CHAPTER 3

STEALING IDEAS FROM NATURE

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3.1 Biomimetics?

The concept of using ideas from nature to further technology has been given a number of names such as “Biomimetics”, “Biomimesis”, “Biognosis” and “Bionics”. In each instance it’s probably fair to adopt the attitude of Lewis Carroll’s Humpty Dumpty and say that the meaning of all four words is whatever I want it to be - and in this instance I shall define the meaning of all four words as the same. Biomimetics is the technological outcome of the act of borrowing or stealing ideas from nature. It is difficult to trace the origins of this approach, since man has looked to nature for inspiration for more than 3000 years (when the Chinese hankered after an artificial silk). In modern times, the word “bionics” was coined by Jack Steele of the US Air Force in 1960 at a meeting at Wright-Patterson Air Force Base in Dayton, Ohio. He defined it as the science of systems which have some function copied from nature, or which represent characteristics of natural systems or their analogues. In 1966 R-G Busnel, of the animal acoustics laboratory in Jouy-en-Josas in France, organised a meeting on the theme “Biological models of animal sonar systems” in which the Office of Naval Research of the USA was involved. They had already funded other work in the general area of biological engineering, such as Torkel Weis-Fogh’s work on resilin (a rubbery type of insect cuticle) and elastin in Cambridge. Busnel’s meeting was one of the first at which these problems were discussed by biologists, engineers and mathematicians in order to discover general principles of technology.

But, in reality, how many ideas of technology have been derived from nature? Mostly they are seen as parallel only once they have become established. Some have definitely not come from nature, so that the comparison between helicopters and sycamore seeds is spurious. The technical problems in getting a helicopter airborne were almost entirely to do with control systems in which biology could be of no help. The Eiffel Tower and Velcro have their inspirational origins firmly founded in nature. The stable wing planform designed by Ignaz and Igo Etrich in 1904, was derived from the large (15 cm span) winged seed of *Alsomitra macrocarpa*, a liana which grows on islands in the Pacific. There is argument as to whether Joseph Paxton really did get his

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ideas for the Crystal Palace from the leaves of a giant water lily. At least one version of a ribbed low-drag surface was derived from studies on shark skin. But nature can still give us confidence in the correctness of a result since computer techniques allow model structures to be modified in response to changing loads, producing very biological shapes in the process.

The interest lies not just in the abstraction of useful ideas from the living world but also in the process by which this is done. The underlying rationale is a common approach amongst both biologists and engineers — expense. How much does it cost to design, make, maintain, and finally recycle, a structure? For engineering structures and materials this is a cash cost, and the lowest believable tender wins the contract. For living organisms the cost is energy, and the competition is not that of the commercial market place, but the more severe one of nature, where the fittest (cheapest?) survive and where failure equates with death. All organisms, whether of the same or different species, compete with each other for the available energy. Plants grow higher towards the sun and out of the shade of their rivals; animals fight for access to territory, sex and food. The species which survives best is the one which leaves more viable offspring per unit energy input than its immediate rivals. The other functions of living (growth, repair, locomotion, etc.) all enhance survival. Depending on the lifestyle and habitat of the organism, the energy it has won has to be shared out optimally between these various functions. The engineer similarly has to optimise the distribution of energy (cash) between the different functions in his contract, depending on the item to be made and the demands of the client. The design has to be properly stressed with the proper safety factors, materials have to be chosen for their intrinsic properties, appearance and durability, the necessary maintenance and management systems have to be integrated with the structure.

The analysis of these systems depends on what you perceive as important and basic. As a biologist, I look at an organism and say "If you are the answer to the problems of living, what were the original questions?" Faced with the problem of designing an integrated and successful structure, the engineer asks "If these are the necessary designs for living, how can I best implement them?" Since organisms have spent millions of years having their structures developed towards the greatest economy it seems rational that engineers with their questions about materials, structures, and even mechanisms, should look to nature for an exposition of some energy-efficient answers to similar problems raised by technology.

3.2 Moving Ideas Around

There is now the problem of "technology transfer". How can I identify the nature of the questions from engineering and marry them correctly with the answers from nature? As a schoolboy I used to practise a mental trick to amuse my friends. How good an analogy could I make to any statement which would then appear to be as unrelated as possible to that original statement? This involved taking the main idea behind the statement or observation and reducing it in some way (I didn't know how) from its original environment and redeveloping it in another direction. I see now that the trick was to identify the problems at a functional level, for instance the effect of temperature on viscosity, the physics of surface hardening. These days I would include other things such as the mechanism(s) of deployment in nature and the ubiquity of folded structures. Since the entire world, living and non-living, is subject to the same "laws" of physics, then this level forms a common ground for the transfer of information between the disciplines. It is presumably precisely because physics deals with nature at such an adaptable level that physicists think of their own science as underpinning everything else and tend to regard all other areas of science as some form of stamp collecting. This degree of arrogance is less apparent in the other sciences, but it is worth considering that there are so many mechanisms waiting to be discovered in biology that perhaps the study of living organisms is the basic science, and physics is just a special case.

This type of technology transfer, where the origin of an idea may lie far outside the accepted limits of a subject area, comes into the general area of “creativity”. The semantics of what constitutes creativity, and the psychology of where it comes from, have been the subject of papers, conferences, monographs and books. This does not necessarily aid the generation of creative ideas, so in parallel the ideal is to generate a methodology which will achieve the same ends. At first sight this may seem counterintuitive. If creativity is the means by which ideas can be generated, how can one generate them with a method which needs to have the ideas incorporated into it at the beginning? However, even the most creative person can imagine only what their brain allows, and that brain can work only from the information available — its database. The trick then is the identification of the problem at some basic functional level and the marriage of that function with another from a different area. This general systemisation has been tried a number of times, and the most recent, and probably the most successful, is the Theory of Inventive Problem Solving (known by its Russian acronym of TRIZ) invented by Genrich Altshuller (1988). He analysed thousands of engineering patents, identifying the most effective solutions. He identified a number of different levels of innovation which are listed below, together with the frequency with which they appear in the database of patent literature.

1. A single improvement to a technical system requiring knowledge available within that system (0.32).
2. An improvement that includes the resolution of a technical contradiction requiring knowledge from a related area (0.45).
3. An improvement that includes the resolution of a contradiction at the level of physics requiring knowledge from other industries (0.18).
4. A new technology which involves a “breakthrough” solution requiring knowledge from different fields of science (0.04).
5. Discovery of a new phenomenon (≤ 0.01).

Obviously in terms of innovation number 1 often does not get patented, being considered part of the “prior art” of the topic area. But then 2 feeds on 3 feeds on 4 feeds on 5. So it is only at the level of new discoveries that the database can truly be expanded. For the rest of it one is left posing questions about the available information in order to find something appropriate to the current problem. However this is still useful. It is not the place here to delve into the extensive methodology developed for identifying the true problem which needs to be solved, and then finding the appropriate answer. The problem is identified as an impasse, and it is the resolution of this impasse which constitutes the solution and is considered to be the act of innovation. Altshuller listed a number of Principles and Standard Solutions to resolve this impasse; these help in making inventions at levels 2 and 3, so that relatively simple tools for technology transfer can thus account for 95% of all inventions. The Principles are a rather mixed bag of general ideas (such as *segmentation* and *mechanical vibration*). These are then subdivided into Solutions, so that segmentation, for instance, suggests that an element in the problem should be divided into smaller units which may, or may not, be linked flexibly. The list of Principles, together with the

Solutions, can be found amongst the various articles on TRIZ in the TRIZ-journal archives found at http://www.triz-journal.com/.

Examples of these solutions can then be taken from the database and Presto! the problem is (or may be) solved. Since the database is founded on the patent literature it very largely omits mention of anything from biology except at the most trivial level. But the fact that ideas from biology can be transferred into technology shows that this is a fruitful exercise. My reading of the TRIZ literature suggests that the transfer of ideas from biology can be made at a variety of levels, depending very much on how far from the biological model the technical problem lies. The further away, the more basic the analysis of the biological system has to be in order to generate a useful paradigm. This is possibly related to the Contradiction Matrix, which TRIZ uses to resolve the impasse. This matrix allows a variety of physical, mechanical and production parameters to be mapped on to the Principles; 30 out of 40 of these are described by the dimensions mass, length and time, and so are standard mechanical parameters. The trick appears to be deciding which to use under a particular set of circumstances, and it is this type of choice which TRIZ can help make.

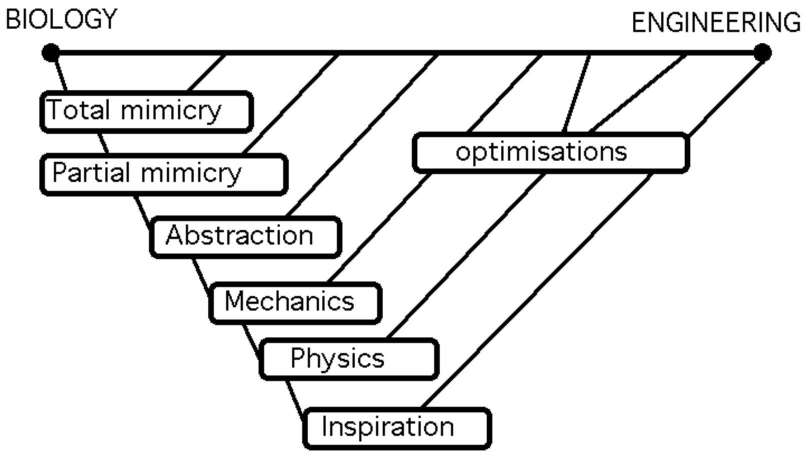

Figure 3.1. A biomimetic "map" to illustrate the idea that the more abstract a concept is, the more adaptable it is within another discipline.

3.3 Biomimetic Maps

I have tried to develop ways of mapping this transfer from biology and show two such maps here which are related to problems which have been addressed by biomimetics. The general concept is that the further down one can move from the natural origin (top left) the more general and therefore more powerful the concept will be. This is shown in a general way in fig. 1. However, ideally one wants to be as specific as possible, and there is an alternative approach (fig. 2) which

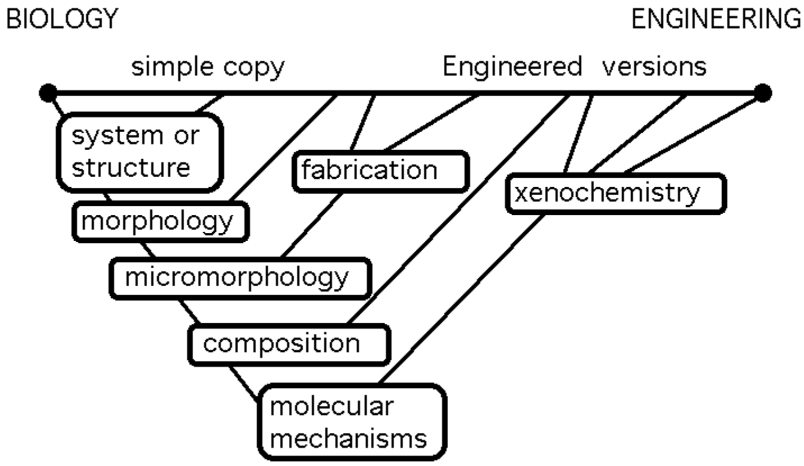

Figure 3.2. A "map" suggesting that the more basic a property is within a structure the easier it is to extrapolate that function into another area.

relates more to materials. There are many versions of this diagram which could be drawn for biological materials such as wood and composite materials. Since silk and other fibres are of current interest I show a simplified version (fig. 3) which suggests that there is some way to go yet in developing an artificial fibre with properties the same as, or better than, silk.

3.4 Biomimetics of Deployable Structures

3.4.1 Folded Plates and Tubes

The mechanisms behind folded structures like the simple leaves of hornbeam and beech are described in chapters 2 and 4. They offer ideas for easily deployed roofing or umbrellas (fig. 2). Unlike the radial actuation of the traditional umbrella and its derivatives, a cover based on the leaf could be deployed and supported from a single extending strut. In a radial leaf, experimentation shows that it can be actuated from a single fold. Concepts based on folded insect wings would probably be rather more difficult to implement since the wing is actuated only from the base, so there may be inertial problems. However, some of the locking mechanisms, based on control of elastic buckling, may well prove interesting. They remain to be analysed in natural systems. The tube of the nematocyst offers some intriguing possibilities, especially in the medical world where a deployable tube could be used as a stent, which is a tube used to hold open a duct, vein or artery. Since the nematocyst tube deploys very quickly and without snagging, its geometry must be suitable for the sort of remote control which modern surgery demands.

Tape springs, which are something like the butterfly proboscis, are already widely used in aerospace for deployable antennae. This structure has not been arrived at by copying nature. One of the problems with the tape spring is its stability, since a structure which has been folded in

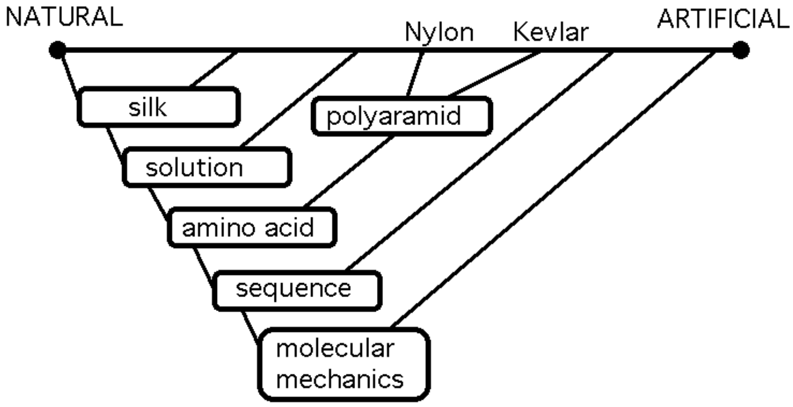

Figure 3.3. A biomimetic "map" illustrating how the successive levels of analysis of silk can lead to fibres with higher mechanical performance.

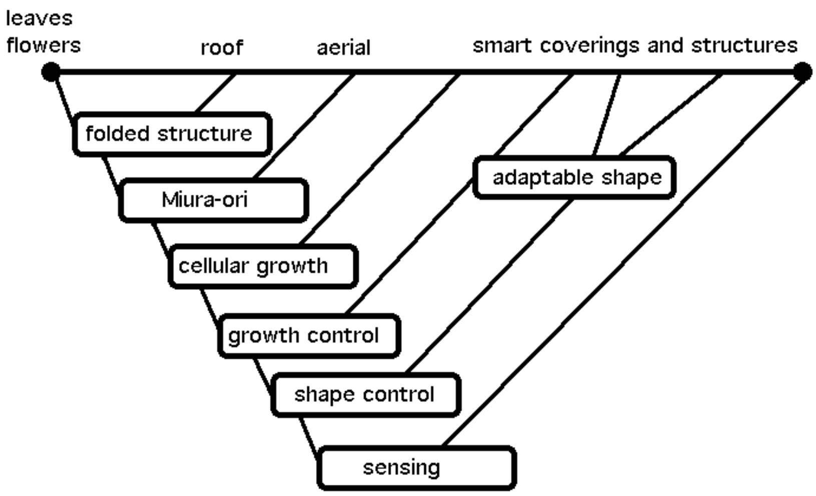

Figure 3.4. Biomimetic map of folding cellular plant structures.

this manner is in a high-energy, unstable configuration and has to be kept within a deployment mechanism which prevents it from jumping towards more stable configurations. Another problem is the deployment mechanism, which can be heavier and more complex than the antenna itself. A bistable version of this mechanism has the tape of composite construction with fibres at $\pm 45^\circ$ to the long axis relying on a strain energy minimum between the two states to keep each state stable. The biological version of this type of structure is stable in the coiled conformation and appears to require energy input (directly muscular? hydraulic?) to keep it extended. It can also be steered remotely and has terminal sensors.

3.4.2 Internal Pressure

Pneumatic structures, the closest technology routinely gets to the hydraulic structures of plants and molluscs, have been studied for some 40 years but have not been successful in general use, despite the excellent insulation properties of air, minimal use of materials, light weight and cheap construction methods. They are difficult to design, non-linear, cannot take high loads and suitably strong, hard-wearing, fabrics are not available. Early inflatable structures tended to be over-symmetrical, repetitive in form and dull to look at and acquired a reputation for unpredictability. Modern computer techniques using finite elements, developed for the design of tensile structures, are opening the way for the design of deployable pneumatic structures which can be more exciting that the average bouncy castle.

A concept which does not seem to have been explored, which occurs more frequently than one might think in nature, is using hydraulic pressure to store strain energy in an elastic component. This is the underlying principle of the Venus Fly Trap and very probably in other micromechanisms involved with pollination, for instance in orchids where a mechanism in the pollen-bearing part of the flower bends over and sticks on to the back of a visiting insect. The elastic energy store is the cellulose in the walls of the cells containing the pressurised liquid; the liquid is more or less incompressible. This approach has the advantage of power amplification, so that the strain energy can be accumulated at a low work rate and released suddenly. This would be useful to power an intermittently working deployment mechanism where power is at a premium, for instance on board a satellite.

3.5 . . . And Finally

It is all very well looking to nature for inspiration, but there are very few instances of successful transfer of technology. The cynical would say that this is because nature’s technology is trivial or that the mechanisms cannot be translated. The difficulty in understanding what is happening in many of these systems is emphasised by the non-analytical approach in this paper, which is imposed by our lack of understanding. The hopeful would say that natural mechanisms have their own optimisations which create design hurdles which are conceptual rather than real. My view is that ideas can come from anywhere. Whilst it is very likely that our recognition of a mechanism of technical utility is seeded within engineering, aspects of implementation and fine tuning will be enhanced by study of other versions of the mechanism, including those in nature developed under the rigorous demands of evolution. The umbrella and the rescue dinghy required painstaking and subtle design. Nature can be just as subtle, and with its help perhaps we can avoid some of the pain!

3.6 References

Altshuller, G. (1988). *Creativity as an Exact Science*, Gordon & Breach, NY.