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The Co-evolution of Species

by A C Sturt

tempora mutantur, nos et mutamur in illis *(times change, and we change in them)*

medieval quotation (anon)

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A. Summary

The validity of Darwin's Theory of Evolution by Natural Selection is demonstrated using everyday observations by a methodology which is comparable to that employed in the physical sciences. The common sense of the approach suggests that natural selection is not a theory but in fact a law, like the laws of thermodynamics, driving evolution by acting on the differentiation of individuals.

The individuals of a species are certainly differentiated. Each has a spectrum of characteristics which is unique to that individual in addition to those which are overwhelmingly common to the species. We know that 99.9% of genetic material is common to all modern humans, but that leaves 0.1% which is unique to us as individuals and produces all the shapes, sizes and colours of people around us. We also observe such differentiation in the higher animals, for instance pets and groups of wild animals, such as wolves and lions.

The proposal here is that differentiation applies to all individuals of all species, whether we can see it or not. Laboratory experiments reveal differentiation among insects of the same species even though they all look alike to us. Bacteria too, and even viruses, may be differentiated. In short there is reason to believe that differentiation applies to all forms of life including bacteria, insects and plants as well as animals. Certainly all individuals are differentiated in at least one respect: they age. As each progresses through its life-cycle of birth, growth, maturity and death, its individual characteristics change from day to day.

In a steady state the individuals, and so their differences, are in equilibrium. If a random event then causes a completely new mutation and so adds to differentiation, this must happen to the DNA of a single individual and then spread through the species by reproduction, because the probability of the same mutation happening to more than one individual at the same time is zero. It follows that there is no reason why several different mutations could not be making their way through a species at the same time. Nor does every new mutation result in morphological change, which could account for the difficulty of obtaining a continuum of evidence in the fossil record.

When a change of physical environment occurs, individuals with some characteristics are favoured in the new conditions, and pass their advantages down to their offspring. This continues as long as the favourable conditions persist. Those which are not favoured, progressively die out. Thus over the generations the characteristics of the whole species changes. Such a mechanism reconciles the dynamics of change of the parts of the system, the individuals, with the dynamics of change in the whole system, which is the population or the species. If the new environment lasts long enough, the changes in the species become permanent. This is evolution by natural selection.

Any exogenous changes of environment are likely to affect a wide range of species, which then begin to evolve in their own ways. The heterogeneous surface of the Earth means that much of this may occur in areas which are isolated from each other. Intrusion by a species from one island into another also constitutes an exogenous influence.

But wherever it takes place, the environment for each individual comprises not just the physical conditions but also every other entity living at the same time. When individuals in more than one species are selectively favoured or damaged by the conditions of the new environment, this affects their mutual effects on each other. The result is that the characteristics of the various species to which they belong change together by the process of natural selection. If the changes become permanent, that is the co-evolution of species. This is the process that gives rise quite separately to both new species of prey and to the new predators that will live off them.

Man invented farming about 12,000 years ago. It now occupies such a large area of the globe that the network of interactions which sustained co-existence in the steady state is becoming frozen. Instead of co-existence leading to co-evolution, the possibility of adaptation is limited and exogenous change may then bring co-extinction.

B. Introduction

Darwin was right, of course. Recent headlines to the effect that he was “wrong” seem to have been based on a single handwritten diagram, albeit a famous one, that failed to capture the entirety of the evolutionary process as it is now unfolding. The complaint is that a theory of all life on Earth put together 150 years ago is not fully comprehensive. This is hardly surprising since that would be difficult enough, some would say impossible, even with the latest modelling techniques, let alone pen and ink. Moreover, he put together the basics of his theory without the knowledge of genes and microbial life, which he therefore failed to incorporate into his diagram.

Nor could he have anticipated the unimaginable length of time over which life on Earth evolved. He just knew it was long. Nevertheless, he did succeed in identifying beyond all reasonable doubt the essence of the process, to the point one might say that his is no longer a theory of evolution; it is in fact a law. A more credible conclusion, therefore, is that his critics did not grasp the full scope of what he proposed.

To be fair to them, Darwin did bite off a rather large chunk. The full title of his great work is more than many could swallow all at once: The Origin of Species by Natural Selection or The Preservation of Favoured Races in the Struggle for Life. So what is natural selection and how does it lead to the preservation of favoured races? How does the process lead to change, and even a superficial look at the record shows that it did change, for implicit in the preservation of favoured races is the elimination of the less favoured, which requires the concept of evolution. According to this line of reasoning, races which were not favoured must have disappeared into the fossil record. Those that were favoured at a particular stage were those best able to survive in that environment. However, when the environment changed, the requirements for survival also changed, and some of those who had been more favoured were no longer so. If this were the only process at work, every living thing would have disappeared from the face of the Earth by now because every “race” would have been less favoured at some stage of a changing environment during the time that life has existed on Earth. The evidence for this is that things living today are not the same set as that which existed before. The corollary is that new “races” must have been created by some process to add to those who were favoured by each new environment. Could this be the mysterious process of “natural selection”?

Kipling has the lovely story of how the elephant got its long trunk; it was apparently stretched in a tug of war which the elephant was having with an unscrupulous crocodile. If nothing else, it points to the need for a second mechanism to replace what has disappeared. Unfortunately for the dynamics, the evidence is that the stretching of an animal’s trunk is not a feature which can be passed on to its offspring. So for instance, those tribes whose women stretch their necks for cosmetic purposes by wearing successive neck bracelets keep having to do it with each generation, and the practice of binding up women’s feet in China did not produce women whose offspring had the “desired” shape of foot; the feet of successive generations of girls had to be bound up in their turn. Thus no physical characteristic imposed exogenously on individuals was passed on.

However, the bigger question is the one which is not asked: where did elephants come from anyway? These had to exist in some form or they would not have been able to take part in the trunk-pulling duel.

Or to put it another way, what was the origin of the species? It is one thing to debate the operation of a process, even if we have to discard the elephant trunk-stretching mechanism. It is quite another to seek the origins of the process, because that is in effect a search for the origins of life itself. Whatever progress we make in evaluating the operation of the processes of evolution, it is much more difficult to discover how it all began on Earth three and a half billion years ago. It is even more difficult and perhaps destined to remain in the realms of speculation, to discover where it began, because there is a disconcertingly large number of “organic” molecules being discovered in space which could have been building-blocks of life on Earth.

However, instead of starting with the origins, there is a perfectly respectable approach to difficult questions about the causes of complex processes, one which is used by physicists all the time, though they would be reluctant to admit it: start in the middle with what you can see and measure. When the nature of the operation of a process has been uncovered, it might then be easier to formulate ideas of how and where it began. For example, take gravity.

C. The methodology used in physical models

Physics likes to claim ownership of some Universal and Absolute truths. Rutherford even pronounced that everything else in science was stamp collecting. One such truth is Newton's Law of Universal Gravitation, which states that two bodies attract each other with a force which is proportional to the product of their masses and diminishes with the square of the distance between them. This is fair enough since it has been confirmed by predicting the motion of planets in their orbits, and by sending a man to the Moon and back.

Now there are laws like those of thermodynamics (rivers run downhill, heat flows from hot bodies to cold, not the other way round), but this is not one of them. Bodies certainly attract each other, but the term "mass" was in fact invented by Newton to enable him to express the magnitude of the force of attraction quantitatively. The illusion of absolute certainty is punctured simply by asking why two bodies attract each other at all. What actually stretches from apple to Earth, to use Newton's first observation, especially when the force operates through a vacuum? What is the piece of elastic which pulls them together? It is no use attributing it to a gravitational field, because this is simply another description of what is observed to happen. It does not say why gravitational attraction occurs.

It would be churlish to deny the extraordinary achievements in space as well as on Earth obtained by using Newton's equations, even if we do not understand the mechanism by which gravity operates. Einstein derided the equations and produced another set which involved the distortion of space/time, as if this answered the question why, and as if space and time existed in a form in which they could be distorted!

The point is that we do not need to know the origin of gravitational attraction to understand and make predictions about the motion of bodies in the space in which we operate. We start with what we can observe and measure, which is the process in operation i.e. we start in the middle of the whole process which stretches from its origin to what we observe now. When we have characterised gravitational attraction, and we can still by no means be sure that this has been achieved for every part of the Universe, we can worry separately about the origins of the forces and the mechanism of their transmission through space.

This methodology may be called system dynamics, the way the system works, even if we do not know what causes it to work.

D. Homogeneity through time

The advantage of physics is that the physical world is homogeneous through time and space. Atoms do not wilt and die during physical processes; they “live” for ever. Nor are we going to find a new set of species of physical building blocks somewhere else in the Universe. This has been verified by spectroscopic measurements which show that the composition of stars, all far removed from Earth, is drawn from our Periodic Table i.e. they are composed of the atoms we already know. Anything else would be unthinkable.

By contrast, biological processes deal with entities which are not homogeneous through time and space. This is the fundamental characteristic of living things; an individual is born, grows and in the course of time dies. This may even be considered as a definition of life. During its life-cycle no individual is the same at any point as when it was younger. It is a different entity; there is a clock ticking. Otherwise there would be no progression to death, and in the absence of chance misfortune, any individual would live for ever.

Aging certainly occurs in animals, and there seems to be no evidence from the plant world that plants could live for ever under favourable conditions, even if they suffer no exogenous mishap. In any case they must have some mechanism for stopping growth at their characteristic height, after which they propagate and die. The same argument seems likely to apply to insects. Bacteria and viruses may be different because they clone, but in the absence of hosts which themselves are living out their life cycle, they have no means to propagate, and if they have any kind of internal activity which requires the expenditure of energy they too must eventually die as their processes consume their internal resources endogenously, which is a form of life-cycle.

In fact all forms of life from the most primitive cells to bacteria, plants and animals have been found to respond according to the circadian rhythms, the daily clock set by the rotation of the Earth with the rising of the Sun.

E. The process of natural selection

The living entities of a species must by definition produce offspring. They must also produce a greater number of offspring than are needed to replace themselves. The arguments are as follows:

- If they do not produce enough offspring to replace themselves, the line simply dies out.
- If they produce a number of offspring which is exactly enough to replace themselves, any chance event such as an earthquake reduces that number, and the result is the same; eventually the line dies out.
- They must therefore produce a “surplus”.

This is the normal course of events in nature. All living entities produce more offspring than are required to replace themselves. But not all the offspring can survive. The process by which their number is reduced is “natural selection”. It is not simply haphazard because it follows certain criteria: the individuals which manage to survive are those best able to co-exist in the environment in which they live. Natural selection is therefore not a theory. It is a law, like the law of thermodynamics which says that water runs downhill, because it is a fact that everybody observes everywhere all the time.

There will be an element of chance to survival, so that some more able offspring might die through bad luck like a falling branch, and some weaker offspring might survive because they happened to be in an area of temporary low predation. One might speculate about their chances of producing strong offspring in their turn. Nevertheless, the clear trend is towards those best able to co-exist in the environment in which they live because of their characteristics.

What tends to be overlooked in the discussion of natural selection is the full scope of the environment in which the individual has to exist. Too often it is equated only with geographical factors such as ambient temperature, rainfall etc. However, in practice any individual living entity has to survive in the total environment, which is as follows.

- The physical conditions during growth such as temperature, light levels, availability of shelter etc.
- Periodic changes of the physical conditions throughout life, such as drought and cold periods.
- All species of vegetation at the time and their responses to periodic changes of physical conditions. This is vegetation as fodder, “air conditioner”, host to insect life etc.
- All animals in this environment at the time, and their responses to the periodic changes of physical conditions. These are predators, prey, competitors etc.
- All insects in this environment at the time, and their responses to the periodic changes of physical conditions.
- All microbial life, viruses, bacteria etc in this environment at the time, and their responses to the periodic changes of physical conditions.
- The parents of the individual living entities and their responses to periodic changes of physical conditions.
- The number and behaviour of their siblings in their attempts to survive.

These are all factors with which the newborn entity has to co-exist, if it is to survive to adulthood and itself procreate. If it can do that, it has been “naturally selected”. A species is maintained by the natural selection of the individuals of which it is composed; it is a population of “naturally selected” individuals.

F. Differentiation

Birds produce a “surplus” of eggs and fledglings because some may be eaten or pushed out of the nest, and never make it to adulthood to reproduce in their turn. Tribes which do not produce enough offspring to cope with disaster simply disappear. Trees produce vast numbers of seeds, of which only a small number germinate and a handful grow to maturity.

But it is not simply a question of numbers of eggs and seeds etc. Those individuals which grow to maturity will have their own characteristics; some animals will be stronger, some weaker, some bolder, some more cautious. Some plants will grow taller, some will not attain great heights, some will adopt a different habit. These will all be variations within the same species and perhaps under the same environmental conditions. Not all tomato plants survive in the garden. Those that do survive grow to slightly different heights and produce slightly different quantities of tomatoes. And we know perfectly well that human beings come in all sorts of different shapes and sizes.

These characteristics may in some degree be reproducible in offspring, so that they are not wiped out with the death of a single individual. If so, there is a continuing balance of differences within species i.e. the differentiation of individuals. We know that this is true of our fellow human beings.

Nor are such characteristics and therefore the differences confined to what we as humans can observe with our senses. It cannot be assumed that what we see or determine with particular analytical techniques is all that there is. All sorts of other attributes may not be obvious or even have obvious effects in the conditions of the time. They may not be large effects, but they may be involved in interactions of which we are not aware, and which manifest themselves only in the course of time. For instance, even in our own lives, it is not obvious why birthweight is correlated with heart attacks in middle age, which has been discovered in recent analysis of records. Something lies beneath the surface which is revealed only when humans begin to live long enough as a regular occurrence to make the effect known. The natural world must be full of such effects. So variation from individual to individual within the same species is the rule; no two individual living entities are identical.

Exceptions to this appear to be bacteria and viruses, which reproduce by cloning in hosts. It is possible that different individual microbes have different affinities with hosts, though this might be difficult to detect. However, one area where there is known differentiation is in their susceptibility to the concentration of bactericides. The effectiveness of a bactericide may be described by the concentration which kills, say, 50% of a type of bacterium. The question is why only 50%? It is not a shortage of bactericide, because you can use as much solution as you choose. It is the concentration of bactericide not the quantity which kills half the bacteria and leaves the other half untouched. This is not just chance, because if the concentration of bactericide is increased, the proportion of bacteria killed also increases. This is what might be expected of a chemical reaction, where rates of conversion increase with concentration of reagents.

What we see as “clones” are not necessarily identical in their response to exogenous inputs such as toxic materials. They could perhaps be differentiated by age though they appear to be identical to our eyes i.e. old bacteria may be more susceptible than young, or vice versa. If this seems fanciful, there seems to be evidence that old fruit flies respond differently to some conditions from young fruit flies. They must change with age, because they have a life span and therefore a clock. They must have a mechanism for dying or they would live for ever.

We tend to assess differentiation by what we observe as human beings, at our level and over our timescales. It is possible that the ticking of clocks in living entities is much more widespread than we recognise at present, and this provides time for changing interactions of which we are unaware.

The most obvious source of differentiation of individuals is sexual reproduction. When male and female come together to procreate, the offspring carries some of the characteristics of each in a new combination. This produces variety in the individual, but it also makes extremes less likely on a statistical basis, which helps to maintain the integrity of the species.

G. Steady State

This all provides a basis on which to consider the whole system, starting with the assumption of a steady state, and then imposing change. First, consider the steady state.

Steady state for any individual living entity is a contradiction in terms, because the whole of life is a process of change. However, it is perfectly possible to postulate a situation of a continuing balance of species. In this case the continuing struggle of prey and predator and the competition for resources by individuals would be unchanged, and the process of natural selection would ensure that each species was composed of those individuals most able to co-exist, but the species would maintain their positions with respect to each other. This is one manifestation of the difference between the whole system and its parts.

The steady state of species implies no change in the physical environment which would alter the balance between them. It implies that all species would be composed of the individuals best able to co-exist in that environment. It would also imply that the interactions between individuals stayed the same. Finally it would imply that the spectrum of characteristics which differentiates each individual from the others as described above remains unchanged, not only those which manifest themselves to us but also those which do not i.e. the scope of their individual characteristics is preserved through the generations. This in turn implies that such characteristics are inherited.

This steady state is a state of perfect co-existence, at least for species. It is completely unrealistic because it denies the passage of time for analytical purposes. However, it sets the scene for evaluating the effects of change.

H. Co-evolution

If the conditions which prevailed during the steady state are disturbed by some exogenous factor such as climate change or a catastrophic event, the balance between species and between individuals within species is changed. If the disturbance continues long enough, the changes become permanent. For a single species this is evolution. Since species interact e.g. as predators, prey or competitors for resources, the process of change is not confined to a single species; they all begin to change together. The result is that co-existence which predominated in the steady state then becomes co-evolution of the species which change.

Two factors are instrumental in this transition from steady state to co-ordinated change: differentiation within species, and inheritance of differences in offspring. The first of these, variety within species, is obvious. We need only look around us to confirm that. Our error is to assume that we can see the entire difference between individuals, based on our own subjective judgment whereas we know that there are many other, less obvious attributes which affect survival. Hence the description here of a spectrum of characteristics for any individual. Another assumption is that such spectra of characteristics are confined to humans, but even microbes and fruit flies may have their own individual spectra of properties, though we humans have to persevere to detect them.

The second factor, the inheritance of individual characteristics by offspring, is also obvious, though again we tend to think of it only as applied to human beings. The elephant trunk hypothesis is wrong, because an exogenous event does not itself produce a characteristic which can be inherited. What can be inherited is a characteristic which a parent already has.

What drives evolution is the process of natural selection as described above acting on these two factors. Natural selection is also what we observe in nature around us. To use Darwin's terminology, it weeds out those less favoured, albeit by a very wasteful, rough and ready process, leaving the more favoured. In the terms used here, it favours those best able to co-exist in the environment of the time in which they find themselves.

Taken together these lead to the following mechanism.

- The exogenous event affects the individuals of a species unevenly because of their differentiation. Their differences were in balance in the steady state, but the disturbance from outside affects some more than others.
- Those who were most badly affected may or may not die, but at the very least they will have fewer offspring and these may be less able to survive, because this depends on the health of the parents. So, for instance, if the disturbance produces a drop in temperature, those least able to survive in a cold environment and their offspring will suffer and decline.
- If the temperature then increases again, the position may be reversed and the balance restored.
- If however the cold conditions persist, the numbers of those least able to cope with the cold will diminish further, and those who can cope with the cold will form an increasingly large proportion of the species.
- If the cold persists long enough, the species will contain no individuals who cannot cope with the cold.
- The species may no longer embody the differentiation which would allow the warm-weather individuals to reappear. It will have changed irreversibly into a new species.
- From time to time a stochastic event may occur which introduces a "flaw", something completely new for a species.
- It is a single individual which becomes "flawed", because the probability that more than one individual would suffer the same "flaw" simultaneously is vanishingly small. Such a flaw is called a mutation. If the "flawed" individual

is, and remains favoured, the flaw will eventually “infect” the whole species, which then embodies the mutation.

- Thus species do not mutate as a whole. The process of mutation of a species is dependent on the slow penetration of the “flaw” through successive generations.
- The process is not exclusive: different “flaws” in different individuals could be making their way through the species at the same time.
- Mutation of the species subsumes all these effects.

This example is deliberately simplistic in order to bring clarity to the explanation. It is the same sort of mechanism which has been proposed to lead to resistant bacteria, as described in a previous paper (1). For low temperature one could just as easily substitute drought, floods and pestilence etc, or all of the above, though not necessarily simultaneously. The whole process may take quite a large number of generations of individuals, but it is only a very short time in the period during which life has existed on Earth.

In this way a new species emerges through the action of natural selection on a population of individuals by processes which can be observed around us. The population is what we call a species.

However, it is most unlikely that a disturbance so calamitous and widespread as to affect one entire species would leave others untouched. The first result would be that all the prey, predators and competitors would have to shift to make way for the new species, or alternatively move in to take advantage. But the cold would have fundamental effects on all other species in the same environment. Vegetation which thrived in the cold and the new rainfall patterns, insects which lived in it and microbes which ate it, would all have their own spectra of characteristics in their own right. Some of these characteristics might well be favoured at the expense of others, as in the above mechanism, and they too would begin to change their species at their own pace.

Moreover, the evolution of some species must also be linked to the evolution of others i.e. they interact during the process. So for instance, predators could not evolve without prey. That does not mean that lions have a physical connection with wildebeest, apart from killing them, which is natural selection, or indeed wildebeest with lions. What it means is that the conditions which gave rise to the one, also gave rise to the other. Similarly, grazers could not evolve without grass, which withstands continuous cropping etc. All the species interact mutually in ways which terminate the existence of some or facilitate the emergence of other species.

What this total process describes is therefore co-evolution. Co-evolution is the transition from a first steady state, in which the balance of species is that which can best survive in that state, to a second steady state, in which the balance of species is that best able to survive in the new conditions of the second state. In fact there are no steady states, just those which persist for a long time in evolutionary terms, and so the process of co-evolution is a continual adjustment of the balance and composition of species to ever changing conditions.

The new conditions may not be completely new in terms of the nature of the exogenous disturbance, but they are always impacting on a new set of species which are the products of successive changes through the ages. This is the biological equivalent of the law of thermodynamics which states that you can never step into the same stream twice. There is no direction in all this except the passage of time because the events which drive it are stochastic; there is no progression from primitive to some pinnacle today. There is a continual increase in complexity, but even that is open to question because some organisms which really are primitive have an extraordinarily large number of genes in their DNA.

There may be more than one response to overarching exogenous events, and while some individuals in a species take a particular path which leads to one new species, others in other places may take a different path which leads to a different new species. It is also possible that some avoid changing at all, if the departure of the rest of the species leaves them with enough room to survive for what may be quite a long period of time.

These are all part of differentiation within a species, and the result is that the balance between species certainly changes, and new species arise, but the total system at any time is composed of the old survivors as well as the newcomers. Darwin’s tree gives the impression that everything old gives way to new, and it may be eventually more or less true, but earlier, primitive life forms like the first prokaryotes and eukaryotes can linger on, especially if they form a liaison with another biological entity which is a survivor.

There is a further twist to the exogenous event which triggers all this off. It is exogenous to the extent that it is outside the influence of individuals, but it occurs by chance in the genetic make-up of some individuals as a result of stochastic modification or poor reproduction of their DNA. Such changes may accumulate over time in the form of additions to their spectrum of characteristics but without significant morphological effect, but eventually their combination leads to separation into a new species, which may be better able to survive than the original. If so, a new branching has occurred.

Further evidence of the dynamic nature of the processes which are occurring in evolution lies paradoxically in the phenomenon of stasis, which literally means standstill or no change. It has been observed that according to the fossil record no significant evolution appeared to take place in a species of beetle over a period of tens of millions of years during which many new species of animal appeared. The conclusion might be that nothing was happening. However, since the beetles still exist today, it was possible to breed some in isolation in the laboratory. The result was that large numbers of variants formed; a species which had remained unchanged for many thousands of years in fact differentiated at the drop of a hat. The conclusion was that the beetles must have differentiated in the past, but this conferred no advantage, and perhaps even some disadvantages in the environment of the time e.g. increased predation, and so they did not survive to appear in the record. Stasis is therefore evidence of the balance of opposing processes, of the sort described in this mechanism.

The vital criterion at every stage is that all individuals of all species which exist in the same environment at the same time are those which are best able to co-exist.

There is another implication of co-evolution which must be taken into account. What has been described is a kind of network where every species interacts with every other, some more directly than others. It has been stated above that the term interaction here does not imply a direct physical connection. It is in fact a statistical term which means that two species are correlated in some way with the fundamental conditions which affect a third species, even if none of the three ever meet. When the balance of species changes, the consequences are therefore incalculable.

The corollary is that a large disruptive event which kills species over a significant area of the Earth's surface, or deprives them of their inputs of food, which amounts to the same thing, may destroy a substantial part of the network of sustenance worldwide. The loss of interactions which promoted the process of co-evolution in response to environmental change may lead to widespread extinction for many species. What was co-existence in a state of stasis and led to co-evolution may then become co-extinction, such as has occurred periodically on Earth.

I. Islands

The basic assumption of this analysis is an overall homogeneity, or in chemical engineering terms, perfect mixing, but this does not always happen. In fact over an area as large as the surface of the Earth, perfect mixing is most unlikely to occur, especially as the surface is constantly changing. The environment in which evolution takes place is as variable as the weather itself. The result is that much co-evolution takes place in large "islands", which are almost completely separated from each other, though continental drift and oceans which are a highway as well as a barrier have brought them into contact in the course of geological time.

The result is similarities between species of forms of life from different "islands". However, separation introduces a new factor into co-evolution, because there is the possibility of intrusion. If species from one island find a way to cross the divide and establish themselves on another, they do not simply occupy space. They interact with all the original species, not just by treating them as food, but by occupying territory which provided them with resources and shelter, or by bringing in new diseases. This applies to any completely new species, but if the incomers are not so much new species as variants on the same species, their effect may be no less catastrophic.

For instance, the North American grey squirrel is still a squirrel, but its presence drives out the indigenous European red with all its own characteristics and interactions, so that the whole balance of species is changed. Similarly, the bluebell which has been introduced from Spain is tending to supplant the indigenous bluebell, and Wordworth's daffodils are threatened by a stronger growing variety which has been introduced from elsewhere.

These are in effect examples of co-evolution in action with the introduced species acting as the exogenous disturbance which starts the whole mechanism working.

J. Genes

The biological world is non-homogeneous through time, as defined above. However, Mendel discovered that the basis of heredity is probabilistic. Heredity must therefore be homogeneous through time, because probability is mathematical. The explanation of this apparent contradiction lies in the difference between the whole system, which is the species, and its parts, which are the individuals of which it is composed.

When the structure of DNA was later unravelled, it became clear that its homogeneity through time occurred at two levels. First, the chemical building blocks of DNA are the bases adenine, guanine, thymine and cytosine, which are homogeneous through time because they are molecules. They combine in definite and reproducible proportions to form two long intertwined helices, which provide the mechanism for self-reproduction. Defined sequences of these bases are called genes. It is the sequences of genes along the length of the helices which are found in every cell of an individual, and so characterise the individual at this level of analysis.

In such a system there is no obvious opportunity for non-homogeneity through time to occur. The chemistry of the bases is fixed, the mode of combination into helical chains is fixed and the pattern of sequential patterns along the chains is also fixed. Admittedly sexual reproduction brings together the different chains of DNA from a male and a female into a new combination, but the sexual mechanism alone would simply produce predetermined variations on the same basic theme, which could not account for new species. In any case not all species involve sexual reproduction. There must be more to it than a sort of biological clockwork mechanism or in systems terms, there must be some slack for it to work.

The conclusion is that differentiation, and so evolution, must result from "imperfections" in the DNA of a favoured individual which either remains favoured or becomes exceptionally favoured in the environment of the time. It must apply to a single individual, because it is most unlikely that the same "fault" would arise in each of a collection of individuals. It would have to be a favoured individual, or the individual and its line would simply die out, taking the "fault" with it. An "imperfection" in a favoured individual would stand a better chance of being passed on to the individual's offspring and then to their offspring, so that it would eventually permeate the whole species. This model provides a mechanism by which non-homogeneity through time can occur in species which are homogeneous through time.

The focus is on "faults" or "imperfections", but of course the great bulk of the DNA remains unaffected, and it is this which gives the species its integrity. However, differentiation of individuals within species may be more widespread than this implies, witness all the different shapes and sizes of individuals which we take for granted. Nor is it restricted to one "imperfection" at a time; many different "imperfections" could be making their way through the individuals of a species which happen to be favoured by the natural environment of the time. Note that it is individuals which are favoured, not the "imperfections"; genes are chemicals, and they have no way of responding directly to environmental change, whether favourably or unfavourably. As long as the "imperfections" do not impair the favoured state of the individual, the "imperfections" persist. If the "imperfections" actually enhance the favoured state of the individual, the chances of their survival are even better.

The result would be a gradual accumulation of “imperfections” to form a spectrum of characteristics around each individual. Such spectra would not necessarily be identical for each individual of a species. It would depend on the extent to which “imperfections” had permeated throughout the population i.e. the rate of mixing or miscegenation of “imperfect” and “perfect” individuals in the population.

The previous analysis used the concept of an individual’s spectrum of physical characteristics as the basis of the process of natural selection. If it is assumed that the differentiation of physical characteristics is directly related to an individual’s DNA, other things being equal, then the spectrum of the physical characteristics of an individual would correlate with its spectrum of accumulated “imperfections” of genetic material.

The result would not necessarily be observable in the morphology, at least not immediately, but it would form a store of potential options which might come into their own if a change in the natural environment favoured them. However, the converse is equally likely, and they might contribute to the individual’s demise. The most probable outcome over long periods is that they would simply lie dormant. This would suggest that it is the abundance of individuals within a species which would be most affected, but from time to time actual morphological change might occur. It is the morphology of mutated individuals which would then appear in the fossil records as a new species.

Genes function in concert with other genes to produce an effect in an individual which may cause it to be more, or less, favoured in the physical environment of the time. The presence of many “imperfections” making their way through the species as described above gives many options for change, because the same physical effects on individuals may be caused by different genes or by different combinations of genes.

Morphology is determined by the aggregation of cells, not by DNA. It must result from interactions between cells in the form of transfers of materials and information between them, because there is nothing else. DNA helices do not themselves constitute morphological structures.

Cells and the DNA which they contain must be subject to aging processes, because the morphology of individuals is seen to change with time, not only during growth but during decline. There seem to be molecular clocks at work. There may be two possible mechanisms for this: either the cell has an internal clock which begins to tick from the moment of its generation, or cells are affected by flaws which accumulate over time as a result of exogenous interventions.

The internal clock is essentially a long, slow chemical reaction which begins in cells at the moment of procreation and is passed on without interruption to each new generation of cells in the individual. Each successive generation of cells then starts life from a position which is further along the life cycle until there are eventually no new cells, the clock stops and the individual dies. The cause of natural death then remains obscure; does the individual die because there are no new cells, or are there no new cells because the individual dies?

The other possibility is exogenous intervention, and the obvious candidate is oxygen. The life of animals can be considered as a long, slow oxidation process. Oxygen is processed in the creature to provide the energy it needs to move and to function, but its reactivity is such that it can also cause oxidation of other chemical entities, not least polymeric chains like those of DNA helices with the production of free radicals which cause cross-links. The effect would be to impede the cloning process in which the spirals separate. If this is the cause of aging, the implication is that the flaws resulting from oxidation could be passed from generation to generation of cells, which seems unlikely. It may simply be that the clock stops when the accumulation of cells with cross-linked DNA is such that there is insufficient generation of new cells for the individual to continue living.

Some genes seem to control the processes of others by prompting them into action at the appropriate time, and so in the appropriate order. This implies that control genes may be the keepers of the molecular clocks. If this is so, all the previous analysis applies specifically to them.

The question for evolution is how any of this could cause permanent change of species. What is the relationship between these “imperfections” or “flaws” and the permanent mutations which are thought to give rise to new species? Most flaws would die with the individual which suffered them. The logic is as follows:

- The flaw must be capable of being passed on to offspring, or it would die with the individual.
- This seems to rule out any flaw which was acquired from exogenous sources during the individual’s life, because it would not appear in the genetic material passed on to offspring (the crocodile/elephant’s trunk effect).
- The flaw must therefore occur at the stage at which the individual’s genetic material was being formed.
- The chances of a flaw occurring are small. The chances of the same flaw occurring in more than one individual are vanishingly small.
- The flaw must therefore occur in a single individual.
- The individual must be among those favoured by the environment of the time, or its line would not survive.
- The question then is how a single flaw in a single individual could infect a whole species.
- Reproduction would spread the single flaw through procreation, as described above.
- For the flaw to become part of the genome, what is recognised as a mutation, it may have to be present in two individuals who mated i.e. a male and a female relative of the individual which had the original flaw, however distant. This appears to be a sort of tribal effect.
- The rate of mutation of the species then depends on the rate at which flaws occurred as numbers per year, and the average number of years between birth of, and procreation by, individuals.
- So according to this analysis, short-lived species should mutate faster than long-lived species, other things being equal.

- The number and extent of mutations in a species depends on the conditions which cause the original flaws.
- If these are environmental conditions, mutations survive only so long as the environment is favourable to the individuals which have the flaw.

The conditions which cause flaws are those which potentially affect chemical structure. These could include exogenous chemicals and radiation, but it could also result from faulty cloning of DNA. Whatever the cause, and it could be more than one of these, the corollary of the preceding analysis is that it would have no effect on evolution, because the flaw would have to be capable of being passed on to offspring. Damage to DNA which had already formed would affect the individual, or more specifically the part of the individual in which it was located. For the “imperfection” to be passed on to offspring, it would have to be a flaw in the individual’s DNA which permeated the whole of the individual exclusively. In fact it would have to be the very first DNA formed in the individual.

This narrows the locus down to a flawed process of combination of male and female DNA or a flawed shuffling of genes, resulting from a flaw in the process itself or from a flawed sperm or a flawed egg. These would have to be flaws which got through the body’s mechanism for rejecting faulty goods. Once this had occurred, there would be a new, mutant variant of the species’ DNA which could then diffuse through the whole species according to the above process.

Mutation has been described in terms of a single species, but any exogenous event such as a change of environment would affect all living individuals, which might result in mutations in other species too. They would all move from a steady state of co-existence into a period of change i.e. co-evolution. Not only would they mutate together but their effects on each other would also change. Some would evolve successfully in the new environment, but others would become extinct; co-evolution or co-extinction. This model seems to fit the succession of new eras of life which has occurred according to the fossil record e.g. wholesale extinction of dinosaurs and their habitat followed by new species, and the extinction of woolly mammoths and sabre toothed tigers, followed by our familiar elephants and a new range of big cats.

Darwin’s analysis is much wider than the genome concept. The two systems broadly correspond in terms of the general dynamics of the processes, even though they may show fits and starts at slightly different stages, but selection by natural characteristics comprehends a much wider range of inputs than the chemistry of the genome. For instance, there is no gene for cognition or the ability to stand back and survey the environment; indeed it is difficult to envisage how there could be a gene, a chemical entity, for consciousness, an awareness of the external world beyond what is immediately sensed. This is of particular interest to man. Nor are there genes which give rise to the state of being adventurous or cautious, traits which are clearly visible even in individuals whose DNA is virtually the same e.g. identical twins. There are genetic bases for the locations in which memories reside, but no genes to initiate the acts of learning or for habits. Above all, there is no gene for creativity or self-ignition, none which kicks the whole system into life. Yet all these are observed not only in man but in all manner of creatures, and they all affect the ability of the individual to survive.

The most important difference between modern man and the Neandertal species which is now extinct, appears to have been the ability of modern men to interact with each other. There is precious little evidence of any other characteristic which could have proved superior in the physical environment in which they co-existed. But it is difficult to envisage how the chemical make-up of one individual in the form of genes could interact with the chemical make-up of another individual, except by the act of procreation of course, which would not have been much use in the process of fending off wild animals, for instance. However, it is just such interaction which leads to the accumulation of shared knowledge, language, counting, writing etc, all of which affect the survival of individuals and so the evolution of species.

Genes as envisaged are essentially parts of the machinery inside chemical factories, that respond to the total environment in which they exist, and process inputs into outputs according to their specific structures. They are by definition the product of shared experience, but they cannot integrate and predict what will continue to be an essentially stochastic process of change.

K. Role of man

There is no reason to believe that modern man evolved by anything other than the process of co-evolution described above. Hominids separated from the evolutionary path of other great apes about six million years ago. The species homo spread out much later from Africa across most of the world. Successive species which followed have been confirmed by their bones, the tools which they left and now DNA. The most recent species in Europe were Neandertal man and modern man. The two co-existed for 10,000 years or more until Neandertal man became extinct about 30,000 years ago, leaving modern man confirmed as the single human species all over the world. The consequence of this evolutionary path is that the genetic difference between any two modern human beings on Earth is less than 0.1% i.e. we all share more than 99.9% of our genetic make-up. Within this limit there is more genetic variety in Africa than in the rest of the world put together.

The first sign of the eventual impact which man would have on the rest of the species on the planet was probably “unnatural” charcoal remains found in Africa which may date back even as far as several hundred thousand years ago, certainly long before modern man and perhaps even Neandertal man existed. Fire changed all the rules of co-evolution. Man at the time was a hunter/gatherer and probably even an occasional scavenger i.e. he used every opportunity to survive which was available to him, just like any other animal. But learning how to kindle fire extended his reach to encompass the use of energy: he could sleep more soundly at night, because predators do not approach camp fires; he might have been able to use fire in hunting by driving out game; and he might have extended his food resources by cooking what was previously too tough to eat.

Much later than the discovery of fire-making, Neandertal man managed to survive in an incredibly harsh cold climate by using what were undoubtedly much more refined versions of the same technology, including fire and the wearing of animal skins. Finally, modern man from about 200,000 years ago was much more sophisticated still, but used essentially the same hunter/gatherer technology. His advantage seems to have been in the interactions between individuals, because physically there was not much to prove his superiority, even in brain size.

Then 10,000 to 12,000 years ago, more or less coincidentally with the end of a major ice age, modern man, the ancestor of us all, decided that he had had enough of being a nomad chasing prey and collecting fruit and berries; he invented farming and agriculture, which allowed him to settle down in one place. Not every modern man became a farmer; some continued hunting and gathering, not least because they enjoyed the freedom, and there is no implied inferiority in that, but the settlers gradually colonised so much land as to make his life-style unsustainable in those areas. The shift to farming changed the rules decisively in favour of the farmers, not just with respect to nomads but also nature as a whole. It is a process which continues to this day.

Darwin described the phenomenon of sexual selection, which he considered different from natural selection. Apparently peahens did not mate with peacocks which seemed to us to be the strongest and best equipped to survive. Instead they chose peacocks which had the biggest, most spectacular show of plumage, even though this must be an encumbrance in flight from a predator. The suggestion was that peahens and not “nature” decided what sort of peacock could best co-exist in the environment of the time.

This sort of “irrational” behaviour may not be as unusual as we think. Lionesses submit to having their cubs killed by the new lion in the pride, which brings them back into season to start producing all over again, even though they are perfectly capable of seeing off the newcomer if they act together. An albino seal which appeared to be perfectly healthy was not fed by its mother, who simply did not recognise it. Cross-breeds of brown and polar bears seem to suffer a similar fate. Human reasoning is of no avail in these circumstances. These are independent individuals in independent species.

But this is nothing compared with what modern man proceeded to do. He captured animals which were easiest to shepherd, as well as the tastiest, and bred them selectively, a process which continues today. He selected particular grasses to farm, which became our cereals. These too have continued to develop, particularly over the past 20 years. The result is in effect a system of monocultures.

It does not matter so much that they are near clones, because these are only temporary adjustments. When left alone to fend for themselves, they revert to their antecedents or die. Stop cultivating and crops are soon annihilated by “weeds”. The maize of today is completely different from the original, which is small, scrubby and most unappetising, but it is the original which can survive on its own in extreme conditions.

The main effect on the rest of living organisms is that crops are grown over large areas and as uniformly as possible to facilitate harvesting. This determines their accompanying pests and diseases to which the natural varieties might have been immune, or at least less susceptible. It spreads them further, so that diversity and the possibility of further co-evolution when conditions eventually change are progressively reduced.

The same is true of animals; turn them loose, and breeds soon revert to what can survive in the environment of the time.

The shift from hunter/gatherer to farming is called the Neolithic revolution, after the most recent “stone age” (2). It was during this period that the origins of our modern societies were formed: organisation and planning, ownership, property, social hierarchies, systems of laws and government, selective breeding, towns, number, writing etc, in fact all the facets of what we consider to be “civilisation”, which is the condition of being a “citizen”, living in a city with all its costs and benefits. Much more recently, in fact over the past few decades, national boundaries have been drawn ever more tightly, marked by signs which nature cannot read and will not respect.

The process of driving out “nature” started with the Neolithic revolution. What enabled all this to happen may be described as “technology”, which is fundamentally the use of sources of energy to extend modern man’s reach, starting with firewood and now encompassing, or even relying on, the Earth’s store of hydrocarbon residues of past eras. Eventually the original very small band of modern men has grown to number billions spread worldwide, surviving in all conditions from searing heat to frozen wastes.

The result is that individuals of the species “modern man” have developed a much wider spectrum of characteristics from which selection can be made. Moreover, the criteria for selection have changed. No longer is the requirement to co-exist with the rest of the species of the time, because the penalties have been reduced, though in the long run this may be more apparent than real. The invention of technology and the accumulation of a shared body of knowledge have made it possible for those other than the “strong” or the “fit” to prosper. The invention of money has enabled some to employ others on their behalf to confront the dangers of living. It is no longer “nature” which is making the selection, though some imagine that money is an expression of the “survival of the fittest”, a phrase which is a travesty of what Darwin meant. The test of this has been the inbreeding of a chosen few from time to time which has resulted in inferior individuals. There are myriads of characteristics in the spectrum of a modern human, which affect the ability of individuals to survive in changing environments.

One characteristic of modern man as an individual is that he is extremely resistant to dying, if he can help it. Medicine, improved food, society etc have increased lifespan to perhaps two or three times what “nature” intended, which has allowed learning and wisdom to accumulate with age especially since the invention of written records. This may have misled some into thinking that man is in some way independent of the Earth on which he lives. However, his relationship with microbial life demonstrates otherwise.

Bacteria and viruses cause diseases which kill, but they are not so effective that they kill everyone, or they would die with the hosts on which they live, and so become extinct themselves. The corollary is that they have become just harmful enough for both host and bacterial species to survive. This is co-evolution in action. Modern man’s response has been to use other forms of life to kill bacteria i.e. antibiotics. However, the bacteria go through the same process of natural selection described above to become “resistant”. This race in co-evolution is one which modern man cannot win, because bacteria are so numerous, and they replicate and change so rapidly.

A fundamental reappraisal may be required of the ad hoc solutions which modern man has applied to many of the problems which deny him his full right, as he sees it. Many solutions have involved the widespread use of chemicals which persist in the environment. They accumulate year by year, a poisonous cocktail, and constitute a new influence on the balance of species. Nor is it just chemicals that accumulate; plastic waste accumulates, not as toxic products, but materials which are far too durable for the use to which they are put. The consequence is that they are killing birds, fish and other forms of life, and again changing the balance of species even in the middle of the ocean. Finally, travel has magnified problems of intrusive species and contaminants by many times. It is now an integral part of modern day life.

None of this would matter in the general scheme of things, if modern man had not grown in numbers to colonise so much of the Earth’s surface and modify it to his needs.

It should not be beyond the wit of man with a good helping of humility to find solutions, having come this far on the back of his creativity, but he does need to be aware that evolution has not ceased. He has simply forced a significant part to suit his own short term needs. He also needs to be aware that the process is in fact co-evolution, and the outcome may not be entirely to his liking.

L. Conclusion

There is a general rule that all systems change in response to changes in their environment. They have no choice, because they draw their inputs from, and eject their outputs into, the environment in which they operate, since they are processes. When environmental changes persist over a period which is long in relation to a system’s operational span, the nature of the system itself must change if it is to survive i.e. it must evolve. Systems with components which are non-homogeneous through time evolve in ways which are unpredictable, but they all evolve.

Darwin was right. In fact his “theory”, which ought to be called a law, is so obvious that it becomes almost a tautology. Living entities must produce offspring to survive, and these resemble their parents, which is the basis of a species. They must produce a surplus of offspring, because some will be destroyed by chance happenings. Offspring are differentiated i.e. they show a variety of characteristics within the same species. Those whose characteristics render them least able to co-exist in the total environment in which they grow, die. This is natural selection. If conditions change, the characteristics best suited for co-existence under the new conditions also change. Individuals with the new “best” characteristics prosper at the expense of the others. In this way the nature of the species evolves.

The point made in this paper is that, if one draws a line horizontally across Darwin’s tree, the environment at that stage of evolution encompasses not only the prevailing physical conditions, and the main branches of evolving species which are shown, but also every other individual of every other species alive at the time. Species interact, because their very existence has a selective effect on the individuals of another species, so that those individuals in this other species which have a particular set of characteristics are favoured at the expense of other individuals. Thus they alter the balance within this species and cause it to change and perhaps evolve. The result is that many species evolve together. The rates and extents may vary from species to species, and not all individuals in a species are necessarily affected simultaneously and in the same way, because of isolation etc. The living entities at the time therefore comprise all the individuals which are not changing as well as those which are evolving. At any stage the population of individuals of every species is that which is best able to co-exist with all the others. This is the process of co-evolution.

It may be difficult to accept the concept that in some way whole species suddenly mutate, but the analysis shows that this model is in fact misleading. It is an individual which is different as the result of an "imperfection" in the formation of its very first DNA. If the individual is favoured by the environment of the time, the "imperfection" is passed on to its offspring, and from them to their offspring, so long as the environment remains favourable, so that it spreads through the whole species. Some inbreeding may be necessary for the "imperfection" to become completely embedded. Nor is it the case of just one individual and one imperfection. There may be several "imperfections" making their way through the species at any time. They accumulate to form the spectra of characteristics around individuals. It may take many generations for change to permeate through a whole species, but then the lengths of time which life has been on Earth are unimaginable to us.

There are enough degrees of freedom in this model for life to evolve over a period of billions of years into the many and remarkably diverse forms which we see on Earth, in spite of or perhaps because of periodic mishaps. The only variable is the passage of time. There is no ladder of ascent to some excellence today. There must be a trend to increasing complexity, say by comparing animals ancient and modern with the earliest forms of life on Earth, but even this needs a certain amount of circumspection, because some primitive species have extraordinarily large genomes, and some extinct species of animal appear to be every bit as complex as ourselves.

Modern man regards himself as the pinnacle of the evolutionary process at his peril. All the mechanisms described above are part of everyone's daily experience, and so they are not easily denied. Nor are they going to cease to operate just because we are now here. Whatever we do to the life-forms which we recognise most, the animals in the zoo, there are others which will certainly survive: viruses, bacteria, fungi, insects (not necessarily the "nice" ones), rats, all kinds of vermin etc. It would be a repulsive world which consisted of them and us.

What has happened on Earth in a near infinity of time and space is nothing less than miraculous, at least we think so because we are a product of it. Yet our species could distort it beyond recognition out of selfish ignorance.

There remains the much broader question of the origins of life on Earth. This is not amenable to the methodology of system dynamics used in the above analysis, because the process of breathing life into inanimate molecules is not known. Various experiments have been conducted to show that mixtures of organic molecules might be persuaded into life, but that assumes the presence of the molecules as well the chances of initiation. Nor is the location known; molecules which could form the building blocks of primitive life forms have been observed by astronomers in all sorts of unlikely locations in parts of the Solar System and beyond. Nor is it known whether they could make their way to Earth. Still less is it possible to prove that they did.

Nevertheless we would dearly like to know whether we are unique in the Universe. We are certainly unique on Earth, because no other species is conscious of evolution, for instance. No other species has such individual and collective creativity, or uses energy so effectively to extend its reach. There is infinite scope for more learning, but ultimately we may have to leave it with the words of the poet and accept that there are "more things in heaven and Earth than are dreamt of in our philosophy".

However, one conclusion is beyond dispute: life on Earth has a unity which we should respect. The medieval quotation at the beginning of this paper is in fact a very comprehensive summary. We are tempted to translate it as "times change and we change with them", which implies that we can choose to change or not, as in the idea that one ought to change with the times to keep up to date with fashion etc. Certainly as a conscious being man has the power to act to influence outcomes, but this misses the point.

What the words actually say is "times change and we change in them". We have no choice, because we are part of the Universal system which we observe; when it changes, we change in it, like it or not. That is practically a definition of co-evolution. In fact that's life!

A.C. Sturt

29 July 2009
Section on genes added 1 September 2009.

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