The Behavioural Ecology of Project-Based Science

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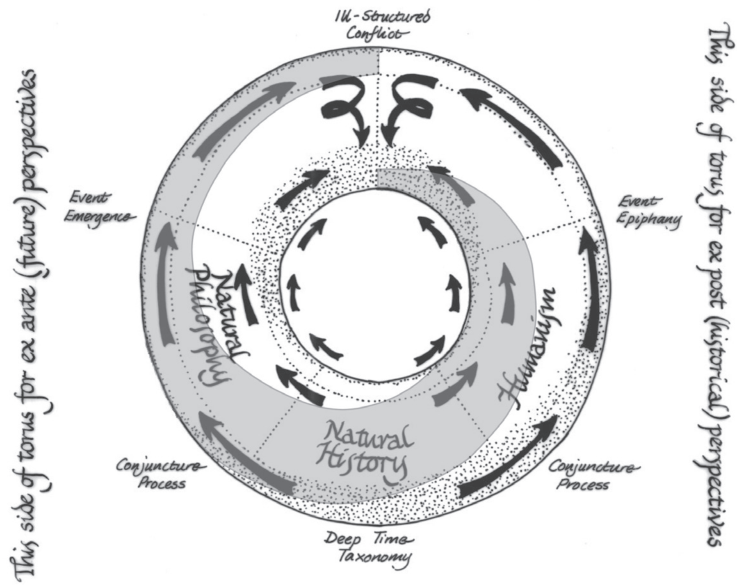

The Behavioural Ecology of Project-Based Science
A Plesionic Approach

by

N.P. Winder & I.C. Winder

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Foreword

The debate about human nature has changed dramatically over the last two centuries. Almost all now agree that our biological heritage is significant. Much emphasis is now given to the relative importance of 'nature and nurture': to what degree is human action a result of genetic heritage (biology) or social learning (culture)? There is very little discussion about whether other aspects of the human condition may be significant.

In a secular society there is little room for anything but scientific approaches to human nature. Spiritual or ethical impulses are often treated as side-effects of neurophysiology or social interaction. Secular extremists may even dismiss them as meaningless epiphenomena, or even as delusions. But those extreme positions beg an interesting question. If ethical and spiritual drives are delusions, then what is so special about science? Is science just another meaningless epiphenomenon?

The ***Human Nature*** series provides an intercultural, interdisciplinary forum for discussing the human condition. It explores the biological, evolutionary, anthropological, psychological and sociological roots of human perception and our ability to adapt and innovate. Authors are encouraged to avoid the conflict engendered by those extreme positions and seek a more balanced approach. If human spirituality is a biological epiphenomenon, then so too are science and technology. If science is a potential source of enlightenment, then so too is philosophy.

Alf Linderman, Sigtuna Foundation

Hans Liljenström, Agora for Biosystems

Acknowledgments

We would like to thank all the scientists and philosophers mentioned in the 'People' index of this book. Additional thanks are due to J K Day, who taught a course on plesionics in the late 1960s. We also acknowledge DG Research for funding under 5 consecutive Framework Programmes, most recently through the COMPLEX project (308601). Thanks are also due to Heather Winder and Roger Seaton for many helpful comments on the manuscript. The views expressed here are our own responsibility.

Note on Revisions

The first (2013) impression of this book drew on a large archive of notes and presentations about the ecodynamics of science. That archive also contained material we planned to use in a second book: *Space, Time and Simplexity*. Some pointers to the second book had survived the cut, along with a few typesetting errors. As the COMPLEX project drew to a close we decided to correct the text and rewrite a few paragraphs to make their meaning clearer.

Our book was written after the crash of 2008 and made it clear that we didn't believe the current phoenix cycle had bottomed out. Nothing that has happened in the course of the last three years changes that opinion. The case for pre-emptive innovation is stronger in 2016 than it was in 2013.

COMPLEX
Knowledge Based Climate Mitigation Systems for a Low Carbon Economy

Contents

Section I : Science as Behavioural Ecology

Anthropology, the study of humankind, spans a gamut from textual deconstruction through ethnography and on to archaeology and evolutionary biology. Our sort of anthropology is natural history. Like many naturalists we are a little preoccupied with named categories and definitions. If you want to know why naturalists use words like *Bellis perennis* to describe things as commonplace as a daisy, you will find out in the next couple of essays. We ask you to humour us for the time being, while we lay a few definitions on you.

Following Thomas Henry Huxley, we define *science* as the search for rationally interpretable order in the universe. The phrase *rationally interpretable order* can be shortened to 'pattern', and the words *in the universe* can be rendered as: 'in space and time' or even as 'natural'. So we could say, '*science* is the search for pattern in space and time' or even '*science* is the search for natural pattern' and we would be saying the same thing. We are not interested in disciplines that study supernatural phenomena, or in the study of non-pattern. If that's what makes your boat float, read another book.

This definition of science is probably a little weak for some tastes. Some hard scientists would probably tighten things up to exclude cultural anthropology, say, or historiography; but even if we were to push the soft sciences beyond the pale, what we would be left with could reasonably be described as a search for pattern in the universe. There is nothing controversial about our definition.

In later modern (17th and 18th century) Europe, there were two broad philosophies of science, each with its own type-specimen. One of these was *superstition* - the belief that enlightened agents 'stand above' the biological automaton, monitoring events and sometimes altering the course of history. Its type-specimen is the 17th century philosopher René Descartes, who believed the human body was dual structure - an objective automaton occupied by a subjective ghost or 'soul' that monitored and directed its actions.

The alternative was a more naturalistic approach, championed in the 18th century by Immanuel Kant. Kant believed humans could never transcend the limitations of their physical bodies. All human knowledge deals with phenomena - with things as corporeal organisms perceive them. Our responses to those phenomena are shaped by embodied intuitions, social learning and aesthetic reinforcement that guides us towards situations we are capable of handling. There are no souls or demonic 'memes' in the Kantian automaton. Consciousness and agency are natural phenomena.

This phenomenological approach is useful. Consider, for example, a colony of bees. As the sun rises and warms the hive, foragers, guards and drones come out to fly. Reproductively competent males, or drones, congregate in mating arenas and fly around looking for opportunities. The foragers - sterile females - head off to collect food, while guards – tired old foragers – patrol the front of the hive. A young queen bee would behave differently to all of these. Her behaviour influences and is influenced by that of her neighbours and her own developmental state. If she is unmated, she may fly off to the mating arenas. If she is mated, she may fly off with a swarm and establish a new colony.

Each of those bees has differently tuned sense-organs and is impelled by slightly different predispositions and life-histories. The difference between a worker and a queen, for example, has to do with the protein content of the larval diet. The difference between a nurse bee and a guard is a by-product of ageing. Each type of bee launches itself into the same morning air, but finds itself operating in an environment that is phenomenologically distinctive. Recognising the role of bodily structure, life-experience and cognitive variation provides information about honeybee ecology that could not be had if we assumed each bee was responding to things as they really were.

In the mid 19th century, Thomas Henry Huxley created an amalgam of Darwin's ideas about evolution and Kant's ideas about phenomena in science, and linked it with an ancient Greek word, *gnosis*. Gnosis originally referred to knowledge, particularly to an abstract, intellectual sort of knowledge that brought people closer to the god-mysteries at the heart of the universe. Huxley recycled it to mean *knowledge of things as they really are*. By extension, a *gnostic* is a person who believes humans can attain gnosis (reliable knowledge about things as they are), and an *agnostic* one who, like Darwin and Huxley, believes all human knowledge relates to percepts and phenomena. Huxley's agnosticism is basically Kant's phenomenology with an evolutionary spin. It implies that the instincts and embodied aesthetics that influence the ways we respond to phenomena have been wrought in our bodies by the evolutionary processes that shaped them and fine-tuned by a process of social learning.

This is a fundamental idea and we need some precise language to describe it. Unfortunately, every word proposed to date has been re-cycled by later scientists and used for a slightly different purpose. Huxley, for example, used the word 'epigenesis', coined by the pioneering physiologist William Harvey, but the word has acquired a different, more specialised meaning with the emergence of neo-Darwinian theory. In the late 19th century a group of German biologists began to use the terms *mnemic* and *engram* to describe embodied memory. Their ideas were introduced to Anglophone readers in a book by James Ward titled *Heredity and Memory* that summarised lectures given in 1912. *Mnemic structure* is embodied memory. By the 1970s most biologists had forgotten about Ward, and Richard Dawkins used the same Greek root for his meme-concept. A *meme* is a cognitive computer virus that infects the neural network and hi-jacks the body, which it uses to colonise space and time. So we are going to set the adjective *mnemic* aside and reserve the word *structure* for all embodied memories. Structure, defined this way, includes conventional DNA and RNA replicators, patterns of neuro-connection in the brain, socially acquired habits and the physical and physiological traces of life-experience. An accident that maims a limb, for example, leaves structural memories in the body.

If a human puts the egg in an incubator and takes care of the chick, the bird will experience particular patterns of sense-data. An image of the human carer becomes woven into the chick's bodily structure and shapes its future development. If the bird contracts a virus infection some of the RNA may linger in its body together with an immune response. Again, these are structural memories. If the bird is attacked by a dog, or is regularly fed by a passer-by, these experiences also leave structural traces in its body. A similar process occurs in humans. Human babies, for example, 'remember' how to suckle and how to acquire new memories as they develop, but the ability to speak French, say, or to find a newsagent are not hard-wired into our bodies at birth.

We need a word to describe this process and have two to choose between. The first is *structuration* - the creation of structure. The second is *contextualisation* which comes from the roots *con* (together) and *texere* (to weave). Structure in the present is the product of contextualisation - an interweaving of pattern and structure - in the past. Without this dynamic interweaving, there would be no social learning, no dynamic, path-dependent memory and no science. Contextualisation is not restricted to humans or to great apes. The worker and the queen bee, for example, are both genetically female and both are fed high-protein 'royal jelly' for the first few days of life. Thereafter, the worker's diet is restricted, while the queen stays on royal jelly. Their lives are changed irreversibly as the process of weaving pattern into bodily structure produces very different types of bee.

If a worker larva is transferred into a queen cell early enough, it will grow into a queen. The later the graft is made, the more fixed its bodily structures will have become and the less able it will be to mate and reproduce. The ability to contextualise pattern varies through the life-cycle. In many animals, bodily structures become more or less fixed at maturity and the adult becomes a biological machine, capable of responding, but incapable of acquiring new structures.

In our species, however, the ability to acquire new structural memories lasts well into maturity. Some of us experience a mid-life crisis comparable to the transformation that turns elderly workers into guard bees, though the range of niches available to us in early old age is broader. Contextualisation in humans is richer and more complex than that observed in most non-human species, but it has parallels in other great apes and in more distantly related animals like elephants, crows and parrots. We aren't the only slow learners on the planet.

Contextualisation is a big idea in natural history. Charles Darwin's *Origin of Species* brought it to the foreground and biologists spent most of the next 100 years trying to ignore it. *Origin* starts with the assumption that there exists a world containing organisms with embodied memories, some of which are heritable. The book has almost nothing to tell us about the anoxic primordial soup in which living organisms came to exist or about the evolution of organisms before they acquired some sort of heritable memory. The nucleic acid based genes that govern protein synthesis in all life forms could not be predicted using natural laws. The animal or plant genome is itself the product of an evolutionary process that involved contextualisation.

Darwin's remarkable book dealt with ecology, ethology and co-evolution, but none of those words had yet been coined. He didn't even have a word to describe the way species-like grades of organisation came into being and used 'origin'. Today's naturalists would probably prefer the word *emergence*, which more accurately represents the process of structuration in an ecosystem shaped by 'descent with modification' under natural selection.

You need to be a little careful with some of these words because other writers use them differently. Sociologists, for example, may use 'structure' to describe patterns of social stratification or social roles. If you can observe it empirically, we would call it a pattern. Similarly, a trawl of the internet will yield a bunch of pages and conferences about 'text and context' that seem to imply the 'con-' syllable comes from the root *contra* - against. Con(tra)text becomes a sort of backdrop (a pattern, in our terminology) against which the text can be viewed. If you are an archaeologist, for example, 'context' can just be a fancy way of describing the place something was found - again, a pattern. These ways of using language are not wrong, but they are different and the difference has something to do with contextualisation. *Caveat lector!*

§ 1. Semantics and the Subject-Object Split

Nobody works on the natural history of everything, which is why many naturalists greet a new colleague with a question: *what are you working on?* We, who write this book, are working on people. One of us (Isabelle) works on early hominins, non-human primates and their interaction with landscape. The other (Nick) started his career as an archaeologist, but now works as an applied anthropologist, studying the natural history of science and using his findings to design and manage research projects.

It isn't possible to take you on a foray through the laboratories and conference-halls, whispering: *Ah! look over there - Scienticus humanisticus, var. postmodensis, in full discursive display,* but our intention is that you will learn enough from this book to do a little fieldwork of your own. We start with the natural history of natural history.

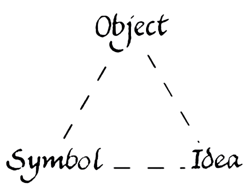
The roots of natural history are buried deep in western philosophy. The discipline draws on a strategy for resolving semantic power-struggles that we call *systematics*. Sadly, some naturalists have forgotten or never learned this and try to persuade their neighbours to use everyday speech systematically. *There is no such thing as a hedge-sparrow*, they will say*, that bird is a dunnock*. When systematic speech patterns are imposed on outsiders in this way, those responsible have appropriated language and asserted their club's right to pontificate.

Naturalists are not the worst offenders in this respect. Nobody was ever murdered for calling a dunnock a sparrow. The same cannot be said about words like *heresy*, or *free-trade*. Semantic power-struggles arise because the same linguistic patterns can be used for at least four purposes. They can be: 1) a platform for co-operation and communication, 2) a device for distinguishing members of some institution from non-members, 3) a way of appropriating language and turning common knowledge into private property, and 4) a way of justifying the repression of outsiders.

You cannot use language for communication and co-operation without creating opportunities for people to pontificate and bully. The systematic language of natural history has been designed to limit attention to objective phenomena and so minimise the scope for strong-arm stuff. One of the reasons naturalists get called ‘nerds’, ‘anoraks’ and ‘twitchers’ is that our jargon and research interests seem irrelevant in the context of social relations, power-politics and technology. That’s not an accident - it was designed that way.

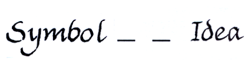
So what does it mean to use language ‘systematically’?

The word ‘dog’ implies a relationship between the smelly, carnivorous mammal on the hearth-rug, the idea of a dog, and the three-letter symbol ‘dog’ that links them. This triangular relationship between thing, symbol and idea is often associated with Aristotle’s book: *On the interpretation of texts*.



To use language systematically is to ensure that the point of the triangle labelled ‘object’ refers to a physical thing or category of physical things that can be apprehended using the senses. In this way we can avoid subjective, ideational structures and focus on observable pattern.

The human soul, for example, the ineffable essence of the human being, is not an object in the sense that Fido on the hearthrug is an object. Neither, for that matter is a number which, when multiplied by itself, gives the answer -1. Imaginary numbers and souls are *not* material objects and their use flattens the semantic triangle down to a line with the symbol at one end and the idea at the other:



Everyday language is stuffed with these flat symbol-idea lines. Systematic method consists of a set of tools for building fat semantic triangles with a material thing linked to a symbol and an idea. Classical Greek and Latin provide a useful store of word-roots that can be used to create new/old words that emphasise the specialness of systematic language. Natural history deals with material things and so allows us to maintain the subject-object split, at least as a working hypothesis.

The subject-object split will be a recurrent theme in this book, so we will pause here to consolidate the idea. The naturalist is a *subjective* agent, struggling to find pattern in nature. S/he is to some extent a prisoner of his/her body. The structure - morphology and physiology - of the body influences the sorts of phenomena s/he can work on. However, experience has shown that the systematic use of language, coupled with a lengthy period of social learning can create a strong consensus about material objects and categories.

Systematic language exists to describe, catalogue and list. It allows us to say what objects are, but not what they are worth or what should be done about them. If you drop your systematic guard, you are very likely to be drawn into *value judgements* (why should we care?) or *operational judgements* (how should we respond?). We shall have a great deal to say about value and operational judgements in this book. Here it is sufficient to understand that systematic method is for *boundary judgements* (what type of thing is it?).

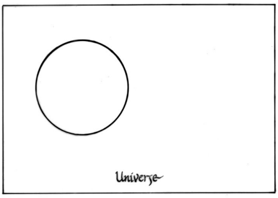
That word, 'type', is significant because it poses a substantial challenge to the systematic ideal. The problem is that named categories are more like ideas than material objects. This problem is ancient - a great deal of ink was spilt exploring it in mediaeval times - but the solution that underpins natural history is still worth understanding.

The words *Prunella modularis* that we apply to the small, dull-looking bird in a hedgerow suggest the existence of an abstract category - a well-bounded 'species' of bird. We know the bird is a thing because it is localised, as it were, in a small interval of space and time and can be observed with the senses, but the species is bigger (in a space-time sense) than we are. That scale-disparity begs some interesting questions about whether species are objective or subjective.

Mediaeval philosophers believed in a creative god-agent that was subjective and purposeful like us, but unlike us was incorporeal and all-knowing. They fell into two broad groups on the species-problem. One group believed species-categories were ideas in the god-agent's mind. As such they were real - independent of human agency - and meaningful even in parts of the universe where there were no sparrows or people to give them names. These scholars were called *realists* or *ancients* because they followed the 'ancient way' (*Via Antiqua*) of scholarship. The other group believed the meanings of category-words were socially constructed - they only existed outside the individual human mind by negotiation and common consent. This group were variously called *moderns* or nominalists because they believed categories were just names.

Those words, *ancient* and *modern* give the misleading impression of a time-trend. The two tendencies - one associated with the teachings of Plato and the other with Aristotle - co-existed throughout the mediaeval period and much of the debate between them centred on the broader status of category words. In ancient logic, universal categories were perfectly well-bounded in the sense that there could be no contradictions like:

This object is AND is NOT *Prunella modularis*



One way of achieving this would be to imagine the universe split into two categories - a collection of things that were *Prunella modularis*, and a *complementary* set (so called because it completes the universe). The logical complement of *Prunella modularis*, for example, contains everything in the universe that is not a hedge sparrow.

By implication, a definition like:

Prunella modularis is a small, drab bird that nests in hedgerows could be re-framed as a statement about the universe:

Everything in the universe, if it is Prunella modularis, is a small, drab bird that nests in hedgerows.

If the universe is logically bounded and closed this way, then every correct species definition implies the existence of a class and a logical complement. This 'closed universe' assumption imposed an austere discipline on ancient logic and also made it popular with powerful religious institutions. It would be easy, at this point, to pretend that the ancients were all dogmatic gnostics trying to impose their worldview on others. Doubtless some were, but others - so-called *moderate realists* - saw logical analysis as a strategy for inferring the creator's plan by analysing pattern in the universe.

In contrast, the modern way of reasoning allowed for the possibility that the universe was logically open. This had two related consequences. First, it affirmed the scholar's right to draw on empirical evidence, to experiment with new ways of defining classes and to challenge dogmatic authority. In this way western scholars - at least those protected by powerful patrons - could adopt a less dogmatic, *humanistic* approach to science. Second, it simplified scholastic reasoning by eliminating many of the features we now think of as mediaeval logic-chopping.

Again, it would be easy to pretend that nominalism is a better scientific philosophy than realism, but the situation is not that simple. If science is to be the search for rationally interpretable order, all approaches to science must be rationally defensible. Suppose, for example, we wanted to impose an absolute embargo on realist philosophy by asserting that:

No definition-statement is universal

this statement is a partial definition of the class called 'definition-statements' and can be re-framed:

Everything in the universe, if it is a definition-statement, is non-universal which would make the category ‘definition-statements’ universal and our embargo self-contradictory.

You can think of this over-enthusiastic use of modernist principles as a sort of *gnostic agnosticism* - the extreme, irrational point on a spectrum of approaches that has dogmatic realism at the other end. The extreme positions do occur in science, in theology and in everyday life, but they are actually rather rare. Most scientists treat realism and nominalism as working hypotheses rather than as universal laws.

Moderate realism, then, is neither inherently illogical nor pernicious, but the dogmatic regulation of mediaeval science brought it into disrepute. The modern antithesis became the platform on which post-mediaeval science was founded. Like the ancients, the moderns thought it important to eliminate contradiction, but their approach was more phenomenological. They held that most of the categories of human language, including attribute classes like 6-ness and greyness, were only meaningful in a specific context. We may be able to speak meaningfully about species of material objects (like hedge-sparrows) but should never assume that the universe would grace those categories with perfectly sharp boundaries and logical complements.

The problem of universals is of interest here because it shows that the tension between gnostic and agnostic philosophy in 19th century natural history, and arguments about the reality or social construction of meaning in the 20th had antecedents in ancient Greek and mediaeval philosophy. When two approaches to science persist over millennia, as these have, natural historians may reasonably speculate about existence of intellectual ‘castes’. Just as workers and queens are different ways of being a bee, so the ancient and modern ways may be different ways of being a scientist.

§ 2. Grand Narratives and Gnostic Agnosticism

§ 1 introduced the concepts of systematics by telling you a story - humanists might call it a *grand-* or *meta-narrative*. Our metanarrative speaks of universals, ancients and moderns and the way naturalists use open-universe assumptions to maintain the subject-object split. The story is plausible, but is not uniquely persuasive. A gnostic philosopher might say, with some justice, that it is not (intellectually) *true* in the sense that there is no historically verifiable sequence of events that would put it beyond doubt. Ours is one grand narrative among many that could be reconstructed from the historical evidence.

Metanarratives are epiphenomena - emergent by-products of the behaviour patterns that go with teaching and learning. In the hands of extremists they can become powerful tools for social control. People may suffer social exclusion and even be killed for challenging politically sensitive metanarratives and indoctrination programmes. In this secular age atheists often link repressive creation-myths with theology and institutionalised religion, but the creation-myths of 19th and 20th century science were also used to justify killing on an industrial scale. Any powerful institution can kill.

In the 1980s and 90s some 'postmodern' humanists began arguing that all metanarratives were political artefacts. Some got a little over-enthusiastic. The impact of their gnostic agnosticism on trans-disciplinary research was to make communication harder and undermine co-operative action. Endless critique is an irritating time-waster and postmodern polemic was soon softened and moderated. Most grand narratives are benign. Lethal metanarratives - the sort that underpin crusades, jihads or ethnic cleansing, are well able to resist critical deconstruction. The institutions that put these repressive programmes into place are powerful enough to ignore most of their critics and vicious enough to crush the rest. There are no simple solutions to complex problems.

§ 3. Empirical Method: Key and Essence

The systematic use of language and empirical method go together in the sense that robust empirical observations usually imply the existence of a material object localised in an interval of space-time accessible to human senses. We say 'usually' because contemporary science uses technical infrastructure to make observations on very large and very small scales - microscopes and telescopes are two instances among many where scientists are making observations of the state of a measuring device, not observing objects directly.

In some cases the logical connection between the state of the measuring device and material objects is so tenuous that one could argue that the system does not exist at all. Theoretical physics and economics, for example, both use technical infrastructure to make observations of phenomena that are so unstable and tenuous that the subject-object split cannot be maintained. We might as well be discussing angels dancing on pinheads. Here we restrict attention to data describing objects and categories of object.

Empirical research requires us to make observations, record them as data and use some symbolic manipulation of those data to make generalisations about the system. The literature on data structures is enormous, but we will focus in on two types of data structure - the *object* and the *attribute*. Imagine a data-table with row and column structure, a bit like a spreadsheet. Each row represents an object - a bird, say. Each column represents an attribute of the bird. We note that the object that is bird specimen number 6 has brown feathers. When we describe this specimen, we slide along to the column labelled 'specimen number' and enter a 6, and in the column 'feather colour', we put the value 'brown'.

Most data analysis works with tables of this sort, because there are lots of clever things you can do to summarise types of observation, draw informative maps of data structures and even develop and test hypotheses. Some attributes (columns) could also be re-presented as objects. For example, you could create a new data table that describes feathers (rows) with a range of attributes, one of which might even be the name of the bird on which it grew. So sometimes a brown feather is an attribute of bird number 6, and sometimes bird number 6 is an attribute of the brown feather.

There is a lot of flexibility in database design, but there are also limits. These limits become manifest when we try to create object / attribute tables. Objective attributes like feathers do occur in science, and can be useful, but they are quite rare. Any table with a row / column structure can be transposed so that columns become rows and rows become columns. These are useful analytical tools and empirical scientists use them a lot. Sometimes transposing a table preserves the object / attribute structure; often it doesn't.

Abstract attributes like brownness or length bring us straight back to the problem of universals. Does the data structure '6' imply the existence of a category that contains all the collections of 6 things in the universe? Is a 6-inch ruler a member of that class? What about the attribute 'brownness', is there a universal category of brown things? Probably not, so how are we to do empirical research in situations where some classes represent collections of objects and other classes represent ideational structures like numbers?

From the 17th century onwards, natural historians had a nice method for distinguishing objective from subjective classes. You can learn the method by walking into a weedy garden, cutting a few swathes and sorting them into piles as follows:

1. Pick up a weed, look at it closely and start a pile
2. Pick up another, if you have seen one like this before then put it on the appropriate pile; if not, start a new pile of weeds.
3. If there are more weeds to classify, go to step 2, else STOP

The routine looks like a sort of computer programme or algorithm and the result is usually a stable, if naive classification. Go through the piles and check the work (combining or splitting piles as you get your eye in). When you are satisfied, you are ready go onto the next stage of our empirical approach.

Select a pile and give it a name. Look carefully at all the members of the pile and make a list of the attributes they share. Your aim is to use attributes to differentiate between piles. You do this by distinguishing *essential* attributes from inessential ones. Ancient scholars, following Aristotle, called inessential attributes *accidents*, but modern scientists tend to speak of 'state variables' or, more simply, of 'variables'. The *essence* (the word means 'is-ness') of the species is the set of attributes that unite the whole pile; the accidents (state variables) individuate the instances of the class.

Repeat this process for all the piles, looking at leaf-form, flower colour, shape, number of petals, hairs - anything you can think of to distinguish the essence of the heap from the states of the individual plants. This takes time and many wannabe naturalists cannot be bothered, but mastering these methods is an important part of a naturalist's training. Once you have characterised the essence of each heap, go back through your list and select a smaller subset of the essential traits that can be used to distinguish the heap from any other. This small set is called the *key* because it unlocks the information used to define the class.

It may be, for example, that all members of the class 'buttercup' have hairy leaves and five-petalled, yellow flowers. Lots of named heaps have yellow flowers, or five-petalled flowers, or hairy leaves, but the combination of these attributes is *sufficient* to identify a candidate as a buttercup.

You can set the relationship between key, name and essence out in a syllogism of the form:

If key then name
If name then essence

and slot your data in. For example, you might write:

If five-petalled yellow flowers and hairy leaves then buttercup

If buttercup then (five-petalled yellow flowers and hairy leaves) AND many stamens and, …

That is an empirically testable hypothesis. You can take your sickle, trudge off into the garden, cut some more weeds and test it. Identification is the earth-wire of empirical method because it grounds the classification in the empirical evidence and establishes a rolling programme of hypothesis-testing. If you discover a new type of weed that possesses some buttercup traits, but is different, you may have to rethink.

Your primary aim, however, is not to test hypothesis about what a buttercup really is, but it is to develop a theoretical platform for future work. There are many types of scientific theory, but here our theory takes the form of a classification. We know we are on to a winner if the classification is stable, i.e. if no amount of testing seems to break it *and* the essence is much larger than the key. The key, as we have said, is so called because it unlocks all the essential information built into the class. A small key that unlocks a lot of essential information seems more impressive, somehow, than a large key that unlocks a tiny bit.

So what about those subjective, abstract categories like imaginary numbers or souls? Well, ancient theologians seemed to think that everything that distinguished the human from brute creation could be explained in terms of the soul. Souls are not material objects, though you can infer the existence of the soul by observing the corporeal agent that is a human being. The result is a sad sort of syllogism:

If human then soul
If soul then human

You can do the same with the imaginary number, *i*

If $x=i$ *then* $x^2 = -1$
If $x^2 = -1$ *then* $x=i$

These syllogisms are sometimes called *circular* arguments, but a better word would be *sterile* - they unlock no objective information because the key of the class is also its essence. Sterile syllogisms are not useless - actually, they can be very useful indeed - but they don't really belong in (17^{th} century) natural history which, by convention, dealt with material things, empirical evidence and systems where the subject-object distinction could be defended.

The idea to take home from this essay is that the simplest way to resolve the subject-object split is to work with a coherent 'kind' of object. We have suggested plants, but you could use people or beads or feathers or stars, … You classify these objects naively and then tighten the work up by characterising a convenient set of attributes and creating some data. The attributes must be observable, but need not be objects in their own right. Define a key and essence for each sub-class of thing and test the hypothesis by collecting and identifying new specimens. After a while, the classification will stabilise.

Empirical method has nothing to do with universal truth. It is a way of using nice fat semantic triangles as a starting-point for designing data structures. A database is a collection of idea-symbol links - often presented as a table with rows and columns - that can be explored analytically. The purpose of that analysis is to characterise rationally interpretable patterns and test hypotheses.

A few centuries ago these analyses were done by hand and the results summarised as pen-and-paper descriptions with drawings. These days we may use automatic data capture and process megabytes or even gigabytes of data. Still, empirical method remains the bedrock on which the natural history approach to science stands. The open-universe approach at the heart of empirical method can be traced back to the *Via Moderna* and beyond.

§ 4. Physiology and Three-Phase Time

Many research projects create databases and use analytical methods to find patterns in the data. These projects are easier to manage if the data represents the attributes of objects. You need not actually demonstrate that the key of a category is smaller than the essence to work this way - sometimes it is intuitively obvious - but it's worth remembering that data-rich projects are more likely to go wrong if scientists get sloppy about the subject / object split.

Sometimes you have no choice. The problem, in a nutshell, is that the things you can observe are not very interesting and the things that interest you are impossible to observe. The best way to tackle this problem is to re-shape your own beliefs in a way that 'makes sense' of data patterns. We will give you some practical hints about how to do this in § 17 below. The ability to make these connections shifts you from empirical science and *morphology* to analytic science and *physiology*.

The origins of this approach to living things can be found in the physical sciences, among the *natural philosophers* of the 17th and 18th centuries. Natural historians didn't get involved in this work till the 19th century. The word 'physiology' comes from the root *phusis*, which means 'nature'. Physiology, then, is an old-school naturalist's word for natural philosophy.

Morphology deals with statics and *what?* questions - What type of bee is this? What attributes distinguish it from other types of bee? These *what?* questions all refer to classes of objective things and, as such, represent the heartland of old-style natural history. Physiology deals with dynamics and *how?* questions - how does it fly? How does it find food?

One of the reasons working with honeybees is rewarding is that morphology and physiology are *consilient* - they 'spring together' in a satisfying way. You need not sit outside the hive observing behaviour to distinguish a reproductively competent male from a sterile female. If you know, on morphological grounds, that this bee is a drone, you can predict how it will behave. If you see a honeybee in the distance foraging for pollen and nectar, you can be confident that, when you get close enough to examine it, it will have the morphology that goes with a worker.

It often happens that morphology and physiology are inconsilient. When it does, the problem usually boils down to a difference in space-time perspective. Morphology, as we have already explained, describes the form of a system. There is no point defining morphological classes like species in respect of attributes that change from one observation to the next, so morphologists deal with attributes that are stable or almost stable, even when viewed from the *deep-time perspective*.

Physiology deals with the processes that transform the system, a preoccupation that draws attention away from deep-time stability. The trick is to ignore the essence and key of the class and focus on attributes that change in an observable way. Scientists call these changeable attributes the system's *state*. You cannot learn much from one instance of a class, of course, so physiologists work with populations of similar organisms and analyse the evidence in a way that distinguishes the special from the general. In history, this middle-range perspective is sometimes called *conjuncture*.

The state is smaller, both temporally and spatially than the process that transforms it. Think of a film made up of successive frames (events) and you have the idea. In the time it takes to measure the speed of a bee, its position (state) has been smeared across several frame-events. In order to generalise about bee flight, then, you would need to make many measurements and this would push you up from the event-time of individual observations to conjuncture.

Put bluntly, the naturalist has been lucky who discovers a study-domain in which all three space-time perspectives - event, conjuncture and deep time - come together prettily. Honeybee ecology is such a study-domain. You can take a bee off the comb, infer from its size, furry body and tottering habit that it is a newly emerged worker and predict that it will become a housekeeper, serve as a nurse, secrete wax, then start to forage and, if it lives long enough, end up a bald, tatty, bad-tempered guard bee.

Almost any study-domain can be resolved into a deep-time perspective (slow dynamics, stable categories) a middle range, or conjuncture, and a narrative chain of events and small history. However it is important to remember that these are contextualised phenomena. We are not dealing with a deep-time that is 'out there' in the material world, but with a structural model of the world that includes a deep-time perspective. Deep time in archaeology, for example, may be millennia; in economics conceptual taxonomies may fall apart after a decade or so. In geology categories may be stable across hundreds of millions of years.

These ideas are useful because they help us speak about situations where morphology and physiology are inconsilient, i.e. when the logical connections between objective categories and processes are weak and the naive approach won't do. You cannot use gross morphology to distinguish (say) a post-modern sociologist from a quantum mechanic. Well, you can a little. Some sciences tend to be populated by males and others by females. Mathematics tends to be male-science and sociology more attractive to females, but you cannot see a woman on campus and predict the subject she is studying.

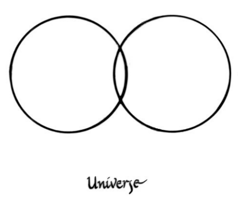
You certainly cannot distinguish a prehistorian from a cultural geographer by counting the bristles on their abdomens. Indeed, it is sometimes hard to tell them apart on physiological grounds too. A humanistic sociologist and a cultural geographer, for example, may use language in different ways and appeal to different literature sources, but the *how?* questions about their work often have similar answers. They may both use talking, writing and reading methods (sometimes described collectively as 'discourse'). When morphology and physiology prove to be inconsilient, you need to explore new ways of thinking about form and function. § 5, below, will provide an illustrative example.

§ 5. Knowledge and Institutions

We humans are large tailless monkeys with too little hair and too much imagination to be comfortable in the world as it is. So we create artificial ecosystems and innovate - changing the ecosystems we occupy by changing our minds. That is too much work for a solitary monkey, of course; but we chatter until our mental structures and actions seem to be consilient, each with the others, and then we can act as a complex super-organism. Those super-organisms (let's call them *institutions*) depend critically on knowledge.

Let us define *knowledge* abstractly as 'a set of shared beliefs that enable individuals to co-operate'. Thus defined, knowledge is not an objective thing. You cannot count it or weigh it or poke it with a stick. Knowledge is an abstract idea.

We, who have written this book, know what it contains. If we were to use a piece of paper to represent a space of all possible beliefs about the natural history of science, that paper would be a map of our universe of discourse. If we could so design the map that our shared beliefs were all close together, we could draw circles to bound our individual and collective knowledge-sets as follows:



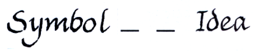
That picture is a map of our universe of discourse. The universe is unbounded, but the sets that represent our respective beliefs are presumed closed. That weak (non-universal) closure allows us to distinguish the beliefs we both share (the intersection of those two sets) from those that one or the other of us does not accept, but it does not permit us to make generalisations about universal complements.

Now imagine we were to invite a third author to join us in this venture. We aren't going to draw that third knowledge-circle for you - it could be anywhere on that map. It is possible, for example, to imagine an author whose knowledge would coincide perfectly with ours, or one who disagreed with us on all points. If the author were selected at random, however, the most likely effect would be to reduce our collective knowledge.

This exercise in elementary set theory has taught us an important corollary of this definition of knowledge. If knowledge is a set of shared beliefs that enable individuals to co-operate, then the more people you bring together, the less they can reasonably be expected to know. It might seem, at a first glance, that knowledge defined this way is useless stuff. Firstly, the definition is subjective - its key and essence are the same. Secondly, knowledge defined this way is an obstacle to communication in large groups. If that is how our definition seems to you, we ask that you to go with the flow a little while we build a metanarrative around it.

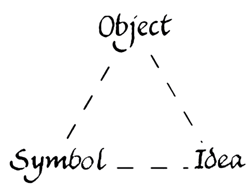
The cost of bringing a large group of people together is that their knowledge shrinks until it becomes the intersection of their respective knowledge-sets. The benefit is that they can acquire great power - the sort of power needed to create a mine, smelt and work metals, build an aeroplane factory, create a network of airports and air-traffic control systems and so on. Science, by this conception, is a special case - an instance, if you will, of a category of human activity that negotiates a trade-off between these costs and benefits and allows humans to create institutional super-organisms.

We are stepping through this reasoning process slowly, aware that some will already have made the connections and want us to go faster. We do this because we want to do a little more than generate a working hypothesis about science as knowledge creation. We want to illustrate an important pattern of scientific reasoning that creates a quasi-morphological definition of some things or categories and develops a symbolic map. Each definition gives us a flattened semantic triangle that links an idea to a symbol.



We read those definitions abstractly, as hypotheses formulated for the sake of argument and manipulate the symbolic map to work out some analytical corollaries of those definitions. Those corollaries may be counter-intuitive - indeed, we must expect them to be counter-intuitive if we are working in a domain where morphology and physiology are inconsilient. If the problem were readily solved, we wouldn't be working this way.

Our next step is to find some theoretical glue that fixes these abstract maps to the objective domain. Then we can check for goodness of fit. If the objective evidence lines up reasonably well, the semantic triangle has been pumped up again and we have re-established the subject-object split and can proceed systematically.



In this case, the map seems to work reasonably well. The collective power mobilised by an institution often carries hidden costs - patterns of environmental degradation caused by industrial intensification and patterns of social exclusion among dissenters, for example. An economist might call these *externalities*. Externalities become manifest as costs or as benefits. Institutions, for example, often create niches that others can exploit, or spin-off opportunities for providers of goods and services. These externalities will become manifest as deviations between observed and expected system behaviour and can often be characterised empirically.

Humans are very good at negotiating shared knowledge, but there are limits beyond which our ability to co-operate would be compromised and we would have to make a choice between becoming a chaotic alliance with hardly any collective power, or negotiating some sort of veto, often backed up with coercive action. That veto maintains the group's operational integrity by punishing people who think differently. Once these receptivity barriers are in place, the institution's stability and power would depend on its ability to protect its knowledge-base.

A population of nascent institutions would compete for the loyalty of individual humans, each of which would be making some sort of cost-benefit analysis. Some of these individuals would be exploiting externalities. Some of these externalities would undermine institutional stability, while others would strengthen it. Natural selection would favour those institutions that could attract large numbers of individuals and maintain the coherence of their core beliefs.

The result would be an equilibrium-seeking system in which stable institutions would be those that maintained the cost-benefit relationships that guaranteed them the loyalty of their members. We would expect those institutions to hunt through a 'space' of possible knowledge-sets and constraints until they located attractive regions (*attractors*) that allowed them to persist.

The stablest institutions would be those able to adjust these cost-benefit functions in ways that allow them to compete effectively for supporters and marginalise dissident perspectives. If the cost of accepting the institutional veto is high, then either the benefits must match them or the sanctions imposed on dissenters must be severe. Some institutions develop an internal stratification that diverts benefits to a prosperous few and distributes costs over the many. This internal stratification is sustained by sub-institutions, each with their own receptivity barriers and vetoes.

§ 6. Culture and Exaption

Institutions are not corporeal objects with an independent existence of their own. They are expedient alliances formed between people for a specific set of purposes. Our ability to use a bankcard, for example, depends on a set of shared ideas about financial institutions that constrain our actions and, perhaps counter-intuitively, give us the benefit of collective power and influence. The ability to trade without cash is underpinned by institutional vetoes or disciplines that push certain types of knowledge (and people, and patterns of action) beyond the pale. If that consensus were to collapse, the result would be a great loss of collective power.

At their simplest, institutions become manifest as traditions of socially learned behaviour. These behaviours generate patterns in human actions and in the distribution of the material objects people use, but they clearly aren't the whole story. We must also take account of knowledge (tacit and explicit) and the exercise of potentially coercive power. It is hard to see how institutional vetoes would hold, were it not that we evolved from organisms that were somehow predisposed to institutional discipline.

Stephen Jay Gould gave us a useful word, *exapt* (*ex* = out of; *apt* = fitted). To be exapted is to be in a state of readiness. All newborn mammals, for example, are exapted to suckling. All primates and many non-primates are also exapted to a raft of social learning experiences. There are phenomenological constraints, of course. The study of genetics, morphology and physiology are valuable sources of information about these constraints and capabilities. The chimpanzee may be able to tweak termites out of a tree trunk with a stick, but would struggle to make a violin or speak French. The violin-maker may speak three languages, but would struggle with some of the memory-feats achieved by laboratory chimpanzees.

The new-born primate (human or non-human) is not beamed into the world fully formed. It is the product of a complex interaction between embodied structure and external pattern *in utero*. The unfertilised ovum incorporates information from a sperm, which sets in motion a sequence of events and processes that allows the composite to implant and absorb nutrients and gases from its mother's blood-stream.

The process of weaving external pattern and internal structure together does not cease at birth, but continues to shape the development of the infant right through into adulthood. At each stage in the process, the organism is exapted to a range of behaviours and actions. The developmental pathway it actually takes is shaped by the circumstances in which it develops.

An institution is the emergent by-product of a programme of social learning that makes certain habits and behaviour patterns seem natural. We seem to be exapted in a way that enables us to develop habits and taboos, which eventually that become hard-wired into our neural networks. We only know that cultural norms exist when they have been violated and we feel ourselves becoming angry, embarrassed or distressed. Let us therefore define *culture* as a psychological constraint or taboo that prevents humans taking, or even considering, certain types of action.

This constraint allows humans to become acculturated into powerful super-organisms and exploit the benefits they create. The behaviour patterns and habits serve as a badge or uniform that allows us to recognise people likely to react to certain situations in a predictable way. The more critically dependent on them we are, the more closely we scrutinise their behaviour - *can we trust them? Will they keep faith, even when the threat to their own safety is real and immanent?* The simplest institutions would probably have sustained patterns of resource exploitation, exchange and food-sharing. Collective defence and ritualised aggression would also have been significant.

Conflicts between populations of humans and between humans and prey species are *ecodynamic* phenomena in which the actions of one species or population influence patterns of survivorship and adaptive potential in another. Kenneth Boulding coined the word 'ecodynamics', which gives the impression that ecology and economy are different ways of looking at the same thing. In small, hunter-gatherer societies, institutional vetoes would have been limited by group size. In a band of 20 - 50 people, a conflict that killed or maimed 6 could undermine everyone's fitness. In an urban society, alas, the deaths of a few hundred citizens can be shrugged off and institutions can develop that kill and maim on an industrial scale. As world population has grown, the scale of the killing has inflated to the point where our institutions have entrained planetary life-support systems.

Urban societies have developed a rich ecology of institutions based on written laws, custom and coercion. Humans can find themselves trapped in a vicious bind. The cost of culturally embedded knowledge is that people use language, or patterns of dress, or stated beliefs as cultural markers. As hostility increases, rival institutions retrench, cranking up the pressure on their own members to conform. In these war-like situations, individuals cannot set institutional vetoes and taboos aside until the threat has passed, but the threat will not pass until those receptivity barriers have softened.

Institutional vetoes harden in the run-up to conflict and soften again in the periods of glasnost and perestroika that follow, creating the phoenix cycles of system lock-in, collapse and renaissance so characteristic of the 20th century. Cultural diversity plays a role in human ecodynamics comparable to that of bio-diversity in natural resource management. It is a source of adaptive potential that sustains system *resilience*, which the ecologist C S Holling defined as the ability of a system to spring back after perturbation.

Most institutions cut their members a little slack when times are easy. Two people standing side-by-side in church, for example, would not necessarily interpret its creed the same way. One might think of the creed as a beautiful allegory, but only poetically true. The other might insist on a more rigid interpretation. In periods of peace and prosperity, institutions can tolerate a great deal of constructive ambiguity, but that wriggle-room is harder to maintain when institutions come under pressure.

In Western Europe, for example, young Muslims who a decade ago might have been indistinguishable from their neighbours, are now adopting more traditional patterns of dress and behaviour, and political institutions are beginning to legislate against those behaviours. These culturally embedded disciplines are by-products of ecodynamic stress, which leads institutions to veto knowledge that seems to subvert their interests.

This intellectual hegemony can develop into open war, genocidal repression or catastrophic damage to cultural and natural life-support systems as institutions come into conflict about cultural norms and tacit knowledge. As the economist Ernst Schumacher explained: *The greatest danger invariably arises from the ruthless application, on a vast scale, of partial knowledge.*

All primates and many non-primate species have the ability to weave pattern and structure into a culture-like context, but our species does it in spades. It is perhaps unwise to over-generalise about the ecodynamics of structure and pattern, but there may be a weak relationship between aesthetic attractors, cultural repellors, stability and conflict.

If a behaviour pattern seems beautiful or recreational, then the individual is probably operating within its contextual comfort-zones. The delight we take in cultural activities like language, music, ritualised activities, courtship and habit is reinforced by an embodied aesthetic that guided our ancestors towards the sorts of situations they could cope with. If that pleasure turns to embarrassment or indignation with those who do not share our values, or generates neurotic stress among the members of some institution, then there must be some conflicts of interest between rival institutions.

§ 7. Super-Normal Institutions and Science

Cultural exaption is an important bridging idea because it helps explain the evolution of deeply stratified, complex societies. Exaptive traits and predispositions that enabled our distant ancestors to thrive became hard-wired in their bodies where they remained, like an unexploded bomb that could be triggered and reinforced by later events. Behavioural scientists sometimes refer to these exaptive spirals as 'super-normal stimuli'. Birds that have acquired a tendency to devote more resources to incubating larger eggs, for example, can be persuaded to abandon their own eggs and sit on football-sized fakes.

In the same way, those humans driven to abandon their mobile, extensive lifeways and settle on critical resource-patches at the end of the Pleistocene period were exposed to patterns of violence, competition and epidemic disease - that forced them to develop more intensive and coercive institutions. Doubtless some of these nascent civilisations collapsed, but some passed through cycles of intensification, collapse and re-establishment to create modern polities and the super-normal institutions we are so familiar with today.

These institutions collapse from time to time. In the mid 18th century, for example, the technocratic empires of north-west Europe must have seemed unstoppable, but the American Revolution, the French Revolution, the Reign of Terror and the Napoleonic Wars shook them to their foundations. Europe entered a period of recession and political repression in the 1830s that lasted more than 20 years. The Birth of Nations uprisings of 1848 were ruthlessly crushed. In Britain they hardly happened at all, but mid 19th century institutions were by now too weak to resist calls for universal male suffrage, open-access education and political reform.

Nobody wanted a return to the revolutionary politics of the 18th century, so a massive programme of reform was initiated that created a system of technical education for the poor and enhanced social mobility. Mediaeval universities were also reformed and a rash of new universities and colleges emerged that taught the *-ologies*, flashy new 'sciences' with Greek-sounding names. A few of these institution-names were already old. The word 'anthropology' apparently existed in the renaissance period, for example, but the disciplines we associate with these names - study domains like biology, archaeology, anthropology and sociology - became recognisable academic professions in the course of the 19th century. We consider these 19th century reforms to mark the beginning of the *neo-modern* period in Europe.

By the time Charles Darwin published *Origin* in the 1860s, an innovation-cascade had occurred. The post-revolutionary sciences we are familiar with today already existed in nascent form. Some of Darwin's admirers struggled to assimilate his ideas about agency and choice. The list is long and must start with Thomas Henry Huxley and Alfred Russel Wallace. These scientists can reasonably be said to have been culturally unreceptive to those elements of Darwin's work, even though they agreed that species were mutable.

Although biology in the second half of the 19th century is often portrayed as a battle-ground between evolution and theology, old institutions like the church were now toothless and the aristocracy was greatly weakened. Social mobility was high and younger men were exploring scientific models outside the institutional mainstream. These fledgling institutions were culturally diverse and able to tolerate a large measure of ambiguity. By the closing years of the 19th century, however, this was no longer the case. The young 'men of science' had grown old. Some had acquired knighthoods and noble titles. The embattled empires of northwest Europe came into conflict with each other and with powerful resistance movements in annexed territories. Social mobility was poor, institutional vetoes became stronger and cultural markers were more strictly policed.

§ 8. Epiphany and Rapid Cultural Adjustment

Charles Darwin believed evolutionary systems never made sharp jumps. He used a Latin phrase associated with natural philosophers like Newton and Leibniz: *natura non facit saltum* - nature doesn't make jumps. Thomas Henry Huxley, however, argued that the evidence of saltations in evolutionary systems - now more often called *non-linear dynamics* - is too strong to be ignored. Nature does make jumps.

We have already presented some anecdotal evidence that innovation-cascades occur when institutional hegemony slips and people are free to think the unthinkable. However we have also suggested that institutions are epiphenomena - they can be explained in terms of cultural embedding, cost - benefit relations, social learning and coercion.

Knowledge that is embedded in the cultural repertoire of an individual is terribly difficult to set aside. Some cultural knowledge is religious, of course, but plenty is not. Culture is the reason we try not to fart in a crowded lift and would be reluctant to address the American Association for the Advancement of Science wearing two tassels and a G-string. To break these taboos wouldn't just be impolite; it would be mortifying. In a simpler world, one might expect institutional and cultural constraints to stifle innovation, and they do, up to a point, but the history of the post-mediaeval or *modern* period suggests that these regulatory constraints collapse from time to time, generating a saltatory, stick-slip cycle.

This essay will deal with an important feature of that cycle, which we call the *epiphany*. We begin with a story:

In 1973 one of us sat in an audience hearing about a sailor washed overboard into a stormy sea. As he fell, he cried: *God help me!* A second wave lifted him back onto the deck, bruised, but alive. Thereafter he believed in god, stopped gambling, drinking and swearing.

Hallelujah!

That sailor's epiphany told him something about the world (improbable events make a difference) that spontaneously changed his mind (he became a christian) that in turn influenced his behaviour (no more cuss-words), that altered the pattern of life for his shipmates. This was an *epiphany*, an altered sense of reality, linked to a change of behaviour that had knock-on effects which modified system dynamics.

If you compare the sailor's epiphany with others from your own experience or from history books, you may recognise a characteristic form. In most cases a perceived threat or challenge is turned into an opportunity. We don't mean this simplistically - it isn't that the first wave was a threat and the second an opportunity. The sailor had almost certainly been unhappy for some time and his anti-social behaviour was a symptom of that unhappiness. That unhappiness was sustained long enough to become contextualised, shaping new neural pathways in his brain.

The event shook him up and made him realise that life was too precious to waste on unhappiness. The new ways of thinking and acting were already nascent in his embodied mind - he was exapted to this change. When those neural pathways all came on-stream at once, he linked the 'act of god' to some dimly remembered rigmarole about christian morality and took the first steps of his spiritual journey. The event did not cause the new cultural configuration, it triggered a cognitive adjustment in a receptive (exapted) mind that gave him a new perspective and a new metanarrative to explain it. He switched straight into a gnostic position consistent with deep cultural embedding.

Although epiphanies influence habits, and habitual behaviour can influence survival and reproductive success, there is no logical link between specific beliefs (knowledge) and well-being. An atheist and a christian, for example, can both reproduce successfully, live happy, fulfilling lives, treat their neighbours with courtesy and win the respect of those around them. There isn't even a robust link between knowledge and action. People need not be christians to be sober and sociable, for example, and many reprobates profess christianity. A lot depends on the way people re-formulate those beliefs into metanarratives and the characteristic behaviours this contextual knowledge supports. The point is not that beliefs don't matter; they matter in a *complex*, i.e. logically unconnected way.

Cast your mind back to § 6, where we argued that institutional vetoes tended to harden as ecodynamic conflicts develop and soften in the period following an institutional collapse. Epiphanies will occur when people are ready to experience them, of course, but institutional vetoes are likely to be stronger in periods of ecodynamic stress. The effect can be a backlog of repressed and unconsummated epiphanies that aggravate social exclusion.

Our impression (not based on empirical analysis) is that young people (teens to mid 20s) are more likely to experience epiphanies than people in their late 30s and 40s. Many people also become exapted to epiphanies as they make the transition to early old-age in their late 40s and 50s. It therefore seems reasonable to speculate that the innovation-cascades that occur as institutional vetoes are softened may have a characteristic trans-generational signature.

§ 9. Reflexive Science

Readers who have persevered to this point will have realised that these introductory essays can be read in two ways. They can be read subjectively as a set of descriptions of the scientific process. They can also be treated objectively as specimens in a 'cabinet of curiosities', which the naturalist is invited to study, describe and research.

So far we have encountered two strategies for practising science without compromising the subject-object split. The natural history approach limits us to well-bounded categories of material object, whose keys are smaller than their essences and so ties the work to empirical method and morphology. When old-school natural history meets physiology, it tends to do so in a small sub-set of problem-domains where the three time-perspectives - event, conjuncture and deep-time - spring together neatly.

In contrast, the natural philosophy approach flattens the semantic triangle down till it becomes a line connecting an abstract idea and a symbol. These structures are not constrained to a small interval of space and time and cannot be observed directly. The payoff for introducing them is that you can create databases and use analytical method to work in problem-domains where objective morphology and physiology are inconsilient. Form and process are as consilient in natural philosophy as in natural history, but scientists tend to approach the semantic triangle from a different direction, starting with abstract, symbol-idea lines and constructing plausible metanarratives that change the way we think about the world.

Natural history is great fun, but of limited use in applied and experimental science. Relaxing the empirical constraint opens up a great new field of scientific research, but also generates ethical and moral dilemmas. Work on the physiology of ecosystems in the later 19th and early 20th centuries led to a number of scientific travesties - Lysenkoism in Stalin's Russia and Nazi eugenics, for example, that created ghastly self-fulfilling prophecies. The science wars of the early 20th century killed on such a hideous scale that a new word, *genocide*, was coined to describe them.

By the end of World War II it was clear that the subject-object split could not be trusted to protect society from genocide. Some ethical, legal and moral oversight was needed. The result was an innovation-cascade in which scientific disciplines were softened and many institutional vetoes were set aside. In the late 1960s and 70s it was possible, at least for a while to think of organisms as purposeful agents, capable of remembering, anticipating and planning. In his book *Behind the Mirror*, for example, Konrad Lorenz built on foundations laid by Darwin and Kant to argue that every organism reflects, in its own external face, the objective patterns manifest in others, but each of these biological mirrors also has an internal, subjective face. There are no one-sided mirrors in *reflexive* biology; no subject-object split, and no science so well-regulated that ethical oversight is not required.

Lorenz' story is remarkable only insofar as he was briefly 'successful' in the prize-winning hoopla and then fell from grace. Today, if one reads about Lorenz, Niko Tinbergen and Karl Von Frisch, who shared the 1973 Nobel Prize, one is struck by the difference in emphasis. Lorenz is portrayed as a loose cannon - a former Nazi sympathiser whose ideas about animal agency and reflexivity were always controversial.

The view from the humanities is somewhat different. A century and a half ago, animals and plants were objects to be used and wasted, and museums became great charnel-house collections of animals, plants and artefacts plundered from around the world. This objectification (post-modernists sometimes call it 'othering') was extended to savages, children, women, criminals and dissidents. They were objects, whose needs could be brushed aside. The introduction of a reflexive dimension into the life-sciences opened a Pandora's Box filled with shameful histories and ethical dilemmas.

Eventually political and commercial institutions decided that the recounting of these histories was undermining their credibility. Vetoes were tightened in a desperate attempt to put the lid back onto Pandora's Box. Through the Cold War years, politicians aggravated this paradigmatic tension by re-distributing resources and marginalising dissident perspectives. Scientific institutions responded by becoming less tolerant of cultural diversity. Natural philosophers mounted another rear-guard action, re-presenting the social construction of phenomena as if it were the social construction of things and accusing reflexive scientists of believing that any knowledge system, however absurd and useless, was worthy and beautiful.

One of us remembers being taught that a dog whining and scratching a closed door was not trying to get it open. The dog was an objective automaton and the behaviour was a conditioned reflex. Unlike the dog, the scientist was a subjective agent. When challenged with evidence of cleverness and forward planning among dogs, monkeys, crows and elephants, the teacher mounted a bizarre rear-guard action, demanding incontrovertible proof that the animal was actually thinking or experiencing pain, while ignoring the possibility that his own subjective experiences could be a delusion wrought in his body by the evolutionary processes that shaped it.

The biologists who policed this veto tended to be experimental and applied scientists. The students who found it most irksome were often those interested in animal welfare and environmental degradation. To those students it was clear that this Cartesian backlash had more to do with institutional stability, status relations and patterns of resource exploitation than with scientific objectivity. Today this orthodoxy is largely associated with Richard Dawkins, whose book *The Selfish Gene* linked these ideas to Neo-Darwinism.

Dawkins' principal contribution to anthropology was his *meme hypothesis*, which held that humans were not subjective agents at all. Discrete cognitive viruses called 'memes' take possession of human bodies and use them as vehicles to colonise space and time. Some anthropologists tried to reconcile the meme hypothesis to empirical evidence, treating memes as cultural archetypes, rather than as discrete replicators, but Dawkins, in his *God Delusion* perseveres with the original model. Unlike gene theory, which was based on inferences drawn from experimental data and substantiated by later work on protein synthesis, there is no evidence memes exist. A meme is a cognitive demon that possesses your body. Dawkins' model reversed the polarity of the debate between scientific atheists and theologians.

40 years ago Wallace's ideas about the intelligent universe had been set aside. Scientific theories of human origins tended to be naturalistic and religious explanations tended to be superstitious. Evangelical christians asserted the literal truth of Genesis and denied even the possibility of Darwinian evolution. Dogmatic christians, while they accepted evolutionary theory, used Cartesian dualism to preserve the doctrine of the soul. Both parties drew a sharp line between humans and brute creation and railed against agnostic science - the Roman church called it the 'modernist heresy' - because it undermined Cartesian superstition.

Since the 1970s, however, Dawkins has been telling us that memic possession is a naturalistic model. Huxley's agnostic phenomenology was apparently a debating-chamber fiction and research on human agency is superstitious. Given the absence of supporting evidence, it is hard to see how this *volte-face* can be marketed as natural science.

Political institutions threw their collective weight behind the gnostic atheists of the 1970s and reflexive science shattered into a host of micro-disciplines, each engaging with 'modernity' in mock gladiatorial combat. Words like *scientism*, *reductionism* and *positivism* were used to 'other' the natural scientist and the post-modern anti-science backlash had begun. The sociobiology debate of the later 70s and 80s marked a return to the enlightenment stand-off between Cartesian and Kantian factions, this time with hard-line atheists backing the Cartesians. Political institutions were back in their comfort zones.

This complex of political and operational constraint creates a multi-scale dynamic in which the actions of individual scientists are shaped by a combination of private hang-ups and institutional vetoes. The natural historian working on the ecodynamics of science will struggle to distinguish *traits* - heritable attributes that are hard-wired into the scientist's genetic memory - from *emergents* - attributes arising as by-products of social learning and circumstance. The strategy we have taken here has been to assume that the subject-object split is sometimes a working axiom and at other times a receptivity barrier that protects an institution by pushing dissenters beyond the pale. This requires us to take account of a third species of scientific endeavour - *humanism*. In humanistic science, the subject-object split is abandoned as ethically and empirically indefensible.

These three types of approach - natural history, natural philosophy and humanism - have different strengths and weaknesses. The natural history and natural philosophy approaches, which philosophers of science sometimes call empiricism and rationalism, clearly intergrade and so too do natural history and humanism, which intersect in our own discipline of anthropology. Indeed, many scientific disciplines span the gamut from humanism to natural philosophy - geography, anthropology and economics are cases in point. Biology (defined *sensu lato* as the study of living systems) used to stretch almost this far, though the post-modern backlash saw biology departments close ranks to drive natural history and environmental science beyond the pale. In effect, the natural philosophers hi-jacked the name, but narrowed the definition to exclude much of natural history and almost all of the humanities. The result was a much stabler institution than could possibly have been constructed otherwise.

Section II : The Morphology of Research Projects

In a book titled: *The Open Society and its Enemies*, the philosopher Karl Popper explained that there were two ways of reading definitions like:

A project is a body of research work with a start-date, an end-date, a limited resource-budget and one or more well-defined deliverables.

They can be read from left to right as an answer to the question: *What is a project?* or from right to left as an answer to: *what shall we call 'a body of research work with a start-date, an end-date, a limited resource-budget and one or more well-defined deliverables?* Popper didn't like left-right reading, which he thought implied an obsession with universal truth, semantics and social control. According to Popper, true scientists read definitions from right to left.

Well, sometimes they do and sometimes they don't. Much of our Section I, for example, was intended to be read in this Right-Left way, but the definition of projects we have just given is no abstraction. Neither is it an excuse to pontificate about universal truth or make spurious claims of originality. The definition summarises the findings of basic research on the anthropology of science. There is clear empirical evidence that research projects have these attributes and good operational reasons why that should be so.

Project-based research is regulated by contract and institutional disciplines that give it a characteristic pattern. Well-designed projects have an internal division of labour and characteristic life-cycles. Poorly designed projects and those that are over-regulated or ineptly managed, usually cease to be projects. They fail to deliver, run out of time and resources and researchers find themselves in unsustainable and sometimes intolerable situations. You can identify a sick project by signs of mission-creep. Deadlines slip, quality is fudged, budgetary control falters, researchers start playing the blame-game, and funding agencies tighten the screws.

Research projects are common enough to be worth studying, but there are other ways of organising scientific research. Our work on the natural history of science, for example, is an open-ended research *programme*. It need not be completed in a narrow time-window, its resource budget (though small) is not bounded, and there are no pre-agreed deliverables. So we can make an informal distinction between research *programmes* and research *projects*. We are subjective researchers whose open-ended programme of research deals with objects that are time-limited projects.

The key attributes of a project have already been presented, but there are some tricky cases where diagnosis using these features is problematic. Sometimes projects experience mission-creep or run over budget or fail to deliver and people race around finding new resources and excuses to keep them running. In practice, however, project deliverables and budgets are usually defined *ex ante* and projects that drift beyond these boundaries have failed. Failed projects, like dead and dying organisms, are rather common. There are worthwhile lessons to be learned by studying failed projects - some can be restored to health again - but here we are primarily concerned with viable projects.

The first recognisable projects involved seafarers sent out to map the world and undertake scientific research in the 18^{th} and 19^{th} centuries; Charles Darwin and Thomas Henry Huxley were working on projects (voyages) with a start-date, a loosely defined end-date and a number of deliverables. However the hey-days of the project approach began in the aftermath of World War II as methods designed to develop defensive infrastructure and weapons of mass destruction were imported into the university setting. Today, every university student is given experience of project-based work and the completion of a doctoral project is an important rite of passage. This was not so before World War II.

Early peacetime projects (up to the end of the 1960s and early 70s) were often poorly managed. Their deliverables were illdefined and they were prone to mission-creep. Part of the reason for this was that university-based scientists and funding agencies had little experience of project discipline. Scientists made promises they couldn't keep and funding agencies and university departments were too embarrassed and inexperienced to kill failed projects off. The model became more deeply embedded in scientific culture from the mid 1970s onwards. By the early 1980s, doctoral students who failed to deliver on time were being pushed out of the system. By the late 1980s, systems of quality assurance and audit were being developed that would, at least in theory, penalise senior scientists and their employers if they failed to deliver in a legal, timely, lawful, efficient way. These constraints impose a sort of selection-pressure on projects that limits the range of variability.

§ 10. Regulation and Operation

Most projects have an external sponsor - a funding institution or patron that imposes regulatory constraints on the work. We say 'most projects' because, in periods of recession, unemployed graduates sometimes create sponsorless projects to demonstrate their research skills and increase their attractiveness to potential employers. Institutions often help them by supplying facilities and subsistence costs, an act of kindness that can create whole generations of 'disposable researchers' who drift from one project to another.

This phenomenon became manifest in the recessions of the mid 1970s and seems to have returned every time economies turn down. The professional life-expectancy of these gunslingers is short - few last longer than 3 or 4 years. A few stubborn individuals make the transition to competitively tendered, project-based research. One of us (Nick) followed this career path. Even in these sponsorless projects, however, disciplinary constraints become manifest as a set of normative regulations that limit the team's operational 'wriggle-room'.

Regulation is a small component of project management, mots of which has an operational focus. Where regulation management is normative, ops management is responsive and occasionally subversive. Regulation sets boundaries and constraints; operation works round them. The project is realised through a dynamic tension between the regulatory and operational components and the balance is not static.

All projects have three phases. There is an initial 'opening up' or reconnaissance phase, when previous work is reviewed and alternative approaches are considered and a 'closing down' or 'focussing' phase in which some possible approaches are set aside and the project zeroes-in on a well-defined target. Closing down is not the end of the project, but the beginning of the third, 'problem-solving' phase. This is when the plan is put into action and the deliverables are produced. The resource-budget allocated to these three phases may vary widely between projects, but there is always a little reconnaissance that opens the possibility space up, some selection among options to close it down again and an operational phase that delivers the goods.

Every project involves an effort of communication that transmits findings and deliverables to some external stakeholder community. Commercial and defensive projects are often communicated in strict confidence to the sponsor alone. Academic projects are often disseminated widely. Relationships between stakeholders and the project vary considerably. Some stakeholders will be acknowledged explicitly. Some of these will have explicit roles on the project and many will not. There will often be unacknowledged stakeholders. A project to develop a new type of weapon, for example, will not usually communicate the results to competitors and intended victims, though they are stakeholders *de facto*. Unacknowledged stakeholders often include non-human animals and plants, and humans whose interests fall foul of culturally embedded taboos. They may be hostile or even violently opposed to the work.

All projects can be broken down into sub-projects and even sub-sub projects that run in parallel and pass deliverables from one to another. However the fact that they can be broken down this way does not necessarily mean that they should. A medium to large project with a budget estimated in millions of euros or dollars is usually easier to manage if broken down in this way, but there is a law of diminishing returns in place. Sometimes the effort of defining a sub-project and disentangling operation from regulation is more trouble than it is worth.

When a multidisciplinary team comes together to work on a projecty, each must locate the others on a phenomenological map of some sort. Each is constrained by cultural vetoes and an informal disciplinary consensus. Much of the conflict that arises in these circumstances does so because each scientific 'self' pushes an 'other' into a category that fits in with those cultural constraints and vetoes. The sociologist, observing that mathematicians negotiate an informal consensus about patterns of logical rigour, treats mathematics as a sociological object, comparable to literature or creative art. Mathematics becomes a discursive display that establishes, explores, maintains and develops a sort of aesthetic standard. The mathematician, observing empirically coherent patterns in social systems, squashes sociology into a sub-domain of mathematics - it belongs with descriptive statistics and pattern exploration.

When you get these two together, they must try to negotiate some knowledge - some shared beliefs that underpin co-operation. One thinks maths is a sub-domain of sociology and the other thinks sociology is a sub-domain of mathematics. Each worldview cuts across the other in a way that raises hackles. If these meetings are not handled sensitively, the result can be conflict-ridden and uncomfortable.

In applied research, conflict within the project can spill over to impact on external stakeholders. A badly managed or weakly regulated research project can easily de-stabilise cultural and natural life-support systems. The agnostic, or phenomenological approach we have sketched out can sometimes put a little epistemic wriggle-room into the project and good operational management can reduce hostility further. This makes the project more fun and minimises harmful impacts on external stakeholders.

Research managers have two resources at their disposal: one is the collective knowledge of the team and the other is the potential power that could be derived from integrating the whole group. These cannot be exploited simultaneously. If you want to make best use of diverse beliefs, the smart move is to keep people in loose disciplinary alliances so individuals spend most of their time operating within their own cultural comfort zones. If you want to harness the power of the whole group, you need to bring people together.

This involves a careful effort of preparation. You start with social interaction in small groups and negotiate a shared task for the whole group to tackle. When people come together, you need them to leave their cultural hang-ups behind and focus on that shared target. Once that target has been achieved, or substantial progress has been made, you encourage delegates to take possession of part of the shared task and carry it back into their own cultural home-ranges. Just about the silliest thing you can do is to create a trans-disciplinary circus and expect people to operate outside those comfort zones indefinitely. They will fight. There will be winners and losers. The losers will be driven beyond the pale.

What we have described here is not a theory about trans-disciplinary dynamics, but an informal empirical fact. Trans-disciplinary integration is inherently unsustainable. If you want to harness the knowledge of many disciplinary communities, you must keep disciplines apart most of the time and only bring them together when you *need* them to co-operate. Try to create an environment of safety and mutual trust and extend that trust to your team, giving them the time, resources and space needed to take risks and make mistakes. All will be well as long as individuals don't start making the same mistake again and again. If they do, the project manager must act and doing so transforms project management, effectively flipping the manager between the operational and regulatory modus operandi.

This integrative approach works surprisingly often - much oftener than trans-disciplinary crowd-control or the melting-pot approach often demanded by project regulators and advocated by academic experts. Conventional theories about the evils of disciplinary silos and the importance of breaking them down have been tested by project managers and comprehensively falsified. The humanities and the natural sciences are different and the differences cannot be eliminated without compromising trans-disciplinary work.

§ 11. Three Questions; Four Causes

Operational management requires you to consider three broad types of question: the *what?* questions of morphology and the *how?* questions of physiology are clearly significant, but so too are the *why?* questions that engage humanists. It is interesting, when one considers probable responses to these three types of question, that many potential answers begin with the word *be-cause*. The answer to a scientifically interesting question often appeals to some notion of cause.

Western science has been strongly influenced by ideas borrowed from the Socratic philosophers, notably Plato (a gnostic rationalist) and Aristotle (an agnostic empiricist). Plato gave us the distinction of *being* (what a thing is) from *becoming*, which reflects our distinction of morphology from physiology. Being and becoming can easily be translated into causal explanations and Aristotle did this, characterising four types of cause. Two of Aristotle's four causes related to statics and Platonic 'being'. They are *material* cause (what a thing is made of) and *formal* cause (what it really is). The open-universe approach to natural history collapses these two types of cause down into one by restricting attention to objective, material things and key / essence syllogisms.

Aristotle also created two types of cause to handle Platonic 'becoming'. These are *efficient* cause, which is machine-like, logically consistent and hence predictable (at least in theory), and *final* or teleological cause, which has to do with agency and purposeful action. Final cause may be capricious and even perverse. These two types of cause seem to imply different approaches to physiology, which modern scientists have called 'natural philosophy' and 'humanism'.

A natural philosopher asked why a dog scratched at the door would appeal to abstract, transformative processes and efficient cause - describing the animal's innate ability to acquire socially learned responses, the process of habituation and its biological need to socialise. In this way, the dog is reduced to an objective machine and its actions can be explained in terms of efficient cause. A humanist, on the other hand, would be more inclined to empathise with the dog, treating it as a subjective agent and appealing to final cause and purposeful action. Perhaps the dog is trying to get in. Perhaps it is lonely or bored. Perhaps it just wants attention.

Through much of the 19th and early 20th centuries these two types of causal explanation were set out in paradigmatic opposition, with efficient cause being classed as 'scientific' and final cause pushed beyond the pale. Kenneth Boulding, a great coiner of aphorisms, wrote of this: *it is considered science which describes the scratch and not the itch.*

The two types of cause can both be invoked to answer questions about human and animal behaviour, but do so in different ways and operate on different space-time scales. The appeal to efficient cause refers the observation at hand to a named category and appeals to a machine-like process that transforms all instances of that class - all dogs come with these innate, machine-like drives. The appeal to final cause implies an element of choice, agency and self-determination and so treats the case at hand as an individual capable of acting in an un-machine-like way. The difference is that between the *how?* of natural philosophy and the *why?* of humanistic research.

This consideration of causality allows us to contemplate a spectrum from humanistic research (no subject-object split, many appeals to teleology (final cause) and an abiding interest in *why?* questions) through natural history (subject-object split maintained using empirical method and a hybrid of material and formal cause centred on the *what?* questions of morphology) to natural philosophy (subject-object split maintained using rational disciplines, many appeals to efficient cause and a strong interest in the *how?* questions of physiology).

§ 12. Natural History: Type or Attribute?

So far we seem to have suggested that natural history and objective morphology go together (they do). Yet we, as naturalists, have appealed to abstract, quasi-morphological categories when describing human cognition and the ecodynamics of culture. This method belongs to natural philosophy. In Section III we will also advocate a humanistic, reflexive approach that dispenses with the subject-object split altogether. Surely natural historians like us should respect the disciplines of natural history?

Not necessarily.

Natural philosophy, natural history and humanism could conceivably be sharply bounded types of activity or even well-defined collections of people, but they aren't. They are characteristic conjunctures of method and intellectual focus that evolved in response to characteristic sorts of scientific challenge. You can think of them as roles that scientists slip into, and out of, as their contexts change. If a particular scientist claims to be a natural historian, the chances are that empirical method and systematics will lie somewhere in that person's intellectual home range, but very unlikely that any professional scientist will be so narrowly trained that they never leave that range and explore different types of intellectual territory.

These attributes of scientific endeavour allow us to speak about the morphology and physiology of research projects. Research physiology, as any contract researcher can testify, is vulnerable to changes in political fashions and policies. Economic boom / bust cycles and phoenix cycles of war and peace have particularly strong effects and these create links between science and politics, In Section III we will return to this idea, modelling flow patterns in a scientific attribute space, rather as one might model air pressure near the earth's surface, or fluctuating fields around an electro-magnet.

§ 13. Classic and Romantic Science

In literature, music and the fine arts, a distinction is often made between *romantic* and *classical* modes of expression. In classical art there is a clear subject-object split. The artist is striving for a naturalistic representation of the object being described, perhaps embellished to fit abstract ideas about proportion and beauty, but expressed in a way that leaves one with little information about the artist's own personality. In romantic art, the subjective and objective dimensions flow together to create a work of self-expression. The distinction of romantic from classical modes of expression feels a little like the difference between natural philosophy and humanism or that between the ancient and modern ways of mediaeval scholarship. This essay is to tighten that distinction up.

Scientific endeavour is only possible because scientists are able to apprehend pattern and convert it into embodied structure. Pattern is the non-random distribution of phenomena in space and time, as observed in some physical arena. That arena can contain microscopes, telescopes, ancient manuscripts, computerised databases and so on. Pattern is empirically observable, either directly or by studying some sort of database. When we use the word 'structure', however, we refer to embodied memories. These memories are themselves the product of an earlier process of structuration. In practice, many of the most significant structures are represented as knowledge - a set of shared beliefs that enable individuals to co-operate.

So our definition of humanism and natural philosophy must have something to do with the contextual interweaving of empirical evidence and shared beliefs. It has a material component and an ideational component. In natural philosophy, the ideational component invariably includes patterns of reasoning by necessity in which the conclusion can be deduced from working axioms and data. The syllogism:

If A, then B
If B, then C
A therefore C

is an instance of the class. If A is true, then we can deduce that C is also true.

Syllogistic logic is one type of deductive reasoning process among many. Numerical reasoning of the 2+2=4 type also works by logical necessity, as does algebra. You can even build statistical uncertainty into numerical method and still reason by necessity. You can go further and introduce a 'null category' into the work that represents situations where a reasoning problem is ill-posed in the sense that the answer either does not exist or is not unique. The minimum requirement for reasoning by necessity is that there must be some abstract categories or sets and logical relations between those sets.

Natural philosophy methods also tend to have characteristic space-time scales. Even when uncertainties introduce an element of unpredictability into the work, it is usually possible to make some sort of prediction 'on the balance of probabilities'. It is not possible to deduce the outcome of a single coin-tossing experiment, for example, because a coin-toss is *time-asymmetric* - the future is undetermined in the present.

The natural philosophy approach requires us to recognise that the possibility space of a coin-tossing experiment is logically closed (heads or tails). So you slip up a level of aggregation, envisioning a hypothetical population of similar coin-tossing experiments within which it is possible to speak about relative frequencies of different types of outcome and use probability methods.

In practice, the operational judgement that leads us to use analytical method constrains us to work on the meso-scale or conjunctural level. Narrative chains of events are too unpredictable and the deep-time perspective too static to be worth predicting. This combination of bounded categories, deductive reasoning from abstract axioms and data, and a focus on time-symmetric conjuncture is diagnostic of natural philosophy.

The humanities often encounter time-asymmetric phenomena, but tackle them in a way that defeats conventional analysis. The difference is that between uncertainty and meaninglessness. Consider, for example, a prediction of the mean summer temperature on the top of Ben Nevis in the year 2500. Categories like 'mountains' and 'temperatures' are ontologically robust, so natural philosophy methods can generate a prediction that, although highly uncertain, is at least meaningful. Scientists can even use probability methods to get a handle on the level of uncertainty because the ontology is robust enough to make it possible to speak of populations of mountains and long-term climate scenaria.

Predicting the gross domestic product of Scotland in 2500, however, would imply that the polity and its economy would still be recognizable 500 years from now. Such a prediction is not merely uncertain, it is meaningless because a host of innovations could intervene, any one of which would sweep our conceptual taxonomy aside. It is not meaningful to speak abstractly about populations of polities a little like Scotland 500 years from now.

The humanities tend to work with *possible* relations, rather than with necessary ones. Consider, for example, the moralistic text:

For the want of a nail the shoe was lost,
For the want of a shoe the horse was lost,
For the want of a horse the battle was lost,
For the want of the battle the kingdom was lost,
And all for the want of a horse-shoe nail.

All these statements are *possibly* true, in the sense that the verse makes a coherent, *ex post* explanation of the collapse of some kingdom, but nobody would claim that the loss of a horse-shoe nail would *necessarily* lead to the collapse of a kingdom. The logical connections are too weak.

Humanism deals with *ex post* narratives, agency and possible relations. Categories may be weakly defined and system dynamics are time-asymmetric. Natural philosophy handles *ex ante* prediction, necessary relations, well-bounded, abstract categories and time-symmetry.

This distinction creates a substantial 'grey area' in the human sciences. In many 'social sciences', for example, categories that are known to be ill-bounded are treated as if they were well-bounded and statistical methods are used to make predictions, subject to this assumption. Social scientists often apply natural philosophy methods to human activity systems to develop first-cut predictions and tackle *what if?* questions.

You cannot distinguish humanism from natural philosophy by looking at the study-domain alone. You must also look at the behavioural ecology of science. If analytical methods are being used to make predictions, you are probably dealing with natural philosophy. If discursive methods are being used to make sense of human activity systems *ex post*, with the wisdom of hindsight, you are probably dealing with humanism.

§ 14. Plesionic Science

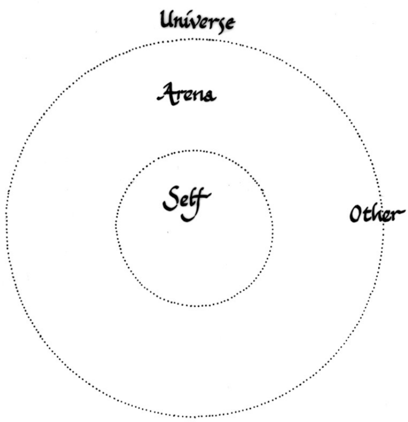
If you go out into the field, as it were, and study scientists in their natural environment, you will soon encounter a bunch of activities that seems to blur this distinction. Natural history, for example, deals with a contextual meld of embodied structure shaped by patterns of interaction with a populated neighbourhood. That gives it a slightly humanistic look and feel, though it is not restricted to the study of human activity systems. Charles Darwin, though celebrated today as a pioneer of evolutionary theory, was in fact the first reputable scientist to work on purposeful agency and patterns of interaction among neighbours in a neighbourhood.

In the best traditions of neo-modern science, we have borrowed a word from the Greek to describe this approach. *Plesion* (πλησίον) means 'neighbour', so *plesionic* means 'of neighbours and neighbourhoods'. *Origin* was the first book in the history of western science that dealt with purposeful agency, contextualisation and plesionic systems.

The plesionic sciences represent the heartland of *integrative research* - of research where natural philosophers and humanists come together to work with external stakeholder communities (including non-human stakeholders). They also provide wonderful opportunities for work on the natural history of science because anthropologists are able to observe patterns of interaction between different types of scientist working on the same projects. One of the most striking features of this research is that the subject-object split is almost meaningless. The scientist *is* a stakeholder whose rights and obligations are indistinguishable from those of a farmer, a bird-watcher or hotelier. The methods one uses to manage and resolve conflict among external stakeholders are broadly similar to those one uses to manage and resolve conflict within the research team.

We are going to need a general model of a plesionic system. The map we will use for this purpose will not change through the course of this book, but the way we interpret that map undoubtedly will! You can't read this essay and assume that you understand plesionic systems, because the idea is complex. A plesionic system is not the same as an agent, for example. A research team can be a plesionic system (sometimes) and the same agent (human or not) can flip from one plesionic context to another.

Let's start by drawing the map. Imagine some subjective 'self' embedded in a physical arena that contains, among other things, objective 'others'. Others can come and go, so we must allow arena to be permeable and set in a larger interval called 'universe'. The boundaries between self and arena or arena and universe are permeable - material and information can flow across them and contextualised memories can develop.



Suppose self is an unfertilised ovum surrounded by fluid containing active spermatozoa. In this context, a single sperm (other) penetrates the ovum, injecting material and information. The ovum ceases to be receptive to conjugation and this receptivity barrier has knock-on implications for other spermatozoa. Arena has become a more hostile environment where the remaining sperm will die without issue. Everything that happens to self has knock-on effects in arena. Everything that happens to arena has implications for self.

Some of the attributes we associate with humanism are also present in plesionic natural history. Systems can be time-asymmetric, for example. There are agents in natural history, but they are not ubiquitous and self-aware as they are in the humanities.

One cannot assume that the organism fabricates itself from some genetic blueprint and that arena is just an inert food source, for example - because the two are locked in a complex, co-dynamic interaction that interweaves pattern and structure. Indeed, one cannot even describe the behaviour of the whole system without comparing and contrasting many contexts. From the ovum's perspective, spermatozoa are 'other', i.e. pattern. From the spermatozoon's perspective, the ovum is 'other'. Conjugation carries material and information from ovum to arena and disrupts these identity relations. Self and other (structure and pattern) merge to become a composite structure. The fertilised egg now signals its lack of receptivity and this information changes the possibility space explored by the residual spermatozoa.

The plesionic sciences are relativistic. By this we do not mean that any way of seeing the world is as useful and worthwhile as another - that sort of relativism is a straw-man argument used by natural philosophers who feel threatened by humanism. Plesionic science is relativistic in exactly the same way that Einstein's relativity theory is relativistic. There is no universal frame of reference that will allow scientists to describe everything that is going on in the universe of discourse. Every phenomenon is contextualised. Biological organisms can also conjugate, merge, diverge, communicate and divide in ways that disrupt the ontological continuity of the things we study. An organism, by this conception, is a transient, complex, self-organising, self-sustaining structure created by contextual interaction between self and arena.

Natural history occupies a middle-ground between the analytic time-symmetric ontologies of classical physics and the discursive time-asymmetry of the humanities. In humans, for example, the mother's uterus provides a complex arena within which the baby develops. If there is no twin present and the egg has been fertilised, we can develop a mechanistic model that treats development as a process that leads from implantation to birth. Ludwig Von Bertalanffy gave us a useful word to describe such systems; *equifinality*. The egg, if it avoids the null state of premature death, will become a human baby. If it suffers some insult or trauma, its development will be modified, but it will *still* produce a baby; the space of possible futures seems to be bounded and this systemic boundedness makes it possible to predict the outcome.

§ 15. Time-Asymmetry and Systemic Messiness

Up to the 1950s and 60s, plesionic scientists tended to assume that well-structured problems could always be characterised. Kenneth Boulding, in a seminal paper on general system theory - *The Skeleton of Science* - written in 1956 said:

In recent years increasing need has been felt for a body of systematic theoretical constructs which will discuss the general relationships of the empirical world. This is the quest of General Systems Theory. It does not seek, of course, to establish a single, self-contained "general theory of practically everything" which will replace all the special theories of particular disciplines. Such a theory would be almost without content, for we always pay for generality by sacrificing content, and all we can say about practically everything is almost nothing. Somewhere however between the specific that has no meaning and the general that has no content there must be, for each purpose and at each level of abstraction, an optimum degree of generality.

Ludwig Von Bertalanffy, the other pioneer of general system theory, was strongly committed to the natural philosophy approach and even more ambitious than Boulding. Like Karl Marx and Herbert Spencer, Bertalanffy seems to have believed that ecosystems and social systems were equifinal. Indeed, his book, *General System Theory*, gives the impression that the world is full of equifinal systems, just waiting for some clever natural philosopher to come along and do a little systems analysis.

By the late 1960s it was becoming clear that many plesionic systems were ill-structured and that there was nothing the scientist could do to change that. In 1973, Horst Rittel and Melvin Webber wrote *Dilemmas in a General Theory of Planning*, which introduced the concept of a wicked problem. They often arise in conflict situations where solutions are not objectively ‘true’ or ‘false’, but subjectively ‘better’ or ‘worse’; there are no stopping rules, no objective criteria for satisfactory solution. Every case study is a unique, one-shot operation and every implemented solution has consequences that cannot be undone. In 1979, Russell Ackoff produced a paper titled: *The future of operational research is past* in which he declared that 'managers do not solve problems, they manage messes'. The terms 'wicked' and 'messy' refer to ill-structured problem-domains, where there is no 'optimum degree of generality'.

Our book has almost nothing to say about wicked complexity beyond observing: 1) that it exists; 2) that patterns are often so unstable that *science* - the study of natural pattern - can find no leverage, and 3) that ill-structured systems are ethically challenging. Simply to have someone in the corner of the room taking notes can change the nature of the system and these changes can be propagated through space and time in a way that actually changes the way the system operates.

Kenneth Boulding was right about systems science in general. As long as there is scope for the practice of science, different ways of bounding the system create an object with a different space-time signature. Each of these perspectives brings some patterns into the foreground and backgrounds others. Some of these systems and perspectives appear to be equifinal, but many are time-asymmetric.

Equifinal systems tend to be well-structured - almost isolated from their neighbours. Like the developing foetus, they are enclosed in a womb, bathed in amniotic fluid and buffered by the homeostatic mechanisms that sustain the mother. Darwin's Galapagos islands were also almost isolated. Flows of material and information between them were so weak that the process of contextualisation was constrained and they developed as if they were creating themselves from an internal genetic blueprint or founder population. Systemic openness and free exchange of material or information between neighbours undermines the principle of equifinality by introducing a measure of path-dependency and contextualisation.

Equifinality is not a law of nature, but an emergent phenomenon that can only be valorised on certain space-time scales. It is something to do with the system boundaries that constrain patterns of plesionic interaction on some space-time scales. Let us take the interaction between the cells of the human body as a starting-point. If the body were an unconstrained plesionic system, each cell would be engaged in a competitive free-for-all with its neighbours. But it isn't. Cells are constrained by chemical gradients and bounded into almost-closed systems called organs.

We can re-cycle a term from our analysis of institutions above and say that organs and organisms have receptivity barriers that suppress certain patterns of micro-scale interaction. These barriers enforce a rapprochement between the cells, effectively protecting the whole from cancerous pathologies. System bounding is not a law of nature, but an emergent pattern that evolved by a Darwinian process of descent with modification. Indeed, the diversity manifest among different types of organism raises questions about the 'organism problem' comparable to those Darwin raised about species. There is no definition of an organism that covers all bases.

The boundaries that characterise organs, organ-systems, organisms and interbreeding populations weaken adaptive potential, converting an anarchic system into one that is much less complex. If the strategy is successful, these systems may replicate, creating a recognisable species whose life cycle is more or less equifinal. Equifinality, however, isn't the only show in town. In the plesionic sciences, system boundaries may be poorly defined. The system as a whole can hunt through an unbounded space of possibilities until it locates a region where some sort of stability can be maintained. This stability is not the product of an innate, genetic blueprint. It is the upshot of plesionic friction between self and other in a populated neighbourhood.

In plesionic science there are always phenomena that cannot be predicted from a given contextual perspective. Scientists tend to favour conceptual models that reduce the likelihood of inconvenient surprises. Each model implies a different set of boundary judgements and space-time scales. Plesionic researchers choose these perspectives in a way that suggest classes of almost self-contained object, located in a populated arena and interacting with neighbours in a relatively mechanistic way. These boundary judgements are shaped in part by temperament and interest and, in part, by the receptivity barriers of disciplinary communities.

Those who are comfortable with the systemic messiness of plesionic systems tend to make boundary judgements that weaken the subject-object split and bring time-asymmetry into the foreground. Those who want to make predictions tend to shift system boundaries in a way that pushes time-asymmetry into the background.

No competent scientist makes boundary judgements perversely. If boundaries are so weak that nothing meaningful can be said about the class, then there will be no pattern to work on and the whole scientific enterprise collapses. These are situations where advocacy, diplomacy, coercion or mediation may have something to offer, but not science.

§ 16. Two Types of Truth

This essay will consider two models of truth. The first, which had its roots in mediaeval thought, sees truth as a sort of resonance between intellect (i.e. understanding) and things. Intellect is the product of a process of structuration. This *intellectual* model is often associated with the mediaeval scholar Thomas Aquinas, who defined it thus: *veritas est adaequatio intellectus et rei*. *Intellectus* is understanding and *rei* could mean reality or things. *Veritas*, of course, is truth. *Adaequatio* is a rather unfamiliar word - in comes from *ad* (to) and *aequus* (equal). The semantics suggest a passive equation, but the word also implies an intuitive act of recognition. William Whewell was appealing to a similar idea when he coined the word 'consilience' - a springing together. Intellectual truth is a consilience of understanding and things.

This intellectual model has always been tricky, because it leaves the notion of 'things' undefined. Human language, as we have seen, can refer to at least three types of things. There are objective patterns - the warm-blooded furry creature by the fireside; there are ideational structures - the idea of a cat in a person's mind, for example, and there are symbolic hybrids like the cipher 'cat' that links them together. This diversity often compromises the scientific endeavour, and disciplinary institutions have emerged that veto certain types of thing. The two commonest strategies are to restrict science to material things - this is usually called *empiricism;* or to restrict them to analytical things - variously called *rationalism* or *formalism*.

The boundaries between empiricism and rationalism are always tricky. Karl Popper, a self-proclaimed rationalist, famously defined science as the investigation of falsifiable hypotheses. Falsification, of course, is an empirical discipline. In defining science this way, Popper recognised that it involves a mix of rational and empirical work. These are different types of thing.

This inferential link between abstract things and predictability is very important in natural philosophy and enlightenment science. A Newtonian force - that which disrupts a body's uniform motion - is a thing because we can feel the effects of forces on our bodies and observe their effects on others. We cannot observe a force directly, but it can be described mathematically and, in some cases, be used to predict the behaviour of material things. This consilience of intellect and evidence builds confidence.

Abstract categories like 'force' and 'action' seem 'real' in the sense that would have been familiar to the ancients of mediaeval science - one gets the impression that they are independent of human agency and belief. Concepts like force and momentum would be meaningful, even in places where there were no people to feel the pull and make predictions.

As the Enlightenment ran out of steam and Europe entered its neo-modern, or post-revolutionary period, scientists began to take the plesionic dimension more seriously. Plesionic science requires us to take account of things that cannot be observed directly and are not subject to the constraints of abstract reasoning. A nation's credit-rating, for example, cannot be observed directly (except in the trivial sense that we can look it up on the internet) and neither can it be deduced from mathematical axioms. A credit rating only exists by negotiation and common consent - it is something to do with contextual knowledge and receptivity barriers. Nonetheless, we can predict that a country with a poor credit-rating will be a less congenial place to live than a richer one.

From a natural philosophy perspective, these socially constructed things create some challenging problems because our predictions are only as dependable as the consensus that sustains those institutions. From a humanistic perspective, however, this time-asymmetry is rather encouraging. When one is dealing with highly contextualised, socially constructed categories, the past is a poor guide to the future. It is possible to innovate, emancipating people from the tyranny of the institutional veto and changing the course of history.

When environmental scientists predict a global catastrophe - anthropogenic climate change, say - powerful institutions often go into intellectual mode, arguing about whether global warming is 'real' and the truth or falsity of the prediction. They play empiricists and rationalists off against each other. This is part of a ritual display that reinforces institutional receptivity barriers. The scientists making the prediction, however, are much less interested in testable hypotheses than in changing the way people think about habitual behaviours. In plesionic science, the best and most powerful predictions are those that trigger innovations, which render them meaningless. In Aristotelian logic, these predictions are called *future contingents* because they carry a tacit conditional clause: *X will happen (if these conditions are satisfied).*

Viewed from an evolutionary perspective, the quest for intellectual truth is one of many emergent by-products of human ecology. One can imagine an ancestral ape developing a simple language system, comparable to the alarm calls of other monkey species. One shout means 'snake'; another means 'hawk'. We know that monkeys are smart enough to learn these signals across species boundaries, so there must be a contextual dimension to the work. Yells of encouragement can also acquire a semantic significance and primate language has developed both nouns and verbs.

One can easily imagine the tendency to seek intellectual truth becoming a strongly adaptive trait. An ancient ape that could interpret a neighbour's alarm call as representing a snake and not a hawk or a big cat would clearly be better able to survive than one that needed to see the object before responding appropriately. Likewise a sense of number and distance - two of the fundamental intuitions of mathematical reasoning - and the ability to reason abstractly by running mental simulations of future situations would obviously produce an ape that was better able to locate opportunities and minimise risk. But this would only be true in situations where truth were linked to action and action to well-being.

The ability to contextualise semantics and acquire socially learned behaviours exapted our ancestors to more complex abstractions, social rituals and non-adaptive behaviours. Philosophy, dance and music, for example, are externalities - unforeseen by-products of simple semantic communication. The intuitions and mental structures that drove our ancestors to seek intellectual truth exapted them to situations where super-normal institutions could use the quest for truth as a smokescreen that prevents us seeing a mob of over-sexed monkeys fighting to control planetary life-support systems.

In mediaeval and early modern societies these institutions often appealed to academics for scholarly, theological and intellectual support. From the end of the 18^{th} century onwards, however, scientists began colonising these gnostic niches and their social role was broadly similar. Institutions could not and must not set receptivity constraints aside until scientists / theologians / philosophers have established the intellectual truth or falsity of some proposition.

The existence of this caste of professional experts creates a wonderful excuse for institutional veto. Before we can act, scientists must prove that smoking causes cancer; sugar rots your teeth; methane aggravates global warming. The institutions that police these receptivity barriers provide great wealth and prestige to a minority, but there is little evidence that this conspicuous wealth has much impact on fitness. The millionaire beneficiaries are not better able to reproduce and rear children than environmentalists or epidemiologists. One has to go to the other end of the spectrum to find a measurable fitness differential. There is no doubt that the institutional veto can have catastrophic impacts on unacknowledged stakeholder communities.

The agnostic antithesis to the intellectual model of truth holds that all human knowledge is derived from sense-data, filtered, as it were, by cognitive skills and intuitions. These skills have been wrought in our bodies by a combination of social learning and biological heritage. Since great apes cannot know things as they really are, then the definition of truth as consilience between understanding and things cannot be defended and we need something a little subtler. A promising definition would be that (operational) truth is consilience between context and action.

When Darwin wrote his book about the 'origin of species', for example, several of his scientific friends were troubled by the discussion of agency and selective co-operation. Darwin argued that females, by selectively choosing attractive mates, could change the course of evolutionary history in the same way a stable-master could influence the blood-line of his horses by pairing stallions and mares selectively. Their problem wasn't that Darwin's statements were intellectually false; it was that his friends didn't know how scientists should act in a world where a female ape could change the destiny of her species by falling for a gentle weakling with nice hair and bearing his children.

For most practitioners, intellectual truth is the *sine qua non* of science. There is no point telling them that science is something smart monkeys sometimes do, because culturally embedded knowledge, reinforced with years of training and practice prevents them taking this seriously. Yet from an evolutionary perspective, this operational model of truth makes much more sense than the intellectual model. It is hard to see how the obsession with intellectual truth would have evolved when the logical connections between what people believe to be (intellectually) true and their actions are so weak.

Empathy is obviously a key component of social interaction, and natural selection fixed this cognitive skill in our ancestors along with a bunch of exaptive traits that facilitated social interaction. We know that some birds and mammals have a sense of number and it seems likely that similar quantity- and distance intuitions exapted our ancestors to analytical reasoning, god-intuitions and natural science.

Our human fixation on intellectual truth and falsity is probably an emergent by-product of that monkey-quest for consilience between belief and action. In some contexts the most appropriate course of action is to drink beer or dance the Macarena; in others it seems more appropriate to debate the intellectual merits of Darwinian theory or Genesis II.

§ 17. Mapping your role in a project

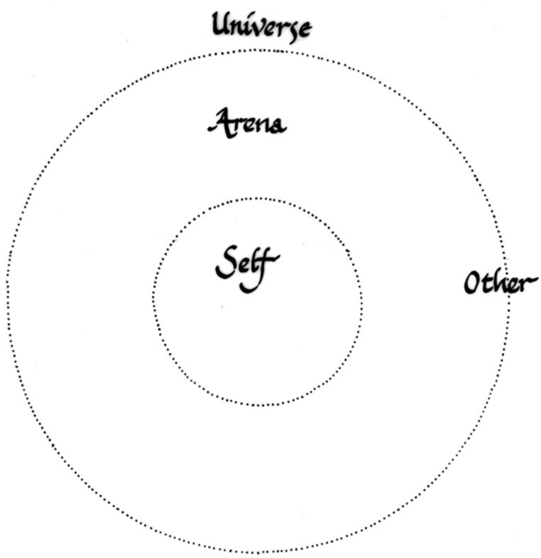
Every scientist who supervises early career researchers will be familiar with the crises they can experience when trying to reconcile intellectual aspirations to the practical business of 'doing science'. Many have acquired the culturally embedded belief that science is a set of protocols and methods for testing the (intellectual) truth or falsity of some belief-set. They will have been taught this in good faith, by teachers who genuinely believe that the purpose of (say) archaeology is to test hypotheses about the past and the purpose of geography is to test hypotheses about mappable spaces. As students they will have been taught to critique and challenge other people's work. The result is a bundle of culturally embedded taboos and institutional vetoes that prevent them seeing science as a sort of ritual designed to establish and maintain institutional affiliation.

Then they have to make that uncomfortable shift between critiquing other people's work and doing some work of their own. Nothing they have been taught has prepared them for this challenge and they don't know what to do. They cannot challenge the (intellectual) truth of all that hard-won cultural and institutional knowledge because to do so would be to write off too much sunk capital. Neither can they deny the uncomfortable fact that everything they know about science seems to be (operationally) false. They simply don't know what to do next.

In this essay we will describe a conceptual map that can sometimes be used to get them out of difficulty.

We start by re-visiting the plesionic model introduced above, in which an organism acts as a subjective *self* interacting with *others* in an interval of space-time called *arena*. Arena is the interval of space-time the organism is currently monitoring. Others can come and go, giving the impression of some larger interval of space and time (*universe*). Self can be any co-located organism or super-organism - a cinema, say, or an ant colony - but it cannot be an abstract, incorporeal entity.

Institutions like nation-states or merchant banks may have some organism-like properties, but they are not organisms in this strict, plesionic sense.



Imagine that this is a map of you, the arena in which you are embedded and your close neighbours. It isn't much of a map - just a dotted circle labelled 'Self', so let's add some detail by taking a new piece of paper and drawing a more detailed map of your 'Self' as a collection of circles on a piece of paper. Each circle represents a set of contextual beliefs that have certain features in common.

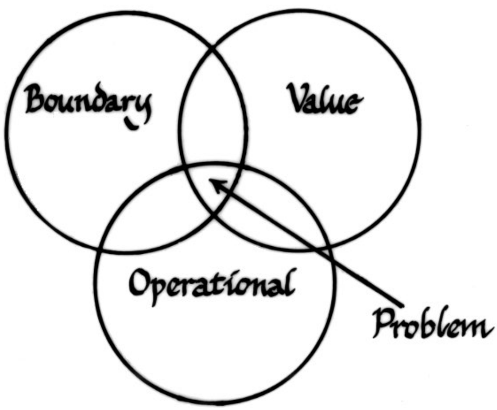
The first circle represents *value judgements* - the things you care about and the answers to those *Why?* questions - *why are you contemplating this course of action*? The region inside that circle represents the beliefs that are consilient with your values.

Some of your values may be big deal aspirations; others may simply refer to things you like. If you find snails interesting and beautiful, that is a value judgement. When you have drawn the circle, pause a while to make a list of those value judgements as they relate to your current project.

Ignore value judgements that seem implausible or irrelevant in the context of the project. You may want to save the whale or end world hunger, but that is going to take longer than three or four years. If you want to get a PhD or write a paper that will get you a good job, put that down, it's always a good idea to consider your exit strategy. Make room for some fun in your project. If you love working with mosses because they are so beautiful or you really like working with children, put that down. Value judgements are not just about doing something worthy; they are about having some fun and getting something out at the end.

Now draw another circle, this time to represent the *boundary judgements* that seem consilient with things and species of thing. Pay special attention to the objective things and classes that already exist, but also give a little thought to the things that could exist, if we wanted them to. Boundary judgements answer the *What?* questions - *what things and sorts of things exist or could conceivably exist in the future?* Make sure you include some empirically observable objects, but don't run shy of subjective things like complex numbers or institutions. Again, draw the circle and make an explicit list of your boundary judgements. While you are working, make room for a list of deliverables. Deliverables should be auditable things - a literature review, a computer program, a paper in a good journal, a database, … If you can't observe it empirically and undertake some sort of quality control, it isn't a deliverable.

Budgetary constraints and contractual obligations belong here too. If you expect an archaeological excavation to produce half a million artefacts and it takes ten minutes to describe one object, you will need 83,000 hours to create the database. A full-time researcher works about 1650 hours a year on research (that leaves some time for vacations, training and admin) so it would take one person about 80 years to make the database. How much money do you have for lab-work? How much does it cost to employ skilled technicians to help with this work? These constraints belong on your list of boundary judgements.



Look at time-dependency too. If you cannot do analysis until you have generated some data, then you need to collect data early. If you cannot collect data until you have consulted clients and other stakeholders, then data capture has to wait. Build a flow-chart of some sort and try to multi-task. If you cannot work on two tasks at the same time, you may run out of time. These considerations form a bridge between boundary judgements and the *operational judgements* that answer *How?* questions - *how am I going to reconcile my boundary and value judgements and design a satisfactory exit strategy for the work?* This is your chance to build some action into the work. Make a list of the methods and procedures you plan to use. Pay special attention to the sweet spot in the middle where boundary, value and operational judgements intersect. If you can find that sweet spot, you will have built that bridge between intellectual and operational truths and characterised the research problem(s) that will occupy you over the next few months or years.

In practice, most researchers, particularly those committed to the intellectual model of truth, will struggle with one of the three types of judgement. Eco-warriors, for example, tend to be long on values and short on method. Many hard scientists are much better at methods than values or boundaries. This bias is a useful source of information about what sort of scientist you are.

You can often re-balance the diagram by relocating elements on the longest of your three lists to the shortest. If you are really good at operational judgements, but struggle to define system ontology, see if any of the former can be re-framed as boundary judgements.

For example, suppose you plan to use an agent-based simulation model. What sorts of agents will you define? Suppose you plan to carry out an attitude survey. What sorts of things will you ask questions about? What sorts of people will you ask these questions of? Perhaps you are especially strong on values. If so, read the list of value judgements to see whether there are any disguised operational or boundary judgements hiding there. Suppose, for example, you feel it is important to protect organic agriculture. What sorts of methods can you use to distinguish organic farming from other activities? What sorts of crops do organic farmers grow? Who buys them? If you want to build a bridge between intellect and action, you will need all three lists to be well-populated. The simplest way to do this is to examine one sort of judgement to look for hidden or unspoken judgements of another type.

Sometimes this cannot be done. There are problem-domains so messy and ill-structured that any attempt to impose a problem-ontology on them falls foul of receptivity barriers and alienates external stakeholders. Even in moderately well-structured problem-domains, you may need to negotiate a little contextual wriggle-room with your peers and with external stakeholders. Receptivity barriers are not just perverse habits; they exist for a reason. That reason usually has something to do with co-operative action, the ability to mobilise resources and maintain social status. If your research design subverts those receptivity boundaries, you must expect your neighbours to attack you. If they feel strongly enough, you will not be able to establish a stable problem-formulation and your research is on a hiding to nothing.

If you have never done this before, we recommend you to take a little time out and do it now. If you are actually using this book to develop a research design, you should be prepared to spend a few days or even weeks on it. If you have lots of research experience, you should be able to knock one of these out in a couple of hours. When you have done so, read on …..

If, like us, you have spent some time helping other scientists build these maps, you will have learned that different types of scientist tend to specialise in different types of judgement. That is useful, because it implies that researchers can evade institutional vetoes by finding out what sort of judgements they are good at and joining the right disciplinary institution. One of the commonest causes of failure among early career researchers is a reluctance to look dispassionately at their own cultural predispositions.

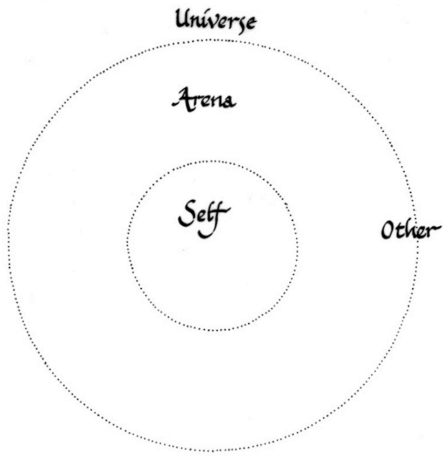
Roger the researcher wants to write about theoretical physics, but is far more interested in critical deconstruction than applied mathematics. Sorry, Roger, that's not going to work! Agnes desperately wants to solve the problem of social exclusion in inner-cities but would rather build computer models than spend long periods of time building trust by talking, listening and taking practical action. That's a non-starter, Agnes!

The best way to avoid conflict and establish a successful career is to join a disciplinary community whose receptivity barriers do not conflict with your boundary, value and operational judgements. Doing this need not jeopardise your career aspirations. Roger, who wanted to deconstruct physics, could work on the anthropology or philosophy of science. Agnes could join a multi-disciplinary research team working on social exclusion. There are ways of reconciling your aspirations to value-, boundary- and operational judgements, but trying to gatecrash a disciplinary community that doesn't value the sort of science you need to do isn't one of them.

Some students cannot accept this advice. They are seized by Quixotic impulses that keep them on the wrong side of receptivity barriers that could be avoided altogether if they made wiser career choices. There is little one can do to help them, alas, and they are a pain in the neck to work with.

§ 18. Mapping the Project itself

Let's go back to that picture of a plesionic system. One of the nice features about this map is that it can be used to talk about intuition and perception at a personal, subjective level, or to talk about scientific behaviour-patterns at a project level.



We have defined science holistically so we can integrate the hard and soft sciences. Soft scientists tend to be interested in the subjective domain and the relationship between self, other and arena. Hard scientists tend to be more interested in the relationship between the objective arena and universe. The distinction is ancient, but the words keep changing their meanings so our problem is to know what to call them. Let's lay out 5 cells to represent the focus on different regions of the plesionic diagram. The left-most cell is a sort of classical extremism directed towards the study of universals. The right is a sort of romantic extremism, obsessed with self and personal experience. Between them we set the agnostic mainstream of science:

	Natural Philosophy	Natural History	Humanism	

Note the dotted lines between cells - these disciplines are not hermetic. Natural philosophy and natural history intergrade. Note further that there is some blank space to the left of natural philosophy and the right of humanism - not all intellectual endeavour is agnostic science.

We are primarily interested in science, and science is methodical. So far we have explored three broad classes of method: analytical (linked to mathematics and efficient cause), discursive (linked to purpose and final cause) and empirical. Let us set them out in columnar form thus:

Analytical
Discursive
Empirical

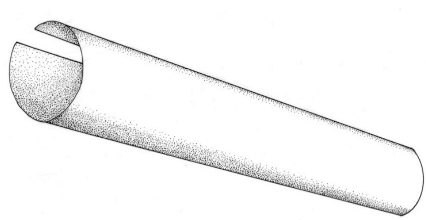
It is easy to form a combinatorial 'product' of the row and column structure - a grid with rows and columns, thus:

	Analytical Natural Philosophy	Analytical Natural History	Analytical Humanism	
	Discursive Natural Philosophy	Discursive Natural History	Discursive Humanism	
	Empirical Natural Philosophy	Empirical Natural History	Empirical Humanism	

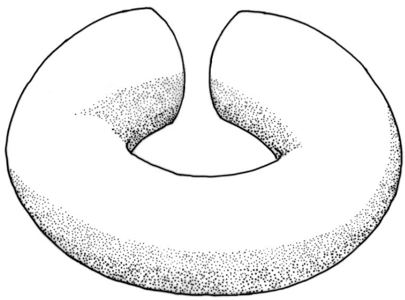
This grid defines a space of scientific endeavour, but it isn't the sort of space in which you can locate a project uniquely, as a point. The humanities, by and large, tend to focus on the relationship between self and other in arena. As you get further to the right of the humanistic column, the focus becomes more subjective and smaller. Presumably the white column to the right of humanism contains some gnostic preoccupation with the self and small history. Natural philosophy tends to be more interested in the relationship between arena and universe. To the left of the natural philosophy column we find pure mathematicians and theoretical physicists.

Imagine a project that studies the complex cycle of links between farmer's crop choice, irrigation, water abstraction, seawater intrusion into subterranean aquifers, land degradation and plant health. That project involves a discursive element, talking to farmers, hydrologists, agronomists and the rest, and a mathematical element, simulating the distribution of crops across a landscape and the effect on water needs. Connecting the analytical and discursive dimensions will be challenging, but there is no sharp discontinuity. Farmers take account of cost-benefit and tradition and soil type, …

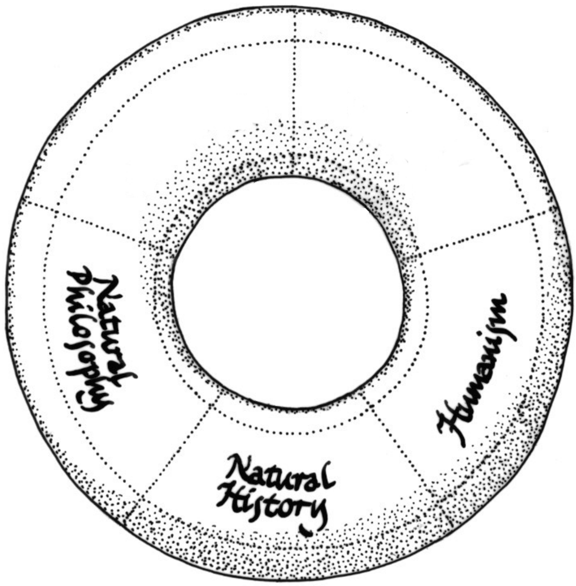
If we located that project on this map there would be a break or singularity between the types of method that didn't feel like a break in the context of the project. We shouldn't put gaps into our map of a project unless the project itself feels 'gappy', somehow. Happily the map can be tidied up by means of a little judicious folding and gluing. We imagine the space we have constructed mapped out as a grid on a flexible surface like a stretchable rubber sheet. We roll the grid to form a tube, thus:



Now we can also do this again, rolling the tube round to form a ring and joining the two gnostic columns to make a doughnut or, to give it its mathematical name, a *torus*:



Everything is glued together to create the doughnut model of science, which we have drawn without the methods for clarity of representation:



It is important to understand that the grid map and the doughnut map are different ways of representing the same space. When you look at the grid as a flat map, you hold the torus in your mind by remembering that it is edge-connected. If you wander off the right hand side of the grid, you immediately re-enter on the left. If you leave via the top edge, you reappear via the bottom edge.

Section III : The Physiology of Research Projects

In Section I we joked that you cannot tell a prehistorian from a cultural geographer by counting the bristles on their abdomens - the morphology and physiology of science were inconsilient. More seriously, we argued that there was substantial convergence between (say) the physiology of disciplines like geography, anthropology and archaeology. This convergence often forms the pretext for hostile take-over bids.

Back in the 1960s, for example, Ludwig Von Bertalanffy was arguing that history and anthropology were really sub-domains of mathematical biology. Systems researchers at the humanistic end of the spectrum were unimpressed. About the same time an influential group of 'new archaeologists' were arguing that *archaeology is anthropology or it is nothing*. Distinguished archaeologists who, for decades, had seen their work as an extension of classical history, were understandably browned off. Geography experienced similar acts of intellectual imperialism at the same time.

The late 60s and early 70s were the hey-days of social engineering, a time when post-war governments saw wartime Big Science methods and project-based research as a panacea. Our doctoral supervisors' doctoral supervisor, who was active during these years, used to joke that *science is like selling soap*. There was good money to be had for project-based research, but one needed a plausible brand. General System Theory was one brand among very many.

The general systems revolution of the 1960s failed for two reasons, both related to consensus. The first was that many of the pioneers didn't know enough about project-based science. Wartime projects to develop weapons of mass destruction and defensive infrastructure succeeded because people were united by a common goal and a common threat. There was no need to negotiate informed consent for the work and very little ethical oversight. Peacetime projects failed because it was peacetime and martial discipline was no longer acceptable. External stakeholders didn't buy in; some openly opposed and undermined the work, and many raised ethical objections.

The second problem was lack of consensus among internal stakeholders. Successful brand leaders struggled to deliver on their promises and failed to carry their peers with them. The more money they mobilised, the more vocally they were opposed, a phenomenon partly explained by professional jealousy and partly by incompetence. Carrying a project through a complete cycle and delivering on time, within budget, is a non-trivial skill. It is easy to promise too much and deliver too little, a mistake which one's rivals soon notice and exploit.

By the early 1970s universities and policy makers knew that incorporating the humanistic and natural philosophy approaches into a single institution wouldn't work. The result would be an institution that knew too little. Governments and commercial sponsors responded to this by tightening the regulatory screws in a way that drove them apart again and, coincidentally, aggravated social exclusion and dissent.

There were two sets of winners in this competition. The first were disciplines like biology that could colonise the territories of natural philosophy by pushing natural history and humanistic endeavour beyond the pale. They became technical problem-solvers *par excellence* and won substantial research revenues. Even in areas like molecular genetics, which have promised much more than they have delivered, the prizes of curing all hereditary disease and solving all the problems of human origins were considered so valuable that investment-levels have been maintained, even though the return on investment has been disappointing.

The second set of winners has been an informal alliance of environmentalists and humanists who came together to oppose what they saw as the hegemony of the hard science approach. Although their research income was relatively small

- too small to create powerful institutions - this anti-science backlash attracted many students and disaffected external stakeholders. The situation varies geographically, of course, but in much of north-west Europe, hard science departments are often struggling to recruit students and subsidising teaching effort with research revenue. Humanities schools may use teaching revenues to subsidise research. The situation in southern and eastern Europe, where citizens still see technocracy as a pathway to prosperity, is somewhat different. We imagine that this will change as people tune in to the cost of rural depopulation and environmental degradation.

As younger scientists make their bids for brand identity, they create patterns of social exclusion that trigger a backlash. Paradigmatic factions form that argue one side or the other. Micro-disciplines form and re-form like lumps on the surface of boiling porridge. These scientific combatants feel able to deny the accusation that they are playing politics by appealing to the intellectual model of truth.

This book has tried to step back from the porridge-pot and look at the relationship between these disciplinary bubbles and operational truth. Biology, archaeology and anthropology, for example, hardly existed as named disciplines before the 19th century, but the distinction of classic science (natural philosophy) from humanism is ancient. With the eye of faith, these ideational tendencies can be traced back to late mediaeval times and beyond. The sceptical, agnostic tendency is particularly interesting because it always seems to be present and yet gets suppressed or discredited and rediscovered. In the 12th century the tension was that between 'realists' and 'nominalists'; the realists being those who believed the categories of human knowledge, including incendiary categories like 'heretic' were real, while the nominalists argued that the meanings of words were socially constructed. By the end of the middle ages there were 'moderns' and 'ancients'.

Note the way the meanings of some of these words have reversed. To be 'realistic' today is to give evidence priority over ideas. In a book titled: *Luther: man between god and the devil*, Heiko Oberman explains how Martin Luther (a protestant fundamentalist) studied and abominated the agnostic philosophies of moderns like William of Ockham. The protestant reformation and the catholic counter-reformation were united by their loathing of modern humanism. Would this make Luther a 'post-modernist? Maybe it would if we were writing in a reformation context, but many of today's sceptical humanists describe their approach as 'post-modern'. These semantic flips are by-products of a political process that 'remembers' and 'forgets' classical scepticism.

Hardline atheists sometimes tease theologians by saying that the ancient Greeks knew the sun was the centre of the solar system, but the western church forgot this and didn't remember till the renaissance period. Some of those Greeks also knew humans cannot achieve a god-like omniscience, but powerful institutions seldom remember this for more than two decades at a stretch. As Oberman put it: *"Later academic history shows how tempting it is to accept the convictions of great scholars, enabling new "schoolmen" and new scholastic thinking to establish itself again and again. The discovery of the uncertainty of knowledge must be made ever anew."*

One of the questions we would like you to consider while reading Section III is: *why is this so?* Why is it that western science can 'remember' Galileo, Copernicus, Newton and Einstein, but keeps forgetting agnostics and moderns? If agnosticism is simply not worth remembering, why is it that communities struggling with the institutional veto seem to rediscover it again and again?

Part of the explanation, we believe, has to do with the shape of the project-map we developed in Section II. Natural historians, particularly those who deal with human perception and cognition, are normally agnostics of convenience. A lot of fruitless squabbling can be avoided by remembering that all human knowledge refers to phenomena rather than to things as they really are. But when they get locked into arguments about ethics and right living, we have almost no choice but to flip up to the top of the doughnut and re-frame the agnostic hypothesis as if it were a law of nature. The following words, written by Thomas Henry Huxley in 1884, illustrate this behaviour pattern:

The theological "gnosis" would have us believe that the world is a conjuror's house; the anti-theological "gnosis" talks as if it were a "dirt-pie" made by the two blind children, Law and Force. Agnosticism simply says that we know nothing of what may be beyond phenomena.

Here he is writing in 1874 and adopting a more combative tone:

Of all the senseless babble I have ever had occasion to read, the demonstrations of these philosophers who undertake to tell us all about the nature of God would be the worst, if they were not surpassed by the still greater absurdities of the philosophers who try to prove that there is no God.

Huxley's agnosticism was part scientific method and part value-judgement. The more passionately he asserted the principle, the further he deviated from the agnostic ideal.

From a humanistic perspective, the gnostic impulse is a snare that draws societies into less tolerant configurations, but from a natural history perspective, it is an ecologically significant feature of human physiology. Geoffrey Vickers, a system theorist, captured this idea perfectly when he wrote that:

A trap is only a trap for creatures which cannot solve the problems that it sets. Man-traps are dangerous only in relation to the limitations on what men can see and value and do. The nature of the trap is a function of the nature of the trapped. To describe one is to imply the other.

The gnostic trap is the region in our phenomenological map where paradigmatic conflicts harden. It is also the place where abstract, intellectual disciplines like pure mathematics, metaphysics and theology routinely operate, and the subject-object split is hardest to maintain. These disciplines have developed a range of analytical and discursive tools for resolving or accommodating contradictions. Naive set theory, for example, deals with sharply bounded, paradigmatic structures. However any discipline can generate a paradigmatic stand-off by making a brief excursion to the top of the doughnut and formulating a question about sharply bounded, abstract categories.

Huxley provides one instance among many of this 'gnostic agnosticism'. Consider, for example, those post-modernists who want to abolish the modern ideology of progress by reforming society to correspond to their own post-utopian ideal and critiquing metanarratives.

The only way to avoid the gnostic trap is to remain vigilant. Universal principles like: *always walk away from paradigmatic conflict* won't protect us because the intellectual surface we are exploring, though it contains a great singularity at the top of the doughnut, is geometrically connected. The more distance we put between ourselves and the gnostic trap at one end of the torus, the more closely we approach the same trap from the other side.

To make agnosticism work in practice, project managers need to create a little constructive ambiguity and schedule the work in a way that allows participants to play to their personal strengths. This is easier to do if they know a little more about the process of knowledge creation and contextualised action. That is the focus of this section of our book.

§ 19. Rebuilding the Subject - Object Split

Section I explained how natural historians used systematic method to make fat semantic triangles with a defensible subject-object split. We also showed that moving from morphology (static descriptions) to physiology (dynamic analysis) was difficult whenever the pre-defined classes and dynamic processes were inconsilient. A good way of tackling this difficulty is to think about processes abstractly, creating skinny idea-symbol lines and using analytical methods to work out the corollaries of those definitions. One then builds a metanarrative that re-connects these ideas to the objective domain. This work often requires scientists to create unfamiliar classes, re-thinking system morphology in a way that brings it into line with abstract ideas about physiology.

We tried to do this for science, defining knowledge as shared beliefs. This led to the conclusion that large groups, *ceteris paribus*, tend to be less knowledgeable than small ones. But large groups of people can command more resources and wield more power than small ones. This tension creates a sort of natural selection that favours institutions that protect their shared knowledge-base. Accepting a little institutional discipline allows individuals to mobilise considerable power.

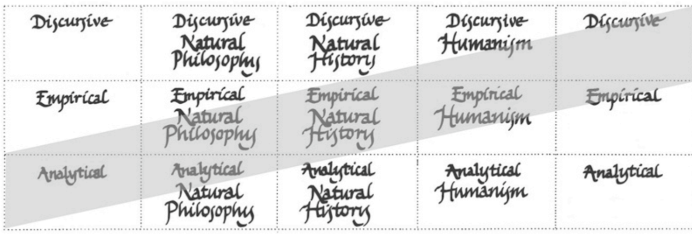
Institutions are not corporeal objects or groups of actors co-located in space and time. They are loose alliances of people, so the only way this system could have evolved is if humans were predisposed to acquire shared knowledge and conform to socially constructed norms. This predisposition - we spoke of it as 'culture' - exapted our ancestors to institutional discipline. Culturally embedded knowledge and institutional vetoes usually become manifest as taboos or coercion. Structurally embedded skills are reinforced by an embodied aesthetic that guides us towards situations where we are likely to thrive.

None of this was empirically testable, of course, but the theory was broadly consistent with experience. In Section II we started to rebuild the semantic triangle by zooming in on the research project which, we argued, was an objective class whose key was smaller than its essence. We did not suggest that the class of projects was universal. Doubtless there are many hybrids and malformed projects in the world, but we do have reason to believe that projects and open-ended research programmes are different, though evidently related activities. There are good operational reasons to believe that projects which do not possess the attributes we describe are, in some sense, inviable. The institutional constraints that regulate projects effectively force them to accept disciplines that reinforce the objective boundaries of the class.

Our science-torus or doughnut map isn't a classification, but a 2-dimensional ordination that defines an attribute space within which project activities can be located. Ordination is a systematic method, like classification. The same principle of getting more information out than you put in, applies here. The ordination is overlain by a grid of three rows by 5 columns, each loosely bounded so you can drift between adjacent cells. We concentrated on the 9 agnostic cells in the middle of this array. The right hand column represents more or less gnostic approaches to the sub-humanly small; the left hand column represents gnostic approaches to the super-humanly large. The three rows represent three types of method - rational, empirical and discursive; the three agnostic columns represent a scale-trend from humanism to natural philosophy.

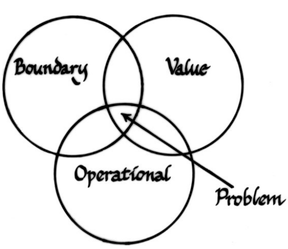
Section II described a characteristic pattern. The class of activities we refer to as the humanities, though they occasionally use analytical method, tend to make heavier demands on discursive and empirical approaches. Natural history requires us to think about categories and empirical data. Natural philosophy favours a mix of rational and empirical approaches.

We can accentuate this physiological structure by re-arranging the rows that represent the three great classes of method to put empirical method in the middle. The emergent conjuncture of method and discipline now forms a diagonal stripe across the grid in the agnostic disciplines, which we conjecturally extend into the gnostic outliers. When the grid is re-formed into a torus, that diagonal spirals around it.



Please understand that we are not speaking about a really-truly torus in your head, we are saying that if you become familiar with this toroidal attribute space with a high-density diagonal stripe, a lot of baffling facts about the morphology and physiology of project-based science fall into place rather beautifully. More information comes out than was put in.

Compare the personal map of boundary, value and operational judgements we developed in § 17 with this striped torus. Each of the three great disciplines specialises in one of those three types of judgement. Humanists, with their combination of discursive and empirical skills, tend to be good at understanding values. Naturalists tend to be good at conceptual taxonomies and natural philosophers specialise in analytical method. This implies a special interest in operational judgements.



Now you might imagine that all three disciplines would have a shared interest in that sweet spot where all three types of judgement intersect and well-posed problems are located. If so, you'd be right, up to a point.

In the humanities, for example, well-posed problems are rare and tend to be the end-product of a research programme. In natural philosophy, on the other hand, the work starts with a problem-statement and moves smoothly to a solution. If both types of work are going on at the same time, the result will be an awful mess. One wants to change the question; the other wants to find the answer.

As we have already seen, even when their interests coincide, natural philosophers, naturalists and humanists tend to have different time-perspectives. Humanists are good at widening our understanding of a problem and *ex post*, historical perspectives. Natural philosophers are experts at problem solving and *ex ante* prediction. Natural historians work to reconcile the *ex ante* and *ex post* perspectives and end up focussing on deep time.

But what of those two gnostic columns to the left and right of our toroidal grid? Can we extrapolate safely? The answer is that sometimes we can, but often we cannot. If we restrict our attention to project-based science, the diagonal stripe can be extrapolated with some confidence. The participants who colonise these columns will tend to treat categories as sharply bounded and universal. Natural philosophers who stray up into the gnostic region tend to hang onto analytic method, while humanists in that region tend to favour a more discursive approach. Natural historians working in these regions tend to refer back to their empirical roots, mistrusting both romantic discourse and abstruse analysis. Unsurprisingly, humanists and natural philosophers feel no qualms about dismissing their concerns as amateurish and old-fashioned.

§ 20. Paradigms Redefined

The word 'paradigm' is commonly and often unhelpfully used to describe a conceptual model that underpins a domain of scientific endeavour. Thomas Kuhn's *Structure of Scientific Revolutions* does this, treating paradigms as a tacit consensus about how science should be done, which Kuhn links to the exploration of a rich domain of challenging but tractable problems. Kuhn's 'paradigms' are *incommensurable* in the sense that one cannot buy into two rival mindsets at the same time. Kuhn also rejects the idea that science is an unending quest for universally dependable knowledge about the universe. Rather, he sees it as a stick-slip dynamic in which long periods of 'normal science' are punctuated by paradigmatic revolutions. Kuhn argues that it is not obvious at the time paradigms make way, one for another, that the new paradigm is a priori superior to the old.

Kuhn's book was part of a post-war innovation-cascade that changed institutional knowledge, particularly in respect of plesionic science and reflexivity. Ironically, these innovations made it easier for some scientists to rebut Kuhn's claims. Scientists who have read the book are aware of the problem of unexamined and tacit knowledge (at least in the past). That awareness changed scientific practice, allowing them to claim that Kuhn was wrong to imply that scientists don't think carefully about theoretical and tacit knowledge. The political and social conjuncture has changed and some of the Cold War paradigmatic conflict has become irrelevant.

It is often hard to distinguish cause from effect in reflexive disciplines, where the research community has the same structure as the communities they research. It is not clear, for example, whether Kuhn's understanding of science was erroneous or whether Kuhn's book changed the nature of science itself. It isn't even clear whether Kuhn's book actually caused a sea-change in the way some scientists thought about their work, or whether the way scientists thought about their work was changing and Kuhn's book was just one by-product among many of a wider innovation-cascade that was happening in the late 50s and 60s.

Some of the objections to Kuhn's ideas about the incommensurability of successive paradigms can be resolved by distinguishing the *ex ante* (forward-looking) from the *ex post* perspective. Viewed from a renaissance perspective, for example, it isn't *a priori* obvious that putting the sun at the centre of the solar system and giving everything else a circular orbit would provide a better foundation for problem solving than keeping the earth at the centre. That said, it was obvious that the two models were incommensurable - you couldn't have the earth and the sun stationary because there is clear evidence of movement.

Viewed *ex post,* however, the situation looks different because we now know that Newton opened up a rich new problem-domain that capitalised on and extended Galileo's model and turned the circular orbits into ellipses. Einstein has re-framed celestial mechanics in a way that eliminates all the fixed points from the system, so arguments about whether the sun or the earth stands still seem more like matters of computational convenience. Galileo's two 'great world systems' do not seem incommensurable to us because we view the argument with the wisdom of hindsight.

There is no doubt that the *Structure of Scientific Revolutions* has become an influential text. It represents an interesting and significant way of thinking about science. The question we would ask here is: *Can we reasonably call that way of thinking a 'paradigm' in the sense that Thomas Kuhn uses the word?*

The answer is probably *no*. In a postscript to the second edition, Kuhn wrote: *There are schools in the sciences, communities, that is, which approach the same subject from incompatible viewpoints. But they are far rarer than in other fields; they are always in competition, and their competition is usually quickly ended.* This is certainly not true in natural history, where rival schools coexist indefinitely. It isn't true now and it wasn't true in the 1950s, when Kuhn was writing his book.

There seem to be two broad tendencies in science, one of which treats science as a well-bounded intellectual species, while the other treats science as an ecosystem, where there are phoenix cycles of succession, collapse and re-construction; extinctions; immigrants; locally intense competition, and rich patterns of co-operation.

Kuhn would probably see this as evidence that natural history was in an immature, pre-paradigmatic stage of development. Many naturalists would disagree. Kuhn was writing about natural philosophy, which he saw as an esoteric 'game' played by a community whose tacit rules and perceptual models constrained the practice of 'normal science' and opened up a rich domain of 'puzzles' to solve. These 'paradigms' collapsed from time to time as scientists ran out of intellectual wriggle-room and new conceptual models were developed, with new domains of tractable, but challenging problems.

This analogy doesn't work in study-domains where many disciplinary communities must interact with each other and with external stakeholders - citizens and non-human populations. Policy-relevant natural history is not a game or a source of challenging puzzles, and scientists who try to impose a single 'paradigm' on the work can de-stabilise the cultural and natural life-support systems they are supposed to be protecting. Each stakeholder community has its own preoccupations, tacit beliefs and worldview. This contextual diversity must be respected.

The word paradigm comes from Greek roots *para* (beside) and *deiknunai* (show) and so suggests two possible causal models laid out side by side, as it were. This usage is often found in linguistics, where a contrast is made between paradigm and syntagm. The paradigm represents a collection of mutually exclusive options; the syntagm is a collection that can occur in the same context: *big, fat, juicy (apple)* would be a syntagm: *his apple, her apple, their apples and its apple* would form a paradigm. Thomas Kuhn himself hints that paradigms are arguments shaped like a stick, so you feel obliged to pick them up by one end or the other.

In the remainder of this book, we will use the word 'paradigm' to describe a choice between mutually exclusive options. Paradigms are often linked to rivalry between institutional factions. This understanding of the word suggests that the paradigm shifts Kuhn describes for the natural sciences are not spontaneous transfers of support. They have something to do with institutional disciplines, receptivity barriers and time-asymmetry.

When one worldview makes way for another, incommensurable worldview, it does so because institutional vetoes have been set aside and a new generation of scientists comes through the system with different contextual trajectories and different cultural predispositions. They aren't interested in the power-struggles that paralysed earlier generations or the tension between gnostic and agnostic mindsets because the institutions that made them seem important are currently toothless.

Any paradigmatic stand-off suggests a scientific community drawn to the top (gnostic) end of the torus and heavily committed to the intellectual model of truth. Antagonised stakeholders simply assume, as a law of nature, that if two hypotheses are mutually contradictory, then at least one (possibly both) must be false. In our next essay we will consider the distinction of trivial from great truths proposed by the physicist Niels Bohr. To contradict a trivial truth is to speak a trivial falsehood. However it is sometimes possible to contradict a great truth and speak another great truth.

§ 21. Space and Time

This book has defined science as the search for rationally interpretable order in the universe. We abbreviated 'rationally interpretable order' to *pattern* and then weakened the definition a little by saying that the noun 'universe' could be rendered as an adjective - *natural,* or even as *in space and time*. In the intervening essays we have softened the idea further by writing of 'universes of discourse'. We are clearly not asking you to think about the gnostic's universe that Bertrand Russell defined as *the collection of everything that is itself*, but about a phenomenological 'universe as perceived' characterised by an effort of cognitive re-focussing.

We believe that definition to be an informal empirical fact. Every human is interested in natural pattern, but scientists specialise. Any research project, pure or policy-relevant, will contain people who spend a lot of time looking for patterns, describing and analysing them. On integrative projects, where you have a group of scientists working with external stakeholders, the division of labour between them often comes down to a preoccupation with pattern in space-time. By implication we are saying that, in science, the word 'natural' means 'in space and time' and the word 'universe' suggests a collection of natural phenomena characterised by an effort of cognitive re-focussing. The scientist, when s/he is working, unconsciously brings that space-time universe into the foreground and pushes the other stuff further back.

In our discussion of universals we suggested that universes of discourse were logically open in the sense that you could sometimes speak meaningfully about bounded categories, but not about logical complements like the collection of everything in the universe that is not a law-abiding citizen. Bertrand Russell proved that these complementary sets always engender contradictions because they require you to contemplate collections that contain themselves. A collection is not a law-abiding citizen, so the collection of things that are not law-abiding citizens must contain itself. Russell showed that a paradox arises when you ask whether the collection of all the collections in the universe that do not contain themselves is a container or a non-container. If you answer 'yes' then the collection of non-containers contains a container. If you answer 'no', then the collection cannot contain all the non-containers in the universe. In abstract logic, appeals to logical complements are a little like dividing by zero in mathematics. They generate logically incoherent results and so are not allowed.

These considerations - the definitions of science, universe, phenomenon and logical openness - create a special role for space, time and abstract logic in science. There is a literature on the anthropology of space and time, which we have not studied in any detail. One of the key ideas in that literature is that our western, scientific understanding of space and time is not universal. If you want to know more, you will have to go to the library. Here we are primarily interested in that western model, not because we believe it to be a cultural universal, but because project-based science uses it a lot.

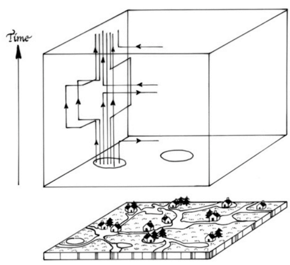
Imagine a reconnaissance drone hovering over a landscape with a camera. There is a clock in the camera that time-stamps each frame. A car is driving along a road and one frame fixes its position at time t. That position is a being - the state of some landscape object - and as such belongs to morphology. Material objects occupy space and appear on the frame as a block of colour. Every camera has limited spatial resolution - there is a size limit below which it cannot resolve two adjacent objects. It also has limited temporal resolution - it takes time to expose a frame and this creates a little smeariness around the image. The image is smearier if the car is going fast; less smeary if it is parked.

If we want to know how fast the car is moving we may look at the next frame in the sequence. The time recorded is now $t+\Delta t$. (By convention the Greek delta letter, Δ, denotes a difference or step.) To calculate speed you obtain the difference between consecutive positions (Δp) and divide this by elapsed time, Δt. The speed of the car is an attribute of the process that transforms its state. A process is a becoming - it relates to physiology and system dynamics.

This *cinematic model* of space-time represents time as an abstract sort of distance. It is possible (using Pythagoras' theorem) to extend the model to three dimensional spaces with a northing, an easting and an altitude. It can even be applied to abstract 'spaces' of system attributes and data structures. The state of a car is not just described by position, it has a mass, points in a particular direction, is more or less heavily loaded, has a certain amount of fuel in the tank and a certain amount of wear on the tyres. The cinematic model can be generalised to these attribute spaces. This is a rich and fascinating source of scientific insights, which you can study by looking for textbooks on data structures, linear algebra, vector and matrix methods and dynamical systems. Here we are going to focus on the cinematic model and landscapes, because it seems fundamental. A lot of our most powerful analytic methods draw on cognitive skills we humans acquired by interacting with landscapes.

The definition of 'landscape', we will use is that suggested by the geographer Torsten Hägerstrand. A *landscape* is an interval of space-time together with all the objects (living and non-living) that it contains. Hägerstrand's plesionic approach to landscape suggests that speed and position are *incommensurable*. In the time it takes to make a single observation of speed, position will have been smeared across an interval of space. The art of reconciling morphology and physiology is to develop a map of states and processes in which uncertainties can be kept within manageable bounds. In practice, scientists seem to have an intuitive aesthetic sense that attracts them to such maps. Morphology and physiology spring together in an appealing way and the map seems beautiful.

Hägerstrand, for example, developed a nice pedagogic model of space-time complexity that borrowed many elements from classical physics. Imagine each of the frames captured by the camera printed on a thin, clear sheet of glass and stacked on top of the others in time-order. The result would look like a transparent block with every corporeal object, including people, forming a sort of life-line in this space-time aquarium.



If you look at the aquarium as we have drawn it here you will see that the life-lines seem strange. They are either horizontal, or very nearly so, or nearly vertical. Remember, these are not the infinitesimally thin lines of abstract geometry; they are sequences of smudges with a halo of dynamic uncertainty. The near-vertical lines represent more or less stationary objects (parked cars, say). The near-horizontal lines represent objects moving so fast they appear to be smeared across a single frame.

This pattern suggests our surveillance set-up is not well designed. There is a problem of resolution - the uncertainty on location is so high we cannot resolve adjacent positions. Everything is either zooming through space so fast it appears as a horizontal blur, or more or less stationary. We could improve the spatial resolution, for example by improving camera performance and flying lower, but there are practical limitations to what we can do. A set-up that worked well for fast cars or aeroplanes, for example, would not work so well for pedestrians and would be almost useless for hedgehogs. This would only be a problem if you wanted to monitor fast cars and hedgehogs in the same exercise.

Whatever you do with this model will involve a trade-off. If spatial or temporal resolution is too good, you will drown in data and the project will over-run all its budgets. It is always tempting to crank resolution up and use the latest computer technology, but there is a law of diminishing returns at work. Smart geographers seek the right perspective for the task at hand.

§ 22. Durée, Landscape Time and Logical Coherence

Hägerstrand's aquarium map - he called it an 'ontology' - is useful. Time geographers often speak of it as if it were *the* ontology of geography, though Hägerstrand himself was careful not to make extravagant claims, and with good reason. Many geographers see space and time rather differently and some have strong reservations about Hägerstrand's aquarium. Humanistic geographers, for example, tend to think of time experientially. An hour in the shade, picnicking with friends and an hour at the dentist, for example, are different phenomena.

The philosopher Henri Bergson made an important distinction between landscape time - the reversible, space-like time represented in Hägerstrand's aquarium, and personal time, which he called *durée*. What this book has referred to as the 'deep-time' perspective, French historians might call *longue durée*, a term which emphasises the experiential dimension of this phenomenon. *Longue durée* is not 'out there' in the material world, it is a contextual structure.

Let us now turn to the relationship between landscape time and *durée*. Every language primer, it seems, contains a section on 'getting around' with conversations like:

Where is the railway station?
Down that road, take first left and second right.

Presumably neither questioner nor answerer can actually see the station directly. Both accept that the station is a special type of neighbourhood - a place in the landscape. Back to that hypothetical language primer:

Is it far from here?
No, about 600 metres.

Here we have a direct appeal to the spatial intuition, but the answerer could as easily have answered in temporal terms:

No, about 10 minutes.

The relationship between distance and time is called 'speed' and the relation between direction, distance and time is 'velocity'. If nothing moved anywhere in space, all speeds would be zero. Of course if nothing moved anywhere in space, we would each be stuck to the ground and there would be no possibility of exploring the landscape.

In the case at hand, for example, the answerer recognises that the questioner is subject to space-time constraints that limit speed, and uses that relationship to convert a distance into a time. Time is related (through continuity-constraints like speed) to space, which is why space and time have similar continuity properties. You cannot go from today to tomorrow without passing through tonight because that would be like going from the railway station to your bedroom without entering your home.

Our understanding of landscape is based on personal experience generalised by negotiating a consensus about landscape time and the landscape itself. If my conceptual landscape and yours cannot be reconciled, we are likely to appeal to the concept of (landscape) time to clear the misunderstanding up.

You weren't in your office yesterday
Yes I was.

Whoops! A contradiction like this is a sign that the two landscape models are inconsilient. See how the conversation develops:

Oh, I called and couldn't find you.
What time?
About 11.
I was probably at coffee.

Note the way questioner and answerer subtly revise their space-time perspectives to create a narrative that eliminates contradiction. The questioner was generalising to the whole of yesterday from a fleeting visit. The answerer narrowed that time perspective and increased spatial resolution to eliminate the contradiction. Both accepted the explanation.

Each had a personal sense of time based on experience, memory and anticipation. These lived time experiences (*durées*) were subtly reconciled through discourse to build a shared map of space and landscape time.

The fact that we worry about contradictory narratives and landscape time suggests that we have become a species that is exapted to life in a landscape a little like Hägerstrand's aquarium. It is hard to see how this could be if those space-time intuitions had not provided our ancestors with a satisfactory basis for action. The upshot of this is that, if one of us believes the nearest post office is to the east and the other that it lies to the west, we tend to assume that someone is mistaken or has misunderstood or is being deliberately misleading.

Adjusting space-time perspectives to construct a logically defensible narrative is a useful tool for clearing up contradictory landscape models, *ex post*, but the *ex ante* perspective is altogether more complex because we have no memory of future events. Opinions about which of two horses will reach the finishing-post first, for example, are often contradictory and no-one thinks this strange. That gives the impression that we humans evolved in time-asymmetric landscapes. Movement in space seems to be reversible, but movement in time does not - you can return to the places of childhood, but cannot return to childhood. Space-time is the product of co-dynamic friction between self and arena that leaves patterns in the arena and creates structures in self.

These who are addicted to paradigms might feel the need to formulate two models of time: one in which landscape time is real and personal time a cognitive artefact and the other in which personal time is real and landscape time a cognitive artefact. Readers interested in these extremes may enjoy Ilya Prigogine's *End of Certainty*. However it is also possible that these two models form a great truth. Let us explore them separately by means of a simple thought-experiment.

Let us suppose that time travel were possible, but that landscape time was real in the sense that any anachronism or contradiction generated by time-travel was spontaneously eliminated. If an ageing time-traveller were to go back in time and wander through the meadows of childhood, then the houses built over those meadows would have to be un-built, the mushrooms would still be growing in the damp grass. Those landscape changes would have knock-on impacts that would resolve anachronism and contradiction. Landscape memories would have to wiped and re-set. People are landscape objects and their memories and physical states would also be re-initialised. The time-traveller's mother would be busy at home, the school-books would be waiting on the shelf and everything would be logically consistent in that interval of space-time. The presence, in such a landscape, of a grizzled time-traveller would be anachronistic and would disrupt continuity intuitions. The time-traveller's body would have to be re-structured in a manner appropriate to that interval of space-time.

Under those constraints, discontinuous time-travel would be possible, but space-time and landscape would heal themselves in a way that made it impossible to know this had happened. If you were to leap forward in time, for example, the subjective memories stored in your mind and the physical 'memories' distributed through the landscape would have to be modified to restore the narrative sense of continuity. You would be older. The gaps in your memory would be filled up in a way that protected continuity constraints. In such a landscape you couldn't go back in time and shoot one of your own ancestors because the chemical elements that make up your body now would probably be distributed through the ancient landscape in a manner consistent with continuity constraints. You wouldn't exist.

Now let us move to the other end of the spectrum. Landscape time, though it seems to describe human experience, is not real. Time-travel, if it could be achieved, would work as science fiction writers imagine. The time-traveller would be able to go back in time and meet his younger self walking through that meadow, thereby creating a bunch of paradoxes that would challenge their space-time intuitions. You could go back in time and kill your grandfather and then hop forward in time to live out your own life among your great, great grandchildren. Of course different people with different time-perspectives could develop logically irreconcilable models of the landscape and neither model would be wrong. Imagine the conversation:

You weren't in your office yesterday
Yes I was.
So was I from early morning till evening
Different perspectives, I suppose.
Don't you just hate time-travel?
I can't answer that
Why not?
I'm not actually here

These two thought experiments only make sense if you assume that one model is universally true and the other trivially false. If you accept that both may be locally true then science becomes much more complex and interesting. In this universe of discourse, human intuitions about landscape time exist because the landscapes our ancestors colonised, like the landscapes we live in, made it possible for people with those intuitions to thrive. The irritation we feel when personal time-narratives generate paradoxes and contradictions is an extension of those space-time intuitions and tell us nothing at all about the universe as a whole. Our sense of number, distance, movement, speed and our tendency to re-work space-time perspectives to negotiate a coherent narrative are the product of contextual interaction between these structures and landscape pattern.

§ 23. Complex Causality and Great Truth

Consider a terrestrial landscape with limestone hills, a mass of streams and an alluvial plain. The streams sometimes disappear in the mountains and bubble up as springs near the foothills. The streams converge into a great river and spread out onto a delta. We are not talking about a bunch of abstract ideas here, but a physical landform shaped by climate and geo-physics.

Viewed from the perspective of deep-time it is clear that the river shapes the landscape, cutting deep gorges into the soluble limestone, depositing sediments on the plain, forcing its way through the alluvium and depositing soft flocculants where it hits the salty ocean.

Viewed from the conjunctural (meso-scale) perspective, however, it is quite clear that the landscape constrains the river. Its banks determine the distribution of running water in the hills and where those streams will disappear. The alluvium impedes the passage of water creating a series of meanders and oxbow lakes, while the mass of soft mud creates a divergent braid of streamlets and small channels.

Seasonal cycles seem to run on this meso-scale too. The meltwaters swell the streams, the salmon return and the insect population explodes. The trees awaken from their frozen sleep. Migratory birds exploit the mudflats and large carnivores come in to feast on fish and birds. Herbivores spread through the lush landscape, breeding before the dry days of summer close in. The lowland river slows to a sluggish, meandering flow, the seasonal water bodies disappear and everything gears down for autumn.

Viewed on the micro-scale of events, however, we can no longer valorise the seasonal cycle or the grinding mill of geo-physics. What we see is a domino-chain of events that form a seasonal narrative with the wisdom of hindsight, but cannot be predicted *ex ante*. We cannot tell whether the next storm will create a normal seasonal flood or bring down a few trees, or expose a deep hole in the karst that turns a permanent river into a seasonal stream that disappears underground in the summer.

Organisms that live in this landscape often do so by modifying its space-time behaviour. Trees stabilise the soils on the hillsides, slowing the rate of colluviation and alluviation. Stable soils reduce the rate of limestone dissolution. Plants on the riverbank protect soils from erosion. Humans build dams and channels, extract water from the aquifer to carry them through dry periods, they clear forests and cause soil to be redistributed, and so on. Different types of human action have different space-time signatures and modify the system's physiology by switching control between scales and causal structures.

It is interesting that natural philosophers who are comfortable with the idea that different time-perspectives change our understanding of cause and effect in a physical system, often get grumpy with humanists who make the same observation about our understanding of scientific or religious texts, or when applied anthropologists tell them that science works the same way. The fact that different models have different logical structures does not necessarily imply that they should be set up in paradigmatic opposition. It is possible that we are dealing with a great truth - one that can be contradicted without speaking a trivial falsehood.

Here is a possible example. After Charles Darwin died, only two of the three voyaging naturalists who shaped 19th century biology were left. Alfred Russel Wallace was one and Thomas Henry Huxley the other. Wallace can reasonably be presented as the founder of the neo-Darwinian approach. His book *Darwinism* makes it clear that Darwin himself would not qualify as a Darwinist. Wallace was a supernaturalist in the sense that he believed science dealt with efficient cause and reasoning by necessity. Humans may have some control over their destiny, but this was so because they were imbued with some higher cognitive faculties that derived, by a process of evolution, from an antecedent spark of universal intelligence.

The French philosopher Henri Bergson formulated a similar theory in his book *Creative Evolution*. Agency was a supernatural phenomenon and evolution was the breeze that fanned the primordial spark of intelligence and helped it grow. Unlike Bergson, Wallace kept these two processes apart in his mind. For Wallace, then, natural selection was a constraint that drove the evolution of animals and plants. Only higher life-forms (like us) could buck that trend and they did so in accordance with the demands of the universal intelligence.

Wallace did not believe in the inheritance of attributes acquired in the course of an organism's life. Darwin was an unreformed Lamarckian in this respect and Huxley kept quiet on the subject. In later life, Darwin came to believe he had over-stated the role of natural selection in his earlier work. Human cognition was a natural process and, as such, could not be explained in terms of a supernatural intelligence. He believed natural selection was sometimes set into abeyance in a way that allowed life forms to explore a range of strategies, many of them co-operative. Darwin's theory was co-evolutionary and co-operative. It assumed agency was a natural phenomenon. Huxley's contribution to this discussion, summarised in his popular *Discourses*, was to emphasise the contextual inter-weaving of pattern and structure, which he described as 'epigenesis', and the evidence for a stick-slip dynamic, which he called *saltation*, the geneticist Hugo De Vries called *mutation* and later biologists referred to as *punctuated equilibria*.

Let us call these theories *neo-Darwinism* and the *Darwin-Huxley synthesis*. The difference between the two is that between believing the bird flies *because* it has wings and believing that birds have wings *because* they fly. More pedantically, the neo-Darwinian theory suggests the bird flies because it has the genetic programme that gives it wings and the itch to use them. That genetic programme was produced by natural selection, which winnowed the genotypes of ancestral reptiles. The Darwin-Huxley model, on the other hand, suggests that the bird has wings because some ancestral reptile found itself in a situation where the ability to fly, or at least jump long distances, made life safer. This jumpy behaviour created a stable nexus of opportunities and threats that influenced the reptiles themselves, their predators and their food.

That nexus of opportunities and threats persisted long enough to put birds with a genetic predisposition to jumpiness and an aerodynamically efficient body-form at a small selective advantage. They didn't have to learn to jump by a process of trial and error, as their ancestors did; they were born with some of that knowledge already incorporated into their racial memories. If the ancestral reptile had been trying to hide in leaf-mould or crawl into holes, those flappy appendages would have been a disadvantage and its descendants would have been more snake-like.

There are two obvious corollaries of this model. The first is that there is a flip between cause and effect as you move from one scientific context to the other. Either the gene-drift caused the change of behaviour or the behaviour created the selective gradient that caused the gene-drift.

The second corollary is that a predisposition to experiment and explore possible behaviours increases the possibility space of future evolution. Ancient social organisms like bees and ants often confine their exploratory behaviour to foraging and feeding. Their core social behaviours are largely structural and genetic. Great apes, in contrast, are evolutionarily young and our own species, *Homo sapiens*, is a real newbie. For more than 90% of our existence we lived in extensive, low-density communities operating with relatively simple technologies. Urban societies are only a few thousand years old and the sciences that we have been writing about have only existed for a few centuries.

19th century biologists, when they wrote about evolution, clearly saw our species as more advanced than other great apes and the great apes as more advanced than the insects. But the empirical evidence all suggests that our species is evolutionarily immature. Many of our core social behaviours are acquired contextually, by a process of social learning. What's more, we seem to have acquired a tendency to explore new behaviour patterns and social behaviours that continually de-stabilise the ecosystems we have created. Most of us grow up in social systems that our great grandparents would scarcely recognise. We humans are exapted to these behaviours - our bodies are structured in a way that predisposes us to exploratory behaviours that maintain and increase the openness of the possibility spaces we explore.

This insight turns enlightenment ideas about social evolution on their head. Early biologists contrasted the insentience of plants with the instinctive, machine-like behaviour of insects and the exploratory, experimental behaviour of vertebrates. It seemed natural, in the context of 19th and 20th century imperialism, to interpret this as a form of ecological progress that culminated in the emergence of anatomically modern humans with their higher cognitive faculties. But insect societies are much older and stabler than ours and there is little evidence that they are likely to compromise planetary life-support systems. Are we really more highly evolved than they are? Or is it possible that our current, chronically unstable social systems are part of a catastrophic re-organisation of planetary life-support systems that must either lead to our extinction or to the emergence of something more enlightened, like a pismire?

So now we have two hypotheses: one holds that a bird flies because it has the genetic predisposition to develop wings and the other that a bird has wings because its ancestors were trying to fly. Each belongs to a different scientific context. One belongs to natural philosophy. It can be used to predict, subject to an acceptable envelope of uncertainty, and manipulated using the hard logic of scientific necessity. The other is more humanistic. It emphasises the emergent nature of conceptual taxonomies, constructs an *ex post* narrative that explains the emergence of bird-like forms in terms of possible rather than necessary correlations and, coincidentally, gives us some ideas that could possibly be used to change the course of history.

The second theory can be used to make a prediction, but adds a tacit contingency:

The apogee of human evolution will be a smelly, sexless machine with the sensibilities of a naked mole-rat (if we do not innovate to prevent that happening).

We could set these up in paradigmatic opposition and argue our favoured model against others, but the empirical evidence suggests that both theories co-exist in the same world. Either we must over-intellectualise science, pretending that one causal model is the preserve of good (enlightened) monkeys and the other the mark of evil, unenlightened ones; or we accept that each is attractive to a different intellectual caste, suggests a different programme of action and operates on a different space-time scale. One model is more useful if you want to predict the course of history, the other is designed to help change the course of history.

§ 24. Context, Empathy and Role-Play

Let us define a *plesionic system* reflexively, as an interval of space-time (arena) containing, amongst other things, a group of one or more agents (self) working together to understand and possibly influence an interval of space-time that contains, amongst other things, some plesionic systems (other). A wolf feeding her cubs is a plesionic system, so too is the pack she runs with, the researchers who work on the wolves, the herdspeople trying to keep wolves at bay, the committee that funded research, the politicians and civil servants who control research investment and the family at N^{o} 11 Omdurman Terrace that wants a change of government.

Plesionic systems, defined this way, are not corporeal agents; they are contextual artefacts - the product of a complex interweaving of embodied structure and pattern.

We illustrate this distinction with a simple example.

A human being is always a mammal and a corporeal object in a landscape, but is not always a member of an international, trans-disciplinary research project. The project we have in mind is not an hypothetical construct, it is a real project with 17 institutional partners drawn from 9 nation states and a budget of € 5.4 m. Large projects invariably have two or more nested layers of sub-projects and may involve cross-cutting research themes. A university-based scientist working on this team may be the manager of a small sub-project that occupies him/her for a few months. During those few months s/he has obligations to two sets of regulators and must reconcile these constraints.

The university has its own managerial line and regulatory staff that constrain the scientist's actions in return for the benefits of institutional affiliation. Salary, resources and facilities are worth having and some sort of institutional affiliation is needed to mobilise these resources. For the few years of its life, the project disrupts and re-organises those institutions. The project brings revenue into the university and, in return, demands the resources needed to create deliverables. For a short while the scientist has two sets of calls on his/her time. The success of this venture depends critically on a process of flexible role-play.

Consider the following example.

Sally, who is responsible for a research task on a large project, gives a colleague, Tom an instruction that he does not understand. Tom asks for clarification. Sally becomes Tom's teacher and Tom her student, taking notes and maybe going to the library to follow up. Then Sally takes her teacher hat off and puts her task-leader hat back. Tom dons his team-member's hat and they slip into different roles. Later Sally slips into the role of doctoral student and Tom becomes her supervisor. The teacher / student roles are reversed. Before Sally leaves the room, Tom asks her (as a project co-ordinator) about the tasks he has delegated to her and Sally (as task-leader) makes a report along a managerial line that now flows in the opposite direction. Finally Sally invites Tom to join a few people for coffee and they slip into the roles of easy friendship. Each of these roles flips the relationship between Tom and Sally into a different contextual perspective that brings some habits and phenomena to the fore and backgrounds others.

The situation we have just described is common on research projects, particularly on large ones where the natural and human sciences must work together. Each of these roles re-forms the plesionic system that we are calling 'Tom and Sally' by changing its focus. Role-playing and honest pretence are important research tools. Every needless constraint a manager imposes on others in these projects reduces operational wriggle-room and makes scientists reluctant to explore new roles and patterns of thinking. Effective managers, then, are those who try to encourage a no-blame culture that allows practitioners to experiment and make mistakes.

However, if a practitioner starts making the same mistake again and again or making mistakes and hiding them, project managers have to pull rank. There is always a price to pay for this flip from operational to regulatory mode. If you do it too often the project will dissolve into bad-tempered recrimination. It may de-stabilise partner institutions and disrupt the lives of external stakeholders. This is always a difficult call to make and many research managers evade or fudge it.

In open-ended research programmes, however, the situation can be very different. People become habituated to a limited range of roles. Those roles and patterns of behaviour become culturally embedded in the individual's sense of identity. Stable institutions depend on role-play too, but the range of roles is constrained by institutional convenience and culturally embedded discipline. In time people cease to be aware of institutional constraints. If you ask them to step outside those familiar roles, they may become defensive or even aggressive. One of the commonest causes of conflict in a large research project is that institutional roles have become fixed and people cannot make the transitions without violating culturally embedded taboos.

We have already hinted that the most stable situations are those that reinforce the culturally embedded beliefs of individual members who, in turn, benefit from the power mobilised through co-operation. These are the situations where you know what is happening without having to think and your knowledge feels 'true' in the operational sense that you are able to respond automatically. This is why we recommend that most of the time one spends working on a trans-disciplinary research project be devoted to work carried out in closely related disciplinary communities.

There is a distinction to be made here between scientific disciplines and institutions. In both our universities, for example, geography and archaeology operate in different institutional settings. They are separate departments, with separate budgets and managers. However the links between individual geographers and archaeologists may be very close. In general, geographers whose interests are humanistic find common cause with proto-historians and physical geographers find it easier to communicate with pre-historians because they belong to the same disciplinary families.

Natural history, humanism and natural philosophy find expression in many institutional settings. Geographers and archaeologists may use different language and appeal to different seminal sources, but the same mindsets are instantiated in both institutional settings. When universities claim to have done some 'inter-disciplinary' research, close examination often reveals that they have done some trans-institutional work that exploits these consilience-relations.

Real trans-disciplinary work - work between the humanities and natural philosophy, say - usually takes conventional academics outside their cultural comfort zones. This sort of work can be useful, but it is also rather tiring. It is not just that the communities use language differently, it is that the language of natural philosophy is inconsilient with that of humanism. The scale-differences between the two study-domains are too great. What to one practitioner feels like a cause, to another feels like an effect.

Effective managers only bring those people together to focus on specific deliverables and tasks and then take them back into their home territories. A large, multi-layer project like the ones we are discussing may only come together in plenary session for 2 or 3 days per year. For those 2 or 3 days, managers have to make it possible for the whole team to operate as a plesionic system, mitigating the effects of culture-shock and preparing people for the experience.

Project managers usually handle this one of two ways. One is to keep people in lecture theatres and hit them with formal presentations. This is dreadfully boring, though it minimises conflict and focuses attention on some sort of deliverable. Twenty years ago scientists attending these sessions used to doodle, read or sleep. These days they check e-mails, browse and sleep. The second option is to organise thematic sessions and break-out groups focussed on specific themes or deliverables. This is more fun, but a little bit risky.

How ever you handle trans-disciplinary communication, there has to come a point in the proceedings when people come together in a single group to meet with the sponsor's representatives, discuss regulatory issues, plan and negotiate consensus. When they do, all those involved, including project managers, speak about the consortium, the regulator, the project's sponsors and external stakeholders ***as if*** they were plesionic systems when they clearly aren't. The sponsor is usually an institution of some sort, the consortium acts as a plesionic system for less that 1% of the project's life, the external stakeholders are not even organised into coherent disciplinary communities. This tendency to speak about incorporeal, diffuse, diverse alliances of people as if they were plesionic systems is one of the strangest and most characteristic traits of our species.

This phenomenon, sometimes called the *pathetic fallacy,* is a pervasive and significant feature of human ecology. It is also manifest as a tendency to empathise with material things - to speak of an angry sky or a threatening sea. It is called 'pathetic' not because it is pitiful, but because it refers to empathy. A better term would be *empathic intuition*. It is the reason humans speak to gods and gods seem to answer. It is also the reason we develop language. It is hard to see how babies would learn to communicate if they were not born with an intuitive expectation that the world would be trying to communicate. There would be no science; no politics, and no institutional structures were it not for this empathic intuition. It is crazy to call it a fallacy, when it is all that stands between most of us and severe autism. The empathic intuition is the foundation on which language, music, art, science and flexible co-operative action are built.

§ 25. Exaption, Emergence and Institutional Veto

We are all familiar with the idea of adaption - of becoming apt (fitted) to some situation. By analogy to *exapt* is to be fitted 'out of' some circumstance. The word, as we have seen, is used to describe a quasi-anticipatory mechanism whereby a structure evolved as part of an adaption to one set of circumstances, creates a nexus of threats and opportunities that opens up a new range of possible evolutionary futures.

The earliest fish-like creatures, for example, had no jaws, but had multiple gill openings. In some of these the gill openings were buttressed with cartilage that provided more or less solid gill arches. These solid arches created opportunities for enhancing the digestive process by means of enlarged, tooth-like scales. In some species the gill ridges migrated forwards, lost their original respiratory function and became prototypical jaws. The evolution of gill arches had exapted the ancestral, jawless fish to a range of possible evolutionary futures that included us.

A more superstitious approach might re-present this narrative as the evidence of planning and intelligent design. Exaption, however, is a naturalistic hypothesis. It makes no appeal to a creative intelligence that sets the universe on a pathway to jaws or higher cognitive faculties. The future evolution of the universe is, and always was, under-determined in the present. The result is a time-asymmetric development in which phenomena have unforeseeable spin-off consequences - called *emergents* - which seem to resolve themselves into pivotal events in some *ex post* narrative.

The concept of emergence is historically associated with three men. C Lloyd Morgan was a student of Thomas Henry Huxley's, who wrote an interesting note in *Nature* and a later book titled *Emergent Evolution*. Morgan was building on foundations laid by George Henry Lewes, a philosopher who, in turn, was building on ideas due to John Stuart Mill, who wrote about an approach to reasoning that he called *resultant*.

Suppose, for the sake of argument, that smoking increases the risk of getting mouth cancer by 25% and drinking alcohol increases the risk of getting mouth cancer by 30%. In the language of the original texts these two causal factors were called *operants*. In this hypothetical example, a reasonable estimate of their combined impact would be obtained by adding the operants: 25 + 30 = 55% to get the cancer risk for someone who smokes *and* drinks. The sum of these two operants is called the *resultant*.

However it may happen that the two risk factors reinforce each other, so the composite operant should be higher than 55%. It is even possible that one risk factor has a protective influence and the composite is less than 55%. Mill had no word to describe these interaction-effects, but Lewes coined one - it is an *emergent*.

In general, given two operants (causal factors):

Operant 1 + Operant 2 = Resultant + Emergent

If the emergent factor is null, then we are dealing with a 'resultant' system (21st century scientists would probably call it a *linear system*). If the emergent factor is emphatically not null, then we have to take account of *emergent* phenomena. Morgan saw this pattern of reasoning as a special case of a wider category of situation in which the whole is not the sum of its parts and non-linear or saltatory dynamics are possible.

In the hypothetical, cancer-risk model we have just described the operants and the emergents are of the same logical type - they are all risk factors - but this need not be the case. Indeed, the word *emergence* often has two related meanings; it can apply to the appearance of some objective pattern and to the subjective unpredictability of that pattern. The numbers that will win a lottery, for example, are unpredictably emergent. On the night of the draw, however, they emerge from the machine, the winners become richer, parties are held to celebrate the win and so on. This cascade of life-changing experiences creates patterns in space and time that could not have been predicted, *ex ante*, but can be explained, *ex post*.

The relationship between unpredictability emergence and self-organising emergence has something to do with time and space. In a single coin-tossing experiment, for example, time can almost be defined as that which transforms subjective, unpredictability emergence into objective, self-organising emergence. Similarly, the behaviour of a single coin-toss in the future is unpredictably emergent, but the long-term average behaviour of a large population of future coin-tossing experiments is a predictable, self-organising pattern. On that large scale, statistical laws kick in and we can predict that the average proportion of heads will be very close to ½. Unpredictability emergence is suppressed by synergetic 'friction' as one moves from the level of the event, up a level of organisation to the conjuncture.

Human institutions are emergent phenomena. They arise as large-scale by-products of co-operative action, often manifest at a very small level. One can imagine an innovation-cascade of small emergents, reinforced by a combination of exaption and adaption, that changes system dynamics irreversibly. Once they have become established, institutions are able to operate on larger space-time scales than individuals. Their behaviour becomes more or less predictable and resultant. Individuals empathise with them, try to interpret their motives as if they were corporeal agents and harness the collective power they can mobilise.

Morgan forged a link between 19th century ideas about emergence and resultance and 20th century work on human cognition and institutions. His work belongs to the same broad pattern of thinking as more recent literature on self-organisation - often associated with Gregory Bateson, whose book *Mind and Nature* is a good introduction, and with Humberto Maturana and Francisco Varela, who coined the word: *autopoiesis* (self-writing) to describe similar phenomena. Two natural scientists who have won distinction working on these topics are Ilya Prigogine and Herman Haken, who prefers the term *synergetics*. There is a subtle distinction to be made, however, between equifinal self-organisation and emergent self-organisation. The natural scientists tend to write about predictable or equifinal self-organisation and about metastable systems that bounce from one known attractor to another. The social scientists are more interested in time-asymmetry and innovation.

Many writers do not bother with this distinction, writing about the germination of one poppy in a tray containing hundreds of poppy seeds as 'emergence'. When you are reading scientific books and papers about emergence, self-organisation, synergetics or autopoiesis (all related concepts) you may need to think about the way the words are being used. This isn't always easy because the difference is an artefact of space-time perspective and the boundary judgements that define things and categories.

The publication of Darwin's *Origin*, with its strange ideas about agency and purposeful action was obviously an emergent phenomenon. However Darwin's ideas had little impact on 19th century science. Wallace's work on natural selection and Spencer's *laissez-faire* liberal sociology were much more influential - at least until the complexity revolution brought Darwin's and Morgan's ideas into the scientific mainstream. The institutional vetoes of the 19th century could not be set aside.

Institutions can mobilise armies, build death factories, commission weapons of mass destruction and compromise planetary life-support systems. Ironically, their ability to do this is an emergent by-product of cultural exaption and empathy that evolved to facilitate co-operation. Young humans who are capable of acquiring socially learned behaviours by observing patterns and incorporating them into the structures of their own bodies, are able to communicate and co-operate more effectively than autistic and learning-impaired infants. Their culturally embedded disciplines become manifest as the tacit knowledge and taboos that underpin co-operative action. Their empathic predisposition enables them to invest incorporeal patterns with personality and all the trappings of agency. Institutions become real. Although they cannot be objectified, their demands and desires can be inferred using rational methods. Institutional norms are often reinforced by culturally embedded consensus, peer pressure and habit.

To challenge a powerful institution is to undermine all the ecodynamic patterns that depend on it. It is enough to threaten major reform to trigger panic action and retrenchment among key players. This defence-mechanism, which is often reinforced by cultural embedding at the level of the individual, can have a profound impact on agency, co-operation and personal freedom. Every institution is an emergent structure that creates new opportunities and threats. These support spin-off developments - also emergents - some of which strengthen the institution, while others undermine its power-base.

The institution consolidates opportunities and channels resources into combating threats. In so doing, it moves the community as a whole into a more gnostic configuration. Dissident worldviews are suppressed and some *de facto* stakeholders are pushed beyond the pale. This social exclusion generates further emergents, many of them unwelcome and dangerous. Over time the institution must either collapse or accumulate more and more power, which it uses to suppress unwelcome emergents. As it does so, it becomes less flexible and resilient - it cannot respond to changing circumstances or spring back after perturbations. Like a great tree it must resist, suppress competition and endure.

Often these emergent challenges are themselves by-products of institutional action, but the weak logical connections between exapted phenomena and the emergents they spawn means the institution can, and almost invariably does deny responsibility. This plausible deniability stimulates debates about the intellectual truth or falsity of claim and counterclaim, which heightens conflict further. In modern societies, intellectual experts are often drafted in to engage in gladiatorial combat and science is pushed up the torus towards the gnostic trap at the top.

Scientists do not cause these paradigmatic squabbles. The institutions they are embedded in create a sort of 'selection-pressure' that polarises the scientific community. Scientists who recognise the difficulties faced by unacknowledged stakeholders find themselves pushed beyond the pale, while those who toe the line can use institutional power to drive their careers along. The institutional worldview becomes culturally embedded and the exclusion of dissident perspectives is reinforced.

Small-scale cultural embedding and institutional power reinforce each other to create a powerful ratchet that aggravates social exclusion. Conflict triggers a gnostic veto and those gnostic certainties aggravate conflict to create a self-reinforcing cycle that can only be broken by softening the boundaries of subjective categories and negotiating a new conceptual model.

The system is trapped in a vicious bind; people will only feel safe after they have innovated, but will not be able to innovate until they feel safe. Even then, cultural constraints make it hard for older people to make the transition. Institutions get locked into a phoenix cycle of gnostic hardening, conflict, collapse and renaissance that can entrain planetary life-support systems. In the 20th century, for example, the 1920s and 1960s were both periods of glasnost and perestroika following terrible wars. Institutions were too weak to hold back the tide of innovation.

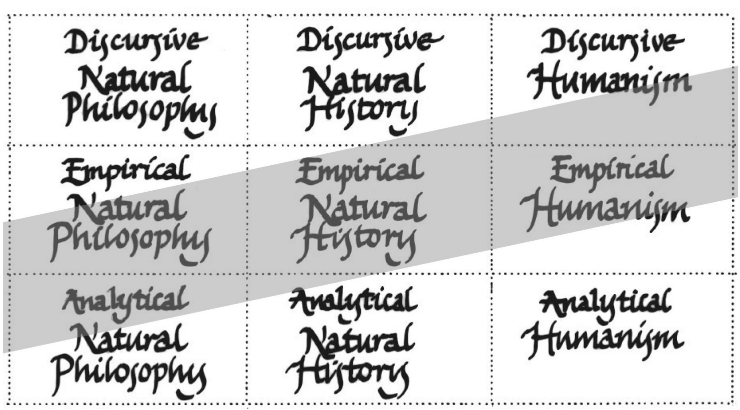
§ 26. Operational Management

Most of the projects we work on try to integrate hard-science and soft-science perspectives. Gnostic extremists find it difficult to participate in these so it is a good idea to keep them out or restrict them to specialised tasks. This is not an institutional veto, since a project does not last long enough to become an institutional structure. However it does illustrate the way such vetoes come into being. If, for example, the same gnostic embargo was imposed on an open-ended programme of research and maintained over a long period, an institution might emerge with its own power-struggles, problems and vetoes. That institution would fudge the meanings of words to re-admit gnosticism by the back door.

There are no simple solutions to complex problems

Eliminating or marginalising gnostic extremists means one can trim the torus down. Instead of having five columns, all fully inflated, it now has three and two reduced to vestiges.

Laid out in grid form it looks a little like this:



Now imagine this rolled and connected end to end to make an agnostic torus. There is still a singularity at the top where large scales meet small scales. Projects often struggle when too many people are working near the singularity, but the stripe just touches in the empirical row and some sort of continuity is possible - possible, but not easy.

In any research team, the humanists tend to take an *ex post*, explanatory view and natural philosophers favour an *ex ante*, predictive approach. Both are trying to integrate the domains of ideas and evidence. Humanists tend to be interested in the relationship between boundary judgements and value judgements. They tend to become engaged by relatively small-scale phenomena, working at individual, village or regional levels, and devote a lot of attention to problems of social exclusion and cohesion. Humanists are experts in the management of cultural life-support systems. If you let humanists loose, their research interests draw them into an open-ended programme of discursive engagement designed to elicit many viewpoints and stakeholder perspectives.

Natural philosophers are problem-solvers. They need conceptual models and problem-ontologies to be stable. Just about the most tiresome thing you can say to a natural philosopher is: *why did you not solve a different problem?* There is no sensible answer to this question other than: *because this one caught my attention and held it.*

Humanism and natural history are incommensurable. One group can only work if problem-ontologies are stable; the other de-stabilises problem ontologies simply by working. If you let both communities work in the same study-domain at the same time, there will be a riot. The humanists accuse the natural philosophers of answering the question they wish someone would ask them and the natural philosophers accuse the humanists of not knowing what they believe until they hear themselves speak.

Don't go there! Bad things happen if you go there.

The trick of helping them all work together is to schedule the operation so control shifts from humanist to natural historian to natural philosopher. We call this the *project cycle* because it carries the work round the agnostic torus clockwise. Viewed on the grid above, clockwise equates with travelling from right to left. The project cycle starts with a programme of *opening up* work, usually co-ordinated by humanists, but regulated by an agreement between the research consortium, external stakeholders and funding agencies. In large, policy-relevant projects, this regulatory protocol is usually underpinned by a binding legal contract, but it is possible for a lone-scholar or a doctoral student to follow this project-cycle approach.

Try it - it's fun.

In mainstream humanistic research there really is no limit to how much time you can devote to opening up. There are ethical constraints, of course, but wickedly complex problem-domains can require an open-ended programme of engagement, conflict management and resolution. The project cycle only works in problem-domains of middling complexity, where some sort of consensus can be negotiated and maintained. That's where the natural history approach is useful. You have to *close the project down* by making value, boundary and operational judgements explicit and negotiating a sufficiently robust consensus to sustain a targeted effort of *problem-solving.*

In the early days of project-based science, the project cycle was often severely truncated or driven in the wrong direction. Powerful institutions defined the problem and hired scientists to solve it. Social exclusion and political dissidence undermined the work, leading to unforeseen and unwelcome consequences. Humanists and specialists in conflict resolution were drafted in to clear up the mess and mend fences. The project cycle of opening up, closing down and problem-solving represents best practice in plesionic science, but the gulf between best practice and common practice can be impassably wide, particularly if receptivity barriers are strong and too many disciplinary institutions and knowledge communities are brought in to the work.

It is a good idea to keep people working in teams of like-minded specialists most of the time, so their shared knowledge-base is robust and unchallenged; bring them together in small groups; create a safe, no-blame culture, exclude incorrigible 'networkers' and high-profile spectators - they make the team noisier and harder to manage. Provide opportunities for social interaction with good food and make sure there is space for break-out sessions. Avoid hedonistic pleasures like poison.

Focus the group on one or more specific, auditable deliverables. Don't bring them together to discuss the problems of child poverty or global warming, or to decide whose fault it is that public investment in science has unforeseen and unwelcome consequences. Concentrate on some small itch that everyone wants to scratch and link it to a concrete deliverable. It could be a draft paper about water stress and agriculture, a plan for dealing with dog-filth in the streets or an agreement to start conservation work on neglected river-channels and footpaths.

If you can build enough trust to persuade people to take a risk and commit themselves to solving a small problem, you will help everyone feel good about the work. The next time you pass through the project cycle, you may be able to tackle something bigger. It is better to start small than never to start at all. One way to build trust is to negotiate formal *boundary conditions* for the work. These are explicit indicators of compliance and system health. Set targets for reducing dog-mess and design rolling programmes of empirical monitoring and stakeholder engagement to see how well you are doing.

You are now ready to move onto the third phase of the cycle, which is problem-solving. The natural philosophers assume executive responsibility for this phase of the work while natural historians and humanists take a back seat. The natural philosophers solve the problem while the others work together to monitor those boundary conditions. As long as the boundary conditions are satisfied, then the project is on-track and the problem ontology is stable.

If the project goes off track, however, the team will need to switch from operational to regulatory action. It will need some protocol that obliges it to pause and re-evaluate performance. Sometimes the effort of re-adjustment is trivial - the team tweaks the research design or adjusts the boundary conditions and off you go again. Sometimes the whole effort goes pear-shaped and you have no choice but to stop, write off the investment and go back to the beginning of the cycle, re-framing the problem and re-negotiating your research strategy.

There is no decision harder to make than the decision to write off an investment. On a large research project with a formal consortium agreement and contract, you have to involve external stakeholders in the process. The group can become large, trust can break down, and people will experience conflicts of interest. That is why you need to make your boundary conditions explicit.

The commonest cause of project breakdown is that some stakeholders find themselves working outside their cultural comfort zones. An engineer gets freaked out by the idea that science deals with phenomena that cannot be measured; an eco-warrior cannot cope with the demands made by commercial stakeholders or an empiricist cannot stop buying or collecting data long enough to deliver some substantial result.

There is no easy solution to these problems. Each situation is slightly different. A conflict-ridden research team is a wickedly complex system. Every action you take is a one-shot operation that echoes across space-time in a way that changes the dynamics of the team. If you manage to re-stabilise the team, you have been lucky. If you fail to re-stabilise, you have been unlucky. The best course of action is to ask the humanists on your team, especially those with experience of conflict and social justice research, for advice and guidance.

Each time a team passes through the project cycle, you build enough trust to take on a more demanding task. If you are lucky, the team will develop its own momentum. Team members start to think you are a good project manager, because all the management activity is operational - the ops team is keeping records, managing conflict, re-adjusting schedules and so on. The leader's task is to *regulate* the team in a way that allows people to take operational control of the work that really interests them. You push resources and accountability down to task leaders who, if they are smart, push resources and accountability down to the specialists who answer to them.

Interestingly, it sometimes happens that projects roll over, end-to-end, to become, in effect, an open-ended research programme. When this happens, part of the project cycle usually diminishes. The opening-up and closing-down phases may be reduced to vestiges and the work becomes an open-ended programme of problem-solving, dominated by natural philosophers. On other occasions, the problem-domain is too complex and ill-structured to sustain much problem-solving work and an open-ended programme of engagement and trust-building follows, which creates an interesting research programme for humanists. Very occasionally the problems are all solved, problems of social exclusion are eliminated and natural historians take over, monitoring, cataloguing and keeping things going. When this happens, professional interest wanes and the field is often colonised by amateurs.

There is often a natural correlation between disciplinary outcome and institutional scale. Large, powerful institutions that operate at national and supra-national levels cannot cope with diverse knowledge systems. They tend to become highly sectorialised. They also command the resources required to undertake large problem-solving and infrastructural projects. They tend to form comfortable alliances with natural philosophers and other problem-solvers. Humanistic diversity is a small-scale pattern and humanists tend to enter the political hierarchy at local scale, where they work with individuals and small stakeholder communities. The regional scale is interesting, because this is the level that commands the resources to communicate effectively with large players, but is still small enough to operate across sectors and disciplines. Integrative research, which requires natural scientists and humanists to work with external stakeholder communities, is often mounted at the regional level.

Research managers working at this level, if they are wise, only step when the boundary conditions are violated or some epiphany occurs that re-organises the dynamics of the team by turning a perceived threat into an opportunity. Most of the time the team manages itself, administrative ('ops') staff keep records and the team leader stands by to cope with exceptions and emergent phenomena. Some of these emergents will be threats, in the sense that they challenge culturally embedded truths and undermine co-operation.

The art of innovation-management is to create a no-blame culture, work in small groups and negotiate new ways of thinking that convert these threats into opportunities. Conflict resolution, though it sounds like a good idea, can actually prevent the team innovating. If you want to innovate, you need a little bit of healthy conflict, a great deal of operational wriggle-room and just enough regulatory oversight to keep things moving in the right direction. The parcel of challenge and opportunity that is a research project must be constrained by the boundary conditions that provide the project's regulatory milieu.

When it works, you will find the project cycles between operational management, regulation and operational management. Wonderful things can happen if you hold the team together through that cycle. Doing so is difficult enough when social mobility is high and institutional vetoes are soft. In periods of geo-political conflict and economic stand-off, alas, it is almost impossible. Powerful institutions do not wish to be told that they are solving the wrong problem and the regulators they appoint will often suppress or veto work that compromises receptivity barriers.

Section IV : Afterword

When we learn to tie a shoelace or ride a bike, that knowledge becomes incorporated into our bodies by a process that re-shapes neural pathways until we can do these things without thinking. The relationship between structure and pattern is not the clear-cut distinction of genes from social learning that we find in many biology textbooks; it is a form of path-dependency in which the impact on the individual of learning to tie a shoelace is no less real than that of (say) the arrival of paternal genes at the point of fertilisation or the amputation of a leg. Some of these experiences are directly heritable; most are not, but they can still create patterns in the plesionic milieux that influence the process of contextualisation in later generations.

Humans acquire those skills by seeking consilience between understanding and behaviour. That consilience - we have called it *operational truth* - enables them to know what is happening and how to respond without thinking. Younger people, if they are not autistic, tend to achieve this harmony by adjusting mental structures to accommodate the patterns they observe around them. The external world changes their minds faster than their minds change the external world. Some become leaders and trend-setters in early adulthood but most of us, as we mature, develop habits that keep us close to familiar situations.

Post-reproductive humans may coerce neighbours into conformity, or conform themselves, engaging in liturgical and semi-ritualised behaviours. The calming effect of ritual co-operation can be seen most clearly among older people. The ability to learn can be lost without serious distress as long as the individual remains in a familiar environment, hence that preoccupation with habit and familiarity we see in well-managed care homes. Some of the anger expressed by those with cognitive impairment is triggered by the bewildering sense that they don't know what to do.

The link between belief, purpose and action becomes irrelevant once the behaviours become culturally embedded and the arenas in which we operate contain no surprises. We can converse without saying anything; we can act without changing anything. We can co-operate without question and even kill without compassion.

There is no evidence to support the view that strong, smart, flexible thinkers are universally fitter than weak, stupid inflexible ones. Beetles are not especially smart or particularly strong, but do pretty well. If, as we suspect, *sapiens* humans are evolutionarily unstable and immature when compared to social insects, then we may envision three broad types of future.

- We continue as we are until our life-support systems collapse and then go extinct
- We continue as we are until our life-support systems collapse and the survivors evolve into something more advanced - the anthropoid equivalent of an ant
- We find a way of mitigating conflict that allows us to stabilise our relations with other organisms and planetary life-support systems

If we knew that the future of our species would either be extinction or an autistic machine with the IQ and social graces of a naked mole-rat, would that change the way we behave now? We think it might, but it could only do so in a world where human agency can make a difference and people can change the course of history by changing their minds.

§ 27. Innovation and Jonah's Law

Innovation, a recurrent theme in this book, is a biological phenomenon. We great apes were innovating long before we were writing books about science, so it seems reasonable to look for evidence of innovation-behaviours in non-scientific contexts. You can find it in ancient literature, both in philosophical and religious sources. The book of Jonah is a case in point. Jonah received an instruction from god to prophesy the destruction of Nineveh, a city whose residents were behaving badly. Jonah refused because the iniquitous population would probably make reparation to god, who would forgive them and so falsify the prophecy.

Jonah was so anxious to avoid false prophecy that he tried to hide. He ran away to sea where a storm and a passing fish forced his hand. When he finally caved in and passed god's message along, he was proved correct. The people made reparation, Nineveh was not destroyed and Jonah went off to sulk on his own. Jonah's dilemma arose because the prediction dealt with a *future contingency* - a prediction, the truth or falsity of which is contingent on another (in this case implicit) precondition. Jonah was telling the people of Nineveh: god will destroy this city (if you don't do something about it). Since the people of Nineveh did do something about it, the truth of the prediction became undecidable.

From this story, successive generations of jews and christians have learned that even when a prediction comes direct from the ultimate source of authority and truth, it can generate undecidable propositions when turned into a prophecy and made public. People can change the course of history by changing their minds. If innovation is possible, scientists who make predictions must come to terms with *Jonah's law*: that we can only predict the course of history in respect of phenomena humans cannot influence and can only change the course of history if our predictions are irreducibly uncertain and quite possibly meaningless. If the subject / object split holds good or logical constraints on system dynamics are such that we cannot imagine a world where things might be different, you can forget about innovation.

Jonah's law is a serious challenge to the classical, enlightenment approach to prediction and a perennial source of conflict between natural philosophers and humanists. When humanists speak of predictive uncertainty, they don't mean that there is some statistical error on the prediction; they mean it is potentially meaningless because it is contingent on the persistence of mental structures that we expect to be modified or swept away.

As we have seen, many 18th and 19th century natural philosophers believed it was necessary to restrict science to objective categories and logically testable propositions. They disagreed about how best to do this - some thought predictions could be verified scientifically, while others favoured a more agnostic approach. Karl Popper argued that science (by which he meant natural philosophy) should be restricted to empirically falsifiable propositions.

In the second half of the 20th century, scientists began to understand that Jonah's law, though it undermined the philosophical foundations of enlightenment science, was actually an opportunity masquerading as a threat. Socio-natural systems were *complex* - natural science predictions were statistically uncertain and human science predictions potentially meaningless. Robert Rosen gave us some useful terms to describe this; they are *computable* and *uncomputable* complexity. Socio-natural systems are uncomputably complex. Natural philosophy methods for testing predictions were no use in ecology and the human sciences, where Jonah's law applied. The up-side of this is that we are not slaves to natural laws and could conceivably innovate our way out of difficulty. The down-side is that there are no simple solutions to complex problems.

The debates about carbon emissions and global warming illustrate this. Climate change sceptics tend to favour the enlightenment model. The prediction that carbon emissions will raise temperatures, acidify oceans, flood low-lying communities and compromise global commons is 'only a theory'.

There is a difference, in scientific practice, between theory (robust, dependable knowledge) and hypothesis that these critics have clearly ignored, but their message is clear. We should not act on this prediction until it has been thoroughly tested and can be treated as a scientific fact. Those who demand pre-emptive innovation, on the other hand, argue that the sceptics are working with a model of science that belongs to the later 18^{th} or early 19^{th} centuries. Science deals with phenomena, many of which can be modified by negotiating new ways of thinking and acting. We can, and many believe we must, use Jonah's law to change the course of history by triggering innovations now.

But Jonah's law is a recursive structure. If any prediction generates uncertainty when set in the public domain, our innovations may have unforeseen and unwelcome side-effects. These emergent phenomena will require constant management, as a cascade of innovations sweeps old conceptual models aside and creates a new type of future. It is relatively easy to come up with heuristic rules that will allow us to distinguish more from less attractive futures. Attractive futures should be resilient - they should be able to spring back after perturbation. They should be tolerant of diverse beliefs and perspectives and should sustain the *adaptive potential* of human and non-human agents.

By 'adaptive potential', we mean the ability of an agent to choose between two or more attractive courses of action. Consider, for example, a chain of transactions in which X grows beans and sells them to Y, who makes bean salad and sells it to Z. The money flows in one direction and the goods in another. If X likes growing beans, Y likes making salad and Z likes eating it, then there's a net gain of utility all down the line. Everyone makes a little money. Everyone enjoys a measure of adaptive potential.

If, however, X has to sell the beans to service debts, even though the children are hungry, Y feels exploited, making salad all day for a pittance, and Z hates bean salad, but can't afford better, then it doesn't matter how much money is made, this chain of transactions is destroying adaptive potential.

At the time of writing, almost nothing is known about how to manage cultural and natural life-support systems in a way that builds resilience and redistributes adaptive potential. The recursive nature of Jonah's law means that any innovation can be subverted by institutions and individuals, and managed in a way that generates unwelcome and unforeseen side-effects.

§ 28. Epiphany and Innovation

This essay will explore the relationship between epiphanies and innovation. An epiphany, remember, is a rapid cultural shift, often accompanied by a changed sense of identity or institutional affiliation, and always leading to new behaviour. An innovation is new (institutional) knowledge that leads to a change of system dynamics. Innovations and epiphanies are clearly related ideas, though they aren't quite interchangeable. One is an intensely personal experience; the other is collective and vulnerable to institutional veto.

Epiphanies are a little like sex. As we get older we tend to experience them less. Very young men and rather old men may over-state their experience, or make nuisances of themselves by trying to do it more than is seemly. Some people think doing it for fun is wicked. People who think themselves past it find themselves swept along by a cascade of epiphanies when they reach the threshold of old age.

The analogy between epiphany and sex is no accident. Many animals maintain social bonds through ritualised grooming and touching behaviours. In all great apes these rituals are generalised from the pair-bond to other types of interaction. The touching, tasting and smelling of a prospective mate is mirrored in the touching, tasting and smelling of a baby or a parent. The purely reproductive function of courtship becomes generalised to pair-bond maintenance and beyond to friendship and social interaction.

The tactile grooming that maintains social bonds among all great apes is supplemented in our species with a sort of *discursive grooming*. We are the chattering baldape. The higher cognitive functions associated with language and co-operation are intimately connected, through grooming behaviour, to the courtship urge. Science, politics, religion and sex, all use the same bandwidth. That's how it comes about that humans use sexual contact as a weapon, and violence for sexual gratification. That's why we apply words like *intercourse*, *fruitful*, *fertile*, *sterile*, *seminal* and the rest to epiphanies and procreation without loss of generality.

If epiphanies are like sex, a contract researcher who moves from one fixed-term contract to another helping colleagues achieve them is a little like a sex worker. An experienced contractor who manages one project after another is more like a pimp or a brothel-keeper. Even the pattern of status relations between contractors and conventional academics, whether or not they use our services, fit the analogy. At the top end of the business the research manager's job is to create a sense of trust, respect and safety. Everyone makes mistakes and appears vulnerable - not just the clients. Everyone experiences conflicting emotions and many find themselves so far outside their comfort zones that they cannot cope.

The epiphany - the momentous conversion experience that brings new neural pathways on-stream - stands in relation to innovation rather as the sex stands to demography. What starts in private may have public consequences. The climax is the consummation of an extended process of contextualisation that creates new neural pathways and changes human lifeways. Often the substance of those new beliefs is logically unconnected to their public consequences.

Many personal epiphanies are inconsequential. Imagine, for example, a person who drives to work every day, frustrated by traffic congestion. One day s/he is driving up to a junction and sees the traffic jam ahead. Irritated, s/he takes another turning and so discovers a new way of getting to work. That would be an epiphany. However this traffic example would only qualify as an innovation if the driver actually had knock-on effects on traffic dynamics on a larger scale.

Many epiphanies - we suspect the great majority - are inconsequential. In evangelical communities, for example, conversion experiences happen all the time and have almost no knock-on impact on wider system dynamics. An innovation is a cascade of epiphanies that makes a difference.

But what does it mean to say of an event that it 'made a difference'?

The epiphanies that make a difference tend to be those that evade or defy the institutional veto and have unforeseen spin-off effects. Most mundane epiphanies have predictable and institutionally desirable consequences - more converts to the cause, as it were. The ones that change the course of history tend to be more surprising and subversive. Innovators are those whose actions change system dynamics in a time-asymmetric way. The system-flip can be explained *ex post* as part of a narrative chain of events, but could not have been predicted, *ex ante*.

Unsurprising epiphanies propagate conventional knowledge. An individual who suddenly turns on to the mixed economy or conventional, western-style democracy is unlikely to trigger an innovation-cascade in north-west Europe, for example, because these are conventional beliefs. The same experience in a totalitarian state would probably cause the individual to be crushed into conformity. Innovations occur at middling levels of constraint, where the new perception is complex (logically unconnected to previous conceptual models) and a little subversive, but not so threatening as to trigger an institutional backlash.

Innovations seldom start with a simple transfer of information through society. The individual whose perceptions change in a way that allows him/her to develop a new computer operating system, for example, does not broadcast that knowledge, as an evangelist or politician might. S/he acts in a way that creates a new nexus of opportunities and threats. People are irritated by those threats and some grow new neural circuits which, when they come on-stream, exapt them to unprecedented behaviours. The result can be an innovation-cascade that re-organises the social systems in which they are embedded.

By the time people get into knowledge transfer and dissemination, the epiphany is long behind and the innovation almost complete. People are exapted to the new ways of thinking and acting, and the evangelists are preaching to the (almost) converted. This is certainly our experience in respect of the project maps we are describing here. 20 years ago, when one of us began work on the natural history of science, early career researchers and academics were unreceptive and the results were hard to publish. A typical response would be: *how will studying the natural history of science make me a better engineer / archaeologist / biologist?*

Academics were culturally unreceptive to the idea that science was something smart monkeys do. Disciplinary institutions did not want to know. These days, when we teach students how to draw and interpret the maps, they pick the ideas up much more easily. Some still have steep learning curves to climb, but the institutional veto and cultural barriers are weakening.

When innovation-cascades occur, the knowledge that comes on-stream is sometimes new, but more often not. Darwin's plesionic model of evolution, for example, was published in the 1860s. The first journal article to use the word 'co-evolution' appeared in the 1960s. Huxley's ideas about evolutionary saltation were rejected, rehabilitated and rejected again before suddenly becoming fashionable in the 1970s as *punctuated equilibria*. Geologists systematically ignored the empirical evidence of continental drift between the 1920s and the 1960s, when the profession suddenly 'discovered' plate tectonics.

Nascent innovations can be suppressed indefinitely until the institutional veto fails and professional scientists are allowed to 'discover' what students, amateurs and unacknowledged stakeholders have known for decades. What seems to happen is not that one mindset is swept away and another takes its place. Rather, conventional paradigmatic squabbles between insider / outsider factions are discredited and unacknowledged stakeholders are given a hearing.

§ 29. Resilience and the Phoenix Cycle

Innovation-cascades - avalanches of emergence, adaption, exaption, innovation and further emergence - have produced some remarkable phenomena. The student of English literature, for example, may be sustained by taxes derived from the person who makes plastic whistles for Christmas crackers, the priest, the insurance salesman, the banker and the estate agent. The best archaeological evidence suggests that the Pleistocene ancestors of all these people were mobile hunters and gatherers, without a single manufacturer of plastic egg-slicers among them. Human society has passed through so many of these innovation-cascades since the end of the Pleistocene that few of us are now capable of getting our own food, clothes and shelter or, indeed, have any need of these skills.

The archaeological and anthropological literature suggests that the adoption of a sedentary life style, an agricultural subsistence base, and life in large conurbations led to increasing social stratification and craft specialisation. This historical narrative points to a series of critical self-organising events which changed the balance of future probabilities (sedentism, agriculture and conurbation). However, it cannot explain the precise detail of the trajectory that led to our present condition, or the minor differences that distinguish one cultural group from another. Why is alcohol proscribed and cannabis accepted by one group of people and cannabis proscribed and alcohol accepted by another? Why did the Old World 'discover' the New before the New discovered the Old? Why does one community require a bride price to be paid to the parents of a marriageable woman while another requires the parents to give her future husband a dowry? All these questions have answers and each answer refers to seemingly random events or differences between past societies that seem to have exapted them to these traits.

Urban societies depend on institutions that regulate and, in some cases, repress dissident perspectives. Once again the archaeological evidence is quite clear. Although hunter-gatherer societies are capable of vicious cruelty, their smallness limits the conflict levels possible within a social unit. Aggression tends to be confined to the occasional mugging and between-group hostilities.

Subsistence agriculture requires humans to domesticate other species and increases the carrying capacity of some territories. The trick is to jump down two steps in the food-chain and disturb the natural plant succession - clear some scrub or forest. If the ecosystem is resilient (able to spring back) this disturbance will trigger colonisation by opportunists able to exploit the nutrients released by burning and clearance. Many of these are attractive food species and humans can not only predict their location in space and time, but also increase the yield. Humans feed on resilience.

Once you start creating these hunting and gathering opportunities, you produce a landscape that is exapted to agriculture. Unwelcome emergents must be managed, and responding to these challenges exapted these societies to new developments. Herding of sheep, cattle and goats, for example, probably began as a way of keeping them out of gardens. Dogs are domesticated wolves that are fed surplus meat and used to control and defend livestock from predators - including other wolves. Spreading human and animal dung manages a waste product, builds soil fertility and re-distributes seeds and plants across the landscape.

Somewhere along the line, humans found themselves forced to congregate around critical resources - perhaps water for irrigation or arable land - and large urban units developed. Conflict within units became sustainable and super-normal institutions emerged to channel and control it. Urban units need armies, civil administration, leaders and, in many cases, slaves. Some of those slaves would have been horses and cattle; others would have been people. The great urban civilizations of antiquity were all slave-owning states in which one group of people domesticated others.

When expressed in these emotive terms, urban civilization seems to be a monstrous thing - a destroyer of rights, both human and animal - but socio-natural systems evolve and things are not now as they once were. The sheep have heavy fleeces they cannot shed for themselves. Cattle produce enough milk to drown a calf and bellow with impatience if the dairyman comes late to work. Healthy, well tended horses come frisking from the stable. Craftsmen think themselves free and delight in their skills.

There is no longer enough room for us all to be hunters and gatherers. Subsistence agriculture is unremitting grind, working 60 or 70 hours a week for bread, cheese and salt meat. How many would willingly put the clock back? We have to move forward, even though doing so creates phoenix cycles of conflict, emergence, intensification, institutional collapse, innovation and recovery.

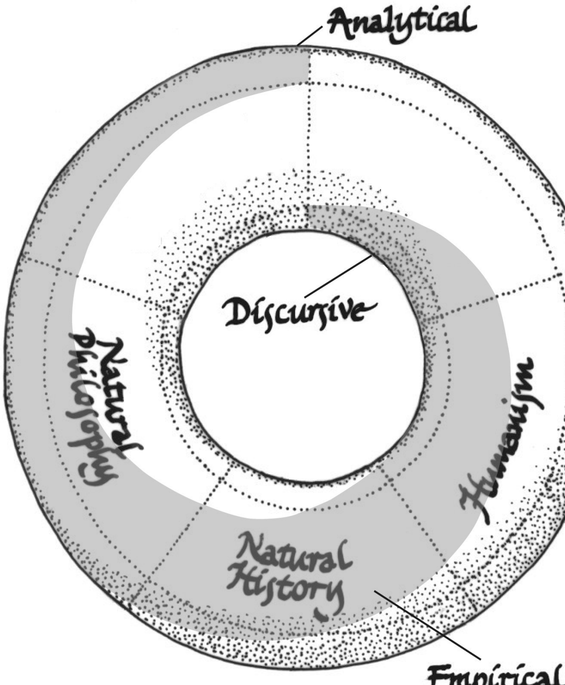
Many people over 50, at least in northwest Europe, will have the impression of a ragged boom-bust cycle with a period of 20-25 years. It is possible that this figure is a by-product of the human life-cycle. Perhaps some demographic succession is required to transfer control from the old to the young. Certainly, some generations of young people seem to have been born to be impoverished, or sent to war by the old, while others grow up in periods of glasnost and perestroika and set the world on its head.

Historical analysis has led some to suggest that there is a longer cycle (sometimes called the *Kondratiev* cycle) with a period of 50 years. There may also be a 200-year, deep cycle, in which the first century is given to exploration and the second to consolidation, with a great crash at the end. The Romanist Chris Going believed such *long waves* could be found in the Roman Empire. We are not competent to comment on this, but the model works fairly well in the post-mediaeval west.

The early modern cycle occupied much of the 15th and 16th centuries. The renaissance of the 16th century was a time of vicious cruelty and religious war. The later modern period (17th and 18th centuries) saw the enlightenment collapse in conflict and proletarian revolution. The neo-modern reforms of the 19th century culminated in a plesionic revolution in the 20th, which bears comparison with the achievements of the enlightenment and renaissance. These developments were accompanied by vicious wars, proletarian revolutions and inequitable trade patterns that killed on a genocidal scale and entrained planetary life-support systems.

Intellectual arguments about whether these long waves are real or figments of the imagination are primarily of academic interest. What matters from a research manager's perspective is that short cycles of boom and bust are well-documented and the collateral damage that goes with long waves becomes more severe with each cycle. The scale of human suffering, both among casualties of war and among those who live miserable, truncated lives because of inequitable trade and institutional repression is terrible, but more alarming still is the mass of evidence that planetary life-support systems are imperilled. Global commons like great forests, river catchments and ocean ecosystems are fast approaching their resilience-thresholds, while institutions continue to use plausible deniability to protect their own interests.

There are no simple solutions to complex problems, so we will not insult you by suggesting one now. What concerns us here is the effect these phoenix cycles have on the relationship between science and society. Recall that humanists tend to be interested in the relationship between self and other in arena; naturalists focus on arena and empirical evidence, and natural philosophers work on the relationship between arena and universe. Each of the three great disciplines specialises in one of the three types of judgement, with a supplementary interest in at least one of the others. Humanists, with their combination of discursive and empirical skills, tend to be good at analysing values. Natural philosophers specialise in method, particularly analytical method. Both humanists and natural philosophers have a secondary interest in empirical method and these disciplines intersect in the middle range of natural history.



In periods of geo-political or economic conflict, the abstract, culturally embedded knowledge of political institutions and professional experts must be protected from empirical refutation. In some of these conflict periods, naturalists were actively persecuted. Over the last two centuries, however, they have tended to be marginalised as fussy amateurs and stamp-collectors. Humanistic and ethical critique can be an inconvenience too and humanists are either repressed or isolated from the serious business of managing institutions. This drives science up the sides of the torus, separating the humanities from natural philosophy.

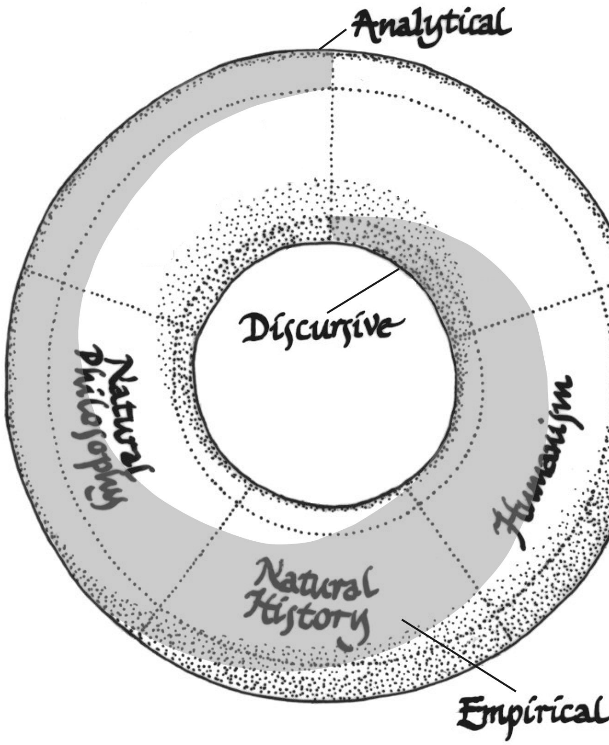
As conflict builds, the mainstream sciences become concentrated in the top half of the doughnut. If the institutional veto holds firm, conflict levels will increase and science is driven towards the gnostic trap, with technocratic and romantic gnostics locked in paradigmatic conflict. When institutions collapse, the constraints that hold scientists near the top of the torus evaporate. Gnostics are discredited and a new generation comes into power that is altogether more relaxed about cultural diversity. Ironically, natural scientists and humanists often blame each other for this cycle, as though they could have prevented the Holocaust by telling Mr Hitler to play nicely or go away.

Individual scientists are a little like loose hairs on the mad dog that is the geo-political conjuncture. Some of us drop out and are sucked into the vacuum-cleaner of posterity. Some hang on and are damned or feted with the rest of our generation. Individual scientists may shape the course of events, as Einstein influenced the course of World War II, but these individual impacts are emergent phenomena. Had Einstein never been born, the small history of events would have been different, but it is not clear what the conjunctural upshot of those differences would be.

Our ability to innovate evolved in a way that influenced social systems on a human scale, but the emergent institutions these create have entrained planetary life-support systems. Individual people do not cause global change any more than individual raindrops cause double-arched rainbows. We have to deal with a pattern created by natural oscillations in an institutional constraint-field through which many cohorts of scientists have flowed.

§ 30. Deconstructing the Torus Map

Let us look again at the torus model of science:



Here we have the whole torus 'pumped up', as it were, with the three great scientific disciplines near the bottom, the gnostic trap at the top and the diagonal stripe passing from analytical method, through empirical and on to discursive.

But the torus didn't always look like that. In later mediaeval Europe, for example, natural philosophy was shrivelled almost to nothing. Natural history was so weak it had become a pretext for copying old bestiaries and floras. Humanism only existed as a dissident perspective, ruthlessly repressed by powerful institutions.

The big focus of 'scientific' endeavour was on either side of the gnostic trap, as theologians argued about whether believing humans had free will was a blasphemous challenge to the omnipotence of god. No mediaeval scholar could possibly have known what science would look like after the humanistic sector had been pumped up and scholars could discuss the idea that humans and their god-agent were co-creators of natural phenomena.

In the course of the 16th century, empirical research on planetary motion laid the foundations of later-modern natural philosophy. Yet another sector of the torus was pumped up. Humanism had been based on an Aristotelian, open-universe model, but natural philosophers revisited the rational realism of mediaeval ancients and Platonists. By the end of the enlightenment period, natural historians could no longer ignore complaints that they were missing out on a scientific revolution. Natural history broke free of institutional control, relaxed its Aristotelian scruples and began to think about system dynamics. Inevitably, some of these evolutionists became moderate gnostics.

The paradigmatic squabbles that developed in the 19th and 20th centuries reversed the polarity of those between humanists and religious gnostics. Where mediaeval gnostics had attacked humanists for downgrading god by acknowledging human creativity, some neo-modern evolutionists argued that allowing biological organisms to be agents would legitimise god-explanations by undermining the subject / object split. Biology could only be 'science' if animals were machines. Scientists, of course, possessed the super-natural gift of gnostic enlightenment that gave them a god-like overview of things as they really were. By the early 20th century, technocrats were colonising the superstitious niches that had formerly been occupied by gnostic theocrats.

Before we leave this topic, it seems worthwhile to speak about the intellectual process that brought the torus-map into being. After a decade or more of research on the anthropology of science, one of us had concluded that space-time disparities between disciplines were fundamental. Compare, for example, the science of cosmology (universal scale, time-perspective in billions of years) with palaeontology (continental scale, a few hundred millions) or archaeology (a few thousands or tens of thousands) and social anthropology (a few months or years). It seemed unlikely that the same mapping conventions could be up-scaled and down-scaled across this range.

By the time the second writer had become involved in the work, these project-maps were already coming together and we were looking for a way to explain that a plesionic system was not the same as a biological organism. A plesionic system is an emergent by-product of purpose, role-play and contextualised knowledge. As we worked together to refine the maps and test them through teaching and dissemination actions, we hit a barrier of our own.

We knew (intellectually) that the maps only worked insofar as they were applied to closed research projects and role-play, but the itch to generalise proved almost irresistible in practice. We found ourselves speaking of natural history (an abstract attribute of a research project) and natural historians (a category of researcher) *as if they were the same thing*. We also spoke of institutions, organisms and plesionic systems *as if they were the same thing*.

Intellectually, we were aware that humanism is an attribute of a project and a humanist is a type of person, but habits of language, thought and culture kept pushing the distinction aside. We would find ourselves using maps of projects as if they were maps of science as a whole, even though we knew that they weren't. It required a small, conscious effort to restrain that impulse until the closing section of this book.

§ 31. Space-Time - an Integrating Concept

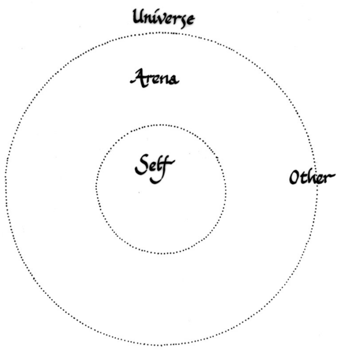
The torus-diagram is a good way of thinking about a project, both intellectually and operationally. As a way of thinking about science as a whole, however, it is an *ex post* rationalisation. It has its operational merits, of course, helping us think and speak about a sequence of astonishing innovation-cascades with the wisdom of hindsight, but as a description of the way science evolved, it is anachronistic. It maps our knowledge and beliefs onto periods of history when people couldn't possibly have thought this way.

Each of those innovation-cascades started with small conceptual re-adjustments that evaded the institutional veto, either because institutions were weak or because they were able to co-exist with the new ways of doing business. These new ways of thinking and perceiving the world exapted societies to yet more innovations that may have threatened some established institutions, challenged culturally embedded beliefs and created new opportunities. Small numbers of scientists actually changed the course of history by changing their minds and they did so without knowing where science was going.

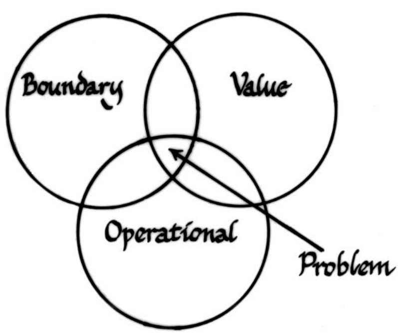
The analogy between innovation and evolution is so powerful, we felt impelled to explore it. Those ancestral reptiles hopping from branch to branch weren't trying to be birds, but they were agents - purposeful, anticipatory systems capable of learning and forgetting. This striving created populated neighbourhoods that were exapted to life in an unprecedented ecosystem. Had those reptiles been trying to burrow in leaf-mould, for example, their descendants would never have evolved wings.

The torus is only one of the mapping conventions we have used to represent the phenomenological 'space' that project-based science explores. The other maps developed included the plesionic map, which consists of a 'self' embedded in an arena containing others. Since 'other' can appear and disappear from arena, we infer the existence of some larger interval of space-time (universe).

The torus and the plesionic map seem to be related, in the sense that humanism (right side of torus) deals primarily with self-other relations near the centre of those concentric circles. Natural history (bottom of torus) is largely focussed on arena and natural philosophy (left side of torus) works on the arena / universe interaction, bringing you closer to the edge of the plesionic map. The gnostic trap near the top of the torus is where the romantic and classic extremists slug it out about universals and the social construction of reality.



The semantic triangle flattens as you move away from natural history towards humanism or natural philosophy. This flattening describes an auto-correlation between both of these maps and the map of boundary, value and operational judgements that represents a scientific 'self'.



This third map, which generalises ideas borrowed from many system theorists, notable among them Kenneth Boulding, C West Churchman and Geoffrey Vickers, was originally developed as a tool for brainstorming research projects, but it is consilient with the other two maps. Natural historians specialise in empirical method and boundary judgements; humanists in discursive method and value judgements and natural philosophers in analytic method and operational judgements.

Scientists, as they move round the torus from romantic to classic science, pass from the centre of the plesionic diagram and small history to the universal. It might seem obvious, then, that there is a time-trend from the very short-term to the very long. In practice, however, this is not so.

The left hand side of the torus (natural philosophy) works with more or less time-symmetric systems and *ex ante* prediction. The right hand-side deals with humanistic systems and *ex post* explanation. One looks forward, the other backwards. At the bottom of the torus we have the heartlands of natural history, where the focus is on stable classification and morphology. This gives natural history its characteristic deep-time perspective.

As you move from natural history clockwise into natural philosophy, your time-perspective actually shortens because processes operate on a shorter time-perspective than stable categories. Natural philosophy requires us to deal with the medium-scale and synergetic conjunctures created by many agents interacting with each other. Continue clockwise and your approach becomes more gnostic and universal. Time perspectives must increase again, this time beyond anything possible using empirical method alone.

Working on this scale forces the scientist to think about qualitative changes and system-flips, which tend to be modelled in terms of large-scale *perturbations* - natural catastrophes that drive the dinosaurs to extinction, say, or wipe great civilizations out. Continue round and as you approach the gnostic trap, your models become more universal, abstract and timeless.

Now return to natural history and travel counter-clockwise. As you do, your focus shifts from the deep-time perspective into broad narratives about nation states, large institutions and processes and on into the small history of events and happenstance. Again, your time-perspective shrinks. By the time you approach the gnostic trap, you are naturally drawn to key events, choices and agency. There are system-flips at this point on the torus too, but now your conceptual model becomes more introspective, personal and romantic. You have to deal with personal epiphanies not great perturbations. Near the top of the torus, there are no processes - just populations of unique agents, each acting and interacting with its neighbours and becoming entrained in stories.

The project cycle we described earlier exploits this space-time auto-correlation. Humanists are interested in social exclusion, reflexive method and multi-vocality. They are specialists in opening problem-domains up. Natural historians use empirical methods, negotiate stable taxonomies and specialise in closing down actions. Natural philosophers are expert problem-solvers who specialise in the use of analytical method.

There is a great deal of leakage and movement between territories, of course, but this auto-correlation between method and space-time perspective creates a striking pattern that can be used to speak about the morphology and physiology of science and to develop protocols for managing science-based innovation. The pattern can even be used to make limited predictions about the future evolution of science. We will attempt this in our closing essay.

§ 32. Whither 'Post-Modern' Science?

We would like to close by setting our backs to the past and looking forward. One of the natural questions to ask is: *what will science look like over the next 200 years?* Thomas Kuhn's research has suggested that the seeds of a paradigmatic revolution are usually sown before the revolution has occurred. Our exploration of time-asymmetry bears this out. If there were no historical continuity, it would not be possible to explain scientific revolutions *ex post*. Since it is possible to do this, we may speculate that neo-modern science is already exapted to the 'post-modern revolution' - whatever that phrase comes to represent.

Jonah's law will probably come into play as post-modern science is shaped and re-shaped by changes in human understanding. People will predict the future on the basis of present knowledge and so change the course of history, generating cascades of spin-off innovations that will change human understanding again and trigger further change. The best we can do by way of prediction is to look for the fragments of irritating grit around which the pearls of post-modern science are most likely to form.

In his book about consilience, Edward O Wilson summarised the legacy of the enlightenment as the belief that *entirely on our own we can know, and in knowing, understand, and in understanding, choose wisely*. We don't need experts to tell us what to believe, or monarchs to rule over us by the grace of some divine fascist; our species is well named *Homo sapiens* - Human (wise). We can find our own path. It was once fashionable, among neophyte humanists, to link this enlightenment ideal to 'modernity' and dismiss both, somewhat bafflingly, as hegemonic.

Wilson explored the hegemonic charge in his book. Like many scientists - including us - he is dismayed by the evidence that the enlightenment, far from making men wiser and more forgiving, culminated in a period of repression and chaos that brought science into disrepute. 19th and early 20th century attempts to develop a universal method that would immunise science against this disease did not succeed, as the social science wars of the 20th century amply demonstrate.

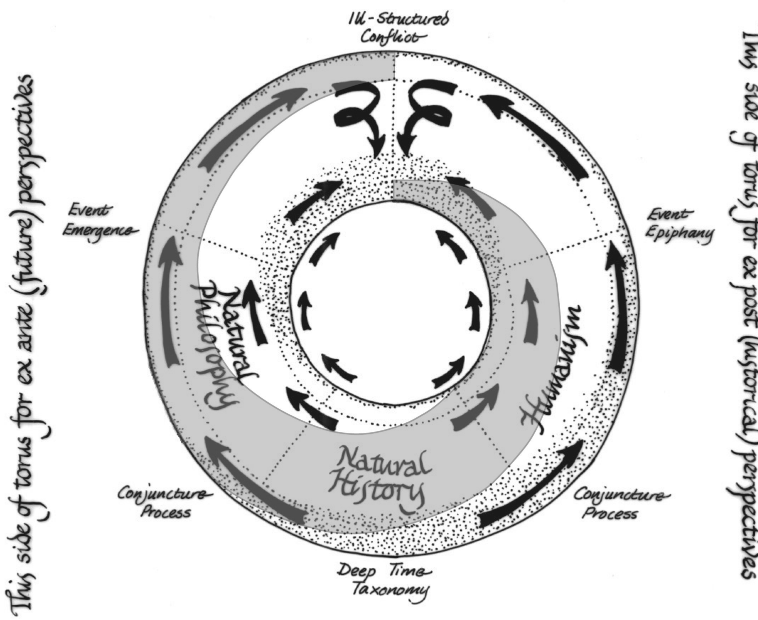
Humanists looking for the flaw in the enlightenment ideal might observe that knowledge is created socially. We can hardly be said to know anything '*entirely by ourselves*'. That is undoubtedly true, but it is hard to see how enlightenment freedom can be blamed for the manifest evils of scientific imperialism. If you were looking for a genuinely dangerous idea, a better option might be to start with the assumption that understanding (intellectual truth) and choosing wisely go together. They don't.

Powerful institutions have a great deal of capital invested in this equation of intellectual truth with wisdom. Some scientists, for example, have become convinced that human carbon emissions are causing patterns of global warming that are melting ice-caps, turning semi-arid lands into deserts and acidifying seas. They have become locked into paradigmatic stand-off with climate-change sceptics and religious gnostics. If those scientists were to declare themselves agnostic, their adversaries would sweep the board. These scientists and their opponents have too much capital invested in the paradigmatic stand-off to 'fess up' and admit that they don't know a thing about the system as it really is and would probably screw it up just as badly if they did.

The hypothesis that understanding goes with wise choices became culturally embedded in western scientists. It ceased to be hypothesis and became *theory* - a robust platform for action - in the later 18th century. Politicians have reinforced that theory with powerful institutional vetoes, including US constitutional law, that make it seem almost wicked to challenge the enlightenment ideal.

We can be reasonably confident that institutions in the west will continue to use science as a tool for policy development; will continue to stumble on the problems of emergence and cultural embedding from time to time, and will toughen institutional vetoes when conflicts of interest arise and will justify that constraint with appeals to the link between intellectual knowledge and choosing wisely.

Under that assumption we can put some physiological detail on the torus- map. We will draw it for you first, using ideas about space-time perspectives developed in this section before talking you through:



Onto the torus we have overlain dark arrows that represent the synergetic field created by cultural embedding and the phoenix cycle. The agnostic region near the bottom is only accessible in the periods of glasnost and perestroika that follow a system-crash. Empirical evidence that had hitherto been vetoed is now taken seriously and a bridge opens between natural philosophy and humanism. Institutions must deal with emergents by vetoing evidence which challenges critical knowledge. Those vetoes marginalise natural historians by downgrading empirical science until humanism and natural philosophy become unconnected.

As institutional vetoes harden, science is pushed up towards the gnostic regions near the top. Humanism and natural philosophy become harder to integrate. Paradigmatic debates open up between classic and romantic gnostics that remain unresolved until institutions collapse or are so weakened that an innovation-cascade occurs.

That phoenix cycle describes, at a first level of approximation, the way the science-doughnut is populated at different phases in the inter-generational boom/bust cycles (more or less 25 years). It also works for the 50-year Kondratiev cycle and, with a little special pleading to selectively 'deflate' some segments of the torus, it even works for the 200-year long-wave cycles that gave us the renaissance, the enlightenment and the plesionic revolution. Each of those long-wave cycles caused more collateral damage than the one before. The next cycle, if we don't innovate in a way that changes the course of history, may damage planetary life-support systems beyond recovery.

If complex urban societies survive that catastrophe, what will the new innovation-cascade do to science? Will we learn to integrate the three great disciplines? Will we learn to innovate pre-emptively in a way that breaks the phoenix cycle before institutions take us to war? Perhaps, like ants and bees, the survivors will be more machine-like and so less inclined to de-stabilise natural life-support systems by generating and exploiting emergents? We do not know.

The only thing we can say with confidence is that 21st century sciences probably won't look like that doughnut. Post-modern science will require a qualitatively new type of map, constructed using qualitatively new mapping conventions and quite possibly drawn from a different space-time perspective. Those maps will subsume ours *ex post* as imperfect approximations to an emergent knowledge-system.

People

This book has referred to three overlapping groups of people. The smallest group contains scientists whose work seems to have been unprecedented and innovative. Natural history deals with generalities and the unprecedented only becomes significant when it spins off an emergent species of thing or action. Charles Darwin belongs to this group. Much had been written about evolution, competition and even about natural selection before *Origin* hit the presses, but none of that work tried to build agency, co-operation and plesionic interaction into biology. The 17th century surgeon William Harvey, whose work on epigenesis and circulation anticipated 19th century developments in evolution and physiology also belongs here.

The second group contains scientists whose work found strong institutional support and so became key figures in paradigmatic debates. Alfred Russel Wallace and Herbert Spencer, for example, had much more influence on early 20th century evolutionary theory than Darwin. Martin Luther had more influence on renaissance institutions than the mediaeval 'moderns' whose work he abominated. Bertalanffy's General System Theory found more favour with Cold War technocrats than Boulding's. Dawkins' gnostic atheism§ eclipsed Huxley's agnostic approach in the later 20th century. Whether you agree or disagree with them, these scientists are historically significant because they, and the mythic histories woven round them represent institutional perspectives.

The third and largest group contains scientists whose work directly influenced our own. We respectfully disagree with these on some points - for example with Alfred Russel Wallace on the inexorability of natural selection and the logical necessity of a god-agent, with Charles Darwin on *non facit saltum*, with Karl Popper on his definition of science, and Edward O Wilson on the relationship between sociobiology and Darwinian anthropology - but we gratefully acknowledge our intellectual debts to them.

ABOUT THIS BOOK

In recent years there have been growing demands for research skills tuition and guidance on the management of research projects. We have responded to this demand by teaching people to draw maps of research projects.

A map of a project is not a map of science as a whole. A project is a closed programme of work with a start-date, an end-date and one or more deliverables. An undergraduate dissertation would have a staff of 2 (student and supervisor). A multi-million international project may involve 100 or so. You can use the same mapping conventions at both ends of the scale.

Our project maps were designed to be used 'cold' – you need not study the behavioural ecology of science to put them to work. However, some of the people we taught came back to ask for background information. Here it is.

Scientific research is usually more profitable if you market it as a source of enlightened wisdom, but inter-disciplinary projects are easier to manage if you accept that science, like warfare, courtship, politics and religion, is a biological phenomenon. There is a natural division of labour among scientists, with a clear correlation between method and space-time perspective.

Different types of scientist respond differently to similar circumstances and prosper under different conditions. They will usually try to re-create those conditions within a project, producing a competitive dynamic that must be managed. Political and institutional constraints can intensify that conflict. This book is to help you understand and manage the behavioural ecology of project-based science.

HUMAN NATURE SERIES