There is no further advancement toward a feather, which requires both elongation and separation of the scale.
2) To move forward, the new SPLIT mutation must occur within the 1% that already has the mutant LONG gene.

How long will it take for the same gene that mutated into the LONG-scale to mutate again into a SPLIT-scale gene in the same 1% of the theropod population that has the LONG-scale mutation?

Step 1: (Getting the LONG gene mutation in 1% of the population.)

1) If we start with the 50% of the population that had the MEDIUM gene, it will take 2,000 generations for the LONG mutation to occur in 1% of these theropods.
2) If we start with the 10% of the population that had the BIGGER gene, it will take 10,000 generations for the new mutation to occur in 1% of these theropods.

Step 2: (Getting the SPLIT gene mutation in the same 1% of the population that had the LONG gene mutation.)

1) BOTTOM LINE: We are starting with 1% of the population that had the LONG gene mutation, so it will take 100,000 generations for the LONG gene to mutate into the SPLIT gene in this same group of theropods.

*After 100,000 generations, 1% of the theropods now have a LONG-scale gene that mutated into a SPLIT-scale gene.

Factor B – A Fairer Mutation Rate Slow-Down

- Britannica’s numbers are based on the “1 in a 100,000” mutation rate, which is the lower end of the range and fastest rate of mutation.
- Factor B will adjust our calculation using a more average rate of mutation.

> “**Evolution, Dynamics of genetic change, Processes of gene frequency change**
> **Mutation –** If the mutation rate is 10 [to a power of -5] **(1 in 100,000) per gene per generation**, about 2,000 generations will be required to change the frequency of A 1 from 0.50 to 0.49 and about 10,000 generations to change it from 0.10 to 0.09.**”** – Encyclopaedia Britannica 2004 Deluxe Edition

> “**Evolution, The process of evolution, Evolution as a genetic function, The origin of genetic variation: mutations, Gene mutations** – **In humans and other multicellular organisms, the rate** typically ranges from about **one per 100,000 to one per 1,000,000 gametes.”** – Encyclopaedia Britannica 2004 Deluxe Edition

Please note that although the numbers are the same, this is different from Factor A.

1) Factor A calculated 100,000 **GENERATIONS** for 2 mutations to occur in the same 1% of these theropods.
2) Factor B describes a mutation rate of 1 out of 100,000 **GAMETES**, not generations.

What happens if we use a mutation rate closer to the middle of the range?

- If we use 500,000 instead of 100,000, **we are slowing down the mutation rate and entire the process by 5 times**.

BOTTOM LINE: This means instead of taking **100,000 generations**, it would **slow down 5 times** to take **500,000 generations** before the **SPLIT-scale mutation occurs** in the **1%** of the theropods that **already** have the **LONG-scale mutation**.

*After 500,000 generations, 1% of the theropods now have a LONG-scale gene that mutated into a SPLIT-scale gene.

Factor C – Backward Mutation Slow-Down

Britannica’s mutation rates did not take into account backward mutations which reverse previous mutations and slow the process down.

> “**Evolution, Dynamics of genetic change, Processes of gene frequency change, Mutation –** The allelic variations that make evolution possible are generated by the process of mutation; but new mutations change gene frequencies very slowly, since mutation rates are low. Assume that **the gene allele A 1 mutates to allele A 2** at a rate m per generation, and that at a given time the frequency of A 1 is p**…**If the mutation rate is 10 [to a power of -5] (1 in 100,000) per gene per generation, about 2,000

generations will be required to change the frequency of A 1 from 0.50 to 0.49 and about 10,000 generations to change it from 0.10 to 0.09…**Changes in gene frequencies** due to mutation occur, therefore, at **even slower rates than was suggested above, because forward and backward mutations counteract each other."** – Encyclopaedia Britannica 2004 Deluxe Edition

Notes:

1) There is no data provided on the ratio of backward mutations so **this factor will be hypothetical**.
2) The slow down from backward mutation must be statistically significant enough for Britannica to mention it. A 1-2% slow-down isn't really statistically relevant enough to mention.

How much will backward mutations slow the process down?

1) If we assume there is **1 backward** mutation for every **1 forward** mutation, then **the process will stop completely** because each mutation would be reversed.
2) If we assume there is **1 backward** mutation for every **2 forward** mutations, then the process will take **3 times as long** because only 1 out of every 3 mutations would actually move evolution forward. The other 2 would counteract each other.
3) If we assume there is **1 backward** mutation for every **3 forward** mutations, then the process will take **2 times as long** because only 2 out of every 4 mutations (**half**) would actually move evolution forward. The other 2 would counteract each other.
4) If we assume there is **1 backward** mutation for every **21 forward** mutations, then the process will take only **1.1 times as long**, which is about **91%** of the original speed, **less** than a **10%** slow down.
   - Take 1 out of 22 and multiply it by 1 out of 100,000 = 1 out of 2,200,000 total gametes.
   - Then take 20 "unreversed" forward mutations out of those 2,200,000 gametes = 20 out of 2,200,000 forward mutations.
   - 20 out of 2,200,000 reduces to 1 out of 110,000 instead of 1 out of 100,000.
   - 110,000 is 1.1 times larger than 100,000 and 100,000 is approx. 91% of 110,000.

BOTTOM LINE: Take our current **500,000 generations** and multiply that by **1.1** to account for our hypothetical "backward" mutation rate to arrive at **550,000 generations**, *statistically relevant but not a huge factor either.*

*550,000 generations for these 2 gene mutations to occur in 1% of a theropod population.

Factor D – Beneficial Mutation Slow-Down
Most mutations are harmful or have little to no affect (on the organism).

> "**Evolution, The process of evolution, Evolution as a genetic function, The origin of genetic variation: mutations, Gene mutations** – The consequences of **gene mutations may range from negligible to lethal."** – Encyclopaedia Britannica 2004 Deluxe Edition

But only beneficial mutations will rise in distribution (through reproduction).

> "**Gene** – **The mutation generally has little or no effect; when it does alter an organism, the change is frequently lethal. A beneficial mutation will rise in frequency within a population until it becomes the norm.**" – Encyclopaedia Britannica 2004 Deluxe Edition

> "**Heredity, Heredity and evolution, The gene in populations, The Hardy–Weinberg principle –** In 1908, Godfrey Harold Hardy and Wilhelm Weinberg independently formulated a theorem that became the foundation of population genetics. **According to the Hardy–Weinberg principle, two or more gene alleles will have the same frequency in the gene pool generation after generation, until some agent acts to change that frequency.**" – Encyclopaedia Britannica 2004 Deluxe Edition

> "**Heredity and evolution, Selection as an agent of change, Natural selection and Darwinian fitness – Sexual reproduction** under simple (Mendelian) inheritance is a conservative force that tends to maintain the genetic status quo in a population. **If a gene frequency is 1 percent in a population, it tends to remain at 1 percent indefinitely unless some force acts to change it.** Outside of the laboratory, **the most powerful force for changing gene frequencies is natural selection.**" – Encyclopaedia Britannica 2004 Deluxe Edition

> "**Species** – **This process of natural selection results in the gene pool's evolving in such a way that the advantageous variations become the norm.**" – Encyclopaedia Britannica 2004 Deluxe Edition

Britannica's estimates weren't concerned with whether the mutation was beneficial or harmful. It was just the rate at which mutations in general occur in the gametes.

So, we need to account for a ratio of beneficial mutations to all other mutations.

Beneficial mutations are rare, the most unlikely kind of mutation.

> "**Evolution, XI MUTATIONS, A Gene Mutation** – **Most gene mutations are harmful to the organisms that carry them; the function of** a complex system such as **a protein is more easily destroyed than improved by a random change.**" – "Genetics," Microsoft® Encarta®

Encyclopedia 99. © 1993-1998 Microsoft Corporation. All rights reserved.

"**Evolution, Causes of evolutionary change** – **Mutations** occur regularly but **are usually infrequent, and most of them produce unfavorable traits.**" – Worldbook, Contributor: Alan R. Templeton, Ph.D., Rebstock Professor of Biology, Washington University.

"**Evolution, The process of evolution, Evolution as a genetic function, The origin of genetic variation: mutations, Gene mutations** – The consequences of **gene mutations may range from negligible to lethal…Newly arisen mutations are more likely to be harmful than beneficial."** – Encyclopaedia Britannica 2004 Deluxe Edition

Notes: This will again by a hypothetical number because not actual ratio data is available (in part because in reality "beneficial" mutations are themselves hypothetical).

Let's imagine that 1 out of every 20 mutations is beneficial.

- This is less than our hypothetical ratio of backward mutations, which is 1 out of 22.
- 1 out of 20 would be 5% of all mutations.
- This hypothetical ratio is generous to evolutionary theory.

BOTTOM LINE: Take our current **550,000 generations** and multiply that by **20** to account for our hypothetical "beneficial" mutation rate to arrive at **11,000,000 (11 million) generations.**

*11 million generations for these 2 gene mutations to occur in 1% of a theropod population.

Factor E – Recessive Slow-Down

Notes:

- At some point, the LONG-scale mutation occurred in 1% of the theropods.
- But as we will see, before the LONG-scale mutation can be perpetuated among future generations of therapods, **it has to start being present due to reproductive inheritance**, not spontaneous mutation (which is what Factor A was using).
- Otherwise, it will pass out of existence before having the chance to mutate into a SPLIT-LONG gene.
- (This allows the 1 in 4 ratio described below to be factored in before and in conjunction with the frequency ratios to determine a number of generations. It is presented out of order for simplicity sake, as are many of these other factors.)

Mutations are recessive.

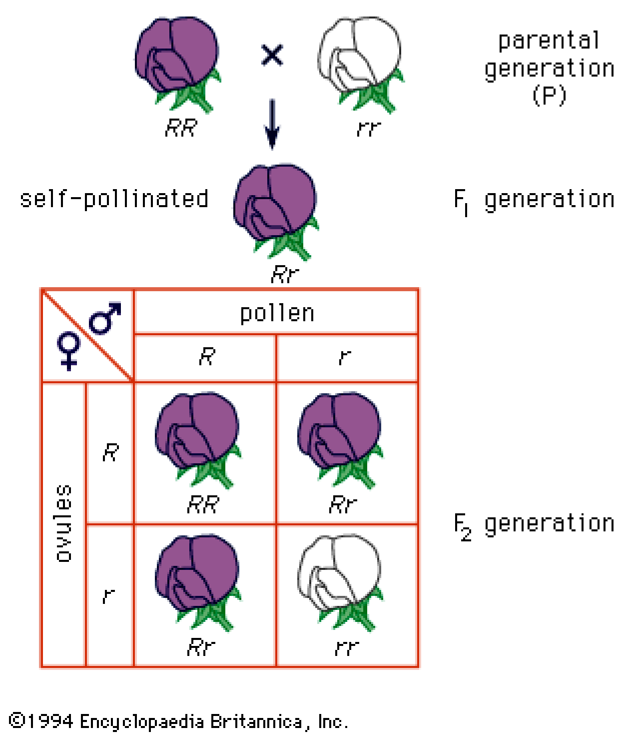
"**Evolution, XI MUTATIONS, A Gene Mutation** – **Mutations are usually recessive, and their harmful effects are not expressed unless two of them are brought together into the homozygous condition.** This is most likely to occur as a result of **inbreeding, the mating of closely related organisms** that may have **inherited the same recessive mutant gene from a common ancestor**." – "Genetics," Microsoft® Encarta® Encyclopedia 99. © 1993-1998 Microsoft Corporation. All rights reserved.

- Whether harmful, negligible, or beneficial, they **won't show up UNLESS** you **1) inherit** the same mutation from **2) both parents**.
- If the mutation does not "show up," it **won't confer an advantage or survive for reproduction**.

Multiplying 2 Ratios Together –

- The odds of getting heads when flipping a coin are 1 out of 2.
- But what are the odds of getting only heads when flipping two coins? 1 out of 4.
- You have to multiply the ratios by each other.

Punnett's Square



"**Heredity, Basic features of heredity, Early conceptions of heredity** – An example of one of Mendel's experiments will illustrate how the genes are transmitted and in what particular ratios. Let R stand for the gene for purple flowers and r for the gene for white flowers (**dominant genes are conventionally symbolized by capital letters and recessive genes by small letters**)." – Encyclopaedia Britannica 2004 Deluxe Edition

BOTTOM LINE:

- We have to account for the Punnett's square probability ratio of getting a theropod with **a manifested mutant LONG-scale gene** that can be

perpetuated long enough to **mutate again** into the **SPLIT-LONG-scale** gene.

- Take our current **11 million generations** and multiply that **by 4** to arrive at **44 million generations**.

*44 million generations for these 2 gene mutations to occur in 1% of a theropod population.

Factor F – Environmental Considerations Slow-Down
NOTE: This still pertains to the point in the process where the LONG-scale mutant gene has to be perpetuated in a population in order to be around long enough to mutate into the SPLIT-LONG mutant gene. (Again, the intention was not to present the factors in order.)

Even potentially beneficial mutations are not likely to be passed on unless the environment changes in a corresponding way as to produce a benefit.

> "**VI SPECIATION** – Because all the established genes in a population have been monitored for fitness by selection, **newly arisen mutations are unlikely to enhance fitness unless the environment changes so as to favor the new gene activity,** as in the gene for dark color in the peppered moth." – "Evolution," Microsoft® Encarta® Encyclopedia 99. © 1993-1998 Microsoft Corporation. All rights reserved.

However, mutations are spontaneous and independent of the environment, so this is a completely random probability.

> "**Evolution, III DARWINIAN THEORY** – **The basic rules of inheritance became known to science** only at the turn of the century, **when the earlier genetic work of Gregor Mendel came to light**…**The discovery was then made that inheritable changes in genes, termed mutations, could occur spontaneously and randomly without regard to the environment.**" – "Evolution," Microsoft® Encarta® Encyclopedia 99. © 1993-1998 Microsoft Corporation. All rights reserved.

> "**Evolution, The process of evolution, Evolution as a genetic function, The origin of genetic variation: mutations, Gene mutations** – …**mutations are random events with respect to adaptation;** that is, their occurrence is **independent of any possible consequences."** – Encyclopaedia Britannica 2004 Deluxe Edition

For the sake of being fair and since this is a hypothetical, we'll give a 50-50 change that there is a corresponding environmental change.

BOTTOM LINE: This requires simply multiplying the **44 million** generations **by 2** to arrive at **88 million generations**.

*88 million generations for these 2 gene mutations to occur in 1% of a theropod population.

G: New Species Threshold
Notes:

- There is no exact data here and (as we have seen) even evolutionists have trouble defining species boundaries, so this will be a hypothetical number.
- So far we have only calculated based on 2 gene mutations occurring in the same 1% of a theropod population.
- (Of course, there would be no proof unless you could determine the capacity to interbreed.)

How many beneficial mutations would it take to constitute a new species?

Human beings have about 30,000 genes.

> "**Human Genome Project** – February 2001 declared that **the human genome actually contains only about 30,000 to 40,000 genes,** much fewer than originally thought." – Encyclopaedia Britannica 2004 Deluxe Edition

There is a 2% genetic difference between humans and chimps.
(Note the assertion that humans and chimps diverged 4-8 million years ago.)

> **"**Now that **scientists have decoded the chimpanzee genome, we know that 98 percent of our DNA is the same…Human and chimps each have somewhere between 20,000 and 30,000 genes,** so **there are likely to be nucleotide differences in every single gene**.**"** – "The 2 Percent Difference," by Robert Sapolsky, DISCOVER, April 2006

> **"Chimpanzee, Taxonomy –** Genetic analysis suggest that **humans and chimps diverged four million to eight million years ago** and that **at least 98 percent of the human and chimpanzee genomes are identical."** – Encyclopaedia Britannica 2004 Deluxe Edition

2% of 30,000 genes = 600 genes.

- To be generous, we'll say it only requires 30 different genes to equal a new species
- (Ultimately, evolution teaches that a new species must be genetically different enough to no longer be able to interbreed with the original species.)
- This is 1/10 of 1%, 20 times smaller than the 2% difference that separates humans from chimps.
- We have been tracking how long it will take a second mutation to occur on the same gene in the same 1% of a population.

- Factor G means that the entire process we've outlined so far will have to repeat 30 times representing the accumulation of 30 new gene mutations in the same 1% of a population before we have a new species.

BOTTOM LINE: Multiply the **88 million** generations **by 30** to arrive at **2.640 billion generations**.

*2.640 billion generations before the mutant theropods become a new species.

Factor H: Generations per Year
In order to determine if there is enough time in evolutionary history, we need to convert generations to years.

Notes:

- How many years this process requires depends on how long the gestation cycle is for the species in question.
- Perhaps the best way (and the shortest way) to measure a generation is how long it takes to reach reproductive maturity.

Reptiles – As little at 1-2 years, but median seems to be around 10 years.
Dinosaurs –

- Information on dinosaurs is minimal.
- Those we do have data for are larger dinosaurs, not necessarily the smaller dinosaurs that could have evolved into birds and may have had shorter generations.
- They require 7-12 years to reach reproductive maturity.

Modern Reptiles –

- Range from 1-2 years to around 10 years for crocodiles and 25 years for longer-lived species, regardless of size.

  "**Dinosaur, Growth and life span** – The evidence concerning growth and life expectancy is sparse but growing...The time required for full growth has not been quantified for most dinosaurs, but de Ricqlès and his colleagues have shown that **duckbills (hadrosaurs) such as Hypacrosaurus and Maiasaura reached adult size in seven or eight years and that the giant sauropods reached nearly full size in as little as 12 years.**" - http://www.britannica.com/EBchecked/topic/163982/dinosaur/31921/Herding-behaviour#toc31922

  "Reptile – Some reptiles are annual species that hatch, mature, reproduce, and die in one year or, at most, two years (as in side-blotched lizards [Uta stansburiana]). **Others,** such as loggerhead sea turtles (Caretta caretta), **are long-lived species that require 25 or more years to mature** and have life spans that exceed 50 years." - http://www.britannica.com/EBchecked/topic/498684/reptile/38439/Africa#toc38441

"**Crocodile, Life cycle - Sexual maturity occurs at about age 10** and at a body length of about 1.5–3 metres (5–10 feet)." - http://www.britannica.com/EBchecked/topic/143679/crocodile#toc38419

"**Komodo dragon** – **They take about eight to 9 years to mature**, and are estimated to live up to 30 years. - http://en.wikipedia.org/wiki/Komodo_dragon#Reproduction

"**Tuatara, Reproduction** – Tuatara reproduce very slowly, taking **10 to 20 years to reach sexual maturity**." - http://en.wikipedia.org/wiki/Tuatara

Birds – Range from 1-4 years.

- Smaller birds can reach reproductive maturity around 1 year, larger birds may take 3-4 years.

"**Northern Mockingbird, Breeding** - Both the male and female of the species reach **sexual maturity after 1 year of life.**" - http://en.wikipedia.org/wiki/Northern_Mockingbird#Breeding

"**Blue Jay, Reproduction** - **Sexual maturity is reached after one year of age**." - http://en.wikipedia.org/wiki/Bluejay#Reproduction

"**Eagle** – They tend to nest in inaccessible places, incubating a small clutch of eggs for six to eight weeks. **The young mature slowly, reaching adult plumage in the third or fourth year.**" - http://www.britannica.com/EBchecked/topic/175537/eagle

Mammals – Range from 3 to 6 months up to 5 to 15 years.

- Rabbits require only 3-8 months.
- Dogs require 6-12 months up to 2 years for larger breeds.
- Otters require 2 years.
- Bears require 3.5-6 years.
- Elephants can take 9-15 years to reach sexual maturity.

"Depending on his/her genetic makeup, a **rabbit will reach sexual maturity somewhere between the age of 3 to 8 months**." - Spay or Neuter My Rabbit, by Dana Krempels, Ph.D., http://www.bio.miami.edu/hare/spay.html

"**Dogs, Reproduction** - In domestic dogs, sexual maturity begins to happen around **age six to twelve months for both males and females**, although this can be delayed until up to two years old for some large breeds." - http://en.wikipedia.org/wiki/Dog#Reproduction

"**Otter, Life cycle** - The gestation period in otters is about 60 to 86 days. The newborn pup is cared for by the mother, father and older offspring.

Female otters reach sexual maturity at approximately two years of age and males at approximately three years." - http://en.wikipedia.org/wiki/Otter#Life_cycle

"**Bear, Natural history** - Bears reach **breeding condition at three and a half to six years of age,** males usually maturing later than females." - http://www.britannica.com/EBchecked/topic/57309/bear/252724/Natural-history

"**Elephant, Birthing and calves** – Play behaviour in calves differs between the sexes; **females** run or chase each other, while **males** play-fight. The former are **sexually mature by the age of nine years** while the latter become **mature around 14–15 years**." - http://en.wikipedia.org/wiki/Elephant

Summary:

- We could say the norm or average is a matter of years, not months, and at least 1 year.

For All Organisms –

- Our original study assumes an average generation is 1 week, roughly 1/50th of a year.
- In order to account for organisms that are simpler than animals, such as bacteria or insects.

BOTTOM LINE: **<u>DIVIDE</u>** the **<u>2.640 billion</u>** generations **<u>by 50</u>** generations per year to arrive at **<u>52,800,000 (52.8 million) years.</u>**

*52.6 million years to produce 1 new species (with our hypothetical 1/10% species threshold).

For Lizards, Such as Theropods –

- Assume a 5 year average instead of a week.

BOTTOM LINE: **<u>MULTIPLY</u>** the **<u>2.640 billion</u>** generations **<u>by 5</u>** years to arrive at **<u>13.2 billion years</u>**.

**13.2 billion years for the mutant theropods to become a new species (with our hypothetical 1/10% species threshold).

For Animals in General –

- Assume a 1-year average
  - which is on the low end for reptiles and birds. It is also on the low end for mammals. Although admittedly some mammals require less time, other require much more time.

BOTTOM LINE: **MULTIPLY** the **2.640 billion** generations **by 1** generation per year to arrive at **2.640 billion years.**

*2.6 billion years to produce 1 new species (with our hypothetical 1/10% species threshold).

Note:

- All of these 3 results are much longer than the 4-8 million years alleged as the amount of time since humans and chimps diverged with a 2% difference in DNA, which is 20 times more mutations than the 1/10% genetic difference we've used for a new species threshold.
- The last 2 numbers are nearly the age of the earth itself, just to produce 1 species by the mechanism of beneficial mutation (using our 30-gene threshold to constitute the emergence of a new species).

Is There Enough Time for Animals to Evolve?
How many animal species are there?

- There are 2 million species of plants and animals that we have identified.
- **Nearly 1 million (953,434) animal species have already been cataloged.**
- And there are possibly 10-30 million more that exist which haven't yet been discovered.
- But the vast majority are animals, an estimated 7.7 million animal species.

"**Evolution** – **More than 2,000,000 existing species of plants and animals have been named and described;** many more remain to be discovered—**from 10,000,000 to 30,000,000 according to some estimates**…**The virtually infinite variations on life** are the fruit of the evolutionary process.**"** – Encyclopaedia Britannica 2004 Deluxe Edition

"**Each year, researchers report more than 15,000 new species,** and their workload shows no sign of letting up...**Scientists have named and cataloged 1.3 million species. How many more species there are left to discover** is a question that has hovered like a cloud over the heads of taxonomists for two centuries...On Tuesday, Dr. Worm, Dr. Mora and their colleagues presented the latest estimate of how many species there are, based on a new method they have developed. **They estimate there are 8.7 million species on the planet**, plus or minus 1.3 million...Confident in their method, the scientists then used it on all major groups of species, **coming up with estimates of 7.7 million species of animals,** for example, **and 298,000 species of plants**. Although the land makes up 29 percent of the Earth's surface, the scientists concluded that it is home to 86 percent of the world's species." - How Many Species? A Study Says 8.7 Million, but It's Tricky, By CARL ZIMMER, Published: August 23, 2011, http://www.nytimes.com/2011/08/30/science/30species.html?_r=0

"Census Results for the Five Kingdoms of Eukaryotes (approximate)

- **ANIMALS – 7.77 million species** (of which **953,434 have been described and cataloged**)
- PLANTS – 298,000 species (of which 215,644 have been described and cataloged)
- FUNGI – 611,000 species (of which 43,271 have been described and cataloged)
- PROTOZOA – 36,400 species (single-cell organisms with animal-like behavior, such as movement, of which 8,118 have been described and cataloged)
- CHROMISTS – 27,500 species (including, brown algae, diatoms, water molds, of which 13,033 have been described and cataloged)."

- 8.74 Million Species on Earth, by Tim Wall, Aug 23, 2011, http://news.discovery.com/earth/plants/874-million-species-on-earth-110823.htm

How much time is there for all animal species to evolve?
ALL Animals Evolved within 590-670 Million Years.

> "**Animals, Evolution and paleontology, Appearance of animals** – **Animals first appeared in the Vendian,** soft-bodied forms that left traces of their bodies in shallow-water sediments." – Encyclopaedia Britannica 2004 Deluxe Edition

> "**Animal, Ecology and habitats, Evolution of ecological roles** – This was probably more common in **the Vendian (the last interval of the Precambrian, from 670 to 590 million years ago** on certain geologic time scales)." – Encyclopaedia Britannica 2004 Deluxe Edition

> "**Period, III PERIODS OF THE PROTEROZOIC EON – The Sinian Era is divided into two informal geologic periods**-the Sturtian Period (from 800 million to 610 million years before present) **and the Vendian Period (610 million to 570 million years before present).**" – "Period," Microsoft® Encarta® Encyclopedia 99. © 1993-1998 Microsoft Corporation. All rights reserved.

Clarification

- Evolution is not strictly linear. It is branching and exponential.
- You start with one species and then you have 2 species. Then each of those 2 species produces another species. Then you have 4 species, etc.
- **<u>In other words, every time a cycle of speciation occurs, you double the number of species that are undergoing the process of producing a new species.</u>**
- After the 21 cycle of speciation, you would have 1,048,576 species.

BOTTOM LINE:

1. **The best case scenario for evolution:** 52.8 million years per cycle, 1 week generations for animals.

   a. In 670 million years, there would only be enough for 12.7 cycles of speciation.
      We'll round up to 13.
   b. If we start with 1 animal species = only be 8,192 species.
   c. If we start with 8 original animal species = only be 65,536 species.
   d. If we start with 64 original animal species = only have 524,288 species.
   e. **Notes:** One more cycle would maybe reach 1 million, but…
      i. The actual number is 7.7 million species. You'd need another 3 cycles = a total of 158 million years (an additional 25% of the timeframe) to get around 8 million species.
      ii. We've been very favorable to evolution in every factor. If it can't work under these favorable conditions, then it can't work.
         1. What happens if you increase the species threshold from 1/10% to 1-2%
         2. What happens if the backward mutation rate is higher than 1 in 22 or the beneficial mutation rate is lower than 1 in 20?

2. **Worst case scenarios for evolution:**
   a. 2.6 billion years per cycle, 1 year generations for animals.
   b. 13.2 billion years per cycle, 5 year generations for animals.

Conclusions:

a. Average mutation rate of 1 out of 500,000
b. Only 1 in 22 mutations is a "backward" mutation.
c. 1 in 20 mutations is beneficial
d. Only 30 new genes are required for a new species
e. The mutations only have to accumulate in 1 percent of the population.
f. Compounding this process exponentially as new species are produced.
g. Whether we use 1 week, 1 year, or 5 year generation cycle.

There simply isn't enough time for beneficial mutation to produce…

- The 1 million animal species we've identified.
- The 7.7 million animal species that are estimated to yet be discovered.
- The tens or hundreds of millions of extinct intermediary or dead-end species along the way to what's here today.

They are billions of years short, if not tens or hundreds of billions.
(As we move forward, consider the impact on the fossil record, which places things like a divergence of men and chimpanzees 4-8 million years ago.)