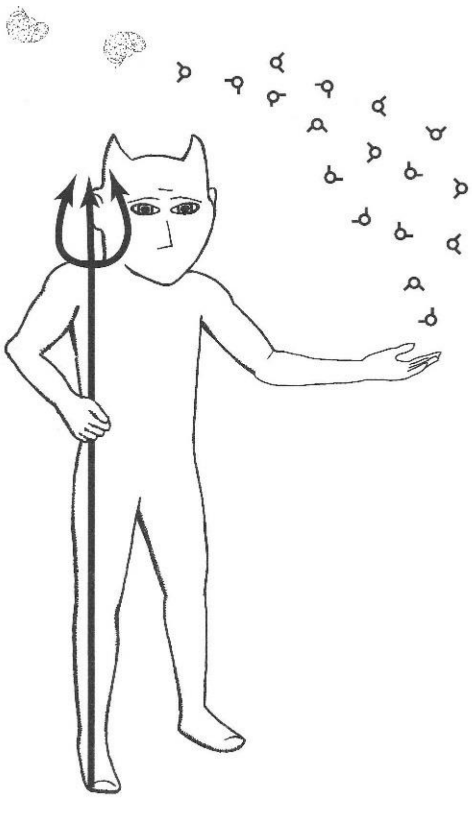
Thales’ Legacy

Part 3

The Living Matrix :

how the demon made water into mind



Chapters

Appendices

1. Quick Review

Planet Earth is distinguished from the other planets by the presence of life. But its origins are similar to that of the others, so we have to explain the special qualities that underlie the appearance and evolution of living forms. Put in more basic language: why did earthly matter begin and continue to reorganize itself into those complex shapes we instinctively recognize as living, while the same matter on the other planets did not? And even more intriguing for us humans is the fascinating sequitur to that question: how did living matter then take the more recent step of producing a form of matter that reflects upon itself? So in addition to the Grand Canyon separating the non-living from the living that set the background scene for the previous two books, the new evolutionary road mapped out in Figure 1.1 illustrates that we now are faced with an even greater divide between non-conscious and conscious matter. If the old divide was a canyon, then this new one is an abyss!

The major source of energy for occurrences on the surface of our planetary neighbours is the sun. On Earth, we have the additional factor that, as scientists seem to accept universally, the magic ingredient for life is liquid water. Even the US space agency, NASA, in its TV reports automatically equates the discovery of water on Mars with the possibility of finding life there too. We do not yet know if Mars has an on-going water cycle – perhaps it once did have – but a well functioning water cycle on Earth is a prominent basic feature of the surface of our planet. The cycle is fuelled by solar energy through evaporation from the ocean surfaces transforming salty water into fresh rain water. From the final chapter of TLP we recall how the interaction of rain with the original rocky surface produced the energized layers that make up the clay minerals.

Fresh water contains more energy than salty water does. Originating in the heat of the sun's rays as water molecules rise from the oceans into the atmosphere above, this osmotic energy is retained in bonds linking them together as the vapour condenses into liquid to be later released as the liquid dissolves the salts of the Earth's minerals. It is available to deliver work during the dissolution process – but there is a proviso of course, and that is, that the dissolution is carried out by a machine. Normally this does not happen because actions like stirring a spoonful of sugar to dissolve it in a cup of tea uses muscular, not osmotic, energy. Even the laboratory chemist uses agitation to mix together the reagents for more technical purposes than making a cup of tea. Stirring processes are dissipative, with the result that the osmotic energy becomes randomized and lost. In the formation of crystal sheets, in contrast, the pixel machine directs the placement of silicate salts into organized layers preventing randomization. In present day clays familiar to us, the energy release is manifested in the phenomenon of swelling and in the early geological time was used in the synthesis of crucial prebiotic molecules when carbon was plentiful on the Earth's surface, probably as carbon dioxide. On a lifeless planet, solar energy is dissipated as weather by the atmosphere building swirling vortices of high and low pressure, whereas on Earth, a portion of the sun's gift is captured by the machines of the biosphere and enters the network we call living matter. We will paint more detail into this broad landscape when we come to Chapter 5, “The Matrix”. In an extreme view, we might do a quick-and-easy classification of planets into two groups according to the answer to the question: does it have only weather, or does it have a forest too?

The machines in the trees of those forests bear no resemblance to the man-made machines we are used to, as a quick thumb through an engineering text will attest. The machines of the prebiotic era, though much simpler, were even more foreign to our concepts. An indication of the way they operated is revealed by the skills of the potter we examined early on in TLP Chapter 3, “The Living and the Dead”. During his labours, muscle power is transferred through layered water clusters as they in turn orient the clay crystals into an aligned macroscopic stack. Because of the order resulting on the micro level, his effort is pixellated rather than simply used to warm up a handful of mud. He operates a down-in machine. We notice that during this act, energy is transferred through the medium that the machine is made of – it travels through the water.

From the viewpoint of our normal idea of machines, this is certainly an unexpected feature. Car motors are made of steel, not water, because we do not want the walls of its cylinders to be affected by the combustion of the fuel inside. A solid construction that is mechanically strong is required by its up-out action, to ensure that the power delivered by the exploding fuel does not escape. Examining this question a little deeper though, reveals that the solid steel construction does indeed get involved, for example, it gets hot – sometimes, like rocket engines, white hot. But this heat release is an unwanted side-effect. To energize the iron atoms in the walls of a steel cylinder is not the aim of motor designers.

In downward-directed action, things are different. Changes to the tumbling motion of water molecules are inseparably linked to the switching states of clusters. So now we are faced with the question: how can machines be made of materials of such diverse natures? Can devices made of strengthened steel on the one hand, and fluid water on the other, be categorized under the one heading, or do terms like “biological machine” represent a convenient shorthand used by biologists for entities like enzymes, simply because they are found in cells (biological) and are known to operate on an orderly way (machine)? Are we then to acknowledge that the term “machine” is just borrowed loosely from engineering, and that study of “mechanical machines” is really irrelevant to biology? In the following chapters we will attempt to answer this question and extend the enquiry that extra step further to touch the realm of consciousness and ask: are our suspicious artistic friends correct when they interject in dismay, “but the mind is not a machine!”?

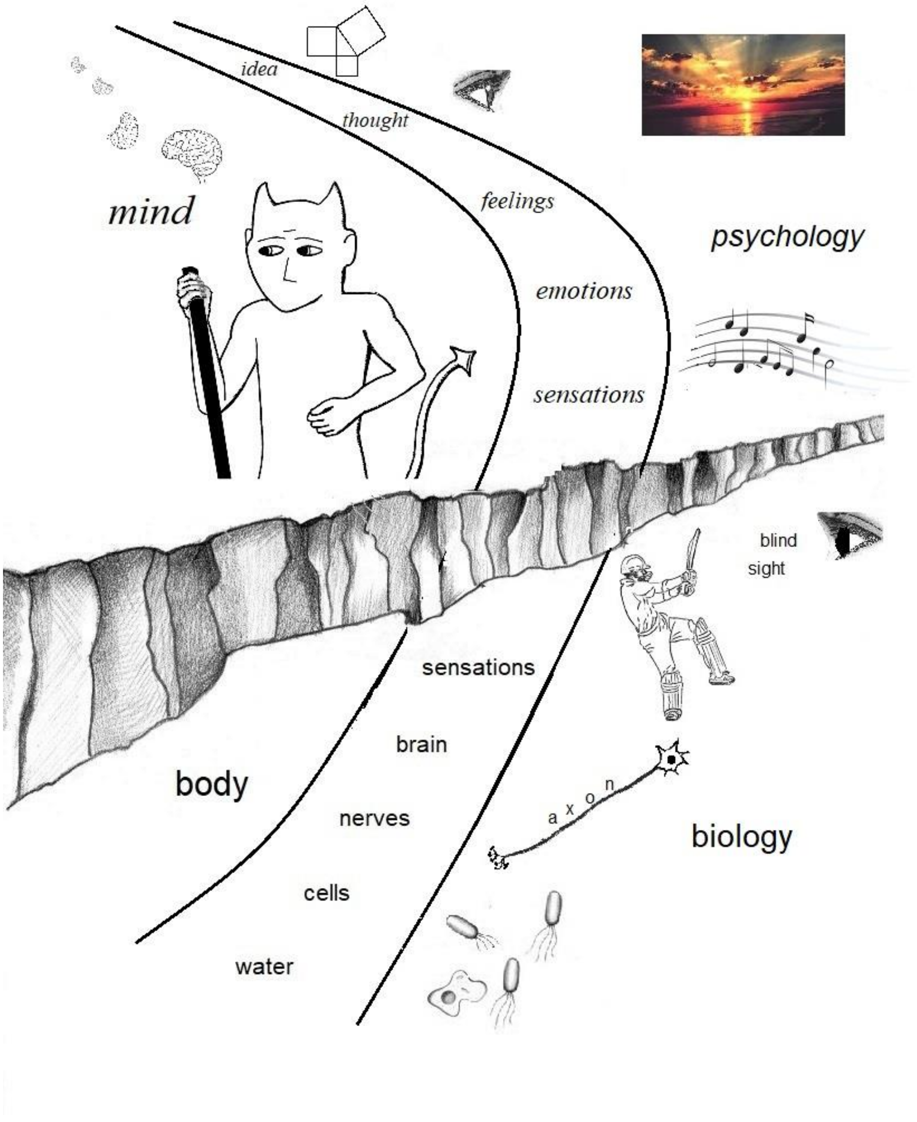


Figure 1.1 The Chasm between Brain and Mind

Like the chasm separating the biological from the physical sciences illustrated at the beginning of our story in Figure 1.1 of The Living Pixel, we now face the separation between the psychological and biological sciences. This time it is the biological sciences on the southern side and the psychological sciences on the northern side of the deep divide at the level of the “sensations” in the evolutionary road from primitive forms of life to abstract thought. Are the entities labelled “sensations” standing on opposite sides of the divide really identical, meaning that the chasm is in fact a fiction? Or is the chasm a bottomless abyss populated with endless circular philosophical argumentation never to be crossed? Or perhaps there is a third possibility, in which the contents of the chasm are composed of natural substance that has evolved to form a bridge linking body and mind? In the following chapters, a holistic approach is taken in the search for those contents, based on the interplay between energy and information developed in the previous two books.

2. Parts and Particles

Had Neil Armstrong and Buzz Aldrin come across a spanner lying in the lunar dust they would have been mighty surprised. But we terrestrials, following their every step on our radios and televisions, would have been saddened by the obvious deleterious effect their great and unique adventure had had on the states of their minds. Still others (of our not-so-scientific planetary cohabitants) would have gone into clinical shock, in the sure knowledge that the end was nigh. However, things turned out as expected. Of course, there was worldwide interest in the treasures of lunar rock that these farthest of travellers brought back, but, for the great majority, daily life proceeded as normal.

So, what is the difference between a spanner and a rock? That one is clearly made by an intelligent being and the other by random forces, does not answer the question for us – it simply begs it. It is true that any sign of intelligence behind the method of an object's fabrication gives it distinction, but from the point of view of the questions raised in these books, we seek an answer on a deeper, non-anthropic level – a difference that makes no reference to human recognition. One objective distinguishing feature is shape or form. The shape of a spanner has elements of symmetry, whereas a random object has none. At first sight it may seem that symmetry is such an improbable property that even the vaguest trace suggests to us a hidden story. Anthropologists sift through piles of rubble where they suspect there may have been human habitation, searching for non-random objects such as a stone showing the signs of being sharpened along one edge but left flat along the opposite edge. Sharp on one side but blunt on the other does not at first sound like symmetrical – but there is symmetry in this opposition. All stone tools display forms in which we recognize symmetry, even if it is symmetry in asymmetry.

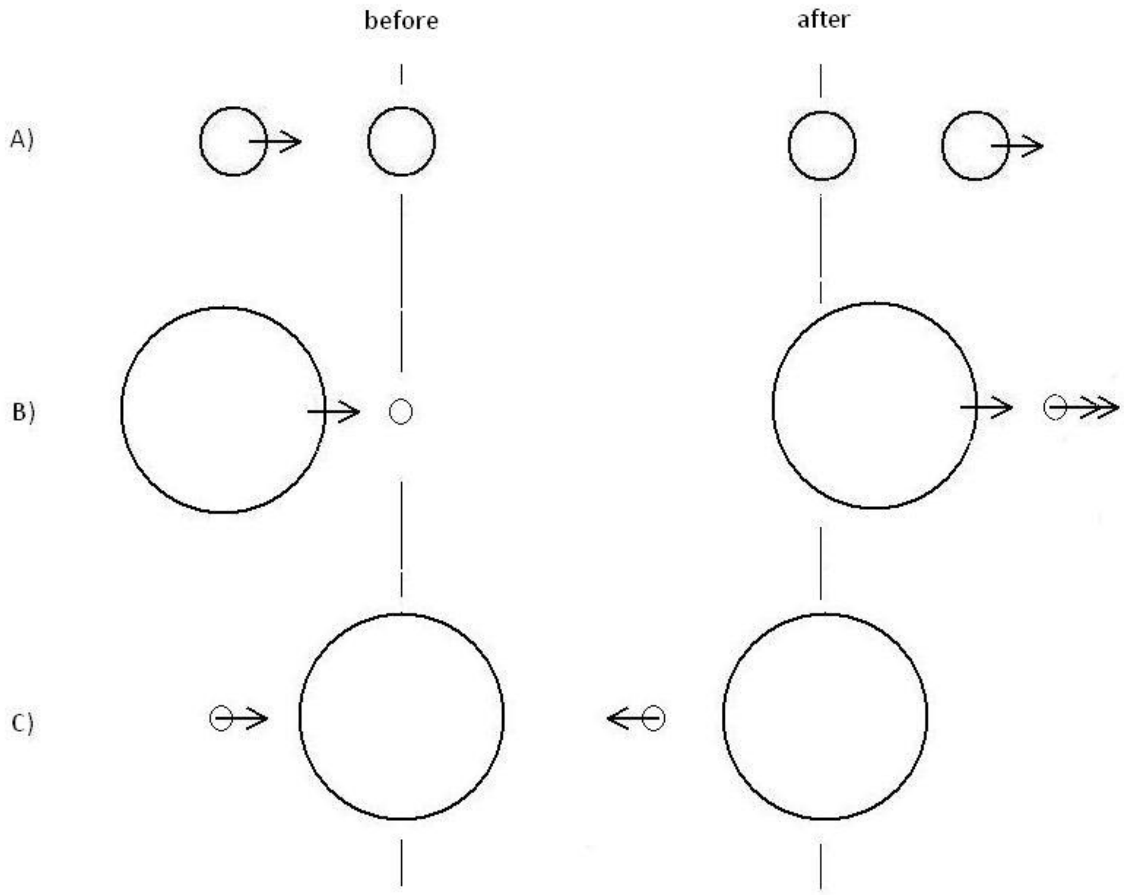
Yet we all know that symmetry is not enough. Many non-living forms possess striking symmetry – just think of a snowflake, or a crystal of salt. In Chapter 3 of the previous book TPM , "Four Machines", we made a distinction for simple one-component machines dubbed mechanical devices, which transfer energy in an immediate way without causing integration or pixellation. A simple parameter of the force applied, like intensity, might change as with a lever, lens or capacitor, but there is no movement up or down to a new level. Muscular force passes straight through a screw driver and emerges still as mechanical force at the point of work. People who have never heard of the law of the conservation of energy, instinctively recognize an instrument of energy transfer – they can differentiate between a stone and a stone tool. So coming upon a discarded implement, the use of which is uncertain, is like receiving a message with meaning yet unknown – a message which seems to suggest: one end energy in, the other end energy out.

Because the job to be carried out is usually forceful, our devices are hard, durable and inflexible – bent or broken tools are discarded. Let's call such objects "particles", since this concept helps in analysing their function a little deeper. Physics texts are fond of the picture of a billiard ball to illustrate the behavior of particles. They are hard, durable and possess symmetry. So is a billiard ball a tool? A ball can be thrown, or shot, at a target. When successful, such usage is an example of the simplest type of mechanical device, because the kinetic energy delivered to it by the propellant is transferred undiminished to the location of the impact. The character of its energy is not affected by the ball's movement.

Throwing stones to kill birds is not a helpful illustration of machine action, because the natures of the target and impact are too vague. To proceed a step further, let's consider the clean situation of the ball impacting upon a second ball of the same material. Now we are back to the billiard balls of physics texts and long known principles tell us in fine detail what happens in collisions between two hard spheres under all circumstances. As illustrated in Figure 2.1, if the collision between identical particles is dead-center, that is not a glancing blow, then the striking ball stops motionless on impact while the target ball moves off in the same forward direction and with the same speed as the first ball had before impact. Put in non-technical terms, there is a clean transfer of energy of movement from the first to the second ball. This tells us that the ball used in this way is a more elementary mechanical device than a spanner, since the energy is transferred unmodified, whereas the lever action of a spanner injects an intensifying factor into the effort. And further, a stone is a device of an even more elementary level, because both the quantity and quality of energy transferred is fairly arbitrary and may not even be under the control of the thrower. With this example we have possibly reached the bottom limit of simplicity in forms of machine action.

To return to the favoured example of the texts in Figure 2.1: let's consider next the fate of the energy after transfer to the second ball. By including two particles in our system we are now a step closer to a machine, where we are interested in the performance of an assembly of moving parts. When a hunter kills a bird with a stone, he is not concerned with the final form taken by his muscular efforts following impact (I presume), as long as it brings the bird down. But to design co-ordinated action emerging from many moving parts, we do need to know the forces at play across each contact point in the assembly. In this example of a collision between two hard particles, we find intriguing behavior, even though we have a very simple scenario under consideration.

Above we saw that for equally sized balls, the first is halted by the impact while the second moves off with a speed equal to that of the first. However, if the second ball is much smaller or lighter than the first, then the first continues straight on through the point of collision without losing its energy. However, the second ball moves off at twice the speed, that is, the target does remain in front of the first and moves increasingly further away from it after being struck. On the other hand, if the second ball is much bigger or heavier than the first, then again there is insignificant loss from the first's energy, but this time, rather than continuing straight on in its course it reverses its direction, while the second remains unaffected. An easily visualized familiar illustration of this third case is a ball bouncing off a wall. Although perhaps too elementary to be classed as examples of machine action as we normally would think of it, this behavior offers us the possibility of variations in its outcomes, so we will call on it again when we come to discuss the role of information in such simple events.

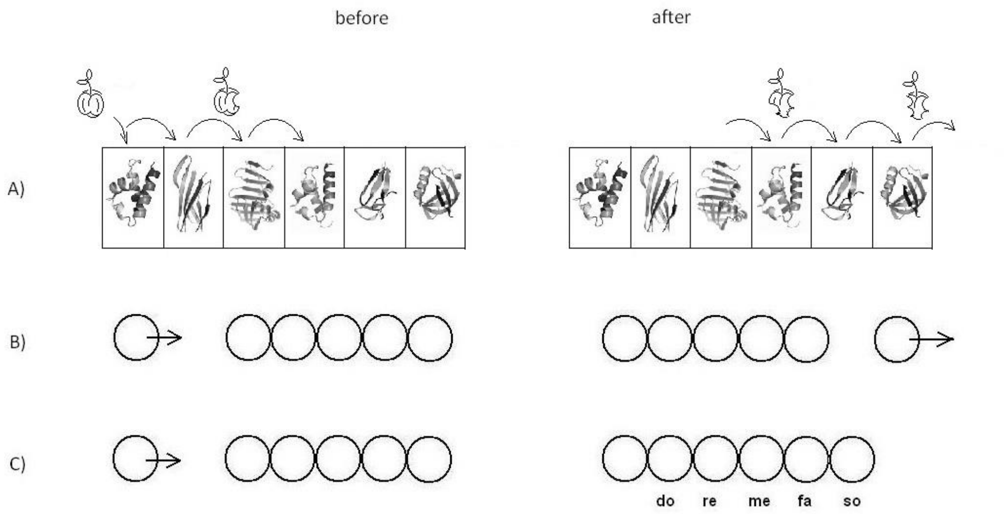


2.1 Three Collisions When two balls collide on a smooth surface the laws of Newtonian mechanics determines the details of the outcome. To illustrate what concept lies at the very bottom of machine operation, we are concerned with just three simplified situations, in which a moving ball hits a stationary ball,

A) if the balls are equal in size, then the moving ball stops while the stationary ball moves off with the same speed,

B) if the moving ball is much larger, then it continues its motion unaffected while the stationary ball moves of with double the speed in the same direction,

C) if the moving ball is much smaller, then it bounces back off the stationary ball which remains unaffected.



2.2 Sequential Collisions

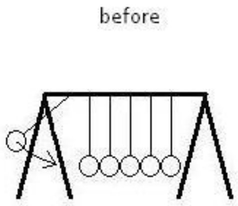
A) In mainstream biophysical theory biochemical reactions also occur as a result of molecular collisions. To illustrate this idea, we recall Figure 2.1 from TLP, in which the metabolism of glucose is shown as a series of collisions between its metabolites and the enzymes responsible. Biochemists know in great detail how much energy is released at each step.

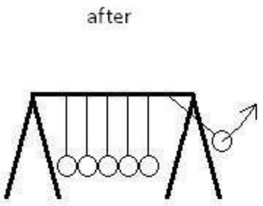
B) When a moving ball strikes the first of a straight row of five touching balls all equal in size to the moving ball, then it stops and remains in contact with the first in the row of five, while the only ball to move is the last, which moves off with the speed of the initial moving ball.

C) In a fanciful analogy to the popular wind-chime apparatus, which produces pleasant melodious tones when suspended in a windy spot, the mass and shape of each ball in the row of five is adjusted such that they ring out the next note of higher pitch in the musical scale, do.. re.. me.. fa.. so. (Readers who don’t like this boring choice of tune can imagine their own favourite ring-tone). Each note used up a portion of the energy supplied in the initial collision, such that the last ball has no energy left to move off the end of the line.

Extending this analysis a step further to include several balls brings us closer to an assembly of machine parts. Most machines have moving parts which we expect to be rigid, robust and strong, giving reliability to the sequence of their separate movements. The common phrase “well oiled” conveys the picture of an efficiently functioning assembly, where the individual energies passed on by each part contributes to the whole through co-ordinated action. In Figure 2.2 we return to a very early scene from TLP Figure 2.1 depicting the biological machine which supplies the cell’s energy needs. In this schematic representation the glucose molecule is passed along the line of six enzymes while being converted to waste carbon dioxide. Although the real cellular event is of course much more complicated, physics tells us that the whole process can nevertheless be reduced, in principle, to a series of simple collisions. So we can draw a parallel between this biological scene and our present problem: how is energy passed along a row of six billiard balls?

To make an initial attempt, let’s imagine the row set in a straight line on a smooth surface. The same principles as used above for a collision between two balls again tell us that, after the first ball strikes at the start of the row, the sixth will move off in the same direction and at the same speed as the first had before impact. In more technical imagery, kinetic energy is captured, transferred along the line, and released at the end. That this feat could be achieved only by a champion billiards player, makes this arrangement a rather fanciful example. However, improved reliability can be introduced by lining up the balls between parallel rails or, as depicted in Figure 2.3, by hanging them from a rigid frame which keeps their positions fixed in a straight line – a well known demonstration apparatus dubbed “Newtons balls” (by engineering students). We notice that we have introduced external constraints, and with them comes the result that random events are prevented and the energy always reaches its target. Physicists refer to such constraints as “boundary conditions”. Boundary conditions are regarded as secondary only to the primary cause of any physical phenomenon, in the case, particle collision. The justification for their lower status rests on the argument that boundary conditions are imposed from above, after the fact so to speak, and therefore cannot contribute to a basic understanding of nature, since causes are before the fact and from below. As I’ve often quoted in these books, reductionist thinkers leave us in no doubt of their position, when they are presented in such strong terms as we found earlier in books by authors such as Gell-Mann and Feynman (1). From the opposite holistic perspective presented in these books, neither hierarchical level of control is the more important, and we already know that external constraints are as essential as any other feature of a machine with upward action.





2.3 Newton’s Balls This apparatus belongs squarely in the real world. It can be purchased from any supplier of kits for demonstrating physical principles. It functions without fail to show how energy is transferred through a series of collisions according to Newton’s Laws of Motion.

Although composed of many parts and although it may function perfectly, you would probably not be inclined to call such an assembly as Newtons balls a machine. But now, let us imagine that each ball is hollowed out in such a way that, when struck, its produces a musical note, with each one being a little higher, or lower, in pitch than the last. In this picture illustrated in Figure 2.2C, each ball behaves as a small bell, and each uses up a fraction, say 20%, of the energy passed on to it to produce its musical signal – just as each of our six enzymes transfers a portion of the energy derived from glucose to a molecule of the cellular energy carrier, ATP. So when the first ball strikes at the right speed, the ensuing collisions ring out the musical scale – do, re, me, fa, so – whereby the sixth ball receives just enough to produce the final note without then moving off the end of the line. Could we call this fanciful apparatus a machine? Well, probably yes, if sold as a game – and definitely yes, if used as a dinner bell, because then it would function as a durable, reliable apparatus for the conversion of kinetic energy into sound waves able to produce follow-on effects after entering the ears of hungry listeners.

On the other hand, there was no question that the row of six enzymes featured at the outset in TLP does represent a machine, though admittedly in a very schematic way. However the oversimplification doesn't worry us – biochemists can tell us in fine detail about the collisions between the breakdown fragments of the glucose molecule and this machine, including the steps where energy is captured and transferred, and the steps where the spent fuel is released as carbon dioxide. Although the box representation was used to illustrate the particle-like nature of enzymes, they must not be viewed as solid, like steel balls or rigid motor parts. Compared to steel, protein is a delicate material which is easily damaged – a property we discussed at length at the beginning of the story in the first chapter of TLP, "Two Views". Our machine parts are hard, those of the cell are soft. The internal oscillatory motion of enzymes means they are active players in the energetic changes. From the zoom-out perspective, this biological machine may appear to operate on a single level only, since the fuel enters as energy locked in the chemical bonds of glucose and the products leave as energy locked in the chemical bonds of ATP. Thus we have a single level inward-directed action, or chemical device, as an analogy to the machine dubbed a "mechanical device" in the chapter "Four Machines". When we zoom in on the other hand, we see the inner activity in each box. As the bonds make and break, their energy is captured and stored in the structure wave ready for manipulation on a higher level – in the wave-cluster model the structure wave is at the heart of enzyme function. From a deeper perspective then, the transfer of chemical energy from glucose to ATP is achieved by sequential up-out, from bond to structure, and down-in, from structure to bond, action. It is obvious from these very elementary considerations, that living matter is composed of machinery which functions as a result of energetic changes in the machine parts themselves – energy manipulating energy.

But let’s pause for a moment – surely the bonds that hold the iron atoms together in a steel ball also play a role in the sequence of events during collisions? On impact, the balls pictured in Figure 2.1 become deformed. Each compresses the other, and this in turn means that their internal bonds become strained. At this instant their bonds are loaded with the kinetic energy carried by the balls prior to impact. This is an example of the elastic collisions of physics, where the material acts like a spring, since the bonds return this energy to the movement of the balls as they bounce off each other. So there is energy transfer first downwards, then upwards – a picture of events similar to those we have just described for enzyme action.

Of course, enzymes do not travel through space with kinetic energy and collide with one another. The momentum of their movement is in the tightening and loosening of the bonds bolding the protein-water complex together – recall this concept being described earlier in TPM Chapter 8, “Hard and Soft Clusters”. Nevertheless, we see now that the events of both worlds are indeed very similar, since transfer between levels occurs in both cases. When the return of energy to the upper level is inefficient, physicists refer to such collisions as being non-elastic or dissipative. Then the kinetic energy is lowered as a result of a portion of it remaining absorbed down at the molecular level becoming heat. Such wasted energy is naturally of no interest in the study of mechanics, because it is manifested by effects such as permanent deformation, breakage and heating of the impact fragments. But in a machine with downward-directed action, this portion is not wasted, but stored in specific bonds. I know that many readers will feel that we have entered a technically difficult area, but the fate of the transferred energy can be described in pictorial terms, while those readers interested in the technical detail can refer to Appendix 1.

Recalling the ball bouncing off a wall, an event illustrated in Figure 2.1c, we know that all the energy stored momentarily in its deformation as it was squeezed into a flattened shape, was returned to reappear as kinetic energy. On impact, all the energy expressed in the forward movement disappears, and consequently the energy reappearing in the backward movement derives directly from lower-level sources, which were loaded by the reaction of the wall. A brittle ball might shatter on impact, in which case some of its energy is spent breaking the bonds that held it in one piece, while the remaining portion is returned to the kinetic energy of the rebounding fragments. Then, if made of a soft material, it might splatter onto the wall, sticking there in the form of a warm blob. In this instance, from a mechanical point of view its kinetic energy is dissipated away as heat on a lower level, as explained in technical terms in Appendix 1. Yet rather than referring to this portion as “wasted”, we prefer to call it “available”, since in the motion of clusters, it is just these molecular bonds which accept and transfer kinetic energy. But in the case of clusters, there is no contribution from a mass moving through empty space, instead the available energy is sourced from the momentum carried by the structure wave in accordance with Newton’s law of action and reaction, or in other words, from the same source as used by the demon to solve the mechanical problems encountered in osmosis.

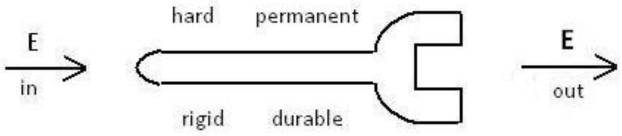
3. Matter and Energy

Thanks to Einstein's penetrating insight of a century ago, every science student today knows that matter and energy are equivalent to one another. Even members of the business community recognize the attention-grabbing power commanded by the string of the five symbols, $E=mc^2$, which explains its appearance in TV commercials along with those other scientific icons: double helices, big-bangs and electrons whizzing around intersecting elliptical orbits. But although scientists are aware of the significance of the oneness, they nevertheless tend to keep the two in separate compartments in their thinking. For instance, chemists talk of the heat of a reaction (energy) released by reacting molecules of carbon and oxygen (matter), and biochemists measure metabolic kilojoules (energy) of glucose (matter). Likewise, engineers design motors (matter) to capture the high temperature of combustion (energy). Our man-made machines function because of the interplay of two distinct components – the permanent solid parts of their construction and the transient explosive power released from their fuel.

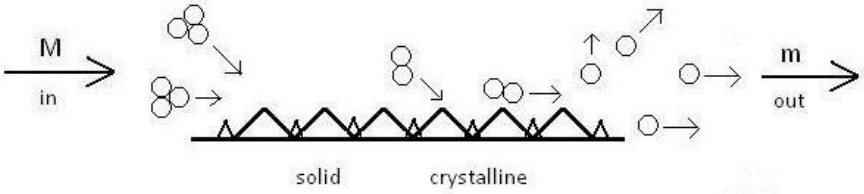
But the bottom line of Einstein's insight reminds us that the iron atoms in steel are themselves also tiny packages of energy. These packages are long-lasting because the energy is trapped in a stable way in that tiny volume of space occupied by the atom. They outlive the motor itself by billions of years. But they could become involved in the machine action, if the energy derived from the fuel became intense enough to interfere with their stability – for instance, the motor could melt, or even catch fire and consume itself. On this point, there are in fact devices which utilize passing that critical point where the energy of action overpowers the strength of the construction material – fuse wire is a good example here, since its function protects circuits from current overload. Normally however, our inventions are constructed out of strong permanent components that remain unaffected by the energies involved. And further, we want our machines to be reliable as well as durable. We do not expect the wiring in a computer to melt, and although we all have heard of a computer crashing from time to time, this is not acceptable for a jumbo jet. Normally then, there is a clear distinction between the two features: material of construction and energy of operation. Figure 3.1 attempts to illustrate the wide spectrum of materials that can be combined together to form a machine.

Describing our man-made machines in these terms makes the comparison with biological machinery even starker, because in the case of enzymes there is no clear distinction like that between steel and petroleum. The material of the machine and the fuel are as one. When fuel, say in the form of a sugar molecule, is consumed, chemical bonds involved in its breakdown belong to the same class as those that constitute the enzyme. So why then – to re-iterate a question we faced back in TLP Chapter 2, "Natural or Man-made?" – is the material of the construction not consumed along with the fuel by the chemistry being played out while enzymes are busy at their work?

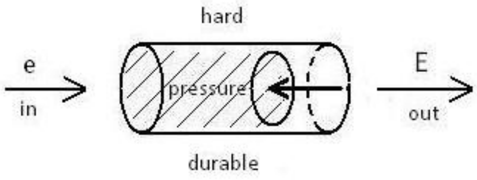
1)


E
in
hard
permanent
rigid
durable
E
out

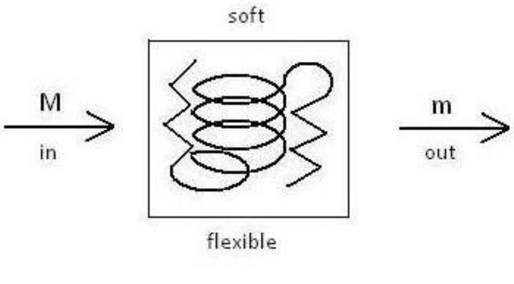
2)


M
in
solid
crystalline
m
out

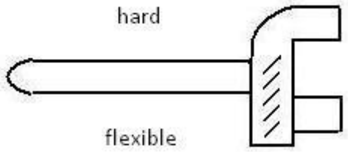
3)


e
in
hard
pressure
durable
E
out

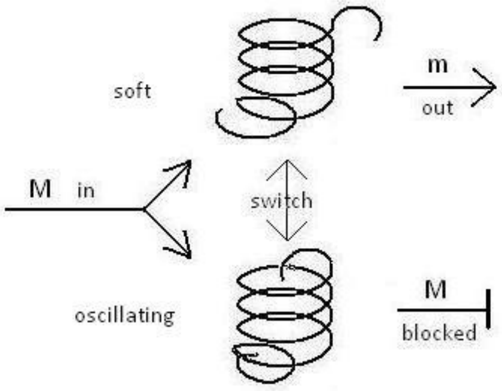
4)


M
in
soft
flexible
m
out

5)


hard
flexible

6)


soft
m
out
M
in
switch
oscillating
M
blocked

7)

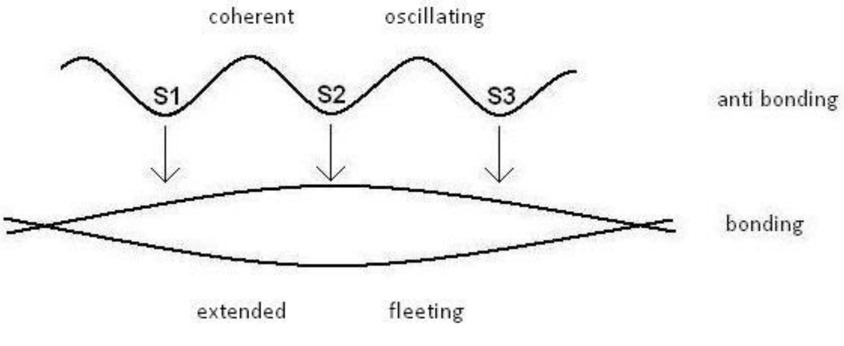

coherent
oscillating
S1
S2
S3
anti bonding
bonding
extended
fleeting

Figure 3.1 Examples of How and Why Components Make Machines

This listing attempts to illustrate how the great variety of machine types is made possible because of the different physical and chemical natures of component parts. The range extends from the familiar constructs of our engineers made out of hard, durable, long-lasting parts to biological machines composed of soft, delicate, transient parts. When we have mastered the technology to construct machines mimicking those in the biological world, we will also use materials which ensure that the intrinsic energies of components are commensurate with the energies of the job at hand.

1) Mechanical Device. This type was defined in TPM Chapter 3, “Four Machines”, as a tool or single component. In isolation, it is not a machine but a machine part, which transfers energy without a change in level.

2) Chemical Device. The chemical industry employs many different materials (usually minerals) as chemical catalysts, which have special surface properties that promote chemical reactions. In this case it is again solid matter, which facilitates the transfer of chemical energy, as for example in the production of petroleum by cracking heavy oils.

3) Piston Engine. The cylinder walls and piston are composed of hard permanent material, say steel, to withstand stresses of high temperatures and pressures generated in our heat machines.

4) Molecular Machines. Enzymes are composed of protein so these machines are soft and flexible. Protein is composed of the same chemical elements as sugars, fats and DNA – the objects of their function. In addition, their own intrinsic energy residing within the bonds that hold them together, takes part in what we normally understand as the job of the enzyme, which is to transfer externally sourced energy, or more commonly, to cause a chemical change in matter (metabolism).

5) Multiple Inputs. Control of machine function becomes possible when there is more than one input operational. Even a simple tool fitted with adjustable parts gives the opportunity of a fork-in-the-road for the energy path from input to output.

6) Biological Control. Along with the ability for simple energy or matter transfer, incorporation of multiple inputs is so prevalent in biological machinery that the ability to control the direction taken by the transfer is as common as the simple transduction step itself.

7) Coded Input. For large enzyme complexes several inputs are needed for their function. Combinations of inputs, whether energetic or material, give supermachines the ability to respond with flexibility to their environment. In the elementary example here, the metabolite molecules (substrates), s1, s2, s3, must all be bound at their specific sites for the complex to respond as a unit, or put another way, s1+s2+s3 is code for an upward transition step – eg, biochemists know the triplet A+A+A as the code for lysine in gene translation.

Traditionally, biologists view the reactions of life as classical chemical reactions. They measure statistical parameters like activation energy, binding energy, and free energy when studying enzyme kinetics. In the last decade however, a non-statistical approach has emerged. For instance, the international Protein Data Bank includes a section headed "Molecular Machinery" in which those proteins that cause cellular movements are grouped together (www.rcsb.org/pdb101/learn/molecular machines). As I've often reported in these books, there is an increasing acceptance by biologists, without being explicitly stated, that working energies must reside within these fragile structures, where they engage in oscillations that exert forces without causing damage to themselves.

And to proceed a step further, the transient forms of water clusters are even more delicate than protein. Yet these flickering structures are also particles nevertheless, which can play the role of quantum machine parts as we've seen in swelling and contraction. In coming chapters, matter having an even more fleeting existence will be introduced when we come to discuss the machines of the mind. So whether we see the levels in nature's hierarchy as a ladder of matter or of energy is a question of our sense of time scales – long-lasting, solid particles are made of matter while transient, flickering particles are made of energy. To illustrate this point, the suggestions listed in Figure 3.1 include energies as possible construction materials along with the steel of our spanner.

Another distinguishing feature is that, in the case of our motors, the construction is extrinsic, while in enzymes it is intrinsic to the action. Larger scale biological systems combine both construction types because organisms can pass energy in both directions up and down their interlinked chains of machines. For instance in muscles, the biological motor systems fuelled from molecular nano stores, the upward-directed action is made possible by the tendons and skeletal lever assemblies, which are long-lasting external machine parts. And just as with our motors, we expect to be able to re-use them throughout our lifetime. On the other hand, the quanta released at the nano level are mediated upwards through the pixel level to be gathered and summed by the external construction units at the macro level. So even though some machines may appear to be permanent and others fleeting, whether seen as hard or soft they all belong to a network that stretches beyond their own boundaries throughout the world of living things.

4. Forks in the Road

In "Quick Review", we saw how life is a phase in the fuller story of evolution. That phase started after the era when the synthesis of hydrocarbons had become sophisticated enough to produce light-sensitive chemicals which provided specialized mechanisms for capturing the sun's radiation. In the preceding prebiotic phase, pixel machines gradually accumulated energy by synthesizing high-energy bonds in carbon chemicals of ever-increasing complexity. By aligning themselves on the ancient ordered structures exposed on mineral surfaces, water clusters become catalysts for the production of those chemicals. Those machines were in fact extending their talents honed earlier in replicating the mineral surfaces themselves in the form of crystalline sheets. In building up a clay bed of identical layers, the clusters had already proven to be competent and reliable copy machines.

But conditions never remain constant. One of the main variations to affect the operation of the copying process would have been the availability of raw materials. We do not know enough about the early Earth's environment, but to speculate about its chemistry for those readers interested in more technical detail, the salts sodium and potassium are good examples of probable candidates for mutual exchange. Because they are sister elements (remember silicon and carbon from TPL Chapter 13), they each fit into the niche made for the other. Soil scientists tell us that when such exchanges occur, there often follows dramatic effects on the physical state of clays. For instance, a solid mass of the type preferred by potters can be reduced to a fluid slurry when the potassium form of the material is converted to the sodium form – a nano-level swap causing a macro-level morph.

Dramatic changes are not necessary however. Subtle shifts in the form of the structure wave would result in altered clusters – the fiddle and the flute can play the same tune but we can all hear the difference in quality of the sound produced by each instrument to the extent that we even recognize which instrument is being played (well, some people can). Altered wave form will alter machine function and finally alter the copies they produce. In addition to the sodium-potassium theme, we have the possibilities of exchanges between other salts with slightly more complex properties – magnesium and calcium, sulphate and phosphate – at the nodes where clusters make contact. Incorporation of differing agents as machine parts opens up new pathways for top-down information flow, since changes in the structure wave would produce layers of different mineral composition at the molecular level as clays crystallize. Or put more simply: the new machines now produce different results to those of the original parent machines. Many years ago, Cairns-Smith painted a similar picture in speculating that clays may have been the original genes because their shifting environmental circumstances set the scene for an early form of natural selection (2).

By virtue of their own nature, crystallizations are, of course, very repetitive growth processes – high in order and regularity but low in complexity and variability. But the introduction of the pixel machine in the role of the replicator brings additional powerful features into play. We note that clusters interact with two other players in carrying out their function of transferring information to the new layer: the old mineral surface to be copied and the available raw materials in the form of dissolved salts to be used in the copy. The involvement of a variety of elements causing shifts in cluster interactions opens up the possibility of switching mechanisms controlling the composition of the new layers, or in other words, producing altered copies.

But to return to a simpler scenario: quite elementary changes in machine components can be the basis for a switching mechanism. In the preceding chapters we revisited student days and recalled a common topic in mechanics, in which the laws of physics tell us what happens when a moving particle strikes a stationary particle of varying size. Here we describe the incident once more, but this time written in a condensed form in terms of the velocities of the striking particle, u, and the target particle, v. Before the collision we had, using this new algebraic shorthand notation,

$$u = u \text{ and } v = 0$$

and then after the collision we had the three possibilities

either $u \rightarrow 0$ and $v \rightarrow u$

or $u \rightarrow u$ and $v \rightarrow 2u$

or $u \rightarrow -u$ and $v \rightarrow 0$.

These three lines are a quick summary of the cases we examined in Chapter 2, "Parts and Particles". In the first case the target is equal in size to the striking ball, in the second it is smaller, and in the third it is larger. All we need in order to produce this three-way response is an input prior to the collision that can alter their relative sizes. The new development here is that the long description given earlier in English text has been translated into a much simpler computer program. This tried and tested traditional text book analogy will prove useful again when we come to delve deeper into codes.

I realize that particle collision, however traditional, sounds quite removed from the main issue to our readers not trained in physical techniques, so let's draw instead a parallel suggested by the biological sciences. Readers familiar with basic biochemical principles will better appreciate the following analogy drawn from modern techniques of drug design. In this field, the researcher's goal is to synthesize an artificial molecule that will interfere with an enzyme's natural function. This happens because the drug molecule can replace the natural agent, or in terms of our present picture, it acts as a foreign machine part that alters function by exchanging with the correct part. As a result, one of the collisions along the line of biological particles in Figure 2.3 causes a malfunction. In our experience with our man-made machines, a part can be exchanged with another as long as the replacement part has a size and shape that is sufficiently similar to allow a close fit, although such exchanges usually cause machines to run less efficiently. Yet other exchanges can cause a change in running mode, as happens with gearing ratios, or more simply, with adjusting the shift spanner in Figure 3.1, all without necessarily causing defective function. But in drug design, the aim is to achieve such a perfect fit that the replacement cannot be removed, so blocking the enzyme and effectively shutting down the biological activity – an off-switch.

5. The Matrix

Energy moves chaotically through the world of non-living matter. In living matter it moves through the network in a predictable way, so in contrast to the non-living, the network has a past, a present and a future.

How do energy and information flow through this network of living forms as a whole? Let's start with the biologists' simplified overview, in which energy enters the biosphere at the fundamental level of photosynthesis and then passes from the plant to the animal kingdom. In a neat summary we might say: plants capture and store while animals use and dissipate. This never-ending flux powers the well known cycles that underpin life – the carbon, oxygen, nitrogen and water cycles.

And information? Although it is accepted that information has an important part to play, nobody seems to know how, when, where or why. The majority view places the information molecule in center stage. Natural selection has accumulated advantageous chance mutations into DNA by choosing the competitively successful species (Gould), or individuals (Dawkins). This explanation continues to be universally taught to biology classes even though pertinent real-life experiences, like those of an addicted gambler, equate it to the mistaken conviction that miracles really do happen (For an extended discussion on this mind-set see TPM Chapter 2 "Mechanism or No Mechanism").

The cell needs both motors and computers, yet the machinery of the cell is all made of the same stuff – wet protein. Adding to the intrigue is the fact that cellular fuel is supplied in the phosphate bond of ATP, while the activity of many enzymes is controlled by ATP. Indeed, as we remember from the very beginning of the story in TLP, in the information store itself, DNA, the bits of information, A, T, C and G, have the same molecular form as ATP. So which is the energy and which is the information?

As we move across the spectrum of machines from motor to computer, the roles of energy and information are reversed – or perhaps better said, they are interchanged as illustrated in Figure 5.1. Your motor mechanic will tell you that there are a lot of fast moving parts in the engine, which he must keep tuned to ensure smooth running of your vehicle, that is, to ensure efficient use of energy. On the other hand, your computer salesman advises that a memory board with a capacity of at least a hundred gigs is required to ensure smooth running visuals in your new computer game, that is, to ensure efficient use of information. Yet far from being incompatible extremes, the fact that the cell functions reliably demonstrates that these seemingly unrelated activities can be interlocked to build a synchronized assembly composed of the same material.

For the last billion years, the biosphere has run on solar power provided by photosynthesis, but since chlorophyll is a highly evolved specialized molecule, we can be sure this was not always the case. In prior stages, the water cycle captured solar radiation of a less specific type, keeping up a constant flow of fresh water on the surface of the planet, which in turn delivered the sun's warmth to the early machinery in the form of osmotic energy. This earlier cycle explains the formation of the Earth's vast clay deposits. Their existence was made possible by the energy transferred from the bonds in fresh water. As a consequence, unlike rock crystals, clays are composed of high-energy layered crystals. This energy enables the silicate sheets to build up the twin forces we see in swelling, pressure and tension, perpendicular to each other, so preventing their mutual cancellation. In forming these forceful structures solar power was retained, not lost, and the symmetry of chaos was broken.

Let's suppose that carbon was in plentiful supply in the Earth's early atmosphere, probably as carbon dioxide judging from the atmosphere of our sister planets. The elements, carbon and silicon, belong to the same family and so have similar chemistry. Because carbon dioxide is soluble in water, it may have been incorporated into the clay crystals in place of silicon as they formed. A more detailed model was described in the last chapter of TLP "Dead or Alive", where carbon dioxide was shown inside the water layer attached to the crystal surface rather than being incorporated inside the crystal sheet itself. In any event, it was proposed that the lateral forces acting throughout these ordered structures provided the downward-directed action that resulted in production of energy-rich molecules based on carbon. In a simplified summary of this scenario we might say: in this first stage, osmotic energy was pumped into base-level carbon in a deoxygenation step through removal of an oxygen atom from carbon dioxide to produce a family of chemicals we call carbohydrates, suggested by the step W → X in the scheme of Figure 5.2.

Let us next suppose that a critical stage arrived when the original supply of atmospheric carbon dioxide began to run out. Since the carbon dioxide molecules had been replaced by the new carbohydrates in the environments of the clay beds, these new molecules built up a concentration surpassing that of their precursor, carbon dioxide. As a result, they too now began to take part in the chemical machinery that produced them. In other words, the lack of an external supply caused the beginnings of a carbon cycle to emerge. Up to this point, there had been steady growth in the conversion of source low-energy carbon into first level energized carbohydrates, but this process eventually consumed all of the original carbon dioxide.

Clays are not all the same. Some swell with water to a small extent, while others (bentonites) absorb large amounts of water which can exceed their mineral volume and exert powerful forces. Still other hydrophobic varieties (kaolinites) do not swell at all. So particular varieties would have been better suited to the initial interaction with base-level carbon dioxide, and yet other varieties to carbohydrates. As we've already seen, chemical constraints can be the basis for downward-directed information flow, since in this step the new carbohydrates began to influence the internal structural detail of an early machine part, namely, the shape of wave-clusters in intimate contact with the silicate faces. With this picture we have now reached the second stage of energizing the original carbon dioxide. In a new simplified summary we might say: this stage saw the removal of the remaining oxygen atom in a second deoxygenation step, injecting even more osmotic energy thereby transforming the carbohydrates into yet higher-energy hydrocarbons, symbolized by the step X → Y.

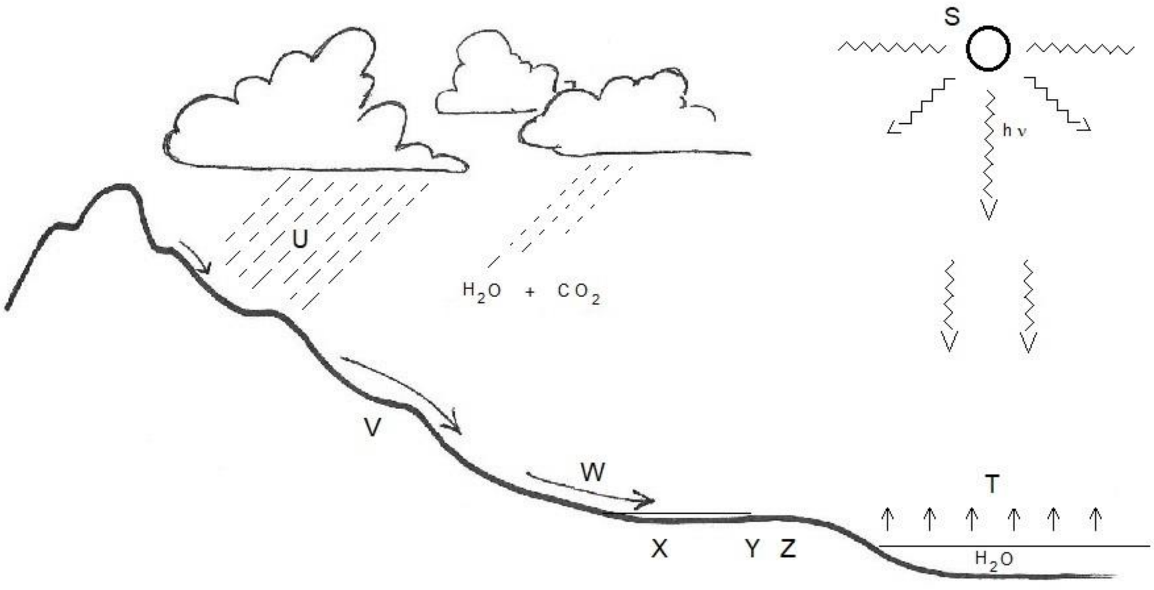
$$\rightarrow \mathbf{E} \rightarrow \mathbf{I} \rightarrow \mathbf{E} \rightarrow \mathbf{I} \rightarrow \mathbf{E} \rightarrow \mathbf{I} \rightarrow$$

$$\mathbf{E} \rightarrow \boxed{\mathbf{I} \rightarrow \mathbf{E} \rightarrow \mathbf{I}} \rightarrow \mathbf{E} \rightarrow$$

$$\mathbf{I} \rightarrow \boxed{\mathbf{E} \rightarrow \mathbf{I} \rightarrow \mathbf{E}} \rightarrow \mathbf{I} \rightarrow$$

5.1 The Spectrum of E and I Machines

In the chapter “The Missing Bit”, the concept of information as a machine part was developed. Normally, we think in engineering mode, that is, we think of a machine in isolation as a device that uses, converts, delivers . . . energy for us. However, we also remember that the biosphere is a network of interconnected machines. The passage of energy through this network is guided by biology’s information content. To simplify this picture, the sequence of E and I represents a linear section of the network. Thinking as engineers do, we would group the E and I components as in the box on the second line to represent a machine, because we are interested in the E-in and E-out steps, while the I component refers to its internal construction which is taken for granted. Conversely, the operator of a DVD player would group the components as seen in the third row, the interest in this case being I-in and I-out, with energetic changes taken for granted. In living systems, this demarcation used to classify machines as being either E or I, is not so clear.



5.2 Early Earth's Water Cycle

Schematic geographical representation of the water cycle in the prebiotic era.

S: the sun as the source of heat radiation.

T: sun's warmth evaporated water from surface of oceans.

U: fresh water condensed as rain, dissolving carbon dioxide out of the early atmosphere.

V: fresh water dissolved minerals from volcanic rocks rich in silicon dioxide.

W: dissolved minerals crystallized forming wet sedimentary clay beds in which the major component was silicate crystalline sheets.

X: deoxygenating chemical reaction catalysed on clay surfaces produces simple carbohydrate molecules.

Y: recycling of carbohydrate molecules produced hydrocarbons through additional deoxygenating reactions still within mineral environments.

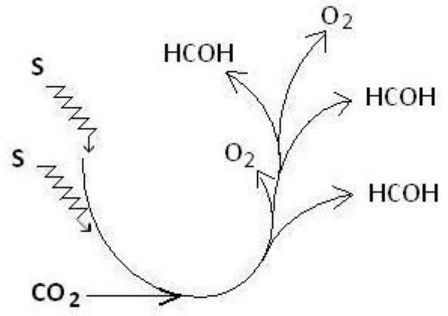
Z: emergence of prebiological structures (stacks of hydrocarbon lamella mimicking the earlier silicate sheets facilitating synthesis of new carbohydrate molecules).

The arrival of hydrocarbons on the evolutionary stage brought an explosion of new machinery. Unlike the carbohydrates, these products are not soluble in water and would have formed oily layers with their own particular interactions with water clusters. Their appearance brought a novel environment onto the scene that proved to be a powerful factor in further breaking the symmetry of natural forces. In fact, they eventually replaced the clay mineral components of the machines altogether. In the present epoch, they exist as the lipid bilayers which, being an integral part of all cells, are ubiquitous throughout the entire biosphere today. These hydrocarbon forms are the foundation of the dazzling array of chemicals we mentioned earlier in the final chapter of TPM, "Information Comes Alive". During this phase of carbon chemistry on Earth, the great majority of this element was trapped in the simple carbohydrate and hydrocarbon forms. Chemists call these forms "organic" chemicals, because they are the products of life, whereas the original carbon dioxide is called an "inorganic" chemical. But now we see that, according to this model at least, fundamental types of "organic" substances must have predated living organisms.

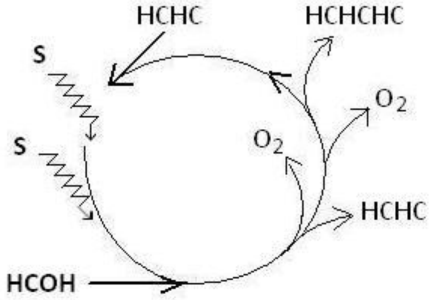
As the carbon cycles turned on the endless supply of fuel provided by osmotic energy, ever more complex hydrocarbons were synthesized charged with ever more energy than their predecessors. The permanent stacks of layered silicates were replaced by arrays of the more versatile hydrocarbons which built structures resembling rudimentary mitochondria and chloroplasts. These flexible machine parts would enter into long-range interactions, that is, take up a mode of supermachine operation and begin to synthesize molecules possessing repetitive symmetry capable of absorbing visible sunlight (precursors of unsaturated hydrocarbons such as carotene, the red dye in vegetables). The new light-absorbing molecules introduced a specific method of trapping the sun's energy, and when they themselves became incorporated into the machinery, vastly superior energetic reactions came into play that resulted in a qualitative change in the direction taken by evolution.

The intensified turning of the carbon cycle added more powerful machinery to the downward-directed action. New elements, particularly nitrogen and phosphorus, were drawn into the expanding network, as illustrated in the diagram 5.3. In the early stage before the cycle took hold, fresh inorganic carbon was continually being recruited from the supply of not yet recycled carbon dioxide that still remained. Thus during that time, there was a type of constant, or gradual, increase in stored energy being trapped in the simple carbohydrates. During the later stages fuelled by photosynthesis, it is generally accepted that the biosphere is turning over in a steady-state. At first, this "steady-state" may sound like a difficult concept to non-technical readers, but it can be put more simply in the phrase "energy in equals energy out". The gradual increase reached its limit and was then replaced by the steady-state turnover – accruing was replaced by recycling.

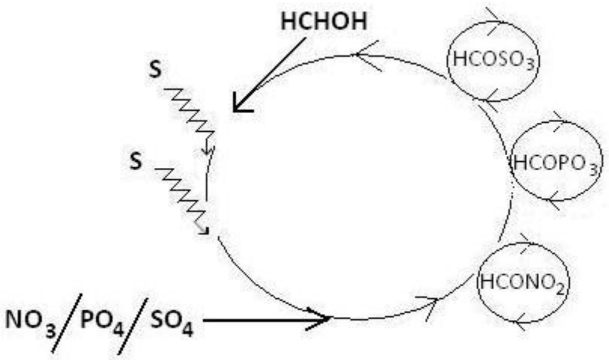
A)


S
S
CO_2
HCOH
O_2
HCOH
O_2
HCOH

B)


HCHC
HCHCHC
S
S
O_2
O_2
HCHC
HCOH

C)


HCHOH
S
S
$HCOSO_3$
$HCOPO_3$
$HCONO_2$
NO_3/PO_4/SO_4

5.3 Evolution of Early Carbon Cycles

A) The initial cycle need not have been a true cycle while sufficient unused free carbon dioxide remained in the atmosphere. Nevertheless, deoxygenating steps probably occurred producing water soluble carbohydrates and free oxygen gas. The distinction between soluble and insoluble chemical products was a decisive step, because it resulted in a physical separation between the accumulating store of carbohydrates in the liquid watery, and free oxygen in the gaseous atmospheric compartments.

B) A further breaking of the symmetry of the early chaos occurred after the cycle closed due to the lack of the original carbon dioxide supply. The simple carbohydrate products were themselves allowed to re-enter the cycle at forks in the road make available by the heterogeneous nature of clay crystals. This time, further deoxygenation produced hydrocarbons, which are insoluble in water and so this new high-energy chemical compound began to build its own type of environment, distinct and physically separated from both the watery layers and the atmosphere. The presence of separate phases enhanced the possibility of novel reactions taking place, because the contact interfaces provided sites of heightened reactivity.

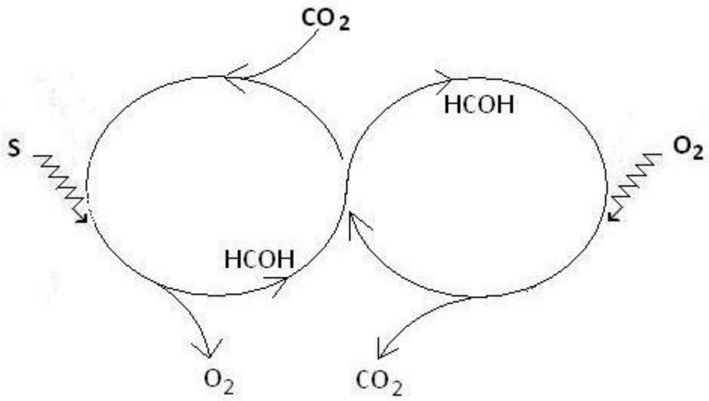
C) The introduction of even more possible locations for forks in the road allowed the other critical elements, nitrogen, phosphorus and sulphur to enter the overall cycle. One possibility is that these secondary elements entered the cycles after being converted to oxides by reacting with the newly available excess free oxygen.

CO_2 = carbon dioxide, O_2 = oxygen gas
-HCOH- = carbohydrates
-HCHC- = hydrocarbons
NO_3 = nitrate, PO_4 = phosphate, SO_4 = sulphate.

However, the turnover dynamics were not always so straight forward as what is implied by this two-phase concept of steady growth followed by constant recycling. We know there have been geological periods when both low- and high-energy carbon was buried in fossil deposits. The former we know today as the limestone rock beds in which carbon is locked up as carbonate. As this is a spent form of carbon similar to carbon dioxide itself, its removal did not affect the energy balance in the network. In contrast, the high-energy deposits encompass the carbonaceous shales and fossil fuels. Assuming these energetically relevant deposits were derived from the original supply of carbon dioxide, the removal of such deoxygenated forms from the overall cycle at later stages would have resulted in excess free oxygen being left behind in the atmosphere. I do not know what proportion of the original supply has been removed by burial, but it is clear that this might have resulted in energizing the atmosphere with free oxygen gas to a level over and above the measure implied by the cyclic simplification, oxygen in equals oxygen out, which holds in the present phase of evolution (as far as I am aware).

Is the energy accumulation phase of the early prebiotic stages that preceded the constant recycling depicted in diagram 5.4, really over? Did it come to an end when photosynthetic mechanisms became so efficient that the turnover of all available carbon could now be accomplished in a single, grand, over-arching cycle? If on the other hand, evolution remains on-going, will this entail only rearrangement of already existing living matter, or will it need new additional input points for the construction of more complex energy-rich forms of life? Or recalling an earlier way of posing the question from the end of Chapter 1 of TPM, “Ladders and Levels” – how can the ladder continue to extend itself without being already equipped with an inbuilt extension? And if evolution will continue (as, I suspect, most readers hope), is it a natural necessity? We will examine this intriguing puzzle later when we come to chapters dealing with social mind.

The image of a network usually conjures up an array of static connections, like a telephone system, the wiring inside a jumbo jet, the links on the internet – an image that is too rigid for an expanding space-filling world we seek, in which the concrete is interlocked with the abstract. Even in a computer, the pulses of electricity travel around its circuits finally exiting, in the same form as they entered, through the pins on the plug in the wall. Living matter by contrast, is better described as a hierarchical matrix of energy quanta where the levels are distinguished by the qualities of the quanta – quanta populating different levels are different types of energy. At lower levels of the biosphere these differences are mainly characterized by physical size. In this multidimensional matrix the interconnections appear and disappear, but this rhythmic oscillation resulting from on-going pixellation and integration processes does not destroy the matrix. The squares on the chessboard of the living matrix sometimes coalesce forming bigger squares on a bigger chessboard, at other times they subdivide into ever smaller squares, but then when the opposite process returns, copies of the previous structures re-emerge, because the pattern of the new interconnections resembles the old one. Though there is a multitude of layers that energy must traverse between molecules and thoughts, the linkage is not lost, because the pulsations are themselves the mechanism of transmission. Of course in very simple oscillations such as the swing of a pendulum, the system returns ideally to an identical state after each cycle, while in contrast, in the matrix the machines at the top and bottom differ vastly in their natures – a thought does not resemble a phosphate bond – nevertheless, they remain linked together. Through its pre-determined interconnections, the matrix remembers its history.



5.4 Oxygen Enters the Cycle Oxygen is a very reactive chemical. For this reason its physical removal from the early cycle as waste was essential to prevent it from reforming the starting material, carbon dioxide, at the point of production. However, its continual build-up in the atmosphere meant it would inevitably begin to react with the new members of the early environment. Entry of oxygen in a similar way to that proposed for nitrogen in the previous diagram, would have driven the cycle backwards and brought proceedings to a halt. In order that the carbon cycle could continue its one-way operation by absorbing atmospheric carbon dioxide, it needed to be separated from an oxygen-absorbing cycle, so that their products, oxygen and carbon dioxide respectively, were released by different structures into different environments. These two half-cycles lay the basis for the emergence of the complementary but distinct particles, chloroplasts and mitochondria, which were later incorporated into fully matured cellular biology.

Changing patterns of our own social behavior offer a good analogy to the matrix concept. In the main we act as individuals, but often we associate into groups like families and teams, then again there can be mass gatherings like religious rituals, pop concerts, political demonstrations and military assaults. Mass behavior is the manifestation of unified psychic energy. In this model, psychic energy occupies a level of the matrix that evolved long ago in order to bond groups of individuals together.

Or moving back down into the harder world of cell biology, we can refer to well known behavior of cells in culture. For instance, when cardiac cells are artificially grown, they gather together, and when their number is large enough, they begin to beat in regular rhythm, that is, the assembly becomes a whole resembling a primitive heart. Or going still further down to a single cell: it is a triviality to say a cell can act as a unit, even though it is composed of millions of units, as when it redirects its locomotion, or begins to divide. Then deeper, there are the concerted movements displayed by mitochondria and chloroplasts, which we have often discussed. And yet deeper, there are the pixel machines of clusters and proteins, each made of thousands of atoms. So finally, the orb spider we met at the beginning of the story, works as a single organism performing her improbable act, as a result of the pulsating connections which permeate that tiny corner of the matrix we call a spider.

In the beginning (please excuse the phrase), there was a supply of low-energy minerals, water, and carbon. In the end, there is an interested human reading a book describing that initial scene. In the intervening few billion years, the sun supplied a constant stream of broadband radiation. In certain spatial arrangements, these three original ingredients combined to break the symmetry of prevailing chaos and produced forces – in other words, they formed a crude machine. The code directing its action was supplied by the minerals and the message by quanta of oscillating osmotic energy derived from the radiation. Acting initially as simple copy machines, they later began to branch at forks we have already attributed to variations in the surroundings. The more flexible machines produced simple carbon compounds of higher energy, which in turn adopted the role of machine parts on the next hierarchical level, producing new compounds possessing yet higher energy able to act as yet more sophisticated machine parts, and so on. The evolution of whole organisms, such as our spider, had to wait until a later phase when the pathways became specific, which allowed the transmission of messages up and down the matrix to become reliable. I realize that biochemists are not impressed by these descriptions of improved function, if only because highly tuned specificity is the bread-and-butter of their profession. For biologists, life is a network of enzymes, and these machines do not need instructions, since rules of behavior are built into their finely tuned structures. On the other hand, IT researchers are quite impressed by the evolution of signal specificity in the workings of blind nature, since that’s what computers cannot do, so the researchers have to invent and write the instructions as input themselves. For them, the rules are the list of externally imposed commands called “code”.

6. Information Evolves

The sparks of life we sought in the canyon between the sciences in the introductory chapter “Two Views”, were produced at the interface between the inward world of crystals and the outward world of gases. The pixel machine derived its energy from atmospheric water after it condensed into the liquid form, and its information from the repetitive patterns presented on the mineral surfaces. Although this scene was the entry point into the matrix for energy and information in the prebiotic era, it no longer plays that role. Today, energy enters at photosynthesis and leaves at all levels as waste and activities like those involving muscular effort. But what about information? – a question that brings us again to Schroedinger’s problem of the information content of living forms, which he thought must also originate in the environment. However, copies of mineral surfaces did not provide much information, since highly ordered arrays are boring, not interesting. So was it also continually added at later stages as more sophisticated new entry points emerged? Or as a counterpoint here we might ask: does all the information needed for life also enter the matrix along with energy at photosynthesis?

When we viewed single-event collisions as switching mechanisms with the eyes of a computer programmer in Chapter 4, “Forks in the Road”, the emphasis shifted from physics to code. Such an approach suggests a promising clue to solving the puzzle of the growing matrix. Let’s examine this interrelationship one step further in a more complicated, though perhaps more familiar, scene. A common game found in amusement arcades is the pinball machine. Older versions of this game used to be operated by the muscle power of young male humans (mainly). It consisted of a table slightly inclined to the horizontal, containing sprung levers positioned over holes which were just big enough to allow the ball to fall through beneath the table and thus end the run – an undesirable result. The ball was set in motion by the impact from a primer spring at the bottom of the table which, depending of the force delivered to the spring by the player, launched the ball up towards the top of the table. From there the player attempted to defy gravity by cleverly guiding the ball back to the top against its natural tendency to roll down to the bottom, where it was funnelled into the final hole-of-no-return. The moves were made by the player triggering the levers located at various intermediate positions on the way down the slope. A skilful player operated these levers with the right force at the right instant to set the ball on a trajectory that kept it from falling into strategically positioned holes.

Although muscle power is needed to operate that older version of the game, the aim was not to achieve the highest or lowest level of energy expenditure (I think I’m right on this point). All attention was paid to scoring the highest number of points accrued through skilfully manipulating the levers and avoiding the fatal holes. So in contrast to hunting a bird with a stone, the aim here is to achieve an abstract ideal. The fact that today’s versions of the game are digital, where the role of muscular exertion is reduced to touching a screen, makes it obvious that the game can be encoded into a short list of switching rules like those we set down earlier to describe a simple collision.

Let’s now invent a variation of the game by installing compressible springs, which get squeezed and click shut when struck by the rolling ball, and then spring open again when struck a second time thereby imparting extra force to the bounce of the ball. In this version, energy stored in these new springs is a variant of the energy injected manually by the player into the older moveable levers. In a composite version containing both manually powered and automatically controlled springs, the ball would move up and down the table slope using both external and captured energy sources.

In the wave-cluster model of the earliest machines, the moving parts were not small steel balls, but the clusters themselves. In bulk liquid without constraints, they move about at random, but under the influence of a mineral surface their flickering motion becomes coherent, stimulating them to fuse into larger structures. These incipient machines generated permanent new surfaces, that is to say, longer-lasting surfaces than their own interfaces at the junctions between individual clusters, composed first of the mineral salts themselves, but then of organic hydrocarbon material later on. Put another way, the products of the original machines became the external constraints, or boundary conditions (for mathematicians) or cylinder walls (for engineers) of the emergent higher-level machine. In the opposite direction, pixellation of the flickering clusters produced an array of locations at the nodal and antinodal positions, where identical chemical circumstances were repeated forming a spatial pattern of reactive sites where concentrated energy could be captured and stored. This time the compressible springs in the pinball machine are analogies for reactive chemical bonds located in a regularly spaced array. These new mineral products began in turn to play their role as the permanent internal constraints, located at focal points (for mathematicians), or gates (for IT engineers), for construction of downward-directed machinery, whose operation heralded in the chemistry of prebiotic matter.

At the early mineral stage, the processing of information must have been very elementary. In the proposed trio of components of information: code → message → meaning, outlined earlier in TPM, meaning would have been missing, since it depends on the existence of a target machine composed of prior evolved structures and possessing the ability to be activated by messages arriving from various sources. Code would also have taken the form of simple low-energy molecules available in the environment – mineral surfaces, salts, dissolved gases. The ubiquitous sodium and potassium salts are good candidates for this role, I feel, since they still play such a prominent and crucial role in conveying messages in the later evolved biological cells, including the human brain. We’ve already mentioned in “Forks in the Road” the telling example known to soil scientists of the switch between sodium and potassium, which affects the state of water in clay gels known as gel-sol transitions. The information systems, sodium → cluster division → sol, and potassium → cluster fusion → gel, remained after mineral layers were replaced by the hydrocarbon arrays, which cell biologists know as reticulated membrane arrays. In this model of evolution, the highly developed modes of information processing operating in the biosphere today still carry traces of basic processing steps from prebiotic times.

The pinball game is of course a ridiculously crude analogy to anything living. That it is thoroughly mechanical does not automatically render it irrelevant to understanding biology however. It is drawn to illustrate steps in the evolution of information, not evolution in the usual sense of the term which concerns itself with organisms. The spring-loaded levers are depicted playing a role parallel to the switch triggered by the sodium-potassium exchange – one situation traps energy, the other releases it. The single collision event illustrated earlier in Fig 2.1, provides us with a similar analogy – a parallel can now be drawn between the sodium/potassium exchange and the switch in relative sizes of the striking and target balls. With such mechanisms the pathways taken by energy became more complex. Controls over the inward and outward flows had to be established early in order to give the matrix the flexibility needed to begin its growth.

The picture I am trying to convey contains elements – energetic carbohydrate bonds, salt switches controlling forces, lamellar stacks of mineral and hydrocarbon sheets – which are simpler in both composition and dynamics than those found in later mechanisms belonging to the phase of mature whole cells. We often read commentators on evolution, say Lovelock ( ), argue that the build up of oxygen in the atmosphere began as soon as chloroplasts entered the scene with their power of photosynthesis. Yet chloroplasts are themselves highly evolved biological systems containing several supermachines in precise alignment embedded within layered membrane stacks. These are multilevel hierarchical structures that could not have appeared spontaneously in the primordial seas. Margolis has proposed that along with mitochondria, chloroplasts originally existed as independent organisms, later to be incorporated as subcells, or organelles, into the first whole cells ( ). While this has proven to be a fruitful theory of the origin of intact cells, it does not explain the origin of chloroplasts, nor of photosynthesis, nor of the early mechanism of the production of free atmospheric oxygen. One of the chloroplast's supermachines is the protein complex called the reaction center, which contains the exotic element, manganese. This enzyme extracts oxygen out of water via a precisely ordered series of chemical reactions – a scenario differing markedly from my model presented in “Dead or Alive”, in which oxygen is freed from carbon dioxide rather than from water at the initial step in the time-line on the way to carbohydrates. Although my model is bound to be overturned, one thing is certain: the production of carbohydrates, hydrocarbons and amino acids, the building blocks of chloroplasts, required the deoxygenation of the original stock of planetary carbon dioxide to have already been completed. As suggested in Figure 5.3, the extracted oxygen may have been set free as oxygen gas by catalysts of a much more basic nature than chloroplasts – simpler machines which did not have the ability to survive under the new conditions of subsequent phases prevailing in the later biosphere, and so became extinct.

7. Extinct Codes

A controversial question in modern-day biology is the role of code in living processes. Is it essential? – even, is it important? If so, did it emerge on Earth in a natural way or did it drop out of the sky? And if it did evolve here, how did it begin?

For us today, concepts of code have been almost totally subsumed into the all-powerful computer sciences. In the twentieth century, the idea of codes conjured up images of Champollion translating the Rosetta Stone or Ventris cracking Minoan Linear B or Turing deciphering the secret messages of the German military encoded on their Enigma Machine. As fascinating, even exhilarating, as these achievements were, the methods used by those earlier workers of the pre-computer age pales in comparison to the awesome analytical power now made available by developments in information theory and practice.

These developments have been so all-encompassing that the pursuit of science has been changed in fundamental ways, ranging from discoveries of new objects in the distant cosmos on one extreme, to directing genetic research in the other. Between these extremes our daily lives are increasingly coming under the control of computers that are invisible to the vast majority of us. The entire human population will soon be reduced to a data bank in which the actual animal components could become superfluous. No wonder that commentators like Yokey can claim that life itself is underpinned by code, or Chaitin can claim that Nature's very existence rests on code, or Page can declare that a conscious computer lies just around the next corner (3).

All the theories I'm aware of, tacitly assume that coding arrived with DNA, and of these, most assume further that DNA (or RNA) appeared by chance in the primordial sea. So it must follow that the information content of DNA also arose by chance out of the sea of chaos. However as I've often stressed, DNA is a large, sophisticated, unstable molecule, in addition to which we are now reminded that its information is also written and processed in a sophisticated way. These facts together leave no doubt that the appearance of DNA could not have been the jump-off point for life on Earth. DNA's messages belong to the ordered secure environment of the cell's interior, not to a pre-cellular milieu of white noise where it could never survive. The machine to which it delivers its messages, the ribosome, is a complex supermachine comprising up to 100 protein units. On arrival of the coded instructions, the ribosome begins the synthesis of protein – a basic biological function that dwarfs the replication of DNA by the PCR machine illustrated in TLP Figure 13.2 in complexity. This machine threads together the 200 or so amino acids in their correct sequence to make protein chains. Yet it is commonly believed, and taught, that DNA preceded protein in the story of the origin of life, because of the linear sequence of operational steps executed in every cell of every present-day organism:
DNA → RNA → protein → cell structure and metabolism.

This scheme – the Central Dogma of Watson and Crick – is taught to biology students to this day. However it is not correct. The relationship between DNA and protein is circular. Protein synthesis requires the message encoded on DNA, but likewise DNA synthesis requires its own protein supermachine. In fact, it requires the PCR machine we discussed at length back in “Dead or Alive” at the end of TLP. And even further, as far as I am aware, all biological molecules in addition to DNA, say for instance vitamin B, are synthesized by their own specific protein machine. So we can safely conclude that DNA was preceded by protein, or protein precursors, in the time-line of emerging life – not the other way round.

Protein precursors? Protein themselves are complex entities possessing specialized abilities unexpected of molecules – we need only recall the PCR machine once more here. This makes them also relatively late arrivals on the biological scene. Like the A,T,C,G sequences in DNA, biochemists tell us that there are even more basic sequences, called the alpha-helix and beta-sheet structures – stretches of just 10 or so amino acids in length – embedded in the overall chain of 200. And then, proceeding another step downwards, we come to the individual amino acids themselves. Why has nature chosen to use just 20 out of the huge variety possible to build these short alpha and beta lengths? We would know the answers if the lists of instructions were still extant for us to read.

And to dig yet deeper, we find there is even more ancient lost information. Where is the code to insert the amino into amino acids? Chemists tell us that this step means the introduction of nitrogen into an early carbon cycle illustrated in the scheme Fig 5.3C. Many of the simple carbohydrates are already acidic in their chemistry, and so too are many minerals. In this case then, proposing a mechanism for the production of acidic carbohydrates at an early stage did not need chemistry involving exotic elements. So clearly, a new extended code was needed for the systematic insertion of the new element, nitrogen, yielding amino acids to replace the old code for the production of just simple, that is non-amino, acids.

Describing the evolution of early prebiotic “biochemistry” in this way is reminiscent of how human language must have emerged. First, simple sounds for the nouns and verbs important for daily life must surely have preceded formal sentences. Rules for manipulating words were needed to develop the complex syntax we find in the language of Shakespeare (for English speakers), although we have receded somewhat since the poetic heights of his convoluted expression (thankfully). Shakespeare probably learnt his Latin grammar at school, but we can be sure he did not have to study stone-age vocabulary nor have to pass exams in the tales recited by hunter-gather bards in the original. Likewise, we do not expect our children to encode ab initio their daily activities into words in a way similar to that used by our distant ancestors who took the early steps in inventing language.

Education is compulsory in most societies today, because it has become generally accepted that the production of social wealth depends on having a skilled population. Education is the recorded history of human experiences. It is the theory partner of that oft quoted duo: theory-and-practice. Encoding the results of life's trials and successes in the ciphers of letters and numbers is a way of feeding forward information so that future generations can benefit from past practice. Mothers do not expect their daughters to invent spoken sounds and written alphabets when teaching them language, they pass on a replica of their own language, the origins of which they themselves know nothing. Likewise, mother cells do not pass on to their daughters the mechanism that encodes protein into DNA, they simply pass on the already highly developed DNA and its decoding machine. And as with language, we also know nothing of the origin of this code (so far). Like the organisms of bygone geological ages, these codes are extinct. But one day, when we unearth their Rosetta Stone, we will be able to invent them again.

8. Symbols, Ciphers, Switches and Re-entry

Our codes are written in letters and numbers. Following Turing's insight we know that these can be reduced to a series of zeros and ones of binary code, or noughts and crosses, or pluses and minuses, or, if you're old enough, the dots and dashes of Morse Code. This insight allowed him to go much further though. His argument goes something like this: the world can be described in language and can therefore be written down using the symbols and ciphers of text and mathematics, and these in turn can be translated into digital format and finally into binary code. This certainly seems like a very powerful argument – but is it right?

From the previous two chapters it is clear that, in some fundamental way, information is central to life. And as often mentioned in these books, the parallel developments in computing and biology have occurred without reference to the basic concepts of science. Nevertheless, the undeniable success of genetic research built on manipulation of the DNA code has been achieved so rapidly, it would seem that we have actually mastered its basics – we understand it all. Then if this is so, we are again faced with Turing's argument, this time in biological terms, that life can also be reduced to code – but is this right?

Traditionally, the use of code has been as the means to an end. Texts tell us stories, maps help our navigation, equations solve engineering problems. Projections, translations, replicas, movies, mosaics, drawings, maps, music scores, the list of ways we humans process codes is a dramatic indication of how the use of representations underpins almost all our capabilities. With the rise of modern computers there has been an explosion in the art and practice of manipulating codes, which has given rise to the information sciences. So successful has this recently arrived field become, that manipulating code has adopted the status of an end in itself, as an established independent academic pursuit analogous to the field of pure mathematics. In TPM Chapter 15, "The Missing Bit", it was described as mathematical information to distinguish it from older aspects of our sense of information such as the much troubled concept of meaning. And just as with pure mathematics, it claims to stand squarely on pure deductive logic.

Many philosophers and theoretical physicists believe that mathematics exists as a world of its own independent of other existential entities such as humans. From this we might readily speculate that other codes, and especially those of a more abstract type, also inhabit their own world. At this point, I know readers will be aware that the philosophy threading through the preceding chapters in these books is quite the opposite. Because codes carry messages, they are in themselves incomplete, if viewed in isolation from their target machines. Or put more concretely, when we speak of codes we necessarily imply the existence of both en- and de-coding processes, and consequently, we imply that at some time in the future predetermined energetic steps will take place – DNA implies ribosomes, motor neurons imply muscles, computer programs imply microprocessors.

In its familiar usage as a means to an end, code usually plays out its role in the form of a record. As we learnt in “Extinct Codes”, a record is the theory part of theory-and-practice. With the creation of a record, the flow through the matrix pauses. Records are stationary. They do not pass on energy over the pauses and therefore a branch of the matrix is usually broken off whenever they are produced. For a record to fulfil its role as a guide to practice, it must re-enter the matrix and come to life. A lost manuscript can never be part of life again if it is not found, as neither can Minoan Linear A if it remains undeciphered. In the first case, we have no code, in the second, no decoding machine. They are extinct.

To become part of the living again, a code must carry a message to a machine. The letter “w” in the word “word” is, in the usual case, a patch of black ink on white paper. When it was created it was energized by the printing process, which gave this patch a definite shape. With age, this long-lasting trapped energy dissipates and the text becomes unreadable (or perhaps silverfish expedite the process). Re-entry occurs when light reflected from the paper enters the reader’s eyes and stimulates nerve endings on the retina. So in the reading of a record there is not a transfer of w’s energy, but instead the flux is restarted by a supply from a fresh source – in this case, external light radiation. This effect is reminiscent of the speaker-to-listener chain where we found the energy emanating from the speaker’s lungs almost died out in the intervening air. Now we see the link would be broken there also, if the speaker must resort to a form of recording, such as using a loudspeaker, to get his intended message across.

The comparison of a leaf with an eye highlights the difference between entry and re-entry. The green dye in the chloroplasts of leaves is well established as the entry point for energy into the matrix. In broad scientific terms, plants are agents that carry out the further processing steps of assembly and storage which follow the capture of single light quanta by chlorophyll molecules. But the retinal pigment at the back of the eye is not really an entry point for energy to be captured and stored, although incoming light is of course radiant energy. Rather, it is the arrival of information, not energy, that the eye awaits – it is a re-entry point and to function it relies on its decoding machine being primed with energy ready to receive. In parallel with the conclusion that photosynthesis supplies the matrix with energy, we now recognize eyes as the gates for previously living information to re-enter the matrix – there is no point to possessing eyes if you don’t know what to look for.

The quantum of light absorbed is minuscule in size compared to the cascade of energy released in steps it initiates. A small change in shape of the molecule retinal, in the light-sensitive cell on the retina, is followed by an action potential involving the inside/outside exchange of sodium/potassium salts across the cell’s membrane – the same salts we met in the clay deposits discussed in “Forks in the Road”. In other words, the event of quantum capture triggers a series of neuronal switches that transmits information forward through contacts between neighboring cells. These intercellular responses represent the first step in information processing by the visual system, because they form clusters of similarly stimulated light-sensitive cells. Higher level machinery in the brain responsible for comparing patterns of such activity identify meaningful messages by judging whether the cluster shape corresponds to the earlier learnt record of “w”.

Let’s apply these ideas to entities such as seeds, that have their own natural pause button, rather than being switched on by a quantum of light. A grain of wheat plays the part of either food or germ. Being made up almost entirely of starch, it is essentially a tiny package of energy (from a bird’s point of view). But alternatively it can become the daughter cell described in the previous chapter, since it also carries the DNA message and its decoding machine passed down from its mother plant. When eaten as food by another organism, we could say it is a source re-entering energy, since starch plays the role of a major component of the food chain . On the other hand, when playing out its role as a gene, DNA is not an energy source. In a seed it is suspended information. Of course DNA is also biological matter, but its role is to carry code, not to supply food. When conditions for germination are favorable, DNA becomes energized and the code becomes a message – DNA triggers the switch for the re-entry of information into the matrix.

We are all familiar with the device we call a “switch”. We learn its meaning early in life. As either noun or verb (in English), it needs no explanation. “Switch on the light” implies that the light will turn on neither accidently nor spontaneously. The event needs an effective prior act. So in defining the living matrix as a network through which energy flows in a predictably way, means that its machinery is a network of switches – each step of energy capture and release is controlled.

One of the major successes of our technological advance has been the ability of industrialized economies to create and store vast amounts of energy to be used as desired for fuel. As we’ve discussed in earlier chapters of these books, prior to industrialization work was fuelled principally from biological sources. However, modern use of available energy supplies has given an added meaning to “switch”, as is in fact implicit in the example above “switch on the light”, since there is an unstated reference to a limitless supply of electricity. In its modern usage therefore, a switch often means tapping into a large source by applying a disproportionately small action – the small controlling the large. How can a “flick of the switch” direct events on many hierarchical levels of size above? How can the muscle power of the dam operator open the floodgates and release the water flow that drives the massive turbines of the hydroelectric station? The conceptual problem here is whether there is a relationship between such energetically disproportionate events?

At the other end of the spectrum, in the information machines the disproportion disappears. To IT researchers, that a computer is a network of switches, is no deep concept – it is a triviality. With the ascendency of computer sciences the means served by codes have changed their essential nature. As mentioned earlier, the means have themselves become the ends. They have now a dynamic of their own, because today’s computations are carried out without concern for energy usage, and thus appear to drive themselves. High speed simulations that give us games are well known examples of this development. Automatons move about without needing the impetus of forces. The heavy emphasis on information flux means that the interconnections throughout the network are best represented by the third panel in Figure 5.1. The success of these applications to illuminating puzzles that arise from observations of natural phenomena having complicated dynamics, has begun to convince scientists that information flux may indeed be the fundamental process at the bottom of living matter, and further, when used for educational purposes these techniques display such impressive explanatory powers, that simulations of real events have begun to replace the world they represent. I have already referred to Dawkins replacing the historical mechanism of evolution with his computer program, and concluding from its illustrative clarity that it confirms the random mutation mechanism of evolution.

Although a copy is usually understood to be a direct replica of the object copied, a computer simulation is much more. Simulations belong to a virtual world. They are composed of fleeting, not long-lasting, energies. The output that displays a simulation is energy, say dots of light on a screen. But two-dimensional parches of colour have no logical relation to the real pinball game of the amusement arcade. Even prior to the output stage there is already a disconnect from the physical world, since any computer program is itself a simulation, though it may not look like one except to a trained programmer. Because there is a series of translations from simulation into simulation between initial input and final output on the screen, there are several exit and re-entry points, each one using a fresh impulse of electricity supplied by the plug in the wall. With each new translation, the version of the copy is one step further removed from the world represented by the input. The gaps between them in turn allows for the flow of time during a simulation run to be arbitrary and open to interference. There is a universe of difference between using muscle power to try to control the roll of the ball and hitting the pause button.

Little wonder then, that many commentators believe that the processing of information does not obey physical laws, and in fact has the power to produce results which are impossibilities in that world – a potent resource for the exploitation of consumer entertainment. Although simulations were originally used as a means of solving intractable problems in the real world, especially problems involving lengthy mathematical calculations, it is evident that such a restriction is not necessary – or even not desirable in the case of creating exciting new games. Because code is written according to rules rather than laws, the possibilities, or perhaps better said, the impossibilities, become almost limitless. By way of illustration here, let’s step a few paces back to our simpler scenario of a real-world event and rewrite the code for describing what unfolds during the collision between two balls. From “Forks in the Road” we have the outcomes of three real situations expressed in algebraic code:

either $u \rightarrow 0$ and $v \rightarrow u$
or $u \rightarrow u$ and $v \rightarrow 2u$
or $u \rightarrow -u$ and $v \rightarrow 0$.

But we could construct a game based on the rules:

either $u \rightarrow -u/2$ and $v \rightarrow u/2$
or $u \rightarrow u/2$ and $v \rightarrow u/2$
or $u \rightarrow -u/2$ and $v \rightarrow -u/2$.

where the speeds of the balls after the collision are evenly split between them. The first program describes the real world but the second is imaginary. Games can be readily designed that do not obey the laws governing collisions – just think of the number of good guys who jump back into action after colliding with a hail of bullets. We could be forgiven for believing that the virtual world is free of the restrictions that apply to the world we know from observation and measurement – the world we like to call objective reality. Such impressive powers could even lead us to the conclusion, that real reality is just a subclass of virtual reality.

In IBM's highly publicised Blue Gene Project, which we discussed at the beginning of the story in Chapter 2 of TLP, "Natural or Man-made", we have an example par excellence of such an approach being applied to the physical world. A complicated series of collisions governed by virtual forces between atoms will, it's claimed, reveal the secret of protein folding. In the first step, the problem is translated into a series of symbols and ciphers of the world of mathematical equations from the field of statistical thermodynamics, and in the second this simulation is further translated into the symbols and ciphers of computer language. The virtual protein that results from this process is thus a simulation of simulations, which is then checked against known proteins derived from laboratory observations. The computer program is then rerun with adjustments aimed at producing a better fit to the observations. The fact that by using this procedure the virtual world can create copies of the real world as faithfully as desired, is proof indeed that you get out what you put in. With Page's claim already mentioned in "The Missing Bit", that success in building a conscious machine is only a matter of sufficiently powerful computation, the ability of information science to explain all levels of biology now seems to be complete. The Blue Gene Project explains proteins at the bottom, Dawkins' random mutation program explains the meso level edifice of evolution, and finally at the top, the awesome power of parallel computing promises to reveal the secrets of how we produce out thoughts.

But all this effort is aimed at producing copies, and copies, however true they may be, do not deliver theoretical understanding. The creative ingredient in those spectacular simulations we all admire derives from a different source – the programmer's brain. We do not know the number of layers of machinery within this biological computer, and we have so far no clue as to the decoding/encoding rules used to run it, though one thing is certain, they do obey natural laws. That Beethoven's brain needed glucose to compose the Moonlight Sonata reminds us here again, that these layered machines are fuelled by energetic changes, including chemical, cellular, physiological, psychological – the rules of which are not of our making. Of course he used the musical code of his tradition as output, and that is what commands out attention. But that output was the result of energy flows, which we like to call artistic composition rather than artistic computation. So in the final analysis, natural laws do underpin the rules used in man-made simulations – not the other way round. To claim that the abstract rules of code are fundamental to natural laws is to forget, ignore, or dismiss the role of the mind.

9. The Canyon and the Abyss

In 1637, Descartes set the record straight for us when he famously proclaimed, “I think therefore I am”. With this he stated his oft quoted solution to the mind/body problem – mind first, body second. His duality cemented a general view that mind and body belong to different worlds, although he proposed that they do connect, or interact, in the brains of humans (actually, in the small pineal gland, which he mistakenly thought was unique to humans). Descartes is one of the fathers of modern science, so it is a strange legacy to find that his overriding conclusion placed mind beyond the realm of scientific investigation. The first tentative steps in an understanding of the scientific method were only just being taken in his time, so perhaps it was more the force of the established logic of the learned, rather than a new experimental approach, that convinced him of the duality. Logical argument led to this view of his own being, but it is doubtful that he would also have proclaimed, “I think therefore you are”, or “I think therefore it is”, because “you” and “it” belonged to the world around him. Or put another way – Descartes, the great humanist, was certainly in favour of investigating nature – the “you” and the “it” – but at the same time, logic dictated that the question of his own being was not a scientific one.

In any case, it is clear that mind and body are made of different material. The body is water and protein, while the stuff of mind, or mental matter, as we called it earlier, suggests notions like feelings, spirit, or even an immortal soul for some people, which describe things endowed with special other-worldly qualities – they seem flighty, abstract and immaterial. And further, there seems to be a great variety and individual uniquenesses of such qualities, much more than we see in physical objects. Feelings do not seem to be related to colours, nor colours to sounds, nor sounds to ideas. Such entities seem to defy even the possibility of scientific investigation, as though their world lies separated from biology on the north side of the abyss illustrated above in Chapter 1, “Quick Review”.

The picture emerging here is reminiscent of that other divide represented by the canyon separating the living from the non-living in the very first chapter of TLP, “Two Views” where our story began. Readers educated in the sciences will feel comfortable with southern side of the new landscape, since it is firmly grounded on the field of biology. There are few philosophical problems arising here, as we track safely north from the cell to the brain. And although it may fill some of us with awe, the secrets of the brain are not considered to be impenetrable to science. It contains about one trillion cells, of which around 20% are the neurons – the nerve cells that carry the electrical pulses, while the function of the remaining majority, the glial cells, is still unknown. Nevertheless, the wealth of experimental information on the massive assembly of neuronal connections continues to grow daily. Brain physiologists tell us of ganglia, nuclei, control centers, and the overall structure comprising the old brain stem, mid brain with the newer cortex on top. In all parts there are stacks of maps of the whole organism, each map receiving from and responding to its allotted bodily function. Researchers have identified which of these centers spring into electrical activity in response to certain stimulation, forming dynamic three-dimensional representations of bodily sensations – flickering patterns resembling an abstract movie, in which the changing scenes depict what is happening to the real-world body. With improved brain-imaging techniques, neurophysiologists will soon be able to see which centers light up when a child answers “two plus two equals four”, finally demonstrating the biological basis of thought. Thus we encounter no obstacles along the road from single cell, the unit of life, to the all-powerful organ of sensation, the brain. The logical flow seems evident. Engineers say the purpose of thermostats is to sense temperature – they call such devices “sensors”. Entomologists say ants can sense when rain is coming – they call it “instinct”. By extension, the brains of humans create sensations derived from massive amounts of filtered and processed information bombarding us from our environment – we call it “mind”.

But psychologists don’t think in this way at all. They use terms like feelings, emotions, motives, rewards, experiences. By sensations they mean quite a different category of concepts, including say, privately felt pleasure, communal grief and personal pain – mental objects that are far removed indeed from nerve cells and the lobes of the frontal cortex. For the thinkers of ancient Greece, philosophy stood at the northern end of the road as the highest achievement of the mind. (I grant that on this point many readers will think otherwise, so please pick your favourite sphere of human creativity to put here at the apex). Plato’s pure ideals – the good, the true and the beautiful – seem even more remote from biology than the subject matter of experimental psychology. Tracking south from these lofty heights we come to the sensations of the psychologists, which we naturally expect must connect logically to the sensations of the physiologists. But instead of the two dovetailing together, we are confronted by the abyss. There is no bridge connecting the perceived colour of red southward over to the electrical activity of neurons – we can be fully aware of viewing the red sunset, but we are blissfully unaware of the visual cortex producing this wonderful display.

In addition to the traditional fields of study embracing biology and psychology, a third has recently emerged – a tough new kid on the block. Over the last couple of decades the popularity of a modern, hard-line, materialist view of mind has won over increasing numbers of supporters. Interested readers can trace this thread through the series of meetings known as the Tucson Conferences on Consciousness (for an academic slant), or by following the immense body of literature on artificial intelligence, which covers the entire spectrum from popular sci-fi paperbacks to specialist journals. Artificial intelligence (AI) indeed presents us with a beguiling explanation of consciousness, that has its roots in the explosion of successes in IT, including the construction of computers which appear to possess human, and even superhuman, intellectual powers. According to IT theory, mental abilities can be created by computation, that is, through the step-by-step rearrangement of objects (in computers these objects are electric charges) following rules of moves set down in code. As covered in the previous chapter, “Symbols, Ciphers, Switches and Re-entry”, this approach identifies mental processes with the same processes that produce computer generated simulations of physical events.

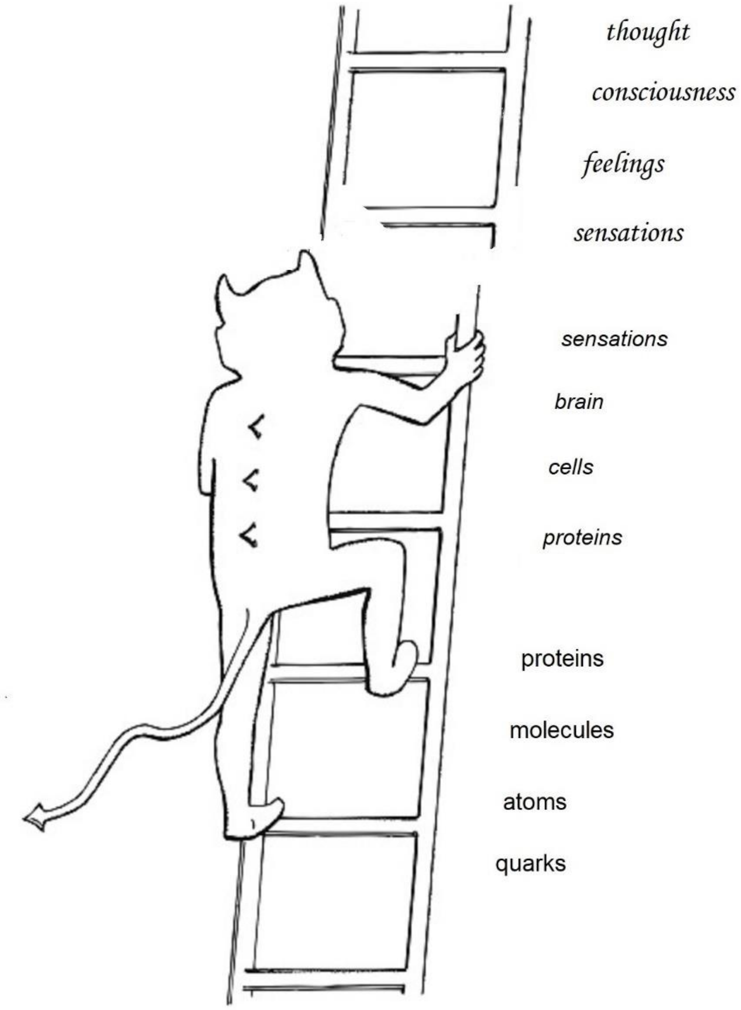


Figure 9.1 The Vertical Ladder from Matter to Mind

Here we revisit the vertical ladder of the first illustration in Part 2, The Pixel Machine. There the demon climbs unobstructed from rung to rung up the energy landscape from quarks to thought. Now we incorporate the break to illustrate, what is commonly called, “the mind-body problem”, shown here between the sensation we are unaware of and those we aware of, representing the abyss pictured in Figure 1.1. As was the challenge with the proteins that straddle across the canyon from the non-living to the living, our search now is for the contents of the abyss that hopefully forms the bridge. Speaking to the diagram, is there a built-in extension of the ladder that joins the upper onto the lower rungs, or is the break permanent since the upper rungs constitute a separate unconnected ladder? In this case, the abyss is bottomless, populated by circular arguments beyond the realm of science forever seeking knowledge of knowing.

Accordingly, now there is no gap to be bridged. The road follows uninterrupted from transistors to consciousness – in this scenario, nerve cells are not even needed because the result is obtainable through non-biological means. Additionally, the authoritative Crick has proposed a clear reductionist theory in his article with Clark, "The Astonishing Hypothesis" (4), that the workings of the mind are to be identified with biochemical reactions in brain cells. As this claim amounts to the same materialist interpretation, only with a biological perspective, it is in essence a marriage of the physiological and computing approaches. So what we have here is a "new reductionism" – a modern form of the old reducto-determinist philosophy that saw the random events of thermodynamics and natural selection underpinning the entire length of the original road from fundamental particles to living matter in "Two Views".

In new reductionism, we have a train of pulses circulating through networks, either living or non-living, as the universal basis of consciousness. It gives us a smooth uninterrupted ride up the road from cells to thought, as illustrated here as the new extended ladder in Figure 9.1.

I'll personify this approach with the initials "TR", for "Turing's Robot". And to see just how tough this new kid is, we need only remember that, since 1950 when Turing set out his famous intelligence test in the article "Computing machinery and intelligence", TR has stirred the imaginations of philosophers, physicists, communication engineers, and anyone interested in the workings of the brain to this day. I gather from meetings such as the Tucson Conferences that Turing's proposal has moved on from a test for intelligence to a test for consciousness, which is not the same thing, though perhaps more interesting. In essence the test is quite simple: suppose there is an agency hidden from view in the next room. An intermediary feeds it your questions and delivers back to you its answers. If you cannot distinguish your conversation from one you may have with your clever friends, then you must conclude that the agency is intelligent – or as we would say today, conscious. Indeed, it may even be one of those friends. So TR is not a zombie. TR can think, or so it is claimed (for a thorough defence of this reductionism see Dennett's book "Consciousness Explained" (5)). But we will see that, at bottom, TR is nothing more than a highly complex program run on a supercomputer and cannot avoid the same problem as that which was faced by a simple program run on any computer. And as highlighted at the end of the previous chapter, the real elephant in the room is the programmer's human mind.

Appendix 1.

Energies Change Levels

When two elastic particles, masses, m_1 and m_2, and velocities, u_1 and u_2, collide, they rebound according to the laws of conservation of energy and momentum. We begin using the ideal model of two billiard balls, which is the favourite scenario of physics texts illustrated in Fig 1. Their velocities of rebound are given by

$$v_1 = v - m_2 d, \qquad \text{and} \qquad v_2 = v + m_1 d,$$

where v is the average velocity

$$v = (m_1 u_1 + m_2 u_2) / (m_1 + m_2)$$

and d is the difference

$$d = (u_1 - u_2) / (m_1 + m_2)$$

Their combined kinetic energy is given by

$$KE = m_1 u_1^2/2 + m_2 u_2^2/2 = m_1 v_1^2/2 + m_2 v_2^2/2$$

$$= (m_1 + m_2) v^2/2 + (m_1 + m_2) m_1 m_2 d^2/2$$

$$= E + D$$

This result describes the ideal case of a collision of perfectly elastic balls. In real events, the kinetic energy is not conserved, and KE after the collision is given by E, but some or all of the portion D is lost as heat.

If their velocities are observed in a frame of reference such that the initial momenta, $M_1 = m_1 u_1$ and $M_2 = m_2 u_2$, are equal and opposite, $M = M_1 = - M_2$, then their average velocity v is zero, so the portion of KE given by the term E also equals zero, and all the energy of motion is given by the term, D. In this case, each reflects off the other by simply reversing their velocities, $v_1 = -u_1$ and $v_2 = -u_2$. If however the particles fuse together, the resulting larger particle of combined mass (m_1+m_2) stops moving and the total KE, equal to D, is transferred down into frictional molecular motion that generates the heat.

In the reverse scenario, when a particle splits into two smaller particles as a result of a sudden release of internal chemical energy, the fragments fly apart with equal and opposite momenta. Here, the energy released in the explosion is set equal to D, representing the sum of their separate kinetic energies

$$KE = m_1v_1^2/2 + m_2v_2^2/2.$$

We notice that their motion can be viewed as equivalent to that after the elastic collision described above, where the rebound reverses the momentum of each particle. Moving the factor 2 to the left-hand side, we write for the total energy of motion

$$2KE = M_1u_1 + M_2u_2 = -M_1v_1 - M_2v_2$$

$$= M (u_1 – u_2) = -M (v_1 – v_2)$$

Where v_1 and v_2 represent the velocities after an elastic collision or after an explosive event. This simple analysis shows that, in the case of a collision, the initial kinetic energy is transferred to the chemical bonds linking the atoms which constitute the material of the balls. Describing the transfer in more detail we can say, that the kinetic energy of ball 1 continues on after impact into the material of ball 2, and similarly for the transfer from ball 2 into ball 1. These waves of energy, resulting from the sum of quantum sized vibrational bond energies, reflect off the boundaries of the balls and return to become kinetic energies of the original balls again, in so doing giving rise to the reciprocal repulsive forces exerted on one another at the point of contact. This explains why the second phase of the collision is equivalent to an explosive release of energy originating from internal chemical bonds which projects the balls in opposite directions.

The diagram in Fig 2 illustrates how the kinetic energy of the faster smaller particle, ball 1, is carried on into the slower bigger particle, ball 2, and vice versa. As a result, the energy density within the combined particle at the moment of impact becomes uniform. These transfers are implied in Equ , in which we see the overall energy D, spread across the combined mass (m_1+m_2), is given by the expression for the energy density

$$2D/(m_1+m_2) = m_1m_2d^2$$

from which the fraction in ball 1

$$m_1(m_1m_2d^2) = m_2u_2^2$$

and the fraction in ball 2

$$m_2(m_1m_2d^2) = m_1u_1^2$$

are the kinetic energies delivered by ball 2 and ball 1 respectively to the combined mass (m_1+m_2).

So far, we have assumed that the particles are balls of the same material, and therefore their masses correspond to their sizes. Next we consider particles made of materials of different densities, for example, let's say ball 2 is denser than ball 1. In this case, the comparative sizes do not indicate masses. However the dynamics are the same, although now the event can be described as, the faster lighter particle colliding with the slower heavier particle, without specifying sizes.

In the introductory example of Fig1, the greater energy of the faster particle was absorbed by the greater number of bonds in the larger slower particle on impact, and vice versa. Here in the second example, the lesser number of internal chemical bonds in the heavier particle must now absorb the equivalent amount as in the first example, in order to result in the uniform energy density, which carries the pressure wave across their point of contact. This is achieved because the bonds between heavier atoms in the smaller particle experience vibrations (oscillations, librations) governed by greater spring constants. Their bonds are tighter and stronger, than those in the original material of the bigger faster particle, which means that they require more energy to move to higher vibrational modes. In technical language, they absorb additional and/or larger quanta released in the collision to populate their excited states.

We have now arrived at a more general picture of how kinetic energy is shared between two colliding particles. In the next section, we will extend the picture to include interactions of a broader nature.

References

1. M Gell-Mann. “The Quark and the Jaguar” Little, Brown and Co, London (1994).
   R P Feynman. “QED” Penguin Books, London (1990).

2. A G Cairns-Smith. “Seven Clues to the Origin of Life” CUP, Cambridge (1985).

3. H P Yockey. “Information Theory, Evolution and the Origin of Life” CUP, Cambridge (2005).
   G J Chaitin. “Algorithmic Information Theory” fourth printing, Cambridge University Press (1992).
   L E Page. address to AAAS, SanFrancisco (2007).

4. F Crick. “The Astonishing Hypothesis” Macmillian International, New York (1994).

5. D C Dennett. Consciousness Explained, Little, Brown Co. (1991).