Evolution in review

Some people have a profound misunderstanding of Charles Darwin's Theory of Evolution. For example, I was listening to a radio program one day and heard a proponent of religion saying something about how believing that mankind just suddenly sprang into existence was as silly as expecting some arbitrarily large number of atoms to "suddenly form a battleship."

There is no evidence – and no science-based claim - of any human having suddenly sprang into existence. Likewise, there is no evidence that a battleship has ever simply sprang into existence. Battleships are in fact an example of "directed evolution". Our ancient ancestors probably made use of floating logs at some point. Later they would hollow out logs and thus form a primitive canoe. With the design of paddles and addition of weapons they were soon designing and building war canoes. We can assume that later generations of designers added planks and ribs to allow more warriors and weapons to be carried. Human powered paddles and oars would soon be augmented with sails. When the war canoes grew too large to be driven by human power, sails became the primary propulsion. The designers passed their evolving plans for warships from one generation to the next. Successful innovations would become enduring parts of those plans. Unsuccessful "mutations" which were less useful were dropped from the plans along with old innovations which had become obsolete. The designers would soon add engines. Subsequent designs relied less and less on sails and eventually modern power-plants replaced sails altogether - resulting in a new type of ship that bore little resemblance to its predecessors made of hollowed out logs. The directed evolution of battleships continued with the incorporation of radar, electronically guided missiles, and even the addition of aircraft. The directed evolution of battleships continues to this day. Stealth technology has been added to counter radar and aircraft which had been added to previous iterations of the battleship. No, the modern battleship did not simply spring into existence. There are even parallels with Dawkins' concept of the blind watchmakers. Our shipbuilders were not blind. But they were surely rewarded for successful designs and punished when their designs failed to win in battle. If the shipbuilders were able to continue generation after generation then we could assume they would eventually design and build something approaching the "perfect" war machine – which may or may not resemble a battleship.

As I said, some people harbor a profound misunderstanding of Darwin's Theory of Evolution. It is important to understand Darwin's Theory on at least two levels. The obvious meaning of Darwin's theory is the one he intended. Darwin's theory should also be understood as an example of something that has evolved over time. For example, Darwin did not have access to modern techniques of microbiology. He knew nothing of DNA. In fact back in the time of Darwin, DNA lay well outside the realm of the observable. The scientific method requires that theories be reconsidered and perhaps modified when new evidence becomes available. Thus the Theory of Evolution has itself evolved since Darwin's day.

Darwin's original theory said there was descendency with change and that the change was modulated by "survival of the fittest" where fittest meant best adapted to the environment. The environment of course included everything from exploitable sources of food to the circumstances of climate and presence of predators and disease.

The Theory originated by Darwin has evolved as additional observations and data have become available. For example DNA was beyond the realm of the observable in Darwin's day. Evolution is now much more clearly understood with DNA playing a central role. The DNA which describes the most successful living things is the DNA which will dominate the various gene pools of successful DNA.

Many people misunderstand the scientific method to the same degree which they misunderstand the theory of evolution. Consequently we will briefly review the essence of scientific methods before delving further into the subject of evolution.

The scientific method is absolutely and indisputably rational and logical. One first observes some phenomenon or other. If the observed phenomenon fits within accepted scientific understanding then no further action is needed. Things are far more interesting if the observed phenomenon does not fit seamlessly within the accepted scientific framework. If one is working in accordance with the scientific method, then one records the circumstances of the phenomenon as accurately as possible. Others will of course want to observe the phenomenon for themselves and they will need the information in order to reproduce the circumstances of the original observation. Everything about the observed data must be reproducible. This is a fundamental tenet of the scientific method. Physical laws are assumed to be constant over time and distance. This is itself a theory – a theory supported by all legitimately observed data to date. Thus if a thing were true for someone over there yesterday it should be true and reproducible for someone else over here today or tomorrow. After carefully recording observable information about the new phenomenon, one formulates a hypothesis to explain the observed data. If the hypothesis conflicts with other observations, then the hypothesis must be abandoned. However, if after some period of time the hypothesis remains the best explanation for the observed phenomenon then the hypothesis is elevated to the status of "theory." In scientific circles the word "theory" obviously implies a much higher level of confidence than it does in common usage.

The phenomenon observed by Darwin was far reaching. He observed many similarities in different animals across a great variety of ecological niches. He then hypothesized that the similarities were derived from common ancestors and that adaptations to new environments lead to the large number of inter-related species which he had observed. Darwin's hypothesis has generally withstood the tests of time and forms the basis for the Theory of Evolution as it exists today.

That evolution occurs is undeniable. Evolution occurs on many time scales. Within the last generation of humankind we have observed evolution of drug resistant bacteria. Humankind changed the environment in which certain disease causing bacteria existed and the bacteria then evolved in a predictable way to adapt to the new environment. With the widespread use of anti-bacterial ingredients in soap and cleansers we can anticipate the rise and spread of more bacteria which are resistant to those ingredients.

Mankind has changed other aspects of the environment. One such change was on a larger scale. During the period 1850-1900 humankind coated large tracts of forest with soot as a byproduct of his "industrial revolution." In those tracts of forest lived a moth, *Biston betularia*, which was perfectly adapted to blend into its environment. This moth was commonly referred to as the "peppered moth" due to its pale coloration with dark speckles that served as camouflage when the moth rested on patches of lichen. A variant of the peppered moth was dark but rarely seen before the industrial revolution. However, the soot of the industrial revolution changed the environment. And the moth population adapted quickly. The dark form of the peppered moth became dominant as it was better camouflaged than the newly conspicuous pale variant. With time humankind recognized that all that soot was unhealthy and took steps in the mid 1900's to reduce it. As one might guess the tracts of forest and patches of lichen were no longer darkened with soot and the population of moths was soon dominated by the pale variety.

On an even larger time scale one can see the unmistakable procession from one life form to another as the evolutionary arms race played out across the planet.

Evolution is reflected in at least three sets of corroborating evidence: the structure of organisms, the time at which various structures of organisms appear in the fossil record, and the percent of DNA held in common by related organisms.

Any human shares 99.9% of their genetic makeup with every other human on Earth. Similarly every human on Earth shares roughly 98.5% of their genetic make up with chimpanzees. That should not be surprising; chimpanzees and humans share all the same basic bones, internal organs, and any number of other structural characteristics. More surprising is the near 50% of DNA that we humans share with banana trees. Obviously, one would hypothesize that the common DNA was not for things like leaves, bones, fruit, or digestive tracts. It is far more likely that the common DNA describes features in common such as cellular metabolism, cell differentiation and cellular reproduction.

There is evidence of a very interesting bit of evolutionary history in every cell in your body – as well as every cell in every other animal. This bit of evidence is contained within every one of the tens of thousands of dead skin cell which you shed each day. This bit of evidence is also contained within every cell of every plant – from the moss on the forest floor to the tallest redwood. Every cell in your body and every cell in every leafy plant is a eukaryote.

What does it mean to be a eukaryote? One way to understand the eukaryote is to contrast it with a typical non-eukaryotic cell such as a bacterium. In a bacterium there is a cell membrane and everything goes on inside of the common space within the membrane. Imagine a factory where the executives and mail sorting were mixed in among hazardous industrial equipment like blast furnaces and vats of chemicals. The secretaries might be adjacent to shipping and receiving while the security force patrolled the entire factory with weapons drawn. In contrast, a eukaryote has more orderly divisions – more like one would imagine a modern business enterprise. This compartmentalization is the result of what is perhaps the most ancient symbiosis on Earth.

There are many examples of symbiosis – though it is easy to get bogged down in the exact definition and where the realm of symbiosis ends and the realm of parasitism begins. One often sees the term “mutualism” used. In general one can think of symbiosis or mutualism as a relationship between different types of organisms in which the fitness of both organisms is enhanced by the relationship when examined from a Darwinian perspective.

There are many examples of symbiotic relationships. One such example is between coral polyps and zooxanthellae. Corals build reefs composed of calcium carbonate in the shallows of tropical seas. The coral polyps provide a place with light and certain waste products which are valuable to the zooxanthellae: carbon dioxide and compounds containing nitrogen and phosphorous. The zooxanthellae are an endosymbiont and use those resources in photosynthesis. The zooxanthellae then share the captured energy with the host coral polyps. In this example the relationship is not symmetrical because the coral cannot live without the zooxanthellae but the zooxanthellae typically live a portion of their lifecycle outside the coral.

Another example of symbiosis is the relationship between leafcutter ants and fungus of the *lepiopaceae* family. This example is interesting in that a third player is involved and was only recently discovered. Actinobacterium are housed in special glands of the leafcutter ant. The actinobacterium secrete toxins which the ants use to control parasitic fungus and microbes which would otherwise ruin the ant's fungus gardens. Fungus generally consists of thread-like structures called hyphae – though most people will be more familiar with the fruiting bodies of some fungi such as mushrooms, puffballs, and truffles. The fungus cultivated by leafcutter ants produces special structures called gongylidia. The gongylidia are harvested by the ants and provide no direct benefit to the fungus. The leafcutter ant has specialized behavior as well as specialized structures which have evolved to support the symbiotic relationship with the fungus. The leafcutter ants forage for leaves but are not able to digest the leaves. The ants instead place the leafy bits in underground chambers and diligently tend the resulting fungus gardens. The ants benefit from the food provided by the fungus. The fungus benefits from the environment engineered and maintained by the ants. The ants have evolved other behavior to better participate in the relationship with the fungus. One such behavior is that the young queen and will collect some of the fungus before her nuptial flight. That bit of fungus is needed in order to start her own fungus garden after she has mated and lands to start her own colony. That behavior is not learned by the ant queen – it is encoded in what Dawkins has called the "first memory" - the behavior is encoded in her genes. In effect her genes "remember" all the "good tricks" which have worked in the past. The instructions for a specialized structure in which to carry the young queen's bit of fungus is also encoded in her genes. The ant queen needs to carry the fungus because it is a very specialized fungus which does not grow except under the care of leafcutter ants.

The symbiotic relationship seen in lichen is also instructive. Lichen consists of a fungus and a "photobiont". The photobiont may be a "primitive" algae or cyanobacterium. The key factor is the photobiont's ability to capture energy from light – a "good trick" which the fungus can't do. There are other "good tricks" which the fungus does do well. The photobiont provides energy for the symbiotic relationship while the fungus provides most everything else. The result of the relationship has proven remarkably durable. If one travels to Hawaii and observes the recent lava flows then they will see that lichens are among the first living things to colonize the barren rock. The algae or cyanobacterium could not survive in the harsh drying conditions. However the fungus allows the algae to exist in a moist and sunny micro-environment. The fungus would be equally unable to live in the harsh environment of the fresh lava flows – there is none of the organic matter from which fungus would normally extract energy. If one travels to Alaska and observes mountainsides recently exposed by retreating glaciers then they will see that lichens are among the first living things to colonize the barren rock there as well. Lichen is able to exist and thrive in these harsh environments where each of its components would quickly die without its symbiotic partner.

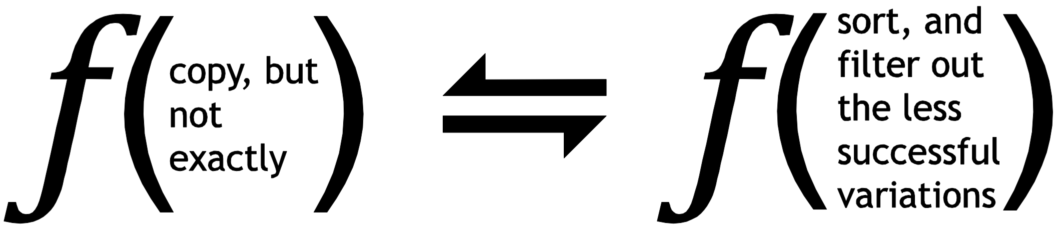
Once one understand these types of relationships it is easy to understand how ancient bacteria might have evolved into the cells we call eukaryotes. This is the bit of ancient evolutionary history which is contained in every cell of your body. [Add discussion of cloroplasts and mitochondria as examples of incomplete assimilation here]

Darwin based his theory on the relatedness of structure in organisms which he observed. It is easy to assemble an evolutionary tree using observed differences and similarities in structure. If one begins to organize a chart of living things based upon structures then a sort of tree-like organization will naturally unfold. Green things here, furry things there. Things with scales over there. Things with flowers over here. The branching nature of the organization becomes ever more evident as one adds more and more living things to the chart near living things with similar structures already in the chart. Furry things with retractable claws end up grouped together, while other furry things with hooves are grouped as a different subset of furry things. Furry things with hooves are then divided into sub-groups such as furry things with cloven hooves like moose or deer. Furry things which have a single hoof on each leg are grouped nearby. This is the taxonomic view of the evolutionary tree of life. It was also the view of Charles Darwin and Carl Linnaeus.

There are data sets generally corroborating the relationships suggested by the structure of organisms. For example, the more similar the organisms, the more similar the DNA. If one arranges all the various living things in a chart according to the similarity of DNA then one will end up with the familiar branching structure of the classic depiction of the evolutionary tree of life. However there will be some minor details which differ from the taxonomic view. For example the taxonomic view lumps warm furry things with hooves together as ungulates and then further sub-divides the group based on features such as even or odd number of toes. Because of a mechanism called "convergent evolution" different genepools may arrive at a similar set of features which work well together in a particular environmental niche. The taxonomist can't see this. However it is revealed in the DNA. As a consequence some scientists will quibble about exactly where a particular living thing fits relative to other living things. The key point is that the overall pattern matches and virtually all scientists agree on the validity of the overall pattern. It is important not to confuse quibbling over minutiae with questioning of the overall pattern. DNA may disagree with the taxonomic view for fairly closely related species – but there is no evidence of major disagreements such as birds being evolved from tigers rather than from a common ancestor with modern lizards.

The relatedness of structures also corroborates well with the fossil record. If one examines the fossil record then it becomes apparent that the changes in living things over time occur in the order predicted by Darwin's Theory of Evolution. Invertebrates appear much earlier in the fossil record than do vertebrates. Cartilaginous fishes like sharks appear in the fossil record before bony fishes. Amphibians appeared later. No evidence has been found in the fossil record of a living thing which appeared “out of order” compared to the order predicted by the basic “tree of life.”

If approached from a mathematical perspective, evolution could be described as a recursive or iterated function. That is to say that the output of the function is taken and run through the function over and over. The recursive evolution function doesn’t act upon numbers. Instead one could consider DNA as a parameter constantly cycled through a recursive evolve function. Carrying this idea a step further it is reasonable to say that the evolve function is composed of two functions – with the output of each being the input of the other. One function could be described as “copy but not exactly”. The other function would be “sort, and toss out the least fit” where “fit” means good at getting copied within the sorting environment.



This mathematical approach becomes very interesting when symbiotic relationships are considered. Returning to the lichen – one would consider lichen as an example of two parallel evolve functions. The diagram would be difficult to draw because the sorting environment for the photobiont is the environment described by the fungal DNA. The sorting environment for the fungal DNA in turn features the photobiont described by the photobiont’s DNA as a major feature.

Understanding the inevitability of evolution: this section will consider three replicators. One copies its blueprints with a large number of errors. Another copies its blueprints with a smaller number of errors. The last hypothetical replicator is “perfect” and copies its blueprints with 100% accuracy. In considering the “perfect” replicator it is important to note that “perfect” is meaningless without the context of an environment. A replicator can only be “perfect” for a single environment. A camel is certainly not the perfect replicator if the environment is the middle of the Pacific Ocean. Likewise a shark is not “perfect” if the environment is the middle of the Sahara desert. The “perfect” replicator is thus “perfect” only in the environment for which it was designed. Thus it may have “perfect” defenses against predators and diseases in that environment. Let us also assume that our hypothetically “perfect” replicator is the absolute best at exploiting materials and energy resources found in the environment. This replicator cannot change in response to changes in the environment because its blueprints are copied precisely with no errors. Even worse it cannot develop countermeasures against exploits developed by replicators with “faulty” copying mechanisms. Thus organisms with “faulty” copying mechanisms succeed over time. It must be assumed that natural selection has favored organisms with optimum “noise” built into their copying mechanisms – too little noise and evolution occurs too slowly. Too much noise and there would be too many non-viable offspring. Thus as we better understand the complex interactions of the DNA replicating machinery it is likely that we will find a mechanism for introducing a well-modulated “noise” factor into the copying process.

One should consider that DNA is essentially a four state digital encoding scheme. In this scheme the nucleotides cytosine, guanine, adenine, and thymine compare to the zero and one found in the binary (two state) encoding schemes used in modern technology.

The importance of digital encoding should also be understood. To understand the importance of this, consider what happens when one copies a copy. If one were to take a page printed from this work and use photocopier to produce several “generations” of the page then the page would quickly degrade to an illegible mess after relatively few cycles. Copying the digitally encoded instructions for a thing is different. Digital copying can achieve bit error rates of practically zero. The digital instructions for this page can be repeatedly copied from computer to computer and each copy can still result in this exact same page after millions of iterations. It is no accident that the instructions for living things are digitally encoded. It is the best “good trick” for encoding instructions and has therefore succeeded over time.

Understanding the inevitability of sex: this section will compare and contrast the way in which useful adaptations are gathered from all germ lines by sexual reproduction as opposed to parthenogenesis where the best of the best cannot be collected from multiple germ lines. Sexual reproduction may have an added benefit of thwarting genetic “hitchhikers.” One must conclude that sexual reproduction is no accident. As an aggregator of “good tricks” it is an unusually “good trick” which succeeds over time.

Evolution must be considered as a continuum with fuzzy species boundaries when the passage of time is taken into account. Science tries to label species as if they could be contained within boxes - an organism is either part of a species or it is not. That approach simplifies things in one sense – but then people must unlearn the over-simplified version before they may more accurately understand the relationships between “species.” A typical standard for a defining a species involves the ability to produce viable offspring. Evolution involves cumulative changes over time. So if one were able to reach back in time and assemble a representative of each generation all the way back to our last common ancestor shared with chimpanzees and then line them up there would be a problem. It would be very difficult to say exactly which generation was no longer *homo sapiens*. If one were able to devise a test to determine the earliest generation which would have been able to produce viable offspring after mating with modern humans then that could be used as a standard. But then say one took an individual about halfway between modern humans the earliest generation which could produce viable offspring when mated with modern humans. Then apply the same test to that individual. That individual would most likely be able to produce viable offspring when mated with earlier individuals than would have been possible with modern humans. If this test were applied over and over then it would reveal a large number over-lapping “species” between us and that last common ancestor which we share with Chimpanzees. So the result of evolution is a continuum and “species” are merely an artificial setting of boundaries for convenience in labeling. Another way of stating the problem is that traditional assignment of species names assumes that species are static. The traditional assignment of species names is therefore useful only in the sense that it describes a type of living thing at a particular time – a snapshot of a genepool which changes continuously over time.

Once one understands the continuum of evolution then it is much easier to understand speciation. Speciation occurs when a gene pool is divided and the resulting gene pools evolve independently. For example a continent may split – as is happening right now along the Great Rift Valley in eastern Africa. In time gene flow will be interrupted along a line from the Dead Sea through the Red Sea and continuing south through the Great Rift Valley. Gene pools which currently straddle that line will be split. If conditions differ on each side of the line then the gene pools on either side will diverge as Dawkins’ blind watchmakers optimize their copying machines for those differences in the environment. Gene pools may be split by barriers much less dramatic in nature than the fracturing of continents. Global weather patterns create a band of deserts laying roughly between 18° and 28° degrees north of the equator and a corresponding band roughly between 18° and 28° south of the equator. The land areas of Earth are thus divided into different habitats by the relative abundance or lack of precipitation. Other elements of climate and weather further divide the planet into different habitats. The waters of the Earth are similarly divided into diverse habitats by differences in temperature, salinity, presence of nutrients, and penetration by light.

There is another important conclusion to be drawn after understanding that species have fuzzy boundaries when time is taken into account. Recall that when time is taken into account then the result of the changes to a gene pool must be considered as a series of overlapping species. This same train of thought should most likely be applied to the very boundary between the living and the non-living. It is unreasonable to assume that a complete modern cell was accidently formed at some point. It is much more reasonable to assume there were early replicators which would not survive the competition for resources seen today. The laws of evolution applied to those replicators and they gradually collected more and more "good tricks." As more and more "good tricks" were added the replicators the more and more their characteristics became those of living things rather than non-living things. Thus if we could line up a representative of each generation of replicating things starting with the very earliest self-copying chemical complexes up to the first archaea, then it is very unlikely that we could agree at which generation to draw the line between life and non-life. The boundary between the living and non-living is fuzzy when the passage of time is taken into account just as the boundary between species is fuzzy when the passage of time is taken into account.

Recommended reading: Berra, T.M. (1990). Evolution and the myth of creationism: A basic guide to the facts in the evolution debate. Stanford, CA: Stanford University Press.