PART 3

The Evolution

of

Evolution
A manager that is in full control of an organisation has the potential to establish a wide range of cooperative activities. In principle, such a manager is capable of putting together any pattern of cooperative specialisation and division of labour. But what particular cooperative activities should it organise? Of all the alternatives the manager could support, how does it discover those that are best for itself and the organisation? Unless the manager is able to discover the most productive forms of cooperation, it will not be able to fully exploit the benefits of cooperation. It is not enough that a manager is able to organise cooperation. It must also be smart. It must be able to discover the cooperation that is best.

Early cells, the first multicellular organisms, and human tribes all had the potential to construct an enormous variety of cooperative relationships between their members. But they had to discover those that were best, and adapt them as circumstances changed. And this did not come easily. Millions of years passed before the cells within multicellular organisms discovered how to specialise and cooperate to form an effective eye. Many more millions of years passed before the cells discovered how to cooperate to produce the complex brain found in humans and other mammals. And it was a long time before humans discovered how to cooperate together to build nuclear power stations, and to send people to the moon.

Organisations that are superior at discovering new and better cooperative adaptations amongst their members will have an evolutionary advantage. Their greater evolvability will enable them to exploit more effectively the immense potential benefits of cooperation. In turn, these benefits will reward improvements in evolvability. So the potential benefits of cooperation drive more than just the evolution of managed organisations of greater and greater scale. The benefits will also drive the evolution of managed organisations that are better at evolving. As evolution unfolds, living processes will get better at evolving, smarter at searching out the best ways to cooperate, and more innovative and creative at adapting their cooperation as conditions change1.
In the next four Chapters, we will look at how evolution has progressively improved the adaptability and evolvability of living processes on this planet, and how it will continue to do so in the future. We will see that the existence of this progressive sequence of improvements raises significant questions for each of us: as individuals, where are we located in the evolutionary sequence? How much room for improvement is there in our adaptability and evolvability? Will we need new psychological capacities if we are to evolve in whatever directions are necessary for us to contribute to the future evolution of life in the universe? Can our knowledge of the direction in which evolvability improves point to how we must evolve psychologically if we are to contribute to future evolution?

The existence of an evolutionary progression in evolvability also raises important questions for humanity as a whole: how much room for improvement is there in the evolvability of human society? How could the evolvability of human society be enhanced? How could we improve the ability of our systems of government to search out new and better ways to manage our societies? Multicellular organisms eventually evolved brains and nervous systems that are far superior at adapting and evolving than the individual cells that form them. Must human society do the same? Must our societies evolve supra-individual adaptive processes that will be far smarter than the humans they contain? If so, how can we construct these supra-individual adaptive processes?

We will see that an understanding of the direction in which evolvability evolves is critically important for future human evolution. Such an understanding will enable us to locate ourselves within the evolutionary sequence and to see what improvements in our adaptive capacities will be necessary in the future. It will point to what we have to do to improve our evolvability, as individuals and collectively. Becoming aware of the direction in which evolvability improves is an important step in the evolution of improved evolvability.

We will begin by looking in detail at how evolvability has improved during the past evolution of life. But before we start to trace this evolutionary sequence, we need first to develop a thorough understanding of the basic process that is used by living things to evolve and discover new adaptations. This will help us to see how the simplest version of the process could be progressively improved by evolution.

The principle that underlies this basic adaptive process is surprisingly simple. Living processes search for better adaptation by trying out changes. These changes can be made within the organism during its life, or in its offspring. The usefulness of the changes is tested by evaluating their effects on the organism in which the change is made. So better adaptation is discovered by trying out changes and then testing their effects to see whether or not they improve adaptation. Trial-and-error is at the heart of the basic adaptive process.

Importantly, this ‘change-and-test’ process can work well even if it does not use any intelligence to decide the changes that are to be tested. The basic process can discover complex adaptations even if the changes that are tested are chosen randomly. It is the testing that sorts through these changes and discovers any that are better. Even if the changes are made randomly, some may be improvements, and these will be discovered when the changes are put to the test. Without any knowledge or insight into what might improve adaptation, a change-and-test process can discover better adaptations.

A number of examples will show how powerful this simple change-and-test process can be, and how widespread it is in living organisms. We will see that it is not only the basis of evolutionary mechanisms that discover adaptations and pass them from generation to generation. It also underpins physiological and other non-evolutionary adaptive systems that adapt organisms or groups of organisms only during their life, and do not produce change across the generations.

The genetic evolutionary mechanism itself is one of the simplest examples. In genetic evolution, changes are generated when an organism produces offspring. The offspring generally vary in a small number of ways from their parents and from each other due to genetic changes. The genetic changes are tested by their effects on the offspring that carry them. If a change causes its carrier to do better, the carrier will produce more offspring, and the numbers of individuals who carry the change will increase in the population. Eventually, all members of the population will carry the change, and it will be established as an adaptation. The genetic evolutionary mechanism will have discovered a better adaptation. When the environment changes, a different change might then do better. Once the new change has spread throughout the population, the mechanism will have discovered a better adaptation to the new conditions.

For an example, consider a hypothetical population of snow hares. The genetic evolutionary mechanism
will tend to produce hares that have the thickness and length of fur that is best for the environmental
temperatures met by the population. It will do this by trying out offspring with a variety of types of fur.
Those with fur that is best suited to the conditions will be the most competitive. But if temperatures
change significantly, offspring with different fur will do better. The length and thickness of fur in the
population will change as the conditions met by the population change. In this way, the genetic evolutionary
mechanism will adapt the type of fur in the population to track changes in environmental temperatures.

In contrast to genetic adaptation, individual organisms adapt physiologically by trying out changes
within their bodies during their life. The changes are tested on the basis of whether or not they produce
a useful effect within the organism. For example, warm-blooded organisms use such a process to discover
adaptations that keep their body temperatures constant despite changes in their environment. The animal
tries out changes that influence the amount of heat produced within the organism, and the rate at which
this heat is lost to the environment. It might change its metabolic rate, its level of movement and other
general activity, the amount of its food intake, its posture, its rate of panting and sweating, the amount of
blood flowing to its extremities, and the extent to which its hair or feathers are raised and lowered. The
animal does not know in advance what pattern of changes are needed to maintain its temperature at the
best level in the face of change in its external environment. This pattern is discovered by trial-and-error,
by testing changes against their effects on the animal’s temperature. In this way, patterns of adaptive
change are made within the animal during its life to track changes in external temperatures.

Some animals are also able to adapt to varying external temperatures by trying out changes in behaviours
that can affect heat gain or loss. The animal may move in or out of the sun and change its skin colour in
the search for changes that will help maintain the desired temperature. Humans may try out different
types and amounts of clothing to adapt to changes in temperature. Many animals also use simple change-
and-test mechanisms for other adaptive challenges. Most complex multicellular organisms are able to
use change-and-test processes to adapt other aspects of their behaviour, and to discover new behaviours
that are better at meeting their adaptive goals.

Societies of humans and other animals also adapt using variants of the basic change-and-test process.
A colony of honeybees can maintain the temperature of its nursery around 34 degrees C (93 degrees F)
despite large changes in temperature outside the hive. This is the best temperature for hatching eggs and
rearing young. Bees can increase the temperature of the nursery by clustering more tightly around it,
raising the rate at which they metabolise sugars, and by flexing their muscles more often. They can
reduce the temperature by fanning their wings to improve the ventilation of the hive, and by increasing
the amount of water that is evaporated within the hive. Nothing in the hive knows the particular pattern
of these behaviours that will maintain the temperature of the nursery at the ideal. The pattern that will
maintain the best temperature is discovered by testing changes in these behaviours against their effects
on the temperature in the nursery.

Human economic markets are an example of a process within human societies that uses a basic change-
and-test mechanism to achieve adaptation. For example, markets can adapt the level of production of
particular goods to the needs and preferences of consumers. If insufficient goods of a certain type are
being produced, manufacturers who increase production will be rewarded with higher profitability. This
mechanism will increase production even if individual manufacturers are completely unaware that there
is an emerging shortage of the product, or have no idea what is causing it. It will work even if manufacturers
use only simple trial-and-error to decide their level of production. In this way, an economic market can
adapt the level of production of warm clothing to track changes in demand as environmental temperatures
vary over a series of winters.

These examples can also help us to see how the basic change-and-test process can be combined with
more complex arrangements to improve the ability of the process to discover adaptations. The basic
process searches for adaptation by trying out changes. It can discover improvements even if the changes
are chosen randomly. But the search will be more efficient if the changes are chosen so that they have a
better than random chance of proving adaptive. Change-and-test processes will do better if the changes
they try out are non-random and are instead targeted at the types of changes that are likely to prove
adaptively useful.

So the genetic evolutionary mechanism will be more effective if the genetic changes that are tested are
non-random, and instead are more likely to be adaptive. We will see in the next Chapter that evolution
has indeed established genetic systems that produce targeted genetic changes. And the physiological systems that adapt warm-blooded animals to differing external temperatures do not test out random changes within the organism. In high temperatures they test out changes that will cool the animal and reduce its internal production of heat. In low temperatures they test changes targeted at doing the opposite. The same is the case for the changes that are tested within beehives in the search for adaptation to varying external temperatures. They still use trial-and-error to discover the best pattern of changes, but do so far more efficiently by targeting the changes.

In some cases the arrangements that target physiological changes are established by the genetic evolutionary mechanism. Genes that cause physiological systems to target changes will do better than alternative genes that do not. But targeting can also be established by learning within the organism. If an organism discovers by trial-and-error that a behaviour pays off in particular circumstances, it will do better if it can learn to immediately try out this behaviour whenever the circumstances arise again. Learning avoids the repetition of costly trial-and-error. The behaviour of young animals generally includes a high level of trial-and-error until they learn to target their behaviour more accurately at their particular adaptive goals.

The change-and-test process can be targeted even more accurately if the organism is able to form mental representations or models of itself and of its environment, and is able to test possible changes against these models mentally, before trying them out in practice. Instead of using the change-and-test process to try out actual changes in the real world, possible adaptive changes are first tried out mentally.

On this planet, we humans have the most highly developed capacity to search for adaptations using mental processes. In some circumstances our modelling capacity is so effective that it can completely eliminate the need for external trial-and-error. When our mental model of a situation can accurately predict the consequences of our alternative acts, we can mentally design an action that will directly achieve our adaptive goal. We then simply implement the changes that we see will achieve our goal. No external change-and-test process is necessary.

When we set out to solve an adaptive problem, it is these mental modelling processes that we are conscious of using. When we plan how we are going to cook our evening meal, think about how to fix a car engine, or imagine what we might have to do to improve our career prospects, we are using mental representations to come up with behaviours that will achieve our adaptive goals.

In contrast, we are not conscious of the simpler change-and-test processes that are continually adapting our bodies and internal organs to variations in temperature and to changes in the availability and usage of food, water and oxygen. We continually experience our mental processes, but have no experience of the workings of these other adaptive mechanisms in our bodies. When we think of how we might solve an adaptive problem, we tend to think of the mental processes we could use.

As a result, we do not have a good mental feel for how change-and-test processes in other living processes successfully solve complex adaptive problems without the use of mental modelling. We find it hard to see how the genetic evolutionary mechanism, physiological systems in other animals, and the adaptive processes in economic markets and insect societies can discover and establish complex adaptation without using the mental processes we associate with intelligence.

This blind spot in our understanding of adaptive processes has been particularly limiting when we have set out to design and adapt our economic and other social systems. We have a tendency to think that these complex systems can be best designed and adapted by the use of human intelligence. We think that if we collect enough information about the system, we can understand it sufficiently to decide the course of action needed to produce the result we want. However, we can rarely have sufficient information about complex and rapidly changing systems to make them predictable enough for us to adapt them in this way. The experience of centrally-planned economies has made this increasingly clear in recent years. Attempts to use central planning to match production levels to the needs of consumers have been spectaculaarily unsuccessful.

The alternative is to produce economic and other social systems that include their own adaptive change-and-test processes. An example is the economic market that we briefly considered earlier. A market system uses change-and-test processes to adapt production to match the needs and preferences of consumers. Such a process will be more effective if it can take advantage of the mental capacities of the participants in the system to better target the changes that are tested. But ultimately it is the systemic
change-and-test process that adapts the system. And such a process can work even if the mental modelling used by participants to target their behaviour is ineffective. We will return to these issues when we consider in detail the future evolution of human societies.

Armed with this broad understanding of the nature of the basic process that living things use to evolve and adapt, we will trace the evolution of the evolvability of living things on this planet. Over the next four Chapters we will see how the potential benefits of cooperation have driven an impressive sequence of improvements in these abilities, and how this progressive evolution can be expected to continue into the future.

We begin in Chapter 9 by looking at how living processes evolved before genetic systems emerged. We will see how autocatalytic sets could evolve without genes, and how their evolvability could improve. Then we will move on to consider the evolution of the genetic system itself. We will look in detail at the evolution of the evolvability of genetic systems. We will see how natural selection has improved the ability of genetic systems to discover adaptations. Genetic systems produce a pattern of mutations and other genetic changes that is far from random. The pattern is biased toward changes that are more likely to produce useful adaptation.

But genetic systems do not adapt organisms during their life. Genetic systems cannot discover adaptations by trying out genetic changes within individual organisms. New adaptive processes have had to evolve to adapt individuals. Our physiological, emotional and mental adaptive systems are examples of what evolution has produced to fill this vacuum. In Chapter 10 we trace in detail the progressive evolution of the internal mechanisms that adapt and evolve individual organisms during their life.

In humans, the internal adaptive processes are now evolutionary mechanisms in their own right—through language, discoveries made by our adaptive processes are passed and accumulated from generation to generation. In Chapters 11 and 12 we will look at how these internal adaptive processes are evolving in humans at present, and how they are likely to continue to evolve in the future. We will see how we must improve our evolvability by developing new psychological skills if we are to contribute to the future evolution of life in the universe.
How smart at evolving are autocatalytic sets? How good are they at discovering new adaptations and passing them on from generation to generation? Does evolution tune and hone the evolvability of autocatalytic sets?

We have seen that an autocatalytic set is a group of proteins in a watery environment that collectively reproduces itself. Each protein catalyses (manages) reactions that lead to the formation of other members of the set. Collectively this produces a proto metabolism in which other molecules (food) are managed by the proteins to reproduce the set.

But autocatalytic sets of proteins do not contain genes. How can sets evolve? How can the members of the set discover better ways to cooperate with the other members, and adapt their cooperation as the internal and external environment of the set changes? How can they do this in ways that will be passed on from generation to generation of sets, producing evolutionary adaptation?

Autocatalytic sets are able to reproduce in some circumstances. This is because they become more likely to break up into smaller sets as they increase in size. The new sets that are produced in this way will compete with each other for the food and other matter that they need for their survival and reproduction. If a change arises within a set, the changed set may prove to be more competitive than others. A changed set that does better will grow in size faster, reproduce more frequently, and tend to take over the population of sets. As a result, a change that makes a set more competitive will be established as an adaptation possessed by all members of the population. In this way, natural selection operating between sets will test the effectiveness of any change that arises within a set.

But evolution can occur in this way only if changes arise within sets, and if the changes can be passed on from generation to generation. How can changes of this type arise?

Perhaps the simplest way is if different parts of a particular set become physically separated, and if the parts happen by chance to contain different components. Any part which contains members that can
reproduce collectively as an autocatalytic set will be able to survive and reproduce as a separate member of the population. If the ways in which a set differs from its parent make it more competitive, it can take over the population, producing a population of adapted sets.

It is conceivable that this simple change-and-test process could even evolve sets that are better at evolving. For example, consider what will happen if sets differ in their tendency to separate into parts. If a set has a tendency to separate into different parts too readily and too often, it risks breaking up effective arrangements and producing daughter sets that are not competitive. Alternatively, if a set never separates into parts that are different, it will not evolve. It risks being out-competed by those that do. Sets that balance these tendencies will be better at evolving, and will be favoured by evolution. All change-and-test mechanisms face this particular dilemma. They must strike a balance between preserving their accumulated discoveries by minimising changes, and boosting the search for new improvements by trying out changes more often. Finding the best balance between conservation and change is an old evolutionary problem.

Nevertheless this simple change-and-test process is very limited in its ability to explore the evolutionary potential of autocatalytic sets. It cannot produce a set that has new members that were not also members of the parental set. It is limited to trying out different combinations of the same members. It cannot discover a new protein that might contribute more to the efficient operation of the set than existing members.

However, there is another change-and-test process that enables new members to be tried out in an existing set. A new protein molecule may form by chance within a set. This might happen through the chance interaction of particular molecules that come together in the right positions and under the right conditions to form the protein molecule. Alternatively, a number of molecules of one or more new proteins might drift into the area occupied by the set. If these new proteins are then reproduced as part of the set, and if they improve its competitiveness, adaptive evolutionary change will have been achieved.

But the ability of this process to test out all the types of proteins that could possibly improve the competitiveness of the set is strictly limited. It can try out only those proteins that, when added to the set, will be reproduced as part of the set on an on-going basis. If a new protein arises in the set by chance, or if it drifts into the set, it will not survive for long unless its formation is catalysed by the set. For a new protein that is not already reproduced by the set, this will occur only in exceptional circumstances. It will occur only if the addition of the new protein to the set causes changes that result in the new protein being reproduced by the set. The catalytic activity of the new protein must set off changes in the set that eventually result in the formation of the new protein within the set.

This is a very restrictive condition. But only proteins that meet this narrow requirement can be tried out and established by this evolutionary mechanism. If a protein does not meet this condition, it cannot be discovered by the mechanism, no matter how much it might improve the competitiveness of the set. Of course, this is an instance of the barrier to the evolution of cooperation that we looked at earlier. The barrier limits the extent to which an evolutionary process is able to exploit the benefits of cooperative organisation. There is a close connection between this barrier and evolvability. All instances of the barrier can be seen as a limitation in the ability of the relevant evolutionary mechanism to discover useful cooperation. And the emergence of managed cooperative organisation and other arrangements that overcome the barrier can therefore be seen as improvements in evolvability.

The limited ability of autocatalytic sets to discover new proteins was overcome once RNA began to manage autocatalytic sets to form proto cells. The RNA had the ability to cause the formation of proteins that were not reproduced by the autocatalytic set itself. It could therefore try out proteins that could not be tried out by an autocatalytic set alone. RNA could discover and reproduce proteins that would improve the competitiveness of the proto cell, but would not be reproduced by the set in the absence of the RNA.

RNA was particularly suited to searching systematically through the great range of new possibilities that were opened up. Each RNA molecule includes a long sequence of four basic units. Each sequence of units will produce a different sequence of the basic units that make up proteins. So a different protein could be tried simply by a change in the sequence of the basic units in the RNA. Importantly, mutations that change these sequences do not alter the basic character of the RNA molecule, and do not interfere with its ability to reproduce. So there were no limits to the types of proteins that could be tried out by RNA management. Not only did RNA have the ability to produce new proteins, it also had the ability to
try out changes easily and systematically in each of the proteins that it produced. The result was a significant advance in evolvability.

The great evolvability of RNA meant that there was advantage in RNA eventually taking over the production of all proteins within the proto cell. Its greater evolvability could be used to search systematically for adaptive improvements in each protein that it produced. But RNA had to proliferate within the protocell if it were to be able to take over the production and evolution of all proteins. This could not occur immediately. It could take place only once arrangements were developed to suppress destructive competition between the various RNA molecules that produced the different proteins. Until the suppression arrangements we discussed in Chapter 6 were in place, the proliferation of RNA in the cell would have produced only destructive competition.

But the suppression of competition between RNA molecules meant that no evolutionary change-and-test mechanism involving RNA could operate within the cell. If it were to operate, alternative RNA molecules would have to be produced and tested within the cell. RNA molecules would have to mutate, reproduce and compete within the cell. But the suppression arrangements would prevent this from occurring. Competition, and therefore evolution, was prevented within the cell. Instead, mutated RNA molecules could compete only through competition between the cells that contained them. If a mutated RNA molecule improved the competitive ability of the cell that contained it, the cell and the molecule could breed up and take over the population of cells. The change-and-test process operated only at the level of the cell. Changes arose in the RNA within cells, but were tested only through competition between cells.

In essence, this is the genetic evolutionary mechanism that produces evolution in all single celled and multicellular organisms. Some of the details have changed: in later cells, DNA took over from RNA as the ultimate level of management. And in multicellular organisms DNA is an internal distributed manager rather than an external manager as in cells. But the evolutionary mechanism is essentially the same in all these cases despite the differences: competition between mutations is suppressed within the organism during its life, and mutations are tested by competition between organisms.

In the remainder of this Chapter, we will take a close look at the evolvability of the genetic evolutionary mechanism. We will ask whether evolution has shaped the genetic systems of organisms to increase their ability to discover useful adaptations. Has evolution produced genetic systems that are smarter than if they used only random trial-and-error? A central issue here is whether genetic systems have evolved any capacity to anticipate the future. Do genetic systems target mutations at the types of environmental conditions that are likely to occur in the future? Does the pattern of genetic changes contain a higher proportion of changes that are more likely to match future evolutionary needs?

To see what such an ability might mean in more concrete terms, we return to our hypothetical example of a population of snow hares. The population faces a critical environmental challenge due to temperatures that fluctuate considerably across the generations. If the genetic system of the population could target its genetic changes, it would not produce changes randomly across all the genes of the organism. Instead, it would produce changes that were more likely to pay-off, given the types of environmental challenges faced by the population. It would target its genetic changes towards producing a variety of lengths and thickness of fur, increasing the chances that the population could adapt quickly to fluctuations in temperature. Changes would be made less often to genes in which any change was likely to be harmful, and less often to genes in which changes would not be relevant to likely environmental change.

A central dogma of evolutionary biology is that genetic mutation is blind to future evolutionary possibilities. On this view, genetic mutation is not targeted at all. Whether a genetic change proves to be useful in discovering a new adaptation or in adapting to environmental changes is completely a matter of chance. Mutation is random in relation to future adaptive possibilities.

But this dogma is not based on hard evidence. No biologist has ever gone out and collected the evidence that is needed to test the dogma. To do so thoroughly, a biologist would have to catalogue the genetic variation produced in a population, assess whether it arises randomly across all genes, and, if there is any bias, determine whether the bias is correlated with the adaptive challenges likely to be faced by the population.

Apart from the practical difficulties in gathering this evidence, doing so has not been given a high priority by biologists. Most have considered that there are strong theoretical reasons to accept the dogma
that mutation is blind to adaptive challenges. First: there is no obvious mechanism that would enable
genetic systems to target changes at future adaptive needs. How could the simple processes that produce
mutations ‘know’ anything about future evolutionary possibilities? Second, even though greater
evolvability would be in the long-term interests of a population, it would not evolve unless it was also to
the advantage of the individuals within the species. Smarter populations or species would be able to out-
compete other species by adapting first when the environment changes, or by discovering new and better
adaptations. But it is not enough that evolvability is good for the species. Unless it also continually
benefits the individual genes that produce evolvability, these genes will be out-competed within the
population, and greater evolvability will not evolve9.

The great problem for genes that improve evolvability is that evolvability might not produce benefits
continuously. The population might not encounter significant environmental challenges for many
generations. When it does, any individuals that carry genes for greater evolvability can do better in
evolutionary terms. These individuals are more likely to produce offspring who are better adapted to the
new environmental conditions. But until the environment changes, individuals who carry genes for greater
evolvability will not gain any benefit. In fact, if the arrangements that increase evolvability are costly, the
individual will be disadvantaged.

This argument does not apply only to genes that improve evolvability. It also applies to the genes that
establish the genetic change-and-test process itself. Foremost amongst these are genes that cause or
allow mutations to arise in other genes. These genes will tend to be out-competed during periods in
which there is no advantage to evolving. The cost of producing genetic changes will be a burden when
there are no significant environmental challenges or other circumstances that make it worthwhile to try
out genetic changes. There will be no pay-off for the change-and-test process if a population is well
adapted to its environment, and if the environmental conditions are stable and unchanging. An individual
will do better in these circumstances if it produces only offspring that are faithful copies of itself. Its
young will be well adapted, like itself. An individual that instead produces some offspring that are
changed from itself is producing maladapted young. Any change will be for the worse. All changes will
be harmful10.

For example, consider a hypothetical population of snow hares that contains a gene that produces
mutations in other genes. The mutations influence the length and thickness of fur. An individual that
carries this mutator gene will tend to produce some offspring with different types of fur. The mutator can
do well if environmental temperatures change significantly every generation or so. The chances are that
one of the offspring will have fur that is better for the new temperature. If so, it will out-compete other
members of the population, including those that produced only offspring that were faithful copies of
themselves. The mutated gene and the mutator gene that produced it can take over the population11.

But if the temperature does not change over many generations, and if the population has the right fur
for this temperature, the mutator will disadvantage any individual who carries it. The mutator will cause
the individual to produce some offspring with different types of fur. The individual will be out-competed
by others who produce only offspring with fur that is right for the unchanging environmental temperatures.
It will be disadvantaged compared with individuals that do not try out anything different through their
offspring.

Many evolutionary theorists argue along these lines that natural selection will favour zero mutation
rates in most circumstances. They argue that organisms often experience stable environments for long
periods, and do not face significant environmental changes every generation or so. During periods of
stability, organisms would do better if they did not produce mutant offspring. Organisms would therefore
suppress mutation if this could be done efficiently, they argue. They acknowledge that genetic mutations
are continually produced in organisms, but suggest this is only because the arrangements needed to copy
genes without mutations are too costly for the organism12.

On this view, genetic evolution would have ended if it had ever discovered a cheap way to stop the
copying errors that produce mutations. The genetic change-and-test mechanism exists not because it
enables new adaptation to be discovered, but because mutations are unavoidable in practice.

However, this position is not intuitively attractive, and many biologists have searched for alternative
explanations of how genetic evolvability might evolve. One approach is to look for ways in which the
living or non-living environment of the species may be continually changing. If a population continually
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encounters adaptive challenges every generation or so, genes can be favoured that cause the production of some offspring that are genetically different\(^{13}\). As we have seen, if the environmental temperatures met by a population of snow hares are continually varying from generation to generation, genes that cause individuals to produce some young with different types of fur could be very successful. They could do better than those that simply produce offspring with the same fur as the parents.

But biologists have had trouble showing that key features of the environment of organisms are in fact changing continuously in this way, every generation or so. The non-living environments of most species appear to remain stable for long periods, and the organisms appear to undergo very little evolutionary change during these periods.

The best candidate for a source of continual adaptive challenge is not the physical environment of a species, but other living organisms, particularly parasites\(^{14}\). When a parasite discovers a better way to exploit a species, the species will benefit if it discovers a way to counter the change in the parasite. In turn, the parasite will benefit when it finds a way around the counter move, and so on, indefinitely. The result is an arms race of move and counter move that produces continual adaptive challenges for the parasite and the host species. Computer simulations have shown that these continual challenges can provide an evolutionary advantage for mechanisms that continually try out genetic changes in the search for new adaptations\(^{15}\).

But this parasite theory is too narrow to explain most of the genetic changes that are continually produced by populations of organisms. The genetic changes produced generation after generation by organisms are not limited to changes that might be useful in combating parasites\(^{16}\). Populations of organisms are continually testing changes in all aspects of the organism. This has been shown conclusively by experiments that subject organisms to artificial selection. Whenever animal breeders have set out to see if they can change a feature of an animal through artificial selection, they have generally met with success. Whatever features they look at, they find that genetic changes are being generated as the animals reproduce, and that these changes enable the animals to evolve in response to selection\(^{17}\).

Another problem with the parasite theory is its prediction that genetic changes would cease to be produced if ever the arms race stopped. It is only the continual adaptive challenges produced by the arms race that provide a profit for evolvability. The parasite mechanism can explain the continual production of genetic changes only if the arms race never stops. But this condition is highly implausible. There is no good reason to expect that all species that continually produce genetic variety are continually engaged in evolutionary arms race with parasites\(^{18}\).

So are most of the genetic changes produced by populations of organisms harmful but unavoidable? Do populations produce genetic changes largely because they are too costly to eradicate, not because they enable the population to evolve? Or can natural selection favour genes that produce evolvability? Can genes that cause genetic changes become established in a population because they improve evolvability, even though the population may experience long periods of environmental stability?

Theoretical work begun by American evolutionist Egbert Leigh in the early 1970's suggests that they can\(^{19}\). He was able to show that in restricted circumstances, natural selection will favour genes that cause populations to continually try out mutations. Further work carried out by a number of theorists has extended his conclusions to a wider range of circumstances and genetic changes\(^{20}\). This work has also shown that natural selection will favour genes that target their genetic changes so that the changes are more likely to meet future adaptive needs.

This new theoretical approach acknowledges that if a mutator gene is to be able to benefit from discovering useful mutations when the environment changes, it must be able to somehow survive periods when the environment is stable. The theory shows how a mutator can do this. It demonstrates that a mutator can always survive periods of stability if the rate at which it causes mutations is low enough. And this is the case even though all mutations produced during periods of stability are harmful because they change an organism that is already closely adapted to its environment\(^{21}\).

The new theory begins by noting that individuals which carry the mutator will not always be disadvantaged in evolutionary terms. An individual will not be disadvantaged unless the mutator causes the individual to produce an offspring that carries a harmful mutation. When it does, the copy of the mutator gene in that offspring will be removed from the population. But until it causes a harmful mutation, each copy of the mutator will do as well as any other gene. The rate at which a mutator gene dies out of
a population depends on the rate at which it produces harmful mutations. The lower the mutation rate, the longer a mutator can survive without discovering useful mutations. A mutator gene will not die out of a population until all of its copies have produced harmful mutations. And if the mutation rate is low enough, there will always be some copies of the mutator left in the population at the end of a period of stability. No matter how long the period of stability, a mutator can survive if its mutation rate is sufficiently low.

If a mutator can survive periods of environmental stability in this way, it can spread throughout the population when environmental conditions change and the mutator produces a successful mutation. When a copy of the mutator causes an individual to produce a useful mutation that takes over the population, the useful mutation will re-establish the mutator throughout the population. Provided the mutator and the mutation are closely linked genetically, all individuals in the population will eventually contain a copy of both. The mutator will hitch hike on the back of any successful mutation it produces.

However, this does not solve the mutator’s problem permanently. Every time that it re-establishes itself in the population by discovering a useful mutation, it then begins to die out again as it produces harmful mutations. To survive, it must again discover a useful mutation before it dies out. And to survive permanently in the population, the mutator must produce a useful mutation each and every time, before it dies out. Unless this condition is met indefinitely, a mutator will not survive continually in a population.

But this condition can be met often in a typical population of organisms. Over long time frames, a population will become increasingly maladapted as environmental changes accumulate. All organisms become increasingly maladapted if they remain the same as time passes. No matter how stable an organism’s living and non-living environment, it will eventually accumulate significant change, and features of the organism that were once adapted will no longer be. So as time passes, the success rate of mutations will get better and better. The less an organism is adapted to its living and non-living environment, the greater the likelihood that a random change in the organism will produce an improvement. As environmental changes accumulate, it therefore becomes increasingly likely that even random mutations will be useful. Mutators with a mutation rate that is low enough will be able to survive until the likelihood that they produce a useful mutation becomes a certainty.

If a population is adapted to its environment, all mutations are likely to be harmful. Many will be lethal because they damage the effective functioning of the organism. The remainder might produce organisms that can function, but they will be less adapted than non-mutants. However, even in a relatively stable environment, as environmental changes inevitably mount over many generations, and as the changes increasingly disadapt the organism, the chance that a mutation will produce an improvement increases. Provided a mutator is able to survive long enough, it will become increasingly likely that its mutations will be useful to an increasingly maladapted population.

To illustrate how such a mechanism can operate, we will look again at our hypothetical example of an evolving population of snow hares. Imagine that the environmental temperatures met by the population usually vary little over a period of 10,000 years, but that over a time scale of 50,000 years, significant change is likely to have accumulated. A population that is very well adapted to the temperatures at the beginning of a 10,000-year period will therefore generally be adapted at the end of the period. Mutations will be harmful during this period if they change features of the snow hare that are suited to the prevailing temperatures. So a mutator that produces a high rate of mutations that change these features will soon die out of the population.

Compare this with a mutator that instead causes an individual to produce a mutated offspring only once every 20,000 generations, on average. If this mutator was common in the population at the beginning of the period and there is one generation per year, the mutator is highly likely to be still common at the end of even the 50,000-year period. But a snow hare population that was adapted to environmental temperatures at the beginning of the 50,000-year period will be maladapted if the snow hares are unchanged at the end of the period. And there will be a much higher probability that a random mutation will produce a snow hare that is better adapted to the new environmental temperatures. If the mutator produces such a change, it will spread throughout the population again.

So mutator genes can survive in a population if their mutation rate is tuned to the rate of relevant environmental change. The environment does not have to be continually changing every generation or so to favour the evolution of this evolvability. A gene that produces evolvability can be successful if it
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operates over a time scale on which the environment is changing continually. And this will hold true no matter how slow the rate of change.

Natural selection can be expected to tune mutation rates to balance two opposing tendencies\(^{24}\): first, a lower rate will improve the ability of a mutator to survive periods of little environmental change. Second, a higher rate will improve the ability of a mutator to discover useful mutations before another mutator does so. The higher the mutation rate caused by a mutator, the more likely it will discover the first useful mutation when the environment changes, provided it still exists within the population.

It can be expected that the optimum mutation rate will be different for different genes within the organism. The ideal mutation rate will be higher for genes that establish features of the organism that are affected by rapidly-changing environmental conditions. It will be much lower for genes that produce features that cope well with all but rare environmental events.

There is growing evidence from studies of bacteria that mutation rates do in fact vary for different genes, and that these differences are not random. Some genes are much more likely to mutate than others, and it is because there is evolutionary advantage in doing so. The higher rates have evolved because they improve evolvability.

For example, a particular group of genes in the parasitic Salmonella bacteria have been found to produce proteins on the surface of the bacterium. The organisms infected by these bacteria use the proteins to identify different types of bacteria. When the immune system of an organism has come up with a way of destroying a particular type of bacteria, it will be used against all bacteria with the surface protein common to that strain. But if the bacteria can change its surface protein, it can escape the defences of the host organism, until the host again locks onto its particular type of surface protein. Bacteria will do best if they can adapt to the continually-changing immune system of the host by continually searching for types of surface protein that are not recognised by the host organism. Researchers have found that genes that produce these proteins mutate far more rapidly than other bacterial genes that do not have to deal with aspects of the environment that are continually changing at such a high rate\(^{25}\).

Natural selection will not only favour the production of mutation rates that vary across the genes of the organism. It will also favour the production of a targeted pattern of mutations that is more likely to include mutations that will meet future adaptive needs. A mutator will be more competitive if the mutations it produces include fewer that damage the individual, and more that change existing adaptations in ways that are likely to be useful as the environment changes. A mutator whose mutations are biased in this way is likely to do much better than a mutator whose mutations are random.

Mutators that are better at targeting their mutations will be discovered by the normal genetic change-and-test process. General mutation will produce a variety of mutators. Different mutators will produce mutations in different genes and in different parts of genes. Of these, the mutators whose pattern of mutations happens to do better at matching adaptive opportunities through time will out-compete those that are less effective\(^{26}\).

For an illustration, we will revisit our hypothetical population of snow hares that experiences significant changes in environmental temperatures every few generations. We will consider what happens in the following circumstances: a particular mutator produces mutations randomly within a number of genes that are responsible for growing fur. Mutations in some parts of these genes change the length and thickness of the fur. When such a mutation produces a type of fur that adapts the hares to the prevailing temperature, the mutation and the mutator will spread through the population. But mutations in other parts of these genes are harmful. They produce hares with no fur, with damaged fur, or with only patches of fur. None of these mutations will ever be useful in the temperatures met by the population. So the mutator that produces mutations randomly across all parts of these genes will produce both useful and harmful mutations, depending in which parts of the genes the mutations arise. But despite producing some mutations that are always harmful, such a mutator can survive in the population, provided it is always able to eventually discover an adaptive mutation before it dies out.

But what will happen if a new mutator arises that has the same mutation rate, but produces only mutations that change the length and the thickness of the fur? The new mutator does not produce any mutations in the parts of the genes where mutations are always harmful. When the temperature changes, this new mutator will be more likely to find an adaptive mutation first, before the original mutator does so. The rate at which it produces useful mutations will be higher. When it is the first to produce an
improvement, the new mutator will spread throughout the population. In contrast, the original mutator will have missed an opportunity to re-establish itself in the population. It will continue to produce mutations that are harmful, and if it continues to be beaten by the new mutator in the search for useful mutations, it will eventually die out. The mutator that is better at targeting its mutations will be favoured by natural selection. The smarter mutator will win.

In this way, the genetic evolutionary mechanism can be expected to improve its own evolvability. It will discover and establish mutators that target mutations at future adaptive needs. But this search process is very inefficient. It relies on costly trial-and-error to discover better mutators, and most of the alternative mutators that are tried will be inferior. Eventually, evolution might improve the ability of the genetic system to discover better mutators. The genetic system may learn to target mutations in mutators, increasing the chances that mutations will produce a better mutator. But again, it will take a lot of costly trial-and-error to develop this ability. There is obvious room for improvement here. A system that could target genetic changes without having to go through this expensive trial-and-error process would have a substantial evolutionary advantage. It would be clearly superior to the types of mutational systems we have considered to this point. The result would be a further significant advance in evolvability.

Evolution overcame this fundamental limitation in the evolvability of mutational systems when it discovered genetic recombination, which is part of the wider process of sexual reproduction. The evolution of recombination and sex arguably have been the most significant advance in the evolution of the evolvability of genetic systems. The great majority of complex single celled creatures and multicellular organisms now reproduce sexually and use recombination. We will see that the immense significance of recombination is that it is far more efficient and effective at producing genetic changes that are targeted at future adaptive needs. Sex and recombination are successful strategies for organisms because they make them smarter at evolving.

How does recombination do this? The genetic changes produced by recombination are better targeted because of the way in which the changes are generated. Recombination produces changes by putting together different combinations of existing genes. Unlike mutational systems, it does not produce changes in the genes themselves. As we have seen, most changes to genes that are already functioning well are likely to be harmful. They will disrupt the effective operation of the gene, and produce a damaged organism. Instead recombination generates changes by mixing existing genes together in different combinations. So the basic building blocks that it uses to produce new effects are genes that are tried and tested, and that already work well in the organism. It does not risk making changes to existing genes that are proven performers.

It works like this. The cells of most sexually-reproducing organisms contain two sets of genetic material. One set is inherited from each parent. Each set includes a number of chromosomes, and each chromosome is formed of a long string of genes. Because the organism has two sets of chromosomes, it has a pair of each different type of chromosome, one from each parent.

Each egg or sperm produced by the organism will have only one set of chromosomes. So when it fuses with another egg or sperm to produce a new organism, the new organism will have two sets of chromosomes. But the single set of chromosomes in each egg or sperm is not just a set selected from the chromosomes of the organism that produced the egg or sperm. Each chromosome in the set is new. It is a combination of the pair of chromosomes of its type in the organism. So each chromosome in the egg or sperm is a combination of the chromosomes inherited by the organism from its parents. Each is produced by a process called crossing over. Parts of the chromosome from one of the organism’s parent are swapped for the same part of the matching chromosome from the other parent. This produces a new, full chromosome that is a combination of the chromosomes inherited from each of the organism’s parents. The result is that the organism produces eggs or sperm that contain chromosomes with different combinations of genes to those in its own chromosomes or in its parents’. It is likely that the new combinations of genes put together in this way will produce offspring that differ from their parents. Natural selection will test which of the new combinations are better adapted.

But what makes the new combinations produced by this process particularly effective is not just that they contain genes that have proven to be effective in the past. It is not just that recombination produces genetic changes without risking the wrecking of existing genes by mutation. The great advantage of recombination is that it generates new combinations that are likely to be advantageous in the future. It
tends to produce changes that are shown by past experience to be likely to be adaptive in the future. To see how it does this, we first have to look at the type of genes that accumulate in the genetic material and that are available for recombination. We will again use the hypothetical example of a population of snow hares in an environment where average temperatures fluctuate significantly every few generations. We will first consider how the genes that affect the length and fitness of fur are likely to evolve over time if the population adapts through the production and testing of mutations, rather than by recombination. Then we will consider what sort of genetic changes would be produced when recombination creates different combinations of these accumulated genes.

Any complex process in an organism will be the result of the action of many genes. So there are likely to be a number of genes that are involved in the production of fur. There are also likely to be many possible changes in these genes that will have an effect on the length and thickness of fur. When environmental temperatures change, the first mutation that arises that changes the length and thickness of fur in a direction that matches the new temperature will be established in the population. Each time the temperature changes, up or down, new mutations that modify the fur for higher or lower temperatures will be established in the population. It is possible that in some cases adaptation will be produced by a mutation that undoes a mutation that was established in the past. But, until many mutated genes that modify the fur accumulate, it will be more likely that the change will be produced by a new mutation in one of the many genes that influence fur production.

As a result, the snow hare population will accumulate a number of mutated genes that have had the effect in the past of increasing or decreasing the length and the thickness of fur to match temperature changes. The extraordinary effectiveness of recombination is that it produces changes by putting together different combinations of these genes—different combinations of genes that each tend to change the length or thickness of fur. Rather than change fur randomly in directions that have not been adaptive in the past, all the changes tried out by recombination will tend to increase or decrease the length or thickness of fur. This will prove to be a very effective strategy for producing genetic changes if environmental temperatures continue to change in the future, as they have in the past. In contrast, the pattern of genetic changes produced by untargeted mutation would be far less efficient at adapting the population. Many random mutations would be lethal, or would produce changes that had nothing to do with changing the length and thickness of fur. So recombination is superior because it continually recreates combinations that have proved effective at some time in the past. And it tends to produce new combinations that change fur in ways that have proved adaptive in the past.

These principles can be expected to apply to any feature of an organism that must adapt genetically to some changing feature of the environment. The population will accumulate a number of genes that each will have changed the feature in a direction that produced adaptation at some time in the past. Recombination will produce changes by putting together different combinations of these genes. Each new combination is likely to change the feature in ways that have produced adaptation in the past. As a result, if future environmental changes are similar to past changes, recombination will be far more successful than mutation at targeting genetic changes at future adaptive needs. And the pattern of genetic changes that are tried out by a population using recombination will be far from random in relation to future adaptive needs.

The rate at which a population tries out new combinations of genes, and the content of the new combinations will be affected by a number of aspects of the recombination process. The rate and content will be influenced by: the frequency of crossing over between chromosomes when sperm and eggs are produced (if there is no swapping there will be no new combinations, and the chromosomes from the parents will be passed on to all offspring unchanged); the proportion of the chromosomes that are exchanged; and the location of different genes on the chromosomes (genes that are closely linked on the same chromosome are less likely to be separated and recombined by crossing over). Because these aspects of the recombination process are themselves controlled genetically, they are evolvable. So natural selection can tune them to optimise the rate and content of the genetic changes that are produced through time. As a result, we can expect that the rate at which recombination produces changes in particular features of the organism will be tuned to the rate at which environmental changes affect the adaptedness of the organism. And we can expect that the content of the changes will be tuned so that changes are targeted more accurately at the types of adaptive opportunities that repeatedly confront
Consistent with these expectations, the rate of recombination has been found to vary widely across different regions of the chromosomes of organisms that have been studied. And artificial selection in the laboratory has been able to readily change these rates of recombination\(^3\). But little work has yet been done on assessing whether these differences in recombination rates are adaptive as a result of their ability to control the rate of production of genetic changes.

There are other ways in which evolution can improve the evolvability of organisms by modifying the pattern of genetic changes that they produce. It can do this by changing other factors that influence the genetic composition of offspring. For example, evolution can program organisms to select mates that are likely to contain useful genes, or to mate with non-relatives so that they produce young that differ more from themselves.

In all these ways, evolution can improve the evolvability of cells and multicellular organisms by shaping the pattern of genetic changes that they produce through time. Selection can tune the rate at which genetic changes are produced, and target them at likely future adaptive needs.

But it is not only by shaping the pattern of genetic changes that evolvability can be improved. The evolvability of a population of organisms depends on their ability to produce offspring with changes that are more likely to meet adaptive needs. But whether offspring will be better adapted will not be determined solely by the nature of the genetic changes that the population generates. It will also depend on what effects these genetic changes have on the way the offspring develop and function. It will depend on the way in which the genetic changes interact with the existing features of the organism to produce actual change in the organism. And this will depend on the way the organism is structured and organised.

From this we can see that selection can shape the pattern of changes produced by a population in a number of ways: it can modify the pattern of genetic changes, or it can change the organisation of the organism, or it can do both. If evolution were unable for some reason to modify the pattern of genetic changes, it would still be able to shape the pattern of actual changes that were produced by genetic changes. It would do this by changing the organisation of the organism so as to modify the effect of the genetic changes\(^3\).

An example will make this clearer. Complex multicellular organisms have physiological systems that enable them to adapt to changes in their internal and external environment. These systems adapt the organism to changes that would otherwise disrupt its efficient functioning. The physiological and other adaptive systems also enable the organism to adapt to internal and external changes that occur as it develops from an egg into a fully-grown organism. Again, in the absence of these adaptive systems, the changes could damage the organism, and disrupt its proper development.

These internal adaptive systems can also enable the developing organism to survive genetic changes that would otherwise be lethal to the organism that carried them. This enables an organism to make fewer costly errors in the search for genetic adaptation. For example, consider two organisms that produced exactly the same pattern of genetic changes in their offspring: the organism with the better internal adaptive systems would produce fewer offspring that die or malfunction as a result of the genetic changes. The organism would take fewer errors to discover a particular adaptation. It would be better at evolving\(^3\).

In recent years, various theorists have pointed to a number of other ways in which an organism could be organised to improve its evolvability. For example, if each of an organism’s internal functions are organised into a separate module or compartment within the organism, evolution can explore changes in a particular module or compartment without necessarily disrupting the functioning of the rest of the organism\(^5\). Redundancy of function can also contribute to greater evolvability: if more than one component of an organism can perform a particular function, evolution can explore changes in one of the components without disrupting that function. This is particularly significant in the organisation of the genetic material. If there are multiple copies of a particular gene, changes in one of the copies can be made without loss of function.

One final example: evolution could readily explore new structures in organisms that are constructed out of basic building blocks that can be combined together in different ways to produce a wide variety of structures\(^6\). Small changes in the type, numbers and placement of building blocks could produce a diversity of structures. The recombination process would particularly lend itself to producing these changes. There is growing evidence that many key features of organisms are, in fact, constructed in this way.
But there is a fundamental problem with arguing that selection for improved evolvability is responsible for significant features of the way organisms are organised. If these features provide a pay-off only while a population is adapting to environmental changes, how do they justify their cost during periods of environmental stability? As we have seen, arrangements that produce genetic changes can survive these periods by minimising their cost to the organism. If the rate of mutation or recombination is sufficiently low, they can survive until the environment changes and they can provide an adaptive benefit. But there is no equivalent way in which a significant feature of the organism itself can minimise its cost to the organism during periods when it does not provide any benefit.

Can this difficulty be overcome in cases where improved evolvability helps the species as a whole to adapt and survive? Species that are better at evolving because they have features that improve evolvability can be expected to out-compete other similar species. They are likely to spread and produce new species at the expense of less evolvable organisms. But there is a problem. The longer-term advantage to the species will not maintain the features during periods when they fail to provide enough benefits to cover their costs. During these periods, organisms that have invested heavily in these features will be disadvantaged compared with those that have not. So the features will be maintained within the species only if they have other effects that are favoured by evolution. If this is the case, they will not owe their existence within the species to their contribution to improved evolvability. And changes in the features that improve evolvability will not be favoured unless they also have other advantages. But features that enhance evolvability will contribute to the success of the species.

Of course, this fundamental problem does not arise if populations are continually adapting genetically to their living and non-living environment. If this is the case, there will be a continual pay-off for features and processes that contribute to this adaptation. However, as we saw earlier, the environments of most animals are usually not thought to be continually changing in any significant way. Many species exist without apparent change for long periods in environments that seem stable. But, as we shall see now, this does not rule out entirely the possibility that highly-evolvable organisms are continually and profitably adapting to small changes in their living and non-living environment.

The living and non-living environment of any organism will always be seen to be changing if it is looked at on a scale that is fine enough. Examined closely enough, everything is continually changing, everything is in a state of flux. Temperatures, wind, humidity, and the intensity of sunlight change from hour to hour and day to day. The characteristics of food organisms, parasites, predators and other members of the species are also changing continually. So if a population of organisms were good enough at evolving, it might be able to find profitable ways to adapt to these continuous environmental changes.

This point is clearly demonstrated by complex multicellular organisms such as ourselves. Our heart rate, blood pressure, breathing, metabolic rate, and many other features of our bodies are being adapted continually to small-scale environmental changes. And the pay-off from this continual adaptation is apparently sufficient to justify the considerable investments made by our bodies in the systems that produce this adaptation.

As genetic evolvability improved throughout evolutionary history, populations can be expected to have got better and better at adapting profitably to finer and finer environmental changes. But are highly-evolved genetic systems that use recombination and sexual reproduction good enough at evolving to continually find profitable ways to adapt? Are they continually producing highly-targeted genetic changes that will adapt the organism to the small-scale environmental changes that all populations experience continually, no matter how stable their environment appears? If they are, organisational features that can improve evolvability might continually be able to provide a sufficient pay-off. They may be favoured continually by natural selection at the level of the individual within the population, and not contribute only to the success of the species.

I think that most populations of organisms are adapting continually in this way. If we could view a greatly sped up movie of a population of organisms over many generations, the population would appear to be adapting as continually and effectively as does a complex organism during its life. The population would appear alive in its own right, continually trying out highly-targeted changes, fluidly discovering new adaptations as conditions change, revising adaptations as necessary, and so on. But my view is little more than an intuitive guess at this time. Our current state of knowledge is a long way from enabling us to decide this issue conclusively.
In this Chapter we have looked at the ways in which evolution can be expected to have improved the evolvability of the genetic evolutionary mechanism. And we have seen that the genetic mechanism is much smarter than has commonly been thought by most evolutionists during this century. The pattern of genetic changes that are tried out by genetic systems, particularly those that utilise recombination, can be expected to be far smarter than random.

However, it is also easy to see that the evolvability of the genetic change-and-test mechanism is limited in a number of ways. As an evolutionary mechanism, it could be much improved. Its limitations leave substantial potential for further improvements in evolvability. And, as we shall see in the next two Chapters, this potential has progressively driven the evolution of new and better evolutionary mechanisms, and will continue to do so.

An obvious limitation of the genetic mechanism is that its capacity to learn is restricted. The targeting of genetic changes involves a form of learning. However, when organisms such as ourselves discover an adaptation that is effective in particular circumstances, we can learn to produce it again whenever those circumstances arise again. This is the ultimate in targeting. Trial-and-error is completely eliminated. But a genetic system cannot do this. It has no way of sensing the environment to distinguish one set of circumstances from another. So it cannot learn that particular adaptations are useful in particular environmental conditions. As a result, the genetic mechanism is unable to respond to specific environmental events by immediately producing a genetic adaptation that it has learnt is effective in those circumstances.

Nor can the genetic mechanism construct complex models of how its environment is likely to change through time, and use these to determine what genetic changes it should produce. Unlike us, it cannot use internal models to plan ahead, to test possible changes before they are tried out in practice, or to maintain adaptations that have no immediate benefits but will pay off in the future. A genetic system can miss a major beneficial adaptation by a single mutation, and never know. And it is unable to use a model of the direction of evolution to guide its search for better evolutionary adaptation.

But it was not these limitations of the genetic mechanism that immediately drove the progressive evolution of new adaptive mechanisms. The key limitation that did this was the inability of the genetic mechanism to adapt the organism during its life. As we have seen, a genetic change-and-test mechanism is unable to operate within the organism. This is because destructive competition must be suppressed within the genetic managers of single cells and the genetic managers of multicellular organisms. If genetic changes could arise and compete within the genetic managers during the life of the organism, destructive competition would undermine cooperation. Evolution therefore favoured arrangements that suppressed the possibility of this competition. But without competition between genetic alternatives, new and better adaptations could not be discovered within the organism. Genetic management could not provide a change-and-test process to adapt the organism during its life.

The inability of the genetic mechanism to adapt organisms continually during their life meant that there was enormous potential for the evolution of new mechanisms that could do this. This drove the evolution of new change-and-test mechanisms within the organism. Initially these were not evolutionary mechanisms. The adaptations that they produced were not passed from generation to generation. But, as we shall see, in humans these internal adaptive mechanisms have evolved into new evolutionary mechanisms that have overcome many of the limitations of the genetic mechanism. And we will see that they have to evolve further in the future to overcome other limitations and to improve the evolvability of humans as individuals and collectively.
An organism that is able to search for adaptive improvements during its life has an enormous advantage. It is able to use its experiences to discover new, innovative adaptations and to modify them as circumstances change. For example, it can try out new ways to get more food or to improve its ability to avoid predators. And when external temperatures drop, it can try out changes within its body to discover how to maintain its internal temperature.

But organisms could not use the genetic change-and-test mechanism to search for adaptive improvements during their life. As we have seen, the genetic mechanism could not try out new genetic possibilities within the organism. The genetic mechanism was unable to exploit the enormous potential benefit of adapting the organism during its life. This meant that any new adaptive mechanisms that could fill this gap would be strongly favoured by evolution. Such an adaptive mechanism would provide immense evolutionary advantages to organisms that possessed it. And any improvements in the new mechanism would also be favoured by evolution. As a result, evolution has established new internal mechanisms that adapt organisms during their life. Examples include our physiological and nervous systems. Evolution has also produced a long sequence of improvements in the ability of these mechanisms to discover adaptation. This sequence of improvements is continuing today.

Somewhat paradoxically, these new adaptive processes have been discovered and established by the genetic mechanism. Even though the genetic mechanism could not try out new possibilities within an organism during its life, it was able to establish new adaptive mechanisms within the organism that could. The genetic arrangements that produced these new adaptive mechanisms would be favoured by natural selection. Individuals that were better at adapting during their life would pass on more of their genes to the next generation. The genes that produced new adaptive mechanisms within individuals would therefore do better in evolutionary terms.

The simplest adaptive arrangement that the genetic mechanism could install in an organism is one that
is completely hard wired. For example, the arrangement might pre-program the organism to change in a particular way when a specific event occurs. The change in the organism would be adaptive if it enabled the organism to deal more effectively with the event. We are hard wired with a number of these types of adaptive arrangements: we are pre-programmed to produce saliva when tasty food is put in our mouth; and we duck without thinking when a rock is thrown at our head. But adaptations that are fully hard wired do not include a change-and-test process. No aspect of the adaptation is discovered by making changes within the organism, and then selecting the change that produces the best result. Hard-wired adaptive mechanisms are fixed and inflexible during the life of the organism.

Hard-wired adaptations are flexible only across the generations. They are discovered and shaped by the genetic change-and-test mechanism. They can be improved and adapted by the genetic mechanism as circumstances change from generation to generation. But nothing new is discovered within the organism. The discovery incorporated in a particular hard-wired adaptation has been made over the generations by the genetic mechanism, and the results have been pre-programmed into the organism.

The limitations of hard-wired adaptive mechanisms are obvious. Every part of them has to be discovered and adapted over the generations by the genetic mechanism. No use whatsoever is made of the experiences of the organism during its life. Potentially an organism can gain an enormous amount of knowledge during its life about what works and what does not. But an organism that adapts only in ways that are pre-programmed makes no use of this potential. If its living or non-living environment changes in ways that make a hard-wired adaptation ineffective, the organism can’t try out changes then and there. It and its descendants remain ineffective until they produce offspring with genetic changes that improve the hard-wired adaptation for the new environmental conditions.

So the potential advantages of being able to search for adaptive improvements during the life of the organism drove the evolution of internal change-and-test processes. Evolution favoured genetic changes that established processes within the organism that could discover new adaptations during its life. These internal change-and-test processes discovered better adaptation in the same way that all such processes do: changes are made to the behaviour or to the internal functioning of the organism, and these are tested against their ability to improve the organism’s effectiveness. For example, a change-and-test process might try out changes in the metabolic rate of the organism, the blood pressure, the amount of blood shunted to the limbs and muscles, the amount of time the organism spends feeding, its hunting techniques, its fighting strategies, or how it avoids predators. And these changes would then be tested within the organism against the results that they produce.

The first change-and-test processes established by the genetic mechanism can be expected to have been the simplest. Smarter processes that needed more complex arrangements would take longer to discover and establish. Countless generations of search by trial-and-error were needed before the genetic mechanism discovered and established the first complex brain. We can use this principle that simpler processes often evolve first to reconstruct the long sequence of improvements in adaptability that have occurred during the evolution of life on earth. We will start with the simplest form of internal change-and-test process, identify its limitations, consider how these might be overcome by slightly more complex processes, identify the limitations of these new processes, consider how they might be improved, and so on.

A change-and-test process, no matter how simple, must include arrangements that try out changes within the organism. It must also include arrangements that test the changes, selecting those that are best. In more complex change-and-test processes, both the pattern of changes and the testing arrangements would be able to be improved by learning during the life of the organism. Both would include their own change-and-test processes that would enable the organism to discover better ways to target the changes and better ways to test them. But in the simplest change-and-test mechanisms, both the process that produces changes and the testing arrangements would be hard wired into the organism. The simplest mechanism would try out a fixed pattern of changes, and test them against some fixed internal standard. The arrangements that target and test changes would be established and adapted by the genetic mechanism.

But before we consider how this simple type of change-and-test process might be improved, we need to understand more about the internal testing arrangements. What sort of internal mechanism could evaluate the changes made within the organism? What mechanism could tell whether a particular change is good or bad for the organism in evolutionary terms? How could the organism know whether it is better
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to increase or decrease the metabolic rate, raise or lower the blood pressure, direct more or less blood to
the limbs, or to fight or avoid another animal that is competing with the organism for food?

Natural selection will tend to establish internal testing arrangements that are able to identify the changes
that will improve the evolutionary prospects of the organism. To be favoured by evolution, the genes that
produce testing arrangements must improve the evolutionary competitiveness of the organism. To do
this, the genes must produce testing arrangements that evaluate the ability of changes to improve the
evolutionary success of the organism. The testing arrangements that are best at doing this will do better
in evolutionary terms. As a result, internal testing arrangements are tuned by natural selection to use
testing criteria that are correlated with evolutionary success. Natural selection establishes testing criteria
that are good indicators of evolutionary success. Testing arrangements are tuned so that an internal
change that would contribute to the evolutionary success of the organism will also do well against the
test criteria.

What sort of arrangements could do this? What sort of testing criteria would be correlated with
evolutionary success? What test could you apply to an internal change that could indicate the evolutionary
impact of the change?

Probably the simplest way to test changes is to see whether they can return the organism to an efficient
state after an environmental event has dis-adapted the organism. If it is profitable for an organism to
adapt to an event, the event will probably have some adverse impact within the organism. So changes
could be tested against their ability to reverse the adverse internal impact of the event. For example,
consider a fall in external temperatures that reduces an organism’s temperature below the level that is
best for its metabolism. To discover how to adapt to the falling temperatures, the organism could test
internal changes against their ability to move the internal temperature back to the level that is best for the
organism. As a further example, consider an organism that is chasing its prey. It will use up oxygen in its
muscles, reducing the level of oxygen below the concentration that is best for muscles to function efficiently.
Possible adaptive changes could be tested against their ability to restore the level of oxygen to the
concentration that is best.

In both these examples, when a key aspect of the organism moves away from its most efficient state,
changes are triggered that are then tested against their ability to restore the aspect to its ideal state. Such
a change-and-test process can be described as goal directed. It has as its goal the maintenance of a key
aspect of the organism in a state that is best for the efficient operation of the organism. The change-and-
test process will search for a pattern of internal changes that will maintain this key aspect of the organism
at the best level through time, despite changes in internal and external conditions.

The genetic evolutionary mechanism will tend to establish these simple change-and-test adaptive
processes for whatever aspects of the organism are best kept constant. These aspects of the organism
have been called essential variables because their maintenance in a certain range is essential for the
efficient operation of the organism. It is worth using the resources of the organism to defend essential
variables against disturbance.

The genetic evolutionary mechanism will tune each of these simple change-and-test arrangements so
that the changes it makes are targeted at the particular essential variable that the process seeks to maintain.
Evolution will favour a change-and-test process if the changes it tries out are more likely to achieve the
goal of restoring the variable. It will also be favoured if it tries out changes only when they are needed,
and if its changes are the cheapest way of achieving adaptation.

These simple change-and-test processes are still used widely within single celled and multicellular
organisms to adapt their internal arrangements to changes in environmental conditions. The complex
physiological systems that are continually adapting our bodies as internal and external conditions change
are based on these processes. They make sure that our cells and organs get enough food and oxygen,
operate at a rate that matches the needs of the organism, do not accumulate damaging levels of toxins, get
rid of wastes, and operate at the best temperature.

But simple change-and-test processes are able to discover the most effective adaptations only for a
limited range of adaptive challenges. In their search for the best adaptations they cannot use information
about circumstances outside the organism, or about likely future events. This is because they use the
actual immediate effects of events within the organism to target and to test the changes that they try out.
So if two events outside the organism have the same effects on the organism, a simple change-and-test
process will try out the same changes and use the same test in the search for adaptation. It is completely blind to the cause of the events, and all it can do is respond to their effects within the organism. So it is unable to target behavioural changes at the particular type of outside event that has affected the organism. It is unable to assess the outside cause of an internal disturbance, and try out behavioural changes that are most likely to deal with the cause.

For example, the internal temperature of an organism might increase either because the general environmental temperature has gone up, or because a nearby object is on fire. An organism that adapts only through simple change-and-test processes will respond to the two events in the same way. In both cases it will search for internal changes that will reduce its temperature. Because both events have the same effect on an essential variable, the organism’s response to each of them will be the same. It cannot target changes at the cause of the particular outside event that is disturbing the essential variable. To do so the organism would have to have sensory arrangements that could distinguish between the two different causes. And it would have to be able to use this discrimination to target the changes it tries out at the particular cause. Only then could it discover that if the increase in temperature is due to a nearby fire, it should move away, but if it is a general environmental change, it might be best to reduce its metabolic rate.

These simple change-and-test processes are also adaptively blind to future events and to the future effects of possible adaptations. They are only able to discover adaptations that immediately correct the disturbance of an essential variable. So a possible adaptation that has very useful future effects but that does not immediately restore an essential variable will not be discovered. No matter how valuable the future effects of a particular adaptation, a simple change-and-test process will not be able to discover it. It cannot take account of the future effects of the possible adaptations that it tests. It has no foresight or ability to anticipate.

For example, consider a predator that lies in wait for its prey at a water hole. This behaviour might eventually benefit the predator, producing a kill. But initially the behaviour will not restore any essential variable to its ideal range, so a simple change-and-test process will not discover it. For another example, consider an organism that has a spear thrown at it. Simple change-and-test processes will begin to adapt the organism only when the spear begins to enter the body of the organism. It is only then that the spear begins to disturb essential variables. This is indeed how a sea sponge would adapt to a spear thrown at it.

For these reasons, simple change-and-test processes in modern complex organisms are largely restricted to adapting the internal processes of organisms to actual disturbances in essential variables. They are of little use for discovering adaptations that intervene in events outside the organism or that produce future benefits. In the terminology used by the great English systems theorist Stafford Beer, these simple change-and-test processes adapt the organism for the inside/now. He contrasted them with the more complex adaptive processes that adapt the organism for the outside/future.

The inability of simple change-and-test processes to adapt the organism for the outside/future drove the progressive evolution of more complex change-and-test processes that could do so. Arrangements that could successfully exploit the potential benefits of discovering adaptations for the outside/future had an evolutionary advantage. The result has been a long sequence of improvements in adaptive ability that is still under way.

In order to develop a good understanding of where this progressive evolutionary sequence has been heading, we need to look at what an ideal adaptive mechanism would be able to do. This will give us an idea of the potential for improvement that existed in simple adaptive mechanisms, and the direction in which this potential would drive evolution.

If an adaptive mechanism is to evaluate possible adaptations properly, it must assess all the effects of the alternatives. In order to select the best adaptation, it must take account of all their effects, whether they are good or bad, or whether they arise within the organism, outside it, or in the future. Any limit to the ability of an organism to predict and take account of relevant events and effects that occur elsewhere or in the future will limit its ability to discover the best adaptations. Any relevant effect that is ignored can lead to the selection of inferior adaptations.

For example, if an antelope is unaware that a predator is lying in wait at a water hole, it will fail to adapt more effectively by moving to another hole. If a lion is unaware that a drought will soon mean that prey will be scarce, it cannot alter its priorities to build up more fat reserves as quickly as possible while
conditions are good. And the ability of humans to adapt effectively is obviously dependent on how far we are able to look into the future to take into account the likely consequences of our acts. A person who takes into account only events a day ahead will adapt quite differently to a person who looks only a year ahead, and both will live a different life to a person who looks up to 20 years ahead. The first person would never plant a farm crop, the second would never do a university degree to improve career prospects, and even the third would not voluntarily pay into an aged pension fund for a large part of his working life.

We see most easily the limitations of a narrow ability to take account of the future effects of adaptations when we deal with organisms whose ability is narrower than ours. Dogs, cats and children appear particularly handicapped in their adaptive ability when we see them ignoring future dangers that we can easily foresee. Of course, our adaptive strategies might look equally as silly to an organism that could take account of the consequences of our acts over even wider scales of space and time than we can.

To meet the adaptive ideal, an organism or a society would have to be able to foresee all the relevant effects of its actions. What is relevant will differ depending on the scale of the organism or society. For example, if human society increases in scale and colonises other planets in the solar system and elsewhere, events and consequences over wider and wider scales would become relevant to the adaptation of the society. Any limit to its ability to take into account any of these relevant events would impair its adaptive ability.

We are currently a long way from this ideal. In part, this is because the ideal may never be able to be fully met. There may be absolute limits to the ability of an organism to predict the future consequences of its acts in a highly complex and dynamic environment. But in most areas we are obviously far from reaching these limits. There are many technological and scientific discoveries that are yet to be made. And there is also much for us to learn about wider-scale processes in the universe that will impact on the future of humanity. We are only just beginning to understand something of the large-scale progressive evolutionary processes that will determine our evolutionary future. Humanity has barely begun to accumulate the knowledge and abilities needed for it to adapt for its outside/future.

Although life on this planet has not yet reached this ideal, it has made considerable progress. The evolution of life on earth has seen a long sequence of improvements in the ability of organisms to take into account events outside the organism and in the future. The sequence began with simple change-and-test processes that were only able to take account of the effects of events within the organism itself. Since then, organisms have progressively evolved the ability to take account of the effects of their actions on events over wider and wider scales of space and time. As these capacities have improved, organisms have used them to discover adaptations that are more effective when the more-detailed and wider-scale effects of the adaptations are taken into account. At each step in the progression, organisms have been able to take account of the effects of adaptation that they were previously blind to.

We will now look at a number of key milestones in this sequence of evolutionary improvements in adaptive ability.

The first major improvement in the ability to adapt for the outside/future required a capacity to sense the external environment. The organism had to have a sensory system that was capable of distinguishing between different circumstances in the outside environment. This enabled the organism to try out different changes in different environmental circumstances, and to discover that some changes restored an essential variable in one set of circumstances but not another.

Change-and-test processes aided by a good sensory system could take account of the different effects that possible adaptations might have in the outside environment. Simpler change-and-test processes used only information from within the organism to determine which possible adaptations were tried out. Only the impact within the organism of external events was used. As we have seen, these simple adaptive processes were blind to the nature of the particular external events that caused the internal disturbances. But with the development of sensory systems, a change-and-test process could also use information about the outside environment. For the first time, a change-and-test process could discover that it was best to try out different changes in different environmental circumstances, even though the internal disturbances were identical in each case.

To exploit fully the benefits of achieving this first milestone, organisms had to develop the ability to learn from their discoveries. The organism could discover by trial-and-error that a particular change would restore an essential variable in certain external circumstances. If the organism could learn from
this experience, it would not have to repeat the costly trial-and-error search for adaptation whenever those external circumstances arose again. Instead, whenever the particular essential variable was disturbed in the future in the same external circumstances, the change-and-test process could then go straight to trying out the change that produced adaptation in the past. The organism would learn that a particular behaviour is likely to produce a desirable internal state in particular external circumstances. The organism could then apply this discovery to future adaptive challenges.

For example, an animal may learn that if it is cold during the day, it can increase its temperature by finding sunlight to rest in. But if it is cold at night, it may discover that the best way to increase its temperature is to curl up in the bottom of its burrow. And if an animal is hungry, it may learn that if it is standing on soft earth, digging is likely to produce food that will satisfy its hunger. But if the ground underneath its feet is rocky, it may discover that moving to another place is better than digging where it is. In both these examples, a change-and-test process that relied only upon information about the state of internal variables could not learn to target different behaviours at the different environmental circumstances. And without a capacity to learn, the animal would have to rediscover the adaptations by trial-and-error each time circumstances changed.

The effectiveness of these types of adaptive processes depend on their capacity to distinguish between different environmental conditions, to store the discoveries they make, and to use them in the search for adaptation in the future. Evolution has exploited the potential benefits of improved adaptability by enhancing these capacities in organisms. It has produced long sequences of improvements in sensory systems and in the size and complexity of the nervous systems that store and apply learnt behaviours.

This has progressively improved the ability of organisms to discover and learn behaviours that act on the outside environment to produce desirable internal states in the organism. The result has been the high level of ability to discover and learn behaviour that is found in rats, pigeons, and other complex multicellular organisms. In these large-brained species, individuals use change-and-test processes to discover and accumulate a wide range of useful behaviours throughout their life.

Humans are largely unaware of the functioning of the simple change-and-test mechanisms that adapt our internal processes. However, we are conscious of the operation of the more complex processes that adapt our behaviour to external circumstances. When our body detects that an essential variable that is maintained by our behaviour is outside its preferred range, we feel a need to take action to restore it. We feel motivated to search for behaviours that will do this. These alternative behaviours are tested against their ability to restore the essential variable. And when we find a behaviour that works, when we achieve the goal of restoring the essential variable, we are rewarded by feelings of satisfaction or pleasure, and by the ending of any discomfort.

So if we lack enough water in our bodies, we feel thirsty and are motivated to try behaviours that have got us water in the past in the type of circumstances we are in. When a behaviour succeeds in producing water for us, when it meets the test of restoring the essential variable, we are rewarded by the pleasure of drinking and by the satisfaction of our thirst. We are hard wired with a system that rewards us for behaving in ways that maintain our essential variables in preferred ranges. The result is that we tend to behave in ways that satisfy our immediate material needs.

But these more complex change-and-test processes are still fundamentally limited in their ability to adapt organisms for the outside/future. They are unable to search for and discover adaptations that produce only future benefits. They cannot take into account the future effects of possible adaptations. This is because they test possible adaptations only against their ability to meet the goal of restoring disturbed essential variables within the organism. Future beneficial effects have no immediate effect on current essential variables. Behaviour that has only future beneficial effects will not satisfy a current need for a higher internal temperature, or more water, or more food. These needs can lead only to the discovery of adaptations that produce immediate results.

To overcome this limitation, evolution had to produce a new motivation and reward system that was not based solely on maintaining essential variables. The genetic mechanism had to establish a new system that would test possible adaptations against their future benefits as well as against their immediate effects. The new system had to immediately reward behaviours that produced longer-term benefits, even though they might not deliver any actual immediate benefits. If attainment of a longer-term goal meant that the organism had to achieve a particular immediate goal, the new system had to produce a need within the
organism to achieve the immediate goal. The need would motivate the search for behaviour that could satisfy the immediate goal, and therefore produce the longer-term benefits. The new system would have to do this even though achievement of the immediate goal might produce no actual immediate benefit to the effective operation of the organism. Rather than test alternative behaviours against their immediate impact on essential variables, the new system had to test alternatives against their ability to produce immediate internal rewards that were proxies for longer-term benefits to the organism.

If reward systems of this kind were hard wired in the organism, the organism would be able to discover behaviours that have only future benefits. This is despite the fact that all the organism ever does is seek immediate reward by searching for adaptations to satisfy its immediate needs. The organism would be hard wired so that its pursuit of immediate rewards causes it to behave as if it takes into account the future benefits of its actions. The better a reward system was at producing immediate rewards for possible adaptations that have future benefits, and the better it got at making the reward proportional to the future benefits, the better the organism would do in evolutionary terms. Natural selection would tune these hard-wired arrangements to match the levels of immediate rewards to the likely future effects of actions.

Sexual activity is a particularly clear example of behaviour that is organised in this way. Behaviour that causes an organism to sexually reproduce does not produce any immediate beneficial effect on the functioning of the organism. It does not restore any “natural” essential variable. Sexual reproduction provides evolutionary benefits to the genes that produce it, but only in the long term. For these reasons, in less complex organisms sexual activity is completely hard wired into the organism, as are other adaptations for the outside/future. There is no ability to adapt sexual behaviour during the life of the organism using change-and-test processes.

In more complex organisms, the establishment of an internal reward system for sexual reproduction enabled sexual behaviours to be adapted during the life of the organism. It also enabled sexual behaviour to be prioritised and integrated with other needs of the organism. The organism was no longer pre-programmed to act in a particular way when a reproductive opportunity presented itself. Instead, it was motivated to seek out reproductive opportunities, and to search for behaviours that would achieve successful sexual reproduction. The organism was rewarded psychologically with pleasurable feelings when it achieved sexual goals. And motivations for sexual activity competed with other motivations within the organism to prioritise the various behaviours of the organism. In this way, the reward system organised adaptive behaviours that had no immediate functional benefits.

Internal reward systems that took into account the future benefits of possible behaviours began to be used more extensively as multicellular organisms evolved complex social arrangements. This is because many of the benefits of social existence are not immediate. Many of the actions that animals must take if they are to live together harmoniously do not have any immediate beneficial impact on the operation of the organism. But the actions are in their long-term interests. For example, it might be in the long-term interests of an animal to submit to a dominant individual long before the dominant does it any physical harm. And it might be useful for an individual to react angrily to the actions of another that undermines its status in the group, even though the actions do not affect it materially straight away. As a final example, it may be in the longer-term interests of an individual to be motivated to care for others in the group, even though the individual will not benefit from this in any material way immediately.

In all these cases, if the individual is to adapt in ways that are best for its longer-term interests, it needs an internal reward system that immediately rewards the adaptive behaviour. The reward system must do this even though the behaviour does not immediately improve the operation of the organism. As a result, when multicellular organisms began to exploit the potential benefits of cooperative social organisation, evolution produced complex new internal reward systems. These systems could motivate and reward the search for social behaviours that provided no immediate benefit, but that served the longer-term interests of individuals by enabling them to interact more effectively with others in the group.

As multicellular organisms such as dogs, monkeys, elephants and apes began to form complex social organisations, the genetic mechanism expanded and diversified the internal reward systems into complex emotional systems. This produced social animals that experience a wide range of emotional feelings. These motivate, reward and punish behaviours that often do not immediately impact on the efficient functioning of the organism, but will in the longer term. We humans, the most social of multicellular organisms, experience a wide range of emotions and feelings such as fear, anger, guilt, love, frustration,
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curiosity, sexual pleasure, self-esteem, grief, delight, shame and depression. All these were initially tuned by natural selection to motivate and reward behaviours that would adapt the organism in ways that produced longer-term benefits.

For example, fear can motivate an individual to avoid future dangers, anger can motivate an individual to attack others to stop them from undermining the individual’s status in the group, guilt and shame motivate adherence to group rules and norms, love can motivate an individual to care for others in the group, frustration can motivate more attention to problem solving, curiosity can motivate an individual to explore new possibilities, sexual pleasure motivates reproductive acts, a need for self-esteem can motivate the individual to improve its status in the group, grief can motivate an individual to take greater care of others in the group, and depression can motivate an individual to try a new way of life.

Organisms with complex emotional systems spend their lives searching for behaviours and ways of life that will produce desirable emotional states, and avoid unpleasant ones. If the genetic evolutionary mechanism has properly tuned the emotional system, the behaviours that produce these internal rewards will also serve the longer-term interests of the organism, and ultimately its evolutionary interests. The social behaviour motivated by the emotional system will ultimately produce evolutionary success. Emotional systems and their goals are means to evolutionary ends.

But most organisms with complex emotional systems such as baboons, dogs, cats, horses and dolphins are largely unaware that their internal reward systems have been shaped by evolution for evolutionary objectives. To them, their internal emotional rewards are ends in themselves. They spend their lives in the pursuit of satisfying emotional states, oblivious that this is evolution’s way of getting them to discover the behaviours that are best for producing evolutionary success. Evolution has produced in them a virtual reality that motivates and organises their behaviour. But for them it is their ultimate reality. They cannot see beyond it to its real purpose. Most humans currently fall into this category. They are unaware that the emotional goals that drive their pursuit of wealth, power, sex and social success are merely means to evolutionary ends, not ends in themselves.

Because these organisms are unaware of the ultimate goal and purpose of their emotional systems, they are unable to adapt and improve them during their life. They have nothing to judge the effectiveness of their emotional goals against. There is no process within the organism that can evaluate whether any changes made to emotional goals would advance the organism’s evolutionary interests. If they tried out new emotional goals, they would have no way of assessing the longer-term effects of alternatives. They have no insight into the purposes of their emotional systems. If circumstances change, and the immediate goals established by the organism’s existing internal reward system no longer produce evolutionary success, there is no adaptive process within the organism to change the immediate goals. The organism will continue to serve the pre-existing goals that are no longer effective.

In these organisms, only the genetic evolutionary mechanism has the capacity to shape and tune the goals established by the internal reward system. The genetic mechanism can do this by producing a variety of individuals that are hard wired with different emotional goals and motivations. Individuals with goals that are better at advancing the evolutionary interests of the individual will have more surviving offspring, and eventually take over the population. The change-and-test process that adapts and improves the goals and motivations established by the emotional system is the genetic evolutionary mechanism.

Emotional systems were a major step forward in the progressive evolution of improved adaptability. They enabled organisms to search for and discover adaptations that had beneficial future effects, but did not produce immediate benefits. Emotional systems enabled organisms to take into account the effects of their actions over much wider scales of space and time. They were a major advance over simpler adaptive processes that could take account only of the immediate impact of possible adaptations on the functioning of the organism.

But, as we have seen, even the most highly developed emotional systems found in the social mammals such as ourselves are limited in their ability to adapt during the life of the organism. The framework for the reward system is hard wired into the organism, and is limited in its flexibility during the life of the organism. The immediate behavioural goals that are established by the reward system are not very adaptable. In contrast, the particular behaviours that the organism can use to obtain the rewards provided by its emotional system are not hard wired. The organism can adapt its behaviour to whatever is needed in specific situations. For example, most social mammals have emotional systems that reward behaviour
that improves their social status and power. But they are free to search for whatever behaviour will serve these goals in the particular social circumstances in which they live. Organisms can change their behaviour in whatever ways are necessary to achieve their emotional goals, but they cannot change their goals. Their behavioural strategies are highly adaptable, but the goals set by their emotional system are not. Means are very flexible, but ends are not.

As a result, emotional systems have a limited ability to take advantage of the experience of the organism during its life. The emotional system has little capacity to use experience to improve its ability to take into account the future effects of behaviour. It is left largely to the genetic system to tune the reward system to take better account of future effects. If the reward system does not establish specific and immediate behavioural goals that adequately reflect the future consequences of behaviour, not much can be done about it during the life of the organism.

In the evolution of life on this planet, these limitations are being overcome by the development of a capacity to use mental models to guide the adaptive process. This capacity has evolved most fully amongst humans. With mental modelling, the organism is able to form a mental representation of how aspects of its environment will unfold over time. It can use these representations to see what effects possible adaptations will have in the future. In its most highly developed form, mental modelling can work out the consequences of a wide range of hypothetical behaviours in hypothetical environmental circumstances.

The evolution of mental modelling is a major improvement in the ability of organisms to adapt for the outside/future. It significantly boosts the adaptability of change-and-test processes. It enables the future effects of behaviour to be taken into account in both the targeting and the testing of possible behavioural acts. Mental modelling can be used to mentally test possible adaptations before they are tried out in practice. This has a number of advantages: the organism can avoid behaviour that has dangerous future consequences; can work out which behaviour will produce immediate benefits without having to actually try out the alternatives; and can identify behaviours that are likely to pay off in the future.

Importantly, the models used by the organism can be improved continually as the animal accumulates knowledge and experience during its life. Where it discovers that a model does not accurately predict the future effects of its actions, the organism can revise the model to take account of its discovery. As the organism gains more knowledge of how its environment is structured, how the environment changes through time, and how different behaviours can produce different effects in different environmental circumstances, the ability of its models to target and test possible adaptation will improve. And this improvement in adaptability occurs during the life of the individual, without any involvement of the genetic evolutionary mechanism.

As the modelling capacity develops, individuals increasingly accumulate substantial stores of knowledge during their lifetime. This knowledge is extremely valuable to the individual, enabling it to use models to discover better adaptations by predicting the effects of alternative actions. For example, the more knowledge that an early human hunter accumulated about game animals, the better he would be at using mental models to predict which hunting strategies would be most effective. But the knowledge accumulated by an individual during his life died with the individual. So as a capacity for mental modelling evolved in early humans, there was an enormous potential evolutionary advantage to be had by any new arrangement that was able to transfer the store of knowledge between individuals. Any individual that could pass his accumulated knowledge to his offspring, or any individual that could obtain knowledge off others would be greatly advantaged in evolutionary terms.

Imitation enabled some transmission of adaptive behaviours between individuals. But it was only with the evolution of language that humans gained a comprehensive ability to share the knowledge they accumulated during their life. Through language, a discovery made by an individual could be passed to others and used by them in their modelling. Importantly, this enabled knowledge to be accumulated and built-on from generation to generation. Each new individual born into the population did not have to start again, with empty models. And in cooperative human societies, particular individuals could specialise in the collection of specific types of knowledge that were useful to the group. The result has been a complex and growing culture of adaptive knowledge that is passed from generation to generation.

As knowledge accumulated across the generations, the modelling capacity improved its ability to predict the consequences of possible behaviours. It became more accurate, could predict the consequences of wider ranges of events, and could evaluate the effects of possible adaptations over wider and wider
scales of space and time. This improvement in adaptability continued the evolutionary progression that began with the emergence of the first simple change-and-test processes that adapted organisms for the inside/now. Since the first simple processes emerged, internal adaptive processes have progressively developed the capacity to take into account the effects of possible adaptations over wider scales of space and time\textsuperscript{18}. The continuation of this progression is now enabling humans and humanity to build mental models of the formation and evolution of the universe.

Once knowledge could be accumulated across the generations, adaptive processes that used mental modelling became evolutionary mechanisms. They could discover adaptations and pass them on from generation to generation. Evolutionary discoveries could now be made throughout the lives of organisms. This was an immense improvement over the evolvability of the genetic evolutionary mechanism. As the modelling capacity improved, it began to make the genetic mechanism redundant. The genetic mechanism would take many generations to produce an adaptation to an environmental change. It would usually take many different genetic changes in many different individuals to find a better adaptation. But mental modelling could discover the same adaptation during the life of a single individual. Within a generation the discovery could spread to all members of the population. Modelling can operate far more quickly than the genetic mechanism. As knowledge accumulates and mental models improve, the genetic mechanism is increasingly pre-empted by mental modelling\textsuperscript{19}. The genetic mechanism plays less and less of a role in adapting the organism.

But of even greater significance is the potential ability of mental modelling to take into account much wider consequences of possible adaptations than can the genetic mechanism. The genetic mechanism is largely limited to discovering adaptations that provide benefits during the life of the organism. If an adaptation pays off during an organism’s life, it will enable an organism to pass more genes to the next generation. But this is not the case if the adaptation produces evolutionary benefits only for future generations, and none during the organism’s life. The gene for such an adaptation is likely to die out before any longer-term benefits accrue.

In contrast, the modelling capacity enables an organism to take into account processes and events that unfold over longer time scales than its life. In particular, it can plan its adaptation in the light of the longer-term evolutionary trends and patterns discussed in this book. It can choose adaptive strategies that will contribute to the evolutionary success of its descendants and of its species. And the organism can support the formation of managed cooperative organisations which ensure that, as far as possible, it will capture the benefits of its support for future evolutionary success.

As we have noted, the only organism on this planet that has a well-developed capacity for mental modelling is humanity. We use this capacity to plan ahead, imagine alternative possibilities, invent and adapt technology, build structures such as houses and roads, radically modify our external environment for our adaptive goals, establish long-term objectives, imagine how we might change the world, develop strategic plans, design projects and successfully undertake activities that pay off only in the future, such as plant crops and feed animals. We undertake scientific and other research so that we can develop models that are more accurate, take into account the effects of our actions over wider scales, and predict the consequences of a wider range of possible acts and interventions in our environment. And we use language in its various forms to transmit knowledge between individuals so we can all use the best models to guide our adaptation. The result is an evolving culture of adaptive knowledge that grows from generation to generation and that enables humanity to progressively improve our evolvability by producing better models.

And we are on the threshold of developing the capacity to do something that no other organism on this planet has been able to do: to consciously use our modelling of the direction of evolution to increase our chances of participating successfully in future evolution. We are in the process of developing complex mental models of the direction of evolution. These will show what we will have to do individually and collectively to contribute to the future evolutionary success of humanity.

But being able to mentally model our evolutionary future does not mean that we will want to use these models to guide our behaviour. We will be like the band of hunter-gathers that we visited in our imagination in Chapter 1: they knew what they had to do for future evolutionary success, but did not want to do it. Their existing behavioural goals and predispositions clashed with what they would need to do to achieve future success. Simply knowing that they had to change their behaviour for future success did not make
them want to do so. Likewise, rather than embrace evolutionary objectives, many of us will prefer to continue to pursue the values and goals established in us by past evolution. We will continue to use our energies to seek social status, self-esteem, power, wealth and the other goals that currently bring us emotional rewards.

The behaviours that will get us these emotional rewards will often clash with what we would have to do for future evolutionary success. As we have seen, our existing emotional reward system has been established by inferior and shortsighted evolutionary mechanisms. These mechanisms are blind to the long-term evolutionary consequences of our acts. They are unable to give us the emotional goals needed for future evolutionary success. If we are to be motivated to embrace evolutionary objectives, we will have to develop new psychological skills. We will need skills that enable us to free ourselves from the dictates of our pre-existing emotional reward system. We will need skills that enable us to find motivation and satisfaction in whatever forms of behaviour are needed for us to contribute to the successful evolution of life in the universe. Our task in the next two Chapters is to identify the new psychological skills we will need, and how they might be developed.
Organisms that can build complex mental models have the potential to model and understand the evolutionary processes that have formed them and that will determine their future. Once they accumulate sufficient knowledge about these evolutionary processes, they will be able to see their evolutionary future. Potentially, the organisms will be able to use this evolutionary knowledge to decide how they will adapt as individuals and collectively. The organisms will continue to test possible adaptations against their ability to satisfy shorter-term material and social needs. But they can also use their modelling ability to test adaptations against their evolutionary effects. This will enable them to choose adaptations that are also consistent with longer-term evolutionary success.

The development of such a capacity is a major step forward in evolvability. An organism that can see what is needed for future evolutionary success and can use this knowledge will be better at evolving. It will do better in evolutionary terms than an organism that is blind to the longer-term evolutionary consequences of its acts, and that is unable to consciously target its actions at future evolutionary success. Once life becomes conscious of its own evolution, its evolvability can improve significantly.

An organism that is unable to model evolutionary trends will be limited to optimising its behaviour only for the shorter-term effects of its actions. The organism’s adaptive mechanisms will be able to discover behaviours that are successful only when the more immediate effects of the behaviour are assessed. The organism will be unable to take account of the longer-term consequences of actions that occur beyond the life span of the individual. As a result, the organism is likely to establish adaptations that are maladaptive when their longer-term effects are considered. And they will fail to discover adaptations that sacrifice shorter-term interests to achieve greater long-term evolutionary success. An organism that can take into account the likely future evolutionary consequences of its actions will achieve greater evolutionary success than one that must rely on the genetic evolutionary mechanism and other
adaptive processes of more limited scope.

Humans are rapidly accumulating the knowledge to model the future evolutionary consequences of our behaviours. As outlined in earlier chapters, we are beginning to see the broader direction in which the evolution of life progresses. We are beginning to see what humanity must do if we are to participate in future evolutionary progress. Successful participation in the future evolution of life means we must continue to form cooperative organisations of larger and larger scale. To enable these organisations to fully explore the immense benefits of cooperation, they must be managed as far as possible so that individuals capture the effects of their actions on others, and therefore treat the other as self. And the organisations must be structured so as to maximise their evolvability. When humanity forms a unified, managed organisation on the scale of our planet, the planetary society must develop evolutionary mechanisms that enable the society to adapt not only for the inside/now, but also for the outside/future. A society whose adaptive ability is limited to tuning its economic and social systems for internal efficiency will not be successful in evolutionary terms. The society must also include mechanisms that enable it to adapt as a whole in relation to events outside the planet, whether the events arise from living or non-living sources.

Once we develop comprehensive models of larger-scale evolutionary processes and trends, we will see in detail what we must do if we want future evolutionary success. But how motivated will we be to want future evolutionary success for humanity? Will we want it enough? If future evolutionary success means behaving in ways that clash with our more immediate material and social needs, will we sacrifice these to continue to pursue future evolutionary success?

To be more specific, how ready are humans to put the interests of a planetary organisation ahead of those of our nation, ethnic community, and religion? Will we abandon any belief, prejudice and value that might stand in the way of our support for a truly global human society in which all individuals of all races and backgrounds are treated equally? What if this means a reduced standard of living? Will we accept and support the development of a capacity for the planetary society to adapt for the outside/future if this means a lower level of satisfaction of our immediate material, emotional and social needs?

The mere development of the capacity to use mental models to understand evolutionary trends will not make us want to adapt in the ways needed for future evolutionary success. By itself, it will not motivate us to put evolutionary success ahead of all our other adaptive goals and motivations. This is because our current goals and motivations are produced by our pre-existing internal adaptive processes, including by our emotional system. And these fail to take account of the longer-term evolutionary consequences of our actions. They have been established by shortsighted evolutionary mechanisms. Our existing adaptive processes have not evolved to reward and motivate the behaviours necessary for future evolutionary success.

When mental modelling is first developed, its main benefit is that it enables us to discover better ways to satisfy our pre-existing objectives and motivations. It helps us to find better means to our ends; it does not establish the ends themselves. Our modelling capacity has enabled us to develop sophisticated technologies and other ways of intervening in our environment. But these technologies serve our pre-existing goals and motivations. If we had different emotional goals and motivations, our technology would be different, as would our systems of government and other social arrangements.

The important point is that our existing objectives and motivations have been established by evolutionary mechanisms and adaptive processes that do not take into account evolutionary effects beyond the life of the organism. Obviously, these objectives clash with those that we would need if we were to pursue longer-term evolutionary success for humanity. So if we use our existing objectives and motivations to decide whether we want to pursue evolutionary objectives, we will decide against doing so. We will not feel motivated to do all that is necessary for future evolutionary success.

An organism whose motivations and objectives fail to take into account the evolutionary effects of its actions will not value objectives that do. Instead, the organism will use the immense adaptive capacity unleashed by mental modelling to get better and better at serving the goals of its existing internal reward systems. It will not matter that these were established by limited and flawed evolutionary mechanisms and adaptive processes. When the organism discovers technological advances of great power such as genetic engineering and artificial intelligence, it will use them to serve motivations and objectives that ignore its longer-term evolutionary needs. The same will apply to the organisms’ systems of government.
and other social arrangements. They will not serve the longer-term evolutionary interests of the organism. No matter how sophisticated its technology and social arrangements, the organism will not achieve evolutionary success. It will get better and better at achieving the wrong ends.

This evolutionary difficulty is likely to be struck by any organism that develops a comprehensive capacity for mental modelling. It will eventually be able to model and understand the larger-scale evolutionary trends that will determine its future evolutionary success. It will know what it has to do to continue to participate successfully in the evolution of life. But, initially, at least, it will not be motivated to do these things. Instead, it will continue to be motivated to use its growing knowledge of the effects of its actions to serve only its pre-existing objectives and motives.

But to continue to be successful in evolutionary terms, an organism must overcome this difficulty. To make a significant contribution to the evolution of life in the universe, an organism must be able to form highly cooperative and highly evolvable organisations on the scale of planets, solar systems, and galaxies. An organism will fail to be relevant to future evolution if it remains unorganised on a single planet, serving objectives and motivations established by flawed and shortsighted evolutionary mechanisms. We can be sure that the organisms that make a significant contribution to the future evolution of life in the universe will be those that develop a capacity to motivate themselves to pursue evolutionary objectives. Future evolution will belong to organisms that can free themselves from the goals and objectives of their biological and social past. The organisms that end up managing the matter, energy and living processes of large tracts of the universe will be those that develop the ability to adapt in whatever ways are required for evolutionary success, unrestricted by the goals and objectives implanted in them by earlier evolution. Those that do not develop this ability will be failed evolutionary experiments.

How can this evolutionary difficulty be overcome? Can evolution change the motivations and goals of an organism to align them with the dictates of future evolutionary success? Repeatedly during the past evolution of life on earth, the genetic evolutionary mechanism has significantly changed the internal adaptive goals of organisms. The cells that grouped together to form multicellular organisms had quite different adaptive goals to the solitary single-celled organisms from which they evolved. The amphibians that moved on to the land had very different internal goals to the fish that were their ancestors. And complex new internal reward systems were needed to motivate multicellular organisms to form social groups.

In all these cases, the new adaptive objectives were established by the genetic evolutionary mechanism. Genes that produced the goals that were consistent with the new form of life were favoured by natural selection. But the genetic mechanism is unable to overcome the specific evolutionary difficulty that confronts us. The genetic mechanism is largely limited to establishing features that pay-off during the life of the individual. Genetic evolution finds it very difficult to establish features that benefit only future generations. A gene that does not advantage the individual that carries it, but helps only future generations, will soon die out. This is true no matter how large the evolutionary benefits the gene delivers to future generations. The genetic mechanism cannot look far enough ahead to establish the motivations and objectives that are needed to produce longer-term evolutionary success.

Of course, this evolutionary difficulty could be overcome somewhat if the organisms were managed as members of a cooperative organisation. The management of such an organisation could redistribute benefits so that organisms that contribute to the future evolutionary success of the organisation are immediately supported and rewarded. This would align the shorter-term interests of the organisms with their longer-term evolutionary interests. But organisms that encounter this evolutionary difficulty will not want to organise themselves in this way. Organisms will invest in forming an organisation that produces longer-term evolutionary benefits only if this is consistent with their motivations and objectives. If they are not already motivated to pursue longer-term evolutionary goals, they will not invest in an organisation that is designed to assist them to do so.

The genetic evolutionary mechanism is unable to hard wire us now with the motivation and goals needed for longer-term evolutionary success. Evolution will not rewire the hardware of our brains and nervous system to realign our motivations and goals with longer-term evolutionary objectives. Does this mean that humanity has no alternative but to forever use its capacity for mental modelling to pursue our pre-existing motivations and goals, even though this would condemn us to future evolutionary irrelevance? Or is there another possibility? Can our motivations and goals change through modifications to our
psychological software? Is it possible for humans to learn to reorganise ourselves psychologically so that we acquire the capacity to consciously choose our motivations, likes, dislikes, goals and objectives? Through our own psychological efforts can we learn the new ways of thinking and feeling that are needed for future evolutionary success?

To begin to answer these questions, we need to look more closely at the sort of psychological capacities that we would have to develop, and consider their feasibility. If we are to free ourselves from our biological and social past, we would have to develop the ability to find motivation and emotional satisfaction in whatever we have to do to pursue evolutionary objectives. This would mean, for example, that we would have to be able to drop our emotional attachments to any ideas, attitudes, beliefs, norms, values, religious systems and moral principles that were inconsistent with future evolutionary success. And we would have to be able to continually change our motivations and our likes and dislikes to fit in with whatever is required for future evolutionary success.

Ideally we would develop the ability to manage our motivational and emotional systems so that we could choose what it is that we want to do. Then whatever actions were demanded by evolutionary success, we could find them rewarding and satisfying. Once we could do this, we would be able to pursue future evolutionary success without sacrificing our shorter-term interests. And we would be able to transcend our biological and social past, able to modify the objectives and motivations established by this past where necessary, and able to choose new values and objectives consistent with evolutionary success. Each of us would become a self-evolving being.

This would be made easier if we could form human societies that redistribute benefits to reward behaviours that help achieve future evolutionary success. The ideal would be to align both our internal psychological reward systems and the external reward systems established by the society with evolutionary objectives.

Will humans change psychologically in the ways necessary to meet this ideal? Can we develop the psychological tools that would enable us to make this major improvement in evolvability? Will we be able to establish evolutionary success as an ultimate objective, and align all our pre-existing adaptive systems with this goal, ensuring that whatever behaviour will produce evolutionary success will be rewarded by our internal reward systems? Can we escape our biological and social past, and become true self-evolving beings?

In the remainder of this Chapter and in the next, I will demonstrate that as the modelling capacity of an organism improves, the organism will tend to undergo a sequence of psychological transformations. These changes move the organism toward making this great improvement in evolvability. Humans have been progressing through this sequence, and can be expected to continue to do so. Although there is no guarantee that humanity as a whole will finally takes this great step in evolvability, the changes currently under way are increasingly making it possible.

This approach immediately raises a key question: how will improvements in our modelling capacity help us develop the ability to align our motivation and reward systems with evolutionary objectives? Improvements in our ability to model accurately the effects of our actions on our external environment can obviously improve our capacity to discover effective adaptations. But how can it contribute to changing the objectives and values that these adaptations serve?

It can do this when the modelling capacity is turned inwards, and is used to model the individual’s own internal adaptive processes. Our ability to mentally model our external environment has enabled us to manage the world outside us, and to intervene in it to achieve our objectives. In a similar way, the development of a capacity to form mental representations and models of our own internal adaptive systems can enable us to manage them and to modify their operation. Once we become aware of our internal thoughts, motivations and emotional states, we can observe how they operate, what influences them, and what adaptive effects they have. We can use this knowledge to build mental models and representations of the operation of our mental, emotional and physical adaptive systems. As an individual learns to do this, the operation of these systems will increasingly become an object of consciousness. The individual can develop the ability to mentally stand outside his thoughts, motivations and emotional states, and gain freedom from them. Psychologically the individual separates into two parts—one that observes, and another that is observed. He no longer experiences himself as his thoughts or emotions. Increasingly he can stand back from them and mentally watch how they unfold, think about how they
will operate and how effective they will be, and consider how they might be modified in the interests of other objectives or to improve their effectiveness. The individual’s internal thoughts and emotions become like objects of consciousness in his external world—he will use mental models to discover how he can manage them for his own ends. Eventually, the observing part of the individual’s psychology develops a comprehensive capacity to manage the other part.

This psychological capacity for self-management will be reinforced and strengthened as it discovers better ways to adapt the individual. It will find more and more ways to do this as the capacity for mental modelling improves. Mental modelling will increasingly improve at taking into account the effects of alternative behaviours, particularly the effects over longer time scales. As mental modelling accumulates knowledge, its ability to discover effective adaptations will increasingly surpass the ability of the pre-existing adaptive systems. Where our mental modelling sees opportunities to improve our adaptability, self-management will modify the operation of the pre-existing adaptive arrangements to implement the improvements. The adaptive benefits delivered by self-management will drive its improvement.

But competent self-management will not completely override and replace the pre-existing adaptive systems. Instead, it will modify them as far as is necessary to realign their goals with longer-term evolutionary objectives. Self-management operates like a new visionary Chief Executive Officer who takes over a corporation and implements for the first time a forward-thinking strategic plan. The elements of the strategic plan are designed to ensure that the company will be competitive and successful in the future despite changes in technology, markets and competitors. The plan models the future external environment of the company, and uses this to identify how the company should change the way it operates in order to continue to be successful.

The challenge for the CEO is to change the way the corporation operates so that it serves the new direction and goals. In most circumstances, he will be able to change the behaviour of the company to implement the plan without replacing or changing the nature of the employees. The employees will continue to have the same personal interests, objectives and internal motivations. But, if the strategic plan is implemented successfully, they will have to behave quite differently to before. Their behaviour will now also have to serve the ultimate objective of long-term success for the company. For this to be achieved, the interests of the employees will have to be aligned with the longer-term objectives of the company.

The CEO can achieve this by changes to the ways in which employees are managed, rather than by changes to their internal adaptive systems. The new management will create a new pattern of incentives and disincentives and other environmental conditions for employees. These will ensure that employees find it personally rewarding to act in ways that serve the corporation’s objectives. Within the internal environment of the corporation, when employees follow their personal interests, objectives and internal motivations, they will contribute to the effective operation of the company.

In the same way, successful self-management does not generally override, repress or abandon the pre-existing mental, emotional or physical adaptive systems that currently adapt us for shorter-term goals. The pre-existing systems are effective at adapting us to meet shorter-term requirements. So all that self-management needs to do is to modify the operation of the pre-existing systems only in so far as is necessary to take into account longer-term considerations. In this way it can align their operation with the longer-term goal of future evolutionary success.

We will now look in more detail at how improvements in modelling ability have driven improvements in the psychological evolvability of humans. In particular, we will look closely at how the continuation of these improvements tend to produce in humans a psychological capacity for self-management. When it is fully developed, this capacity would enable humans to manage their pre-existing adaptive systems so that they could find motivation and psychological satisfaction in pursuing longer-term evolutionary objectives for humanity, whatever this may entail. They would manage their internal emotional system so that it no longer rewarded behaviour that was inconsistent with future evolutionary success. Evolutionary self-management would allow humans to transcend their biological and social past so that they are free to adapt in whatever ways are necessary to achieve future evolutionary success.

It is useful to divide modelling ability into three broad levels. The first, linear modelling, is limited in the complexity of the processes that it can model successfully. It cannot model a complex system in which a large number of components mutually interact. It can deal only with systems that can be analysed
into components that interact in chains of causation that unfold step by step. It can understand systems that can be analysed by logical reasoning. So it is capable of modelling the outcome of the interaction of a small group of people over short time frames, the working of mechanical devices, and the movements of the planets about the sun.

In contrast, systemic modelling can successfully model the unfolding through time of complex systems with many interacting components. So it can model and understand a large social system, a flexible international corporation, or an ecological system. The third level, evolutionary modelling, is able to model the evolution of extremely complex systems over large scales of space and time. In particular, it can model the large-scale evolutionary processes that have formed us, and that will determine the future evolutionary success of humanity.

The progressive improvement of modelling capacity through these three levels is driven by the greater adaptive abilities that the improvements bring the individual. Individuals who improve their modelling will be better equipped to discover adaptations that satisfy their needs and goals, whatever these happen to be. As individuals proceed through the levels, they will be able to model the effects of their actions more accurately, understand the effects on their environment of a wider range of possible actions, and will be able to model the effects of their actions over wider and wider scales of space and time.

In part, these improvements in modelling capacity will result from the progressive accumulation by humanity of knowledge that is more detailed and that relates to processes that unfold over wider scales in space and time. And in part they will result from enhanced mental skills, and from technologies that aid human mental processes such as writing, diagrams, computer simulation, and artificial intelligence. At any point in human evolution, individuals will differ in their access to this knowledge, and in their ability to use it. So at any point in human evolution individuals will have different modelling capacities. And individuals may be able to apply a high level of modelling ability to some of their behaviours, but a lower level to others. The levels of modelling capacity are not mutually exclusive.

Individuals can use these improvements in modelling capacity to discover better ways to modify their external living and non-living environment. But as I have foreshadowed, individuals can also use the improvements to enhance the management of their internal adaptive processes. As the modelling capacity develops, it will be able to improve the pre-existing internal adaptive processes because it will be able to take account of effects that these processes are blind to. So, as we shall see in detail, each level of modelling not only corresponds to a particular level of ability to discover adaptations that impact directly on our external world. It also corresponds to a particular level of ability to self-manage.

We will now look in more detail at each of the three levels of modelling capacity. For each level, we will look first at how an organism can use it to mentally represent and understand the effects of the organism’s interactions with its external environment. Then we will look at how an organism can use the modelling capacity to represent and manage its own adaptive processes. In the remainder of this Chapter, we will deal with linear modelling. Systemic and evolutionary modelling will be considered in detail in the next Chapter.

**External Linear Modelling**

The simplest form of modelling we will consider is linear modelling. It can be used by an organism to mentally model and predict the effects of its actions on its external environment. The ability of linear modelling to predict the effects of alternative behaviours will depend on the extent of knowledge used in the models. As organisms accumulate knowledge across the generations, they will be able to model with greater accuracy the effects across wider scales of space and time of a greater variety of possible actions. The actions that they model will eventually include the use of technology to produce specific adaptive effects on their environment. As knowledge accumulates, the organisms will become increasingly conscious of their external environment and how they can manipulate it to achieve their adaptive goals.

But linear modelling is limited in the complexity of external events and processes that it can model and understand successfully. It models how processes will unfold through time by following chains of cause and effect. It looks for causal relationships between events, and simulates what will happen in a particular set of circumstances by tracing how events will cause other events in a step-by-step manner. Linear modelling breaks processes down into parts, and looks for how simple step-by-step interactions
between the parts can be used to predict how the process will unfold under different conditions. Analysis, reduction and logical deduction are its basic tools.

Linear modelling can work accurately and effectively for processes that are simple. But it is quickly overwhelmed as complexity increases. It is of limited use for understanding processes consisting of many interacting components that all contribute to how the process unfolds. These processes cannot usually be analysed into step-by-step chains of cause and effect. Linear modellers are unable to understand or predict the behaviour of these more complex processes. As a result, linear modelling is also limited in relation to the scales of space and time over which it can model the effects of possible adaptations. Over larger scales of space and time, most processes interact with other processes and become far too complex to understand by linear modelling. For these reasons, logical step-by-step analysis is notoriously ineffective for modelling and understanding the unfolding of complex systems such as human economic systems, ecosystems, human history and the mind and other complex adaptive systems.

External linear modelling is the mental capacity we use most often as we adapt consciously in our day-to-day life. It enables us to understand simple processes and to predict their future behaviour. We have built and designed our technology, our housing and our gadgets so that they can be readily understood and manipulated with linear modelling. The environment we have built around us is far more simple and mechanistic than our natural environment. It has been designed by linear modellers for linear modellers. In contrast, we need a capacity for systemic modelling if we are to manipulate our natural environment successfully.

Linear modelling is also the basis of most science as it is currently practised. The scientific method has been extraordinarily successful at understanding simple, linear processes and parts of more complex systems that can be reduced to simple processes. But the traditional scientific approaches have had little success in dealing with fields that cover complex systems such as ecology, psychology, economics, sociology and the other social sciences.

Humans that are capable only of linear modelling are unable to manage large complex organisations competently. In order to manage complex human social groups successfully, a manager such as a king or other ruler must be able to mentally model the effects on the group of alternative acts of governance. He (or his associates) must be able to mentally simulate the effects of his management on the group. For this reason, until at least some humans had moved beyond the limitations of linear modelling, humans were unable to form complex cooperative organisations managed by external managers. To be competent, external managers must be capable of some form of systemic modelling. It was not until about 10,000 years ago that human societies organised by rulers or other external managers were formed.

External linear modelling is used by the individual to form mental representations of himself, his physical, emotional and mental characteristics, and his skills. These mental representations are essential if the individual is to model effectively how he might interact with his external world to achieve adaptive goals. He must be able to include himself and his capabilities in his external models. But an individual who is limited to external linear modelling will not model how his mental and emotional characteristics might be changed. Without a capacity for internal modelling, he can model different ways of behaving, but not different emotional reactions and modes of thought. He will tend to treat his emotional responses, motivations and ways of thinking as fixed and given. They will not be objects of consciousness that the individual believes he can change.

The linear external modeller looks out at the external world and uses his models to search for ways of acting on the world to satisfy his adaptive goals. But in these models, the goals established by his internal reward systems are not treated as variable. Without a capacity for internal modelling, he has little ability to mentally model how his goals might be changed, and what effects these changes might have. He is largely unaware of the possibility of changing the key aspects of these adaptive processes, cannot consciously choose to modify them, and tends to take them as given.

But as the capacity for mental modelling improves, it inevitably will begin to clash with the organism’s pre-existing adaptive systems. As organisms accumulate knowledge, their mental processes get better at modelling the external world. They get better at predicting how they can act on their environment to achieve their adaptive goals. Eventually, their mental knowledge will be superior in some cases to the knowledge embodied in their internal reward system and other adaptive processes. Their mental models will enable them to take into account effects of their actions that their pre-existing systems are blind to.
They will see that acting in the way dictated by their emotional and motivation systems may be against their longer-term interests in some situations. For example, as we humans mature and learn more about the consequences of our acts, we become aware that in some circumstances it might be best not to respond to emotional impulses such as anger and sexual drives. We use mental modelling to see that acting immediately on these impulses may prevent us from gaining greater emotional satisfaction in the longer-term.

The external linear modeller will not be able to resolve easily these inevitable clashes between his mental modelling and his pre-existing adaptive processes. Earlier evolution will not have given his mental processes the capacity to manage his motivational and emotional systems. When the capacity for mental modelling first develops, it does not have the knowledge or ability to adapt the organism as competently as the pre-existing adaptive processes. To have given it the power to manage these processes before it was competent to do so would have been disastrous. Without the ability to manage his motivational systems, a linear modeller is unable to ensure that he will be motivated to implement any superior adaptations identified by his modelling. A linear modeller might be able to see longer-term advantages in particular actions, but will be unable to manage his internal adaptive processes so that he will find the actions emotionally satisfying. He will continue to be motivated and rewarded for the same actions as before. For example, we might see mentally that dieting is in our longer-term health interests. But this does not make fatty foods less tasty, or dieting pleasurable. And we might see that locking ourself in a room and studying will pay off eventually with a better job. But this does not make study satisfying, or our hobbies less enjoyable. We have little capacity to change these motivations and emotional responses to ensure that they support the findings of our mental modelling.

In order to do what is suggested by his mental modelling, the external linear modeller is likely to attempt to repress and override existing motivations and emotional feelings. This may enable him to improve on his pre-existing emotional responses in circumstances that are uncomplicated. It may pay to override emotional responses where the advantages are clear-cut. But the linear modeller is not well equipped to improve on his existing systems in more complex situations. The problem is that external linear modelling is not competent to assess the consequences of overriding emotional responses in most situations. It cannot model and therefore cannot understand the effects of choosing to ignore internal rewards or motivations. The linear modeller has no comprehensive understanding of why his emotional system provides rewards and motivations for particular behaviours but not others, and why it produces various emotional states in particular circumstances. The individual is not conscious of why his adaptive systems operate in the way they do. The individual is therefore in no position to use mental modelling to decide whether to override or repress particular motivations or internal rewards.

The problem is made worse because the individual does not know that his modelling capacity is limited in these ways. He is not conscious of the limitations of his consciousness. To know these, he would have to have modelled his modelling capacity. He would have to have a capacity for complex mental self-reflection. But he does not have this ability. The individual will be unaware that his mental awareness is grafted on top of a sophisticated and complex hierarchy of pre-existing adaptive processes that routinely and continually solve adaptive problems that he has not even begun to understand.

So an individual who uses only external modelling to determine how he adapts and behaves will have difficulty in integrating his conscious, mental adaptation with his pre-existing emotional and physical adaptive systems. He will continually make mental decisions that serve some internal goals but conflict with others. And the mental models he uses to make these decisions will not have the knowledge or ability to make them competently. He may try to use his mental modelling to decide whether or not to respond to particular emotions, motivations, and physical needs, but he will have little knowledge of why these exist or what specific adaptive functions they perform.

A typical example of the late 20th century is an individual who single-mindedly pursues career goals, repressing and ignoring the internal physical and emotional signals that indicate he should also serve other adaptive needs. And in extreme cases, if the individual continues to ignore stress and depression, the result is physical, emotional and mental breakdown.

The problem will worsen as the capacity for external linear modelling grows. As knowledge accumulates, the growing ability of modelling to discover effective adaptations means that it will be used increasingly to determine how the individual behaves. More and more, mental modelling will guide the
individual on how to achieve the adaptive goals established by his internal reward systems. The result will often be that the individual ignores and represses some of the motivations and needs associated with his pre-existing adaptive system, even though these may be essential for producing behaviour and adaptations that are critically important for the effective operation of the individual.

The need to integrate mental modelling with the pre-existing physical and emotional adaptive systems is a problem that will be encountered by any organisms that begin to develop a capacity for mental modelling. Wherever in the universe mental consciousness emerges, it will initially clash with the processes that have adapted the organism up until then. As the mental system develops, it will be used increasingly to control and run a complex, multi-level organisation that it does not understand or appreciate. It will have ultimate power over a complex system it is only dimly aware of. Initially it will have the power but not the wisdom to manage the organism, and it will not know itself well enough to see its own limitations. On every planet where mental consciousness emerges and develops, there will be a demand for personal growth programs that promote the development of psychological skills that can deal with this problem.

The organisms that contribute most to the future evolution of life in the universe will be those that successfully overcome the problem by developing the higher levels of modelling capacity that we will discuss in the next Chapter.

The linear modeller is like the Chief Executive Officer of a large modern corporation who develops a comprehensive vision of what the corporation must do for future success, but has little understanding of the internal processes that adapt the corporation. He has control over the direction of the company, and knows where it should be headed. The CEO has good mental models of the external environment of the company, but lacks effective models of its internal workings. He has little understanding of the internal patterns of incentives and disincentives that the corporation creates for its employees, and how this impacts on their motivations and work performance. He has little knowledge of how employees will react to particular changes and management actions.

When he sets out to change the way the corporation operates, such a CEO is likely to fail to motivate his employees to go with his new vision. Announcing the changes will not be enough, because this will not change the pattern of incentives and disincentives created by the internal environment of the firm. It will not change the corporation’s pre-existing internal reward and motivation systems. Employees will not change their behaviour if they are asked to do things that do not pay off within the corporation, and to stop doing things that are rewarded. For example, asking employees to take more risks will not produce much change if they have discovered it is best to avoid risk because mistakes reduce promotional opportunities. And if the CEO attempts to override these pre-existing reward systems coercively, he will produce the internal double binds, stresses and low morale that is common in poorly managed modern corporations.

If the CEO is to implement his new vision successfully, he and his executives have to know sufficient about the adaptive characteristics of the organisation to see how the pattern of incentives and disincentives should be changed to bring the employees along with his vision. The operation of the pre-existing internal reward systems of the corporation will have to be modified. Changes will have to be made that align the interests of all levels of the organisation with the future vision, but without disrupting functions and behaviours that will continue to be needed by the organisation. Unless the CEO develops the capacity to do this, he can have a vision and he can explain it to employees, but he will not be able to implement it effectively. Employees will continue to adapt to the incentives and disincentives that they continue to encounter. If a capacity to model the future is to be used to guide the adaptation of the corporation, it must be integrated with the pre-existing processes that adapt the corporation on a day-to-day basis. And to achieve this, the CEO must have effective models of the internal operation of the company. Without these models, he cannot manage the pre-existing processes to realign them with his vision.

The need to integrate the capacity for conscious mental modelling with the pre-existing adaptive systems of the organism can be expected to drive a long sequence of psychological evolution. In this sequence, the modelling capacity will progressively develop comprehensive models of the pre-existing adaptive processes and of their adaptive effects. It will develop the ability to manage them where there is advantage in doing so. Significant advantages can be expected where self-management is able to improve the pre-existing adaptive processes. At first, the modelling capacity will not have the knowledge or wisdom to do this. But as knowledge accumulates, the modelling capacity will increasingly be more
effective at discovering better adaptations than the pre-existing processes. It will be more accurate, and be able to assess longer-term consequences. Psychological processes will have a considerable advantage if they can use this modelling capacity to manage and revise the pre-existing processes to produce better adaptation.

**Linear Self-Management**

The first major step in the evolution of self-management in humans began with the use of linear modelling to model internal adaptive processes. As the capacity developed, mental, emotional and physical adaptive processes became objects within mental models, and therefore objects of consciousness. Instead of the individual experiencing himself as his thoughts and emotional states, he could experience himself to some extent as being outside them, and able to treat them as objects of consciousness that could be influenced. His thoughts and emotional processes were no longer taken as entirely fixed and given.

But the limitations of linear modelling also restricted the level of self-management that it could support. Linear modelling can understand only simple processes that can be effectively represented by chains of cause and effect. It is unable to model complex systems, and is largely limited to modelling the effects of possible adaptations over relatively small scales of space and time.

As a result, linear modelling is able to model and understand only simple mental, emotional and physical adaptive processes. It can model only those that take into account effects that can be followed by linear modelling. If a particular adaptive process deals with circumstances that cannot be modelled and understood by linear modelling, linear modelling will be unable to competently model the consequences of modifying the adaptive process. It will not be able to understand why the adaptive process is structured the way it is, or to follow the effects of modifying it.

Linear self-management is particularly limited at understanding the emotional system. As we have seen, much of the emotional system was established by natural selection to provide internal rewards for behaviours that adapt us in our social life. The adaptive problems we encounter in our social interactions are often complex, and cannot be fully understood by linear modelling. The reasons why our emotional systems reward particular behaviours and not others are often outside the understanding of a consciousness that uses only linear modelling. And if linear self-management attempts to modify and improve upon these emotional processes, it will not do so effectively.

If linear self-management over-reaches itself and attempts to manage tightly all of the organism’s adaptive processes, it can produce a personality similar to the parts of the external environment that are designed and built by linear modellers. The personality will tend to be mechanistic, overly simplified, inflexible and rigid, and ultimately maladaptive.

For these reasons, a linear self-manager will be unable to fully integrate his mental modelling with his pre-existing emotional and physical systems. He will be unable to use his mental modelling to competently manage the pre-existing systems, and unable to resolve the conflicts that inevitably arise. As we will see in detail in the next Chapter, it is not until an individual can develop more complex capacities for self-management that this integration can be achieved.

However, linear modelling can be particularly effective at modelling linear mental processes. This is because these mental processes and the environmental circumstances that they model are simple enough to be dealt with adequately by linear modelling. Linear modelling has the potential to model itself. An individual who is capable of linear modelling has the potential to improve his adaptability by developing the capacity to manage his own mental adaptive processes.

Individuals capable of a high degree of linear self-management are able to mentally stand outside their thoughts, treating them as objects of consciousness that can be examined, analysed and influenced. They can accumulate knowledge about rules of logical inference and deduction, and can develop the ability to use these to test the validity of their thought processes, discarding those that do not meet the tests. They are able to critically evaluate their own thoughts and ideas.

Linear self-managers can develop the ability to learn how to learn. They can analyse the thought processes and mental strategies they use to solve problems, mentally model alternative strategies, and implement those that are shown by their modelling to be more effective. In this way they become increasingly conscious of their mental processes, and use the power of mental modelling to search for
improvements in their mental processes.

The capacity to model their own mental processes may also enable linear self-managers to deal with thought processes that are maladaptive, such as unproductive worry. But this capacity can itself be used maladaptively. The individual may discover that he can manage his thoughts in a way that will produce desirable feelings and avoid unpleasant emotional states, even when he is poorly adapted to his external environment. For example, he may be able to think positively in the face of impending disaster, or learn how to treat the external world as an illusion, reducing its ability to produce undesirable emotional states. This maladaptive self-management short circuits the ability of the internal reward system to motivate behaviour that enables the individual to function more effectively in its external environment.

As the capacity for internal linear modelling develops, it will also undermine a number of the adaptations that organise cooperative social behaviour amongst humans. We saw in Chapter 7 that distributed internal management can organise the members of a band or tribe to behave cooperatively. This management consists of a set of norms and inculcated behaviours that are reproduced in each member of the group. The inculcated behaviours predispose individuals to cooperate in situations where it otherwise would not be in their individual interests to do so. Before the rise of rulers and other external managers about 10,000 years ago, cooperative human groups were organised by internal management of this type. Humans generally lived in small bands that were not controlled by a chief or other ruler. The norms and inculcated beliefs that organised these cooperative bands were often entrenched in myths and religious systems.

Internal linear modelling undermines these norms and religious beliefs because it finds no rational basis for them. It is largely unaware of their complex evolutionary function in the formation of cooperative organisation. Instead it sees them as illogical and irrational beliefs that stand in the way of the individual achieving his more immediate physical and emotional goals. The linear modeller is not conscious of the fact that the norms and religious beliefs that are rejected by his limited modelling capacity are adaptations that have essential evolutionary functions.

Once the linear modeller abandons these belief systems, he is left with physical and emotional goals that are largely self-centred. The internal linear modeller is fundamentally ego centric, driven by goals that serve the functioning of the individual rather than the social group. The rise of internal linear modelling amongst humanity has produced the abandonment of religion and the rise of rationalism and individualism that we have seen in the last few hundred years of human history. It is only with the further evolution of the modelling capacity through the development of systemic and evolutionary modelling that the individual will eventually become conscious of the need to reinstate behaviours that produce cooperative organisation. In the next Chapter we will deal in detail with the characteristics of systemic and evolutionary modelling, and look at the superior capacities of self-management that they can underpin.
External Systemic Modelling

Linear modellers cannot understand and predict the behaviour of complex systems. Unless a linear modeller can analyse a process into step-by-step chains of cause and effect, he cannot mentally simulate the effects of his actions on the process. This is true whether the process is in his external or internal environment. The limitations of linear modelling mean that there are significant advantages to be had by the development of a capacity for systemic modelling. This ability enables individuals to mentally model their interactions with more complex processes such as social systems and ecosystems. Systemic modellers are able to understand and predict how social systems and ecosystems will unfold over time, and how they might be managed. Individuals with a capacity for systemic modelling are also able to model the effects of their actions over greater scales of space and time.

Because the systemic modeller can understand complex aspects of his external environment, he does not have to simplify them in order to be able to manage them. For example, he can manage and participate in social organisations that are not simplified by rigid codes of behaviour or mechanistic organisational structures. And a systemic modeller does not have to simplify his living environment into a monoculture before he can understand and manage it.

Systemic modelling is made possible by the acquisition of generalised mental schema that represent how various types of complex systems unfold and behave through time. Where the individual has a schema that matches a particular system, he can immediately envisage how the key processes of the system will behave. He immediately sees how the system as a whole unfolds over time, rather than having to follow the interactions of the parts of the system step-by-step.

Unlike a linear modeller, a successful systemic modeller does not analyse a system into its parts and then try to predict the behaviour of the system by seeing how the parts interact together in a step-by-step fashion. Where the mental schema match the system, the systemic modeller will see how the system will
behave at a glance, with a flash of insight or intuition.

As systemic modellers improve their ability, they accumulate schema of greater and greater complexity that enable them to model the effects of possible adaptations over wider and wider scales of space and time. They are able to take account of the effects of possible adaptations that linear modellers are completely blind to. But systemic modellers can continue to use linear modelling where it is useful. For example, they still use it where they do not have appropriate schema, and use it as they build up and adapt schema.

Because current science is largely founded on linear modelling, it has great difficulty in accepting and incorporating the findings and insights of systemic modelling. This is the case even where systemic modelling has proven to be indispensable for advancing science. Studies show that few of the great discoveries of science have been produced by linear, logical thinking. A high proportion originated from intuitive leaps made possible by systemic modelling. But before these insights gained scientific acceptance, they had to be translated into simple models based on linear chains of cause and effect. Until this was done, the discoveries were invariably rejected as unscientific.

Importantly, systemic modellers have the potential to manage complex cooperative organisations. They can model mentally how the organisation will respond to their management. They can choose to implement the management that is shown by their mental modelling to advance their interests and those of the organisation. The development of systemic modelling amongst some humans about 10,000 years ago made possible the rise of human communities managed by kings and other rulers.

But until the capacity for systemic modelling is turned inwards to further develop the capacity for self-management, systemic modellers tend to pursue the same kinds of values and goals as linear modellers. They are likely to have already developed a capacity for linear self-management. As a result, they probably have analysed and rejected the religious belief systems that were important in organising cooperation within earlier human societies. They will tend to be ego driven and self-centred, and use their enhanced adaptive ability to serve their existing internal physical and emotional goals. They are likely to use the enormous power of systemic modelling to seek narrow goals such as social status, power, feelings of importance, and sexual and other physical pleasures.

Systemic Self-Management

An individual can use systemic modelling to observe and understand his own adaptive processes, and to improve significantly his capacity for self-management. This will produce major adaptive advantages. We saw that linear self-managers are severely restricted in their ability to model the effects of changes to their pre-existing emotional and physical adaptive processes. This is particularly the case for the emotional system. It adapts the individual in complex social situations that cannot be understood by linear modelling. Systemic modelling is not limited in this way. The individual can use systemic modelling to understand the purposes of his existing adaptive systems, and to model the effects of changes to the systems, even where the effects are very complex.

So systemic modelling has the potential to enable the individual to better integrate his mental adaptation with his pre-existing emotional and physical adaptive processes. Using systemic modelling, the individual can begin to manage these adaptive processes to resolve conflicts between them and to ensure their goals are aligned with the goals pursued consciously by the individual. The greater ability of systemic modelling to discover better adaptation will be used to revise the operation of these pre-existing adaptive processes, ensuring that the wider and more complex effects of alternative adaptations are taken into account. Importantly this can include the use of self-management to revise motivations and goals established by the pre-existing internal reward systems. Increasingly, pre-existing motivations and emotional states will be seen as objects of consciousness that can be influenced. The individual will no longer see these as entirely fixed and given, but as increasingly subject to conscious choice.

For example, as an individual's capacity for internal systemic modelling develops, he will learn to recognise a wider range of his feelings and attitudes and understand how they affect his behaviour, and how this behaviour in turn affects others. So that he can improve his interpersonal skills, he will try out different ways of behaving in social situations, with the intention of building knowledge about his emotional responses and their effects. He is also likely to become aware that some of the emotional responses produced in him through his childhood experiences are maladaptive. For example, he may find that his adaptability is restricted because of a fear of change, a need for certainty and predictability in his
environment, or an inability to stand up against authority figures even when they are clearly unjust. He is likely to act to revise these inappropriate adaptations. For example, with or without the assistance of others, he may revisit the childhood experiences that produced the maladaptive responses, and use systemic modelling to see what responses would have been more appropriate in the circumstances. He can attempt to revise his psychology so that he would now respond in ways that would be more effective.

A systemic modeller might also attempt to educate his pre-existing emotional responses so that they operate more consistently with the broader understanding made possible by systemic modelling. For example, a linear modeller might tend to find fault and blame in others when they act against his interests, and respond aggressively in anger. In contrast, a systemic modeller may see that the actions of the others were an adaptive response to the circumstances in which they found themselves. The systemic modeller might instead respond by considering how the circumstances that produced the actions might be changed. The systemic modeller might see that blame, anger and aggression might serve no useful functions in these circumstances, and may even be counterproductive.

A systemic modeller might also attempt to ensure that his internal motivation and reward system supports the new adaptive behaviours and strategies that are shown by his modelling to be more effective. He might organise his life and his thinking to ensure he is motivated and emotionally rewarded as he implements these new behaviours and strategies.

Because systemic modellers have a much better understanding of the complex adaptive purposes served by their emotional system, they are also more able to use their emotional states as signals that they should pay more mental attention to particular needs. For example, instead of trying to repress and override feelings of depression, they are more likely to take the feelings as an indication that they need to seriously review their life style. The use of self-management to better integrate the mental and emotional systems means that each system will be used to enhance the adaptive capacity of the other.

As the capacity for internal systemic modelling develops, it will increasingly tend to undermine the individual’s self-centeredness. In part this will come about because the individual will begin to see that his particular motivations, goals and values have no absolute value or justification. He will find no valid reason to put them ahead of any other set of goals, and he will be unable to show that a life spent exclusively serving his particular goals and values is inherently better than alternative ways of life. These views will be strengthened as he develops the capacity to model the social processes that have helped to produce his particular set of motivations, goals and values. These models will show that his goals and other adaptive characteristics could have been very different. A different upbringing, different social conditions, a different culture, and he would have different wants and beliefs, and different likes and dislikes. This understanding will begin to undermine the individual’s belief that all his energies and adaptive capacities should be solely directed at satisfying his own particular self-centred reward system. It will also help him understand the different perspectives of others, and the causes of those differences. He will be less able to ignore and dismiss alternative perspectives.

Self-centeredness will also be undermined as the individual begins to model the social processes in which he is embedded over wider and wider scales of space and time. He will quickly become aware of his dependence on the effective operation of his social system. He will see that in many respects, he cannot achieve his personal goals unless the social system functions well. The systemic modeller will understand that in many instances, the interests of the social system coincide with his interests, and it is in his interests to promote the effective operation of the social system.

When his models of the social system can span historical scales of space and time, he will increasingly see himself and others as temporary. He will tend to see himself as just one of the enormous number of individuals who make up the social system at any time, and who each follow their particular dreams and goals for the relatively short period of their life. It is only the social system itself that will appear to be able to have any permanence and significance. From this perspective, a life spent solely serving self-centred internal rewards and motivations will appear particularly absurd. Such a life can contribute nothing to anything in the universe that has any chance of continuing in existence, or of having meaning in any broader context. This wider perspective can make it easier for the individual to find value in supporting the effective operation of his social system, or at least the part he interacts with most often. Alternatively, if the individual continues to live a self-centred life, the broader perspective can produce the existential despair that has been common in the 20th century. A wider perspective makes a self-
The development of a capacity for evolutionary modelling enables the individual to see the effects of his actions over even wider scales of space and time. An evolutionary modeller can model complex systems over evolutionary time scales. He has mental schema that enable him to predict how these systems evolve. The individual can model the effects of alternative actions on the likely future evolutionary success of humanity. He can identify evolutionary trends and future evolutionary events, and use this to see what humans must do to contribute positively to the future evolution of life in the universe.

The evolutionary modeller will see himself and human society as a product of evolutionary processes that have a past, present and future. He will understand that his values, beliefs and other characteristics have been produced by past evolution, and he will know why these take the form they do. The evolutionary modeller will see himself and his society as evolutionary work-in-progress. His mental models will show him that humanity is situated part way along a progressive evolutionary sequence, and he will see the future evolutionary possibilities and challenges that confront us. The evolutionary modeller will see what work he and others must do if humanity is to be successful in future evolution.

The evolutionary modeller will be aware that future success for humanity will require the progressive development of cooperative human organisations of larger and larger scale, and of higher and higher evolvability. And he will see that this will require the development of a new psychological capacity in individuals, evolutionary self-management.

But evolutionary modelling will not have a significant effect on the goals and objectives of humanity while it is used only to model the external environment. Until evolutionary modelling is turned inwards to model alternative adaptive processes, it will produce only mental, intellectual knowledge. External evolutionary modelling will not itself change the goals and values pursued by individuals. External modelling enables individuals to find better ways to achieve their adaptive goals, but it does not change those goals. External evolutionary modellers will have much the same goals, motivations and values as internal systemic modellers.

Evolutionary Self-Management

When turned inwards, evolutionary modelling has the potential to build on systemic modelling to provide the individual with a comprehensive understanding of his mental, emotional and physical adaptive mechanisms, the social and evolutionary processes that formed them, and the effects over social and evolutionary time scales of modifying their operation.

But will the individual want to exploit these potentials? Will he pursue evolutionary goals, and use self-management to align his pre-existing adaptive processes with his pursuit of evolutionary goals? Or will the individual continue to serve the internal reward systems that have been established previously by the genetic and social evolutionary processes?

We have seen how the development of internal systemic modelling can weaken the tendency of the individual to put his narrow personal satisfaction ahead of all else. But systemic modelling leaves the individual in no man’s land. It is unable to replace the weakened self-centred goals with new values and objectives. Internal evolutionary modelling can do this. It can produce psychological conditions within the individual that will increase the likelihood that the individual will adopt evolutionary objectives.

First and foremost, evolutionary modelling enables the individual to see the absolute absurdity of continuing to pursue his pre-existing goals at the expense of evolutionary objectives. With an evolutionary
The individual will see that his pre-existing goals are flawed and short-sighted, the product of inferior and limited evolutionary mechanisms. The individual will know that his pre-existing goals are evolution’s inadequate attempt to cause him to behave in ways that will bring evolutionary success. Once he has much more effective ways of consciously pursuing evolutionary success, he is likely to see it as absurd to continue to serve the flawed goals.

Second, evolutionary modelling enables the individual to see that humans do not have any choice about whether or not they will pursue evolutionary goals. Whether they serve the pre-existing goals, or use modelling to consciously pursue the objective of future evolutionary success, they will be serving evolutionary ends. The only choice they have is about how good a method they will use to pursue evolutionary ends. They can pursue evolutionary ends by serving pre-existing goals that were established by inferior evolutionary mechanisms. But their evolutionary modelling will tell them that these goals will not guide them toward evolutionary success in the future. Alternatively they can use a superior evolutionary mechanism to pursue evolutionary goals. They can use evolutionary modelling to identify and implement whatever is necessary to enable humanity to participate in the future evolution of life in the universe.

Third, evolutionary modellers will see that their personal psychological struggle over what objectives they should pursue has a wider evolutionary significance. They will see that their struggle is part of the unfolding of a critical step in the evolution of life on this planet. A similar psychological struggle will be played out on any planet in the universe where organisms become conscious of the evolutionary processes that have formed them and that will determine their future. Evolutionary modellers will see that the way in which humans resolve this struggle will determine the longer-term evolutionary significance of humanity. They will understand that if humanity turns its back on evolutionary objectives and continues to serve the pre-existing goals, we will be evolutionary failures. In an evolutionary sense, humanity would die. We would be irrelevant to the future evolution of life in the universe. For humanity to choose to continue to pursue only pre-existing adaptive goals would be to choose evolutionary suicide and irrelevance. But this would not be a realistic option for a humanity that is capable of evolutionary modelling. Once an individual develops a capacity for internal evolutionary modelling, to reject evolutionary objectives would be as unthinkable as is suicide to an individual who is psychologically healthy.

And finally, evolutionary modellers will see that once they have developed the capacity for evolutionary self-management, the direct pursuit of future evolutionary success will not involve any self-sacrifice. They will be able to find motivation and emotional reward in whatever is necessary to pursue evolutionary objectives. Evolutionary self-managers will manage their pre-existing mental, emotional and physical adaptive processes so as to align their operation with evolutionary objectives. This will mean that pursuit of their managed and modified pre-existing goals will result in the pursuit of evolutionary objectives. Self-management will ensure that all pre-existing mental, emotional and physical adaptive processes will also serve the evolutionary objectives identified by evolutionary modelling.

For all these reasons, individuals with a comprehensive capacity for evolutionary modelling are likely to decide to pursue the development of the psychological skills needed for evolutionary self-management. They will want to improve their evolvability by developing a psychological capacity to manage their mental, emotional, and physical adaptive systems to serve evolutionary objectives. To achieve this, evolutionary modellers will make use of whatever techniques and practices they can find that will assist the development of this psychological capacity. At this stage in the evolution of humanity, we have not accumulated much knowledge about techniques and practices that will help produce this psychological transformation. At present, very few humans develop any capacity to manage consciously their pre-existing adaptive systems. The way we behave is still largely determined by our biological past and our socialisation. These influences produce the likes, dislikes, emotional responses, habits of thought and other predispositions that determine what we do in our lives and how we react in any particular situation. Psychologically, we are immersed in our responses and our habits of thought, and have little independence from them. Very few of us ever develop a comprehensive psychological ability to stand outside these predispositions and reactions, and to consciously choose which of them to retain, and which to modify or discard. We are not yet self-evolving beings.

To date, traditional science has produced very little knowledge about how humans can achieve this psychological transformation. Science presently understands almost nothing about consciousness, let
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alone about how it can evolve. At this stage in its evolution, science is very effective at helping us understand simple processes in our external environment. But because it relies largely on linear modelling, it has made little progress in understanding complex processes, whether they are external or internal to us. To date, science has almost nothing to say about the issues of greatest importance to most humans—the experience of being, and its meaning.

But some knowledge about the possibility of psychological development has existed amongst humans for a very long time. It has long been known that an individual can develop a psychological capacity that will free him somewhat from the dictates of the external events of his life and from his social and biological past—the individual can acquire a mode of consciousness, which gives him some independence from his emotional and physical states. In most cases this knowledge has been developed and passed on as part of a religious or spiritual system of beliefs and practices. The promotion of psychological and spiritual development has been an explicit part of many eastern religions such as Hinduism, Buddhism and Sufism. And it is at least implicit in many varieties of Christianity. Most of these religions have developed particular practices and activities that are intended to assist psychological and spiritual development. Yoga, prayer and meditation are well known examples.

The spiritual system that comes closest to explicitly articulating practices designed to promote the types of psychological development I have discussed here is the system developed in the first half of the 20th century by George Gurdjieff. He drew on many eastern religions and spiritual practices to synthesise a new system that is specifically directed at producing the psychological transformation of humans into self-evolving beings. But the knowledge about psychological development contained in Gurdjieff’s system and in other religious and spiritual traditions is invariably mixed in with myths, metaphors, parables and stories that have little substance. Nevertheless, shorn of these embellishments, there is a remarkable level of agreement within these systems about how we can transform ourselves psychologically to become self-evolving beings.

Most of these systems emphasise the importance of self-knowledge. To develop psychologically, we must come to know ourselves better. We must be as good at understanding and managing our internal environment as we are our external environment. To achieve this, we must separate psychologically into an observing part and an observed part. Our “I” will be associated with the observing part. The observed part includes our thoughts, self-images, emotional responses, and physical reactions. As the observing “I” develops, it will be able to continually observe our mental, emotional and physical reactions to external events. Our internal processes will become objects of consciousness. The “I” will build a comprehensive knowledge of how we react and how effective these reactions are. The “I” will use this knowledge to model the operation of our mental, emotional, and physical processes so that it can see how they are best managed to achieve the objectives of the “I”.

A further critical ingredient emphasised by most systems is that the “I” must develop the capacity to disidentify with these internal mental, emotional and physical processes. When this is achieved, the “I” will no longer live in and be immersed in these processes. It will consider itself separate to them, will not experience itself as them, and will be able to watch them unfold without being part of them. It can stand outside and observe them, just as it stands outside and observes external physical objects and events.

This leads to the development by the “I” of a capacity to manage the mental, emotional and physical systems. Because the “I” does not identify with and is not influenced by emotional states, it can ignore and let go of those that are inconsistent with its objectives. For example, an “I” that has chosen consciously to pursue evolutionary objectives can let go of emotional predispositions that would otherwise cause behaviour that conflicts with its objectives. And it can support and ‘go with’ emotional responses and motivations that are consistent with its evolutionary objectives. Those that clash with its objectives will be weakened and lose their power, and those that are supported will be strengthened.

An “I” that masters these and other techniques can organise any behaviour that it chooses. It can revise and change any of the behavioural predispositions, habits, likes, dislikes, and preferences that the individual had before the new “I” emerged. The individual will no longer be limited in what he can choose to do by his biological or social past, or by external circumstances. The “I” will operate like a manager of a cooperative group of organisms. Such a manager organises cooperation by supporting members who cooperate and by punishing those who undermine it. In this way, the manager aligns the interests of the individual members of the group with the interests of the group as a whole. In the same way, a fully
developed “I” in a self-evolving human manages the pre-existing adaptive processes so that their adaptive goals are aligned with those of the “I”. The “I” is also like the visionary CEO of a modern corporation. The CEO manages employees so that their interests and goals are aligned with the longer-term vision that the CEO has for the corporation.

The new “I” will be able to consciously manage the resources and capacities of the individual for the pursuit of evolutionary objectives. It will use its understanding of evolutionary processes and the likely course of future evolution to determine what the individual will do with his life. Evolution will have produced a self-evolving organism. Evolution will no longer have to get the organism to do what is best in evolutionary terms by hard wiring it with internal rewards that are correlated with evolutionary success. The organism will no longer spend its life in the pursuit of emotional rewards that are evolution’s indirect way of getting the organism to pursue evolutionary success. By consciously managing its emotional and motivational systems the organism will be able to move at right angles to its biological and social past. The organism will be able to use its own models of the evolutionary consequences of its acts to pursue evolutionary goals directly and consciously.

As evolutionary modelling develops amongst humans, much more effort and resources will be put into the discovery and refinement of practices that will assist the development of the psychological skills and structures needed for evolutionary self-management. The acquisition and use of these skills will produce a mode of consciousness that is increasingly more strategic in its operation. Its primary concerns will be the adaptation of the individual to events and processes that unfold over longer time scales. This evolutionary consciousness will be experienced as a more strategic state of being that is not so buffeted or reactive to immediate events. Like the visionary CEO of a modern corporation, the consciousness will not often be involved in the day-to-day operation of the organisation. The evolutionary consciousness will largely be a spectator or witness in relation to shorter-term events and adaptive processes. The pre-existing adaptive systems, managed as necessary by evolutionary modelling, will continue to adapt the individual in relation to these shorter-term events. And the concerns of the evolutionary consciousness will not be self-centred. They will be more universal, focusing on the effective operation of the social system, the evolutionary success of humanity, and ultimately the successful future evolution of life in the universe. The final allegiance of all beings who attain evolutionary consciousness, wherever they arise in the universe, will be to the successful evolution of life in universe.

* * * * * In the last three Chapters we have looked at how a capacity for mental modelling can evolve and develop. We saw that mental modelling has the potential to be far superior to previous adaptive and evolutionary mechanisms. Its superiority stems from its ability to use models and simulations to anticipate future events and to adapt the organism to them. The models can be improved in the light of experience throughout the life of the organism. Importantly, when mental modelling is combined with a capacity to transmit adaptive knowledge between individuals, a new evolutionary mechanism is born. The knowledge used to construct and operate models can be accumulated across the generations, producing an evolving culture.

Eventually, organisms will accumulate sufficient knowledge about their environment to model and understand the evolutionary processes that have formed them and that will determine their future. They will see that evolution progresses by producing cooperative organisations of increasing scale and evolvability. Potentially, the organisms could use their modelling and understanding of evolution to guide their own adaptation and evolution. If they could use their modelling in this way, they would no longer need to be controlled by internal emotional and physical rewards—they could work out for themselves what they need to do for evolutionary success, and act accordingly. This would be a major step forward in evolvability, and would enable mental modelling to realise its full potential as an evolutionary mechanism. But initially the organisms will be unable to make this transition. They will be not able to use their modelling of evolution to guide their adaptation. When the modelling capacity first emerges, it has neither the competence nor the capability to control how the organism adapts. The modelling capacity is grafted onto a fully functioning organism that is already adapted by complex emotional and physical adaptive systems. The modelling capacity does not understand sufficient about these pre-existing adaptive processes to take them over and manage them competently. Its initial attempts to do so are likely to be maladaptive. It will be interfering with complex processes that it knows very
Furthermore, the organisms will not be motivated to use their mental modelling to pursue evolutionary objectives. What they find motivating and emotionally satisfying will be determined by their pre-existing adaptive systems. The pre-existing systems will not reward the pursuit of longer-term evolutionary objectives. The goals of the emotional and physical adaptive systems will have been established by shortsighted evolutionary mechanisms that are blind to longer-term evolutionary needs.

As we have seen, the full potential of mental modelling as an adaptive and evolutionary mechanism will not be realised until it is used to develop a capacity for self-management. Mental modelling cannot fully take over the adaptation of the organism until this capacity is developed. It will be unable to use its understanding of evolution to guide the adaptation of the organism. The first step toward achieving self-management occurs when the modelling capacity is turned inwards. Just as modelling the external environment has enabled organisms to manage and manipulate it, modelling their mental, emotional and physical adaptive systems will enable the organisms to manage these systems. Once the organisms are able to understand how their mental, emotional and physical adaptive systems operate, the evolutionary and other functions they perform, and the consequences of changing them, the organisms will be able to manage them to adapt more effectively. And the organisms will be able to manage their motivational and emotional systems so that they find satisfaction in pursuing evolutionary objectives.

Initially, the impetus for the development of a capacity for self-management will come from the immediate benefits it delivers to the organism. Once mental modelling has accumulated sufficient knowledge, it can adapt the organism more effectively and intelligently than the pre-existing adaptive systems. But the main impetus for the development of a full capacity for self-management will not come until the organisms begin to understand the direction of evolution and their place in it. This enables the organisms to see that their development of a capacity for evolutionary self-management is an important step forward in the evolution of life. They will know that if they fail to take this step, they will be part of a failed evolutionary experiment. The organisms will see their own struggle to develop the capacity as part of the unfolding of a significant evolutionary event on their planet. When they work on themselves to consciously educate, train and manage their pre-existing adaptive systems, they will be aware that they are participating in an important evolutionary advance.

We have seen that the development of a capacity for evolutionary self-management represents a fundamental transformation in the psychology of an organism. Before this transformation takes place, organisms use their capacity for mental modelling to understand and manage their external environment. They use mental modelling to manipulate their environment to achieve the internal adaptive goals established by their biological and social past. But the organisms are unable to use mental modelling to understand and manage themselves. They do not have the knowledge or skills to form complex mental models of their own internal mental, emotional and physical adaptive processes, and of the consequences of changing these processes. They are conscious of using their mental processes to pick the best strategies to achieve their pre-existing adaptive goals. But the organisms do not choose these goals consciously. Their consciousness is largely directed outwards, not inwards. The organisms treat their adaptive goals as fixed and given. Without mental models of their internal processes, the organisms can barely conceive of how they could choose and modify their own motivations and emotional impulses.

When organisms have fully developed the capacity for evolutionary self-management, their biological and social past will no longer limit their adaptive flexibility. They will be able to adapt in whatever ways are needed for future evolutionary success. The organisms will not only consciously choose their behavioural strategies. They will also consciously choose their goals and objectives. They will see their motivations and emotional states as things that are subject to conscious choice. The organisms will no longer unconsciously pursue goals determined by their biological and social past. They will no longer pursue goals established by past evolution, goals that were past evolution’s best but flawed attempt to get them to behave in ways that bring evolutionary success. Instead they will use their direct apprehension of what will bring evolutionary success to choose their goals and motivations. Free from their biological and social past, they will be able to use the immense power of consciousness guided by evolutionary modelling to determine how they will adapt and evolve.

Humans have barely begun to undertake this psychological transformation. Our psychology is evolutionary work-in-progress. We are an organism in which the capacity for mental modelling has not
yet realised its full potential to take over and improve our evolvability. It is only through conscious psychological effort that we will develop the skills and self-knowledge that will enable us to make this transformation.

This completes our consideration of the evolution of the evolvability of organisms. In the next six Chapters we will trace more systematically the actual sequence of progressive evolution that has unfolded on earth as living processes have formed cooperative organisations of larger scale and greater evolvability. As we do this, we will also examine how the evolvability of societies of organisms (including human and insect societies) has evolved, and how their evolvability is likely to continue to be improved in the future.