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An agnostic approach to ancient landscapes: conversations about the cultural anthropology of archaeological research

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ABSTRACT

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We argue that the phenomenological or 'agnostic' approach to evolutionary systems advocated by Thomas Henry Huxley is applicable in anthropological archaeology and show how agnosticism helps defuse the tension between humanists, natural philosophers and natural historians in integrative research. We deploy problem-framing methods from policy-relevant research in a palaeoanthropological context, developing a model of complex (scale-dependent, irreversible) causality and applying it to the problem of human-landscape interaction and primate foot anatomy. We illustrate this process with a single iteration of the 'project cycle' focussed on human-landscape interaction. Modern humans are co-operative resilience feeders, exploiting complex causality by perturbing stable, unproductive landscapes and feeding on the fluxes of energy and resources released as they spring back. Is it possible that this resilience-feeding is older than *Homo sapiens*?

KEYWORDS: Agnostic, landscape, hominin, palaeoanthropology, phenomenology, project cycle.

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Positioning Statement

This paper is the product of a series of discussions that took place in April 2011 between a palaeoanthropologist who was writing a doctoral dissertation on primate foot anatomy and landscape, and an applied anthropologist working on the social and ecological impacts of environmental policy. The difference between us is that between an older naturalist working on the *ex ante* prediction and management of socio-natural systems and a younger naturalist working on *ex post* explanation in anthropology. We are also father and daughter. We share an interest in the co-evolutionary approach to natural history epitomised by Charles Darwin, and in the phenomenological approach to science that Thomas Henry Huxley (1884) described as *agnostic.*

An agnostic is one who believes that *gnosis* - dependable knowledge of some universal reality - is not something great apes need worry about. The popular view of an agnostic as a faint-hearted atheist is erroneous. Huxley wrote that:

> '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.'

Viewed on a micro-scale, the gnostic / agnostic tension is a philosophical issue. The theoretical physicist who believes the great architect of the universe

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is a mathematician and the mystic who believes the creator has strong opinions about whether great apes should eat sausages are making purely personal statements of belief. However, when we step back to view the meso-scale of the geo-political conjuncture, it becomes clear that this phenomenon is linked to phoenix cycles of conflict and renaissance. In periods of conflict the agnostic perspective is subject to an institutional veto that maintains social cohesion. Those vetoes are softened in the periods of glasnost and perestroika that follow system collapse. Darwin and Huxley came to prominence in the 1860s, just such a period. One of us grew up in the 1950s and 60s - a period when the institutional veto was softened - the other grew up in the 80s and 90s, when the institutional veto was hardening again.

Philosophy, by this conception, is a biological phenomenon, a cultural and behavioural polymorphism that influences patterns of social interaction among our species. Just as social insects kill feeble queens and eject males with the onset of winter so our species kills or suppresses agnostic predispositions in periods of co-evolutionary stress and tolerates them again in periods of recovery.

The concept of a cultural polymorphism is significant because it suggests the existence of an ideational convergence that transcends scholarly lineages and semantic conventions. What we call 'agnosticism' has at various times been referred to as the '*via moderna*' (modern way), humanism, nominalism, scepticism, sophism, phenomenology, modernism, post-modernism and so on. Each of these terms has suffered a form of semantic degradation as institutional vetoes re-wrote history to push them beyond the pale. It suggests a complex, intuitionist approach to phenomenology whereby humans are born unable to communicate, but have evolved an innate predisposition to expect the world to contain communicators. That cognitive intuition becomes manifest as an innate aesthetic sense that guides us towards circumstances in which we are likely to thrive. These intuitive aesthetics have shaped and been shaped by the ecologies explored by our distant ancestors, by the cultural and ecological milieu into which we are born and by the domino-chains of experience that shape us as individuals (Poincaré 1908; Bateson1979). It implies that perceptual phenomena are the products of a co-dynamic interaction between innate ('genetic') and acquired ('epigenetic') experience.

That co-dynamic relationship changes as individual humans develop; as cultural ecologies cycle and species evolve. Our perceptual competence is not that of some ancestral chimpanzee and future generations of humans will probably perceive the universe differently too. Our paper can be thought of as a contribution to anthropology on three levels. First, it is a contribution to the natural history of primates and the emergence of the genus *Homo*. Second, it is a contribution to the *ecodynamics* (Boulding 1978) of co-evolutionary science. The word 'ecodynamics' is intended to give the impression that ecology and economy are different ways of thinking about the same type of phenomenon. Finally, it can be thought of more humanistically, as a contribution to the social anthropology of trans-disciplinary research.

We have no wish to suggest that one of these perspectives is inherently better or more realistic than the others. Rather, we would argue that each of these realities corresponds to a different set of purposes, intuitive aesthetics and space-time scales. Humanists, for example, can reasonably speak of a socially constructed or discursive reality. Natural scientists, on the other hand, often think of reality as that which is independent of human knowledge and belief and can be accessed analytically. From a natural history perspective, however, reality is the product of a co-dynamic interaction of genetic and epigenetic factors that occurs on a range of space-time scales. Reality is that which we find ourselves unable to disbelieve, a more empirical concept. The narrative scale of small history and personal experience is ecologically significant, of course, but agnosticism also implies a deep-time process that takes account of evolutionary change and a meso-scale process shaped by culturally embedded habits and norms.

Different space-time scales and purposes call for different combinations of these three realities (discursive, analytic and empirical) and many of the disagreements between academic disciplines can be understood in these terms. Paul Feyerabend (1973), for example, is quite right to say that scientific knowledge creation is qualitatively indistinguishable from other cultural activities, but clearly wrong to suggest that, in science, *anything goes*. Science is constrained by our innate rationality, by the empirical evidence that presents to us and by socially constructed values and structured behaviours. Our love of archaeology, systems analysis or fine art is part innate and part acquired. The innate part has been honed into approximate convergence with the sort of ecosystems humans create and colonise. That melding of innate and acquired competence makes the natural history of science a fascinating and useful field of research. Many early career researchers, when they design research projects, turn to the history and philosophy of archaeological ideas which, though it makes an interesting narrative, does little to explain the causal mechanisms that kept so many of the neo-modern sciences on parallel paths. By studying the adaptive dimension of scientific behaviour we not only improve our understanding of our own species, we strengthen our own research designs.

This approach requires us to develop a coherent terminology for describing space-time perspective. Like many disciplines, anthropological archaeology has some 'home grown' attempts to do this. Compare, for example, Bailey (2008) with Faber and Proops (1993) in economics, or Liljenström and Svedin (2006) in systems analysis. The most widely used schema known to us is that of *Annales* historiography, summarised for archaeologists by contributors to Bintliff (1991) and Knapp (1992). First, we have to distinguish between landscape time and experiential time, which Henri Bergson (1907) referred to as *durée*. Half an hour in the dentist's waiting room and half an hour asleep may be chronologically equivalent, but our experience of them may be very different. Secondly, we have to distinguish three types of *durée*. First, there is the narrative chain of 'event-time' and small history; then there is the meso-scale time - the synergetic 'conjuncture', and finally there is the deep-time perspective or *longue durée*. These three types of time are not 'out there' in the universe; they are brought into being, as it were, by a sort of cognitive friction between the individual and its ecodynamic milieu.

The deep-time perspective is used to create a grand- or meta-narrative and a conceptual taxonomy that is almost time-invariant. Different study-domains have different deep-time scales, of course, but every study-domain has a conceptual taxonomy and grand narrative. Conceptual taxonomies are never truly universal; they may be swept away or abandoned as societies and circumstances change. This time-asymmetry is reflected at the micro-scale of event time. Narrative chains can often be explained *ex post*, but can seldom be predicted, *ex ante*. Time-symmetry only becomes manifest on the meso-scale of the synergetic conjuncture, when the immediate past provides a reasonable guide to the immediate future. In archaeology, for example, the culture-history approach epitomised by Childe (1925) was explicitly directed towards the deep-time perspective and an evolutionary metanarrative. The processual approach of 1960s and 70s system theory, on the other hand shifted attention towards the conjunctural level and the post-processual antithesis is more inclined to emphasis the small history of event-times and the social construction of grand narratives and conceptual taxonomies.

The three putative revolutions of 20th century archaeology - culture history, culture process and the post-modern approach to archaeology as small history - can reasonably be thought of as a re-adjustment of space-time scale from deep time to conjuncture to event. The central hypothesis of this paper, then, is that every case-study in anthropological archaeology implies at least three space-time perspectives. The tension between different disciplinary communities reflects the values and intuitive aesthetics of practitioners. Natural historians, for example, often focus on deep-time processes, locally stable conceptual taxonomies and the evolutionary meta-narratives that create them and sweep them away. The humanistic approach tends to focus on agency, purposeful action and time asymmetry. The natural science - perhaps a better term would be 'natural philosophy' - approach tends to treat conceptual taxonomies as quasi-universal and focus on time-symmetric processes, formal cause and prediction. Each of these great disciplinary communities operates on a different set of space-time scales and develops a characteristic range of approaches to 'reality'.

By the end of the 20th century the principal focus of agnostic socio-natural science was in study domains where the conflicting demands of cultural and natural life-support systems must be reconciled. Kenneth Boulding (1978) described this focus as 'ecodynamic'. It treats ecology and economy as different ways of thinking about the same sort of thing. Ecodynamic research is always policy-relevant and usually directed towards *innovation*, a change of perception that changes system dynamics (Winder 2007). Few practitioners in these fields refer to themselves as agnostics (evolutionary phenomenologists) and this sort of research has many names. A word one hears commonly is *integrative*. Integrative research must manage conflicts of belief and interest without engineering an over-arching consensus. It does this by creating a temporary alliance - a *project* - with a start-date, an end-date and one or more well-defined deliverables. Integrative projects are governed by Jonah's law: we can only change the course of history in respect of 'realities' human societies can influence and can only predict the course of history in respect of 'realities' we cannot change. In order to innovate, then, researchers must integrate a spectrum of realities, each with its own space-time signature, conceptual taxonomy, methods and values. This work calls for an effort of conflict management that gives research projects a characteristic space-time structure we call the *project cycle*.

Science and co-evolutionary stress: a potted history of integrative research

The word 'science' is ancient, but 'scientist' was coined in the 1830s and became part of an innovation-cascade that marked the transition from later modern to neo-modern Europe. The French Revolution polarised Europe into conservative and reforming factions and generated a power-struggle that lasted through the Napoleonic wars and into the deep recession that followed them. However the many failed uprisings of 1848 weakened conservative resistance, just as the uprisings of 2011 have weakened conservative regimes in the Arab World. The result was an innovation-cascade that consolidated earlier reforms and established new nation-states. Post-revolutionary Europe experienced a programme of imperial expansion that sustained democratic and educational reforms at home. Our system of universal suffrage and popular education is the product of that innovation-cascade. The older disciplines of natural history, natural philosophy and humanism were transformed into an array of neo-modern sciences with Greek names. Biology, ethnology, archaeology, chemistry, anthropology and sociology all made the transition from aspiration to profession in the first half of the 19th century. The older disciplinary traditions did not disappear, of course, and intellectuals struggled to decide what these new 'sciences' would become. Karl Marx and Sir Herbert Spencer became the figureheads of militant social science in the 20th century, particularly in polities drawn into a co-evolutionary maelstrom as the actions of one population influenced patterns of survivorship and fitness among others. This conjunctural friction polarised international relations, forcing stable polities to veto the 'wrong' sort of science, particularly the sort of science that challenged conceptual taxonomies or disrupted the political process.

Viewed from this conjunctural perspective, individual scientists provide human interest and narrative colour and may occasionally play a pivotal role in the domino-chain of events, but these narratives, though they explain and illuminate the historical evidence, do not constitute a causal mechanism. Narrative and cause have different space-time perspectives. Efficient cause comes into focus at the meso-level of the synergetic conjuncture - it is processual. Purposeful agency belongs to small history. It cannot be explained processually. In 20th century archaeology, for example, one can see a clear tension between 'romantic' humanism and the 'classic' natural philosophy approaches in periods of geo-political conflict and economic slump and an agnostic renaissance in the periods of glasnost and perestroika following geo-political catastrophes. The 1920s and 1960s, for example, corresponded to two periods of disciplinary re-integration. These reforms were strengthened by policies intended to promote political stability and economic growth through peacetime applications of defensive technology (air photography and cybernetic systems, for example). The reforms were halted or even reversed in periods of economic recession and conflict - the 1930s, say, or the 1980s. The ecodynamics of neo-modern science have been shaped by phoenix cycles of co-evolutionary stress and the institutional vetoes they impose as the agnostic model is suppressed and later rehabilitated when peace breaks out and social mobility is freed up.

Section 1: an example from palaeoanthropology

We begin by distinguishing two types of complex system. A metastable system is one that is capable of rapid, 'non-linear' system-flips. Many natural systems, including human activity systems, are metastable, but some social systems are also *innovative*. System dynamics are shaped by culturally embedded beliefs and behaviours that underpin the established causal structure. We can predict what will happen within the current conjunctural cycle because we know how a given system works. We can also explain what happened in past cycles, because our *ex post* knowledge covers those possibilities too. However we cannot predict beyond the end of the next system flip because the new causal mechanism is underpinned by knowledge we have not yet acquired and embedded behaviours we have not yet imagined. We therefore define an *innovation* as a change in perception that leads to a change in system dynamics (Winder 2007). The capacity for innovation gives ecodynamic systems their characteristic time-asymmetry. We can explain their behaviour *ex post* but cannot predict it, *ex ante*.

Innovation is potentially subversive and one of the principal effects of political regulation is to create an institutional veto on certain ways of seeing and thinking that marginalises innovators whose work challenges the *status quo*. Evolutionary theory, for example, was ill-conceived gutter science in the late 18th and early 19th centuries when polities in north-west Europe were trying to suppress calls for political reform. This veto collapsed in the aftermath of the 'Birth of Nations' revolutions in 1848 and from the 1860s onward, evolutionary theory was practically an establishment view. By the later 19th century, however, European polities were becoming more repressive. Darwin-Huxley agnosticism had become a political liability and a more gnostic, natural philosophy approach was required. The certainties of political Marxism and social Darwinism suited the needs of powerful institutions rather better than the subversive time-asymmetry of agnostic science.

Innovative systems are an order of magnitude more complex than those which are merely metastable. In a metastable system, predictions are statistically uncertain - we cannot be certain that the caterpillar will become a butterfly - but the space of future possibilities is constrained, *ex ante* and predictions are possible on the balance of probabilities. In an innovative system, however, predictions are simply meaningless because conceptual taxonomies are modified and hardened by the institutional veto and then swept away as institutions are reformed and new ways of thinking and acting are explored. This time-asymmetry is at once an obstacle to policy-relevant research and an opportunity to change the course of history by changing the way we think about social systems.

We can sometimes reduce the complexity of ecodynamic research by focussing attention on extinct ecodynamic systems. This *ex post* perspective allows us to treat a potentially innovative system as if it were merely metastable. We can bound the possibility space it was exploring and develop a range of explanatory theories that could not possibly have been specified *ex ante*. In this section, for example, we will concentrate on Plio-Pleistocene systems and the ecodynamics of non-human and proto-human primates. Like many of the other socio-natural sciences, palaeoanthropology has its origins in the middle of the 19th century, when the Darwin-Wallace papers (1858) and *The Origin of Species* (1859) were published and the first recognisably non-human hominins (Neanderthals) were recovered from Germany and Gibraltar (Henke 2007). In the early years the field was clearly dominated by empirical concerns – finding the missing links, classifying the resulting fossils, and describing material cultures. The prevailing emphasis in this pioneering phase was on discoveries and data collection and objective, empirical solutions to palaeoanthropological problems.

Darwinian gradualism – the prevailing paradigm – implied the existence of 'missing links', and expeditions were dispatched to find them. Eugene Dubois and Davidson Black went to Asia, while Raymond Dart and successors chose Africa. Their finds, and those already recovered in Europe, were then subjected to metrical analysis, in which anatomy and artefacts were measured and the resulting data was analysed statistically to answer questions of phylogeny, systematics and culture history. Developments in prospection and survey eventually produced vast datasets and recovered many fossils, but missing links remained elusive.

The first ostensibly 'ecological' hypothesis of human origins was proposed in 1925, by Raymond Dart. This savannah hypothesis suggested that human characteristics had appeared as a result of a shift in the climate which aridified Eastern and Southern Africa and forced hominins to adapt to less wooded settings. Major debates, however, still centred on questions of empirical support for this model and others (which often focused on cultural traits) – in particular the brains-vs-bodies debate, engendered by the discovery and discussion of the Taung baby (Lewin 1987), and the re-evaluation of Neanderthals that followed the finding of Piltdown Man (Millar 1974). Dart's hypothesis belonged to a near equilibrium approach in which landscape ontology was more or less fixed and human evolution was shaped by a simple colonization scenario and the selection processes it might engender.

The period after the Second World War was different. In the 1960s, palaeoanthropology 'rediscovered' evolutionary theory via the Modern Synthesis (Gundling 2010, Tattersall 2000), with various impacts (Foley 2001). One of the clearest was the appearance of hominin palaeoecology and a focus on the environmental controls/constraints on human evolution. Many scholars began to question the wisdom of gathering data in the hope that some hypotheses would thereby be refuted. The emphasis shifted to a more analytical approach to problem solving based on explicit theories about evolutionary processes. This theory-led approach saw palaeoanthropology borrowing heavily from biology, geology and social anthropology to develop conceptual systems. In effect, the focus shifted from empirical natural history to analytical-empirical natural philosophy; that is, from description and classification to analytic method and modelling.

The post-war period was marked by a proliferation of process-oriented hypotheses, including the development of the Aquatic Ape hypothesis (Morgan 1982) and new models focusing on more complex temporal variability at all scales including more marked seasonality (Foley 1987), increased variability in annual conditions (Potts 1998) and 'turnover pulses' in deep-time (Vrba 2007). This was palaeoanthropology's processual phase, in which analytical (usually scientific) methods, coupled with new cybernetic technologies, shifted the balance between problem re-formulation and analysis and empirical data gathering.

During the 1970s and 1980s, the theory-driven phase paralleled developments in the new and processual archaeologies. Practitioners realised that natural philosophy methods, though they could simulate stick-slip (metastable) dynamics in toy-world models, struggled to represent innovative dynamics in which new patterns of perception and understanding altered the ecological relations between populations of anticipatory systems. Gradually the focus shifted to two dimensions of the work. First it was acknowledged that all interpretation of the past was theory-laden and negotiated in the present. As such it tended to privilege contemporary preoccupations and values. The construction of the past in the present led to calls for a more 'reflexive' approach to theory-building.

The word is perhaps a little confusing. It implies firstly that the community of researchers and the communities they study have the same ontological structures - the academic subject and the ontological object reflect each other. It also implies an ethical need to 'reflect' on the political and sociological implications of the human sciences. The drive for reflexivity meant that earlier models of hominins and their cultures were treated as texts to be analysed and deconstructed. Mischa Landau (1991) for example, proposed that all palaeoanthropology was about attractive narrative rather than objective search for truth. Secondly, it was acknowledged that ancient ecodynamics were shaped by ancient mindsets, perceptions and cognitive competence. This led to renewed interest in the cognitive dimension and raised complex questions about genetic and epigenetic factors, perception and agency. The processual approach to problem-solving was set aside in favour of a more discursive approach with the aim of 'opening up' our understanding of possible pasts and a greater emphasis on the impact of the lived experience both in the past and in contemporary science.

Section 2: Designing an Integrative Project to minimise Inter-Disciplinary Conflict

The pattern we sketched above for palaeoanthropology can also be valorised in geography, anthropology, sociology and archaeology and, with some local variations, in biology. Pre-war approaches were broadly empirical. Scientists needed to choose between many possible hypotheses and their strategy was to use empirical data to close the space of possible hypotheses down - selectively eliminating some hypotheses. This empirical refutation approach, which would surely have met with Karl Popper's (1959) approval, was ultimately unsuccessful. In practice hypotheses about complex dynamical systems are seldom resolved empirically. The institutional veto creates a stick-slip dynamic that hardens science into gnostic factions, which dissolve again in the periods of glasnost and perestroika that follow a co-evolutionary catastrophe. This was true in the 18th century when Georges Cuvier and Jean-Baptiste de Lamarck were arguing about the immutability of species and remains true today. Contemporary debates about climate change and human impacts, for example, or the ongoing squabbles between evolutionists and creationists in the US have not been resolved by empirical research because protagonists can find endless scope for arguing about the correct interpretation of data.

The systems-based approach that became fashionable in the post-war period was initially more analytical and problem-oriented in emphasis. It marked a trend towards natural philosophy and the use of abstract models of cause and effect to solve problems. Natural philosophy and problem-solving go together because these methods tend to use processual models and empirical data to predict the past, as it were. In archaeology Lewis Binford (1983 and elsewhere) dismissed many data-driven models as *post-hoc accommodative arguments.* A small cottage industry seems to have grown up to deconstruct Binford's early polemics. Binford was clearly impressed by Karl Hempel and set out to show that science was the quest for universal laws - causal structures that would apply to all societies without loss of generality. This was clearly a mistake, as Binford acknowledged in the early 1980s as he abandoned processualism. The principal discovery of Cold War systems research was that methods generalise, but theories do not. The application of a specific method in a new context generally turned on the development of a special (i.e. not general) bridging theory that linked the boring things we can observe to the interesting things we would like to know about. Binford called this *middle range research*, an apposite term because it focussed attention on the locally time-symmetric, conjunctural range.

The post-new archaeologies of the later 80s and 90s went one step further, challenging the conventional distinction of research object from theoretical subject. It not only denied the possibility of framing universal cultural laws, it challenged the equation of artefacts with culture and the materialism of many analytical case-studies. Where the natural philosophers were focussing on process and the meso-scale of the synergetic conjuncture, post-modern humanists took a more romantic line, concentrating on domino-chains of events, narratives, small history and thick description. Post-modern reflexivity emphasises the concept of the past in the present, the plurality of perspectives and the social construction of meaning. Its great strength lies in its ability to open a problem-domain up by alerting us to culturally embedded prejudice, tacit knowledge and problems of social exclusion in the present. Different readings of the past often coincide with different stakeholder communities and critical relativism creates scope for the emancipation of hitherto unacknowledged stakeholders.

Although anthropology and archaeology have been associated with extreme social exclusion in periods of co-evolutionary conflict, this link is much weaker in periods of prosperity when more agnostic viewpoints are tolerated and even encouraged. Although the need for ethical oversight in policy-relevant anthropology is clear, the pendulum of scientific fashions has swung so far to the romantic end of the spectrum that the result is often paralysis by analysis. Problem statements are opened up endlessly and any attempt to actually solve a problem is met with critique. Natural philosophers and critical humanists find themselves ranged in paradigmatic opposition: one group want to find the answer; the other wants to change the question.

In the integrative, policy-relevant sciences a research team that shatters into gnostic factions can frustrate urgently needed innovations and even de-stabilise the life-support systems it has been created to serve. There are remote rural communities and decayed inner-city regions where an earnest young researcher with a clipboard may be mugged because resident stakeholders have grown sick of research teams stirring things up and politicising local issues. Researchers parachute in, grab data, raise expectations and then race back to the university to publish. Wise research managers minimise discursive noisiness and increase the likelihood of innovation by keeping naturally antagonistic researchers apart most of the time. Each group has special skills, strengths and weaknesses and the art of research management is to transfer control from one group to the other at the right moment. Often there are many rival ontologies and problem-specifications. Most commonly there are two *de facto* stakeholder communities, an insider and an outsider group. The balance of power between them may oscillate and flip, but their stakeholding is implicit in their place in the political process. If one looks carefully, one often finds an unacknowledged stakeholder community whose interests are effectively marginalised or ignored. That group may be human stakeholders or non-human populations - keystone ecosystems, for example, or a dissident community.

In practice you know you have found an unacknowledged stakeholder community when you mention them and insider and outsider factions close ranks to attack you. Both parties have a vested interest in the *status quo* and will resist any way of seeing the system that undermines it. When the argument is about the best way to drain the swamp, nobody wants the frogs to be re-invented as stakeholders.

Humanists, with their special expertise in discursive method and historiography, are particularly good at opening problem-domains up, but tend to see cultural distinctiveness and plurality of views as intrinsically valuable. Humanists are generally rather poor at prioritising, closing the problem specification down and solving technical problems and will add layer on layer of thick description to the system if you let them. Happily, natural historians are rather good at closing problem-domains down by characterising things and categories of things, summarising the value judgements and evidence of social exclusion and forming a coherent problem-statement. Not every unacknowledged stakeholder is the victim of hegemonic elites, but one cannot demonstrate this using discursive method alone. Sometimes it is necessary to still the discursive chatter and look at the empirical evidence. Social exclusion can be objectified and sometimes even quantified in terms of natural selection, demographic indicators, ecological resilience and public health. Many political outsiders and unacknowledged stakeholders are no less prosperous, healthy or long-lived than insiders. Social exclusion bears on access to cultural and natural life-support systems, not unrequited aspirations and quaint, structured behaviours.

This discursive process of opening up and the empirical process of closing down, taken together, mark the first phases of the project cycle, which together we can call *problem-framing*. In many research contexts, generating a more inclusive, humane understanding of the problem is the best we can hope for. However sometimes one can build enough trust between insiders, outsiders and unacknowledged stakeholders to move onto a problem-solving phase. This is where the natural philosophy approach comes into its own. The trick is to use analytical method and scenario analysis to predict the sorts of circumstances that would obtain in a system where a given problem was solved. The problem can be as simple as doing something about dog mess in the streets or as complex as re-designing institutional and legal structures.

Problem-solving is a risky business and it is usually wise to start with something simple and build the trust to go onto progressively more challenging tasks. With complex problems a 'watching brief' may be required to monitor the empirical evidence and system health. If the match between predicted and observed outcome is good and there are no unforeseen and undesirable side-effects, the problem-solving programme is allowed to run to completion. This project cycle is so-called because many sequences of opening up, closing down and problem-solving may be needed to solve deeply engrained problems of social exclusion or environmental degradation. With luck and good management one can sometimes manage conflict within the team *and* build enough trust to help communities find their own way out of the difficulties they face. The trick is to prevent humanists, naturalists and natural philosophers from working in parallel. One group wants to open the problem up, the other to close it down and the third to solve the problem. It is like hiring someone to paint your house pink and then stopping them half way through to ask whether green might be more popular with the neighbours or whether it would be more useful to fix the roof than to paint the wall. People get cross with each other and nothing gets done.

From a manager's perspective, the easiest projects to bring to completion are those that cut out part of the cycle. If there is no evidence of ecological, economic or demographic hardship, for example, there is nothing to be gained by opening the problem-domain up. So the manager will stand the humanists down and scrap the first phase of the cycle. If the problem-domain is well understood, then there is little to be gained by a closing down exercise and the natural historians can be stood down too. If the problem-domain is so ill-structured that a stable consensus is unlikely, analytical problem-solvers are not required. Send them home and concentrate on mediation and advocacy. One only needs all three phases of the project cycle in situations where one wishes to innovate, to change system dynamics by changing the way people think about the system.

Many integrative research projects involve early career researchers, often working alone on doctoral and post-doctoral research projects. Most of those early career researchers earnestly wish to innovate, to influence patterns of disciplinary discourse by changing the way peers think about the study-domain. It is very rare for such a project to change the course of history. Louis De Broglie (1924) may have won a Nobel Prize for ideas developed in his doctoral dissertation, but most doctoral students would be content to influence the external examiners and get their work into press. Interestingly, the same project cycle can be followed on these projects too. One starts by reviewing the state of art, opens the problem-domain up a little to examine alternative priorities and conceptual models, closes it down again to identify a targeted research strategy and moves into a problem-solving phase. The next section will explore the way this works in the context of palaeoanthropology and specifically primate / landscape interactions.

Section 3: Applying the Project Cycle Approach

Opening Up

Our problem domain is Plio-Pleistocene primate/landscape interactions, and the research arises directly from the unfolding of the palaeoecological approach to palaeoanthropology (section one). In particular, we begin with the latest development in the series of environmental hypotheses of hominin evolution that began with Dart's savannah hypothesis: the *complex topography hypothesis* (King and Bailey 2006; Bailey *et al.* 2011; Winder *et al.* 2013). This is the first hypothesis to explicitly invoke spatial heterogeneity and change, as well as temporal variability, as a factor in primate evolution, and suggests that early hominins chose to live in active tectonic landscapes (like the African Rift Valley and South Africa) because these were inherently attractive. This attraction was felt because tectonic environments offered complex mosaic habitats – in which many resources could be found in a small area – and a tactical advantage over other animal species. In this way, it is the first model to employ a version of the more complex Darwin-Huxley synthesis of evolutionary theory, where agency is significant, rather than the neo-Darwinian perspective, where natural selection drives the system. The model recognises the importance of behaviour and cognition in hominins' *choice* of places to live. This model, in which both landscapes and agent behaviours vary at a range of scales, is more likely to show disequilibrium stick-slip dynamics and emergent change than one which invokes simpler changes. It thus offers a new way of looking at our lineage's history.

Palaeoanthropological value judgements are, as suggested above, simple compared to the balanced considerations of stakeholders and social systems required in the study of current cultures. The primary stakeholders in palaeoanthropology are academics, who have the opportunity to share their opinions in press and at conferences, and funding bodies who express their views in choosing projects to pay for. This means we can characterise tacit values by looking at what "palaeoanthropologists have claimed as 'interesting' research", and via literature review (Winder 2012a). In this case, an extensive review of the literature is not really necessary to justify the value of the work, as hominin evolutionary ecology and the relationships between primates and their environments are long-standing foci for academic projects and public interest. A summary is available in Winder (2012a).

However, one area would benefit from further scrutiny. The tectonic hypothesis suggests that the Darwin-Huxley model of evolution might be more useful than the neo-Darwinian adaptationist program in this case, but it also raises the question of scale. Most of the earlier models of hominin interactions with the environment assumed that landscapes were static, at least at the scale of interest. This assumption is justifiable under neo-Darwinian models because these largely assume that event-scale microdynamics average out to produce static conjuncture-scale surfaces, which are then subject to change through time as a result of deep-time processes like climatic change or tectonic activity (table 1).

We have already observed that different types of explanation go with different purposes and space-time perspectives. We now observe that scale is in fact a vulnerable assumption in much of archaeology, where the events of interest typically occur at the smaller scales – of ecodynamic interactions – while the systems we can study occur only at larger scales of the population and/or region. For instance, in studies of evolutionary anatomy, each individual specimen is the result of a set of complex interactions between individuals and between individuals and their context, but these can only be studied when static 'landscapes' of social systems and physical environments can be assumed and intra-individual anatomical variation is subsumed under population- or lineage-level patterns. This has been true of studies of extant primates as well as extinct ones. In the work on the primate talus by Lisowski *et al.*, for instance, the primates under consideration are grouped into species level samples, and the preference of each group for arboreality/terrestriality and quadrupedal versus brachiatory modes of locomotion is assumed to be constant (Lisowski *et al.* 1974, Lisowski *et al.* 1976). Landscape choice and interactions – although recognisably important in generating morphology – are unresolvable at the scale of analysis where the neo-Darwinist assumptions hold true, although they may be invoked in interpreting results. We will have to bear this in mind when developing research designs to close down an investigation of primate/landscape interactions, as the scale of study may determine both the patterns visible and the interpretations that can be made, and may act as a significant constraint on the possibilities available.

	Micro	**Meso**	**Macro**
Viewpoint	Ecological	Population dynamics	Evolutionary
Context	Dynamic in terms of small, stochastic 'events'	Static (or averaged)	Dynamic at the large scale (e.g. tectonics, climate change)
Annales scale	Event	Conjuncture	Deep time

Table 1: characteristics of three different scales of evolutionary enquiry
http://www.arkeologi.uu.se/digitalAssets/197/197003_jaah9_winder_table1.pdf

Closing Down

This brings us neatly on to the next stage in the project cycle: empirical closing down of the problem domain to produce something (hopefully) amenable to a later problem-solving activity. In palaeoanthropology, as in many other socio-natural sciences, the clearest constraint on research activity comes from the amount and types of evidence available (with taphonomy and space-time resolution particularly affecting the ways we can link evidence to question), and there are fewer ways of constructing middle-range theories and conceptual taxonomies that provide solvable problems than in many of the natural sciences. In this case, as palaeolandscape reconstruction itself is difficult, we need an alternative source of empirical evidence. Humans are known to have different pedal morphologies if they are habitually shod than if they are habitually barefoot (Trinkaus 2005; Trinkaus and Shang 2008), and there are differences in locomotor biomechanics between groups that behave differently and live in different places (D'Aout *et al.* 2009; Lieberman *et al.* 2010). This suggests that landscape configuration might be important in determining foot anatomy, and that a comparative approach investigating the variation and ecological significance of anatomical differences among extant primates might provide the basis for interpreting hominin morphologies. Empirically speaking, if the neo-Darwinian model is accurate we would expect those morphologies to be dominated by environmental pattern with some influence from phylogeny reflecting constraint or 'relic' features. If the Darwin-Huxley 'emergence' model holds better, morphologies would be more complex and difficult to pick apart into coherent ecological and additional factors as more behavioural and cognitive impacts become relevant and the interaction between factors increases in importance.

If we survey past work, we see that some analyses of primate foot anatomy don't look at reasons for variation – they simply characterise it empirically (e.g. Kidd and Oxnard 2002) as though the evidence can be explained primarily in terms of genetic (i.e. innate) 'memories' transmitted with modification from one generation to another. There have, however, been both quantitative (e.g. Lisowski *et al.* 1974, 1976; Kidd and Oxnard 2005) and qualitative (e.g. Harcourt-Smith and Aiello 2004) attempts to understand functional morphology via analytical means. These have not typically focused on latent data pattern, though, instead usually making assumptions *a priori* about the important factors and selecting measurements that reflect these assumptions (e.g. Kidd *et al.* 1996 or Tocheri *et al.* 2011). The majority focus on ecological function (without distinguishing genetic from epigenetic factors), with a few also addressing the impact of individual factors, like phylogeny, explicitly (Polk 2002) or attempting to control for the effects of body mass, though there is to date no clearly reliable technique for doing so (Albrecht *et al.* 1993). This is a natural philosophy approach, and although it suggests that the methods concerned – simple morphometrics and qualitative analysis – might be able to pick up signals from ecology, phylogeny and body mass (among others) it excludes complex explanations. The next step, therefore, is to establish whether these methods can be used on a system like that proposed by the complex topography hypothesis.

It was decided to use simple morphometrics and exploratory analyses of data structure to explore the hypothesis that a more complex understanding of causality may be needed to explain the relationship between genetic and epigenetic factors. A sample of 130 non-human primates and 150 modern *Homo sapiens* was selected for analysis. Data was collected using a system of quantitative measurements used by Kidd *et al.* (1996) and Kidd and Oxnard (2002), supplemented by qualitative assessments of features such as joint facets, from specimens held in the University of Sheffield (Sheffield), the Duckworth Laboratory (Cambridge), the Natural History Museum (London) the Grant Museum (London), the Royal Museum for Central Africa (Tervuren), the American Museum of Natural History (New York), the Florida Museum of Natural History (Gainesville) and the Smithsonian Institution National Museum of Natural History (Washington DC). This dataset was then subjected to exploratory analyses designed to characterise latent pattern (see, for instance, figure 1 which shows the result of an exploratory discriminant function analysis of eleven measurements of the calcaneus).

Data was collected using a system of quantitative measurements used by Kidd *et al.* (1996) and Kidd and Oxnard (2002) and supplemented by qualitative assessments of features like joint facets and surface contours. This dataset was then subjected to exploratory analyses designed to characterise latent pattern (see, for instance, figure 1 which shows the result of an exploratory discriminant function analysis of eleven measurements of the calcaneus).

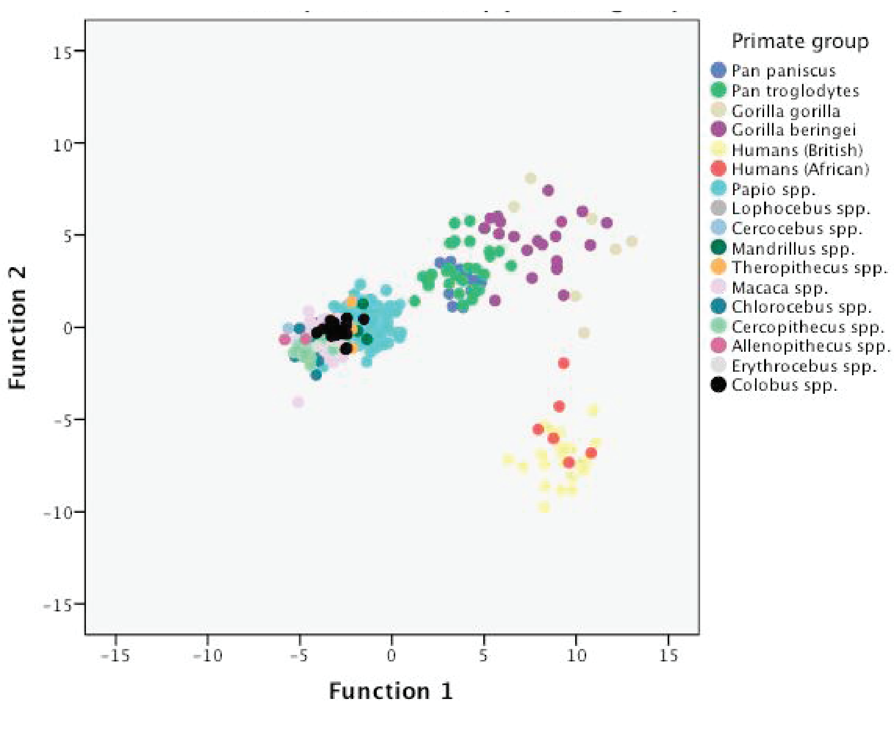

Figure 1: a scatterplot of scores on two discriminant functions based on calcaneal data, showing the separation of taxa into different clusters.
http://www.arkeologi.uu.se/digitalAssets/196/196997_jaah9_winder_fig_001.jpg

Figure 1 shows that interpreting the results in terms of the relative importance of different causal variables is difficult. The analysis has classified the specimens into three or four groups: modern humans (bottom right), the non-human hominoids (top right, partially segregated into two groups of

Gorilla and *Pan*) and the Old World Monkeys (middle left). These could be phylogenetic groupings but for the fact that modern humans have not clustered with their close relatives; they could be broadly groups based on locomotion (bipeds, knuckle-walkers and quadrupeds respectively) if not for the fact that chimpanzee and bonobo locomotor patterns differ more from each other than either does from the gorillas. Body mass seems to contribute to separation on function one, but imperfectly as modern humans are not as large as or larger than gorillas (though they bear more of their weight on their hind legs as a result of locomotor pattern variation). Clearly, even this very simple analysis is showing us that there is no single factor that predominates in explaining primate foot morphology and, in particular, there is no evidence that ecology does any better at explaining the results than body mass or phylogeny. This seems to imply a complex causality: while at one space-time scale external conditions and landscape seem to be controlling anatomy, at another, the morphology of the organism acts to open up particular opportunities and impose constraints that result in the colonisation of different landscapes. Since primates are capable of learning new behaviours and acquiring old ones without concomitant genetic change, what we are see is a complex of interacting factors that influence the balance of genetic against epigenetic, and short-term landscape choice against long-term patterns related to phylogeny and environmental change.

Figure 1 seems therefore to represent an evolutionarily stable state, in which no single component clearly dominates another but the organisms concerned are nonetheless ecologically well-adapted and persistent. At other points, however, these interactions can set up oscillating feedback systems that might flip the system into an unstable state (causing, for instance, a particular group to 'jump' from one adaptation to another via rapid evolutionary change). In the case of species with complex cognition, these shifts might not only result from environmental collapse like major extinction events, but also from smaller changes in landscape or social systems which trigger flexible behavioural responses. Primate agency could be a significant driver of systemic re-organisation that ultimately leads to a different balance of genetic and epigenetic factors and a different suite of explanations emerging at various space-time scales, and might explain the major success of the order (and particularly the hominins) over the last six million years.

The same kind of complex patterning is visible when we look at morphology at a smaller scale. To take just one example, there is variation in the pattern of articulation between the calcaneus and the talus in extant primates, with modern humans showing a range of facet configurations (a single oval facet, a single hourglass shaped facet, or two small facets) on the proximal calcaneus. The non-human apes, in contrast, always show single facets, while the Old World Monkeys again have more variation (see figure 2).

This qualitative pattern has been noted previously, with *Homo neanderthalensis* shown to have an almost exclusive predominance of single facet configurations, which were attributed to this species' greater body mass placing

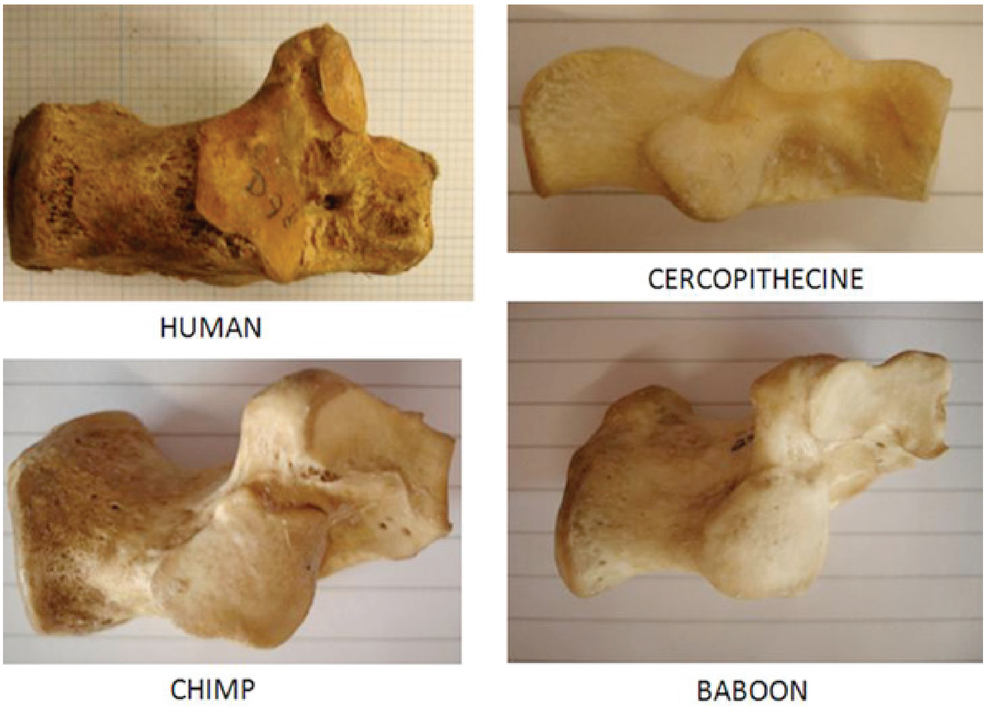

Figure 2: photographs showing the superior calcaneal facet configurations of a human, a chimp (*Pan troglodytes*), a baboon (*Papio anubis*) and a cercopithecine monkey (genus *Cercopithecus*). http://www.arkeologi.uu.se/digitalAssets/196/196999_jaah9_winder_fig_002.jpg

requirements on the bones for broad weight-bearing joint surfaces while humans were able to vary more by dint of their smaller size (Tattersall 1983). This sample, however, disproves that argument. The groups with variable facet configurations include the smallest of the primates sampled, as well as modern humans – which although weighing less than larger male gorillas, carry all their weight on their hindlimbs, and thus should need the largest (presumably single) facets by this argument. Equally, phylogeny cannot be the explanation, and neither can ecology – none of the Old World Monkey species sampled walks bipedally in a manner comparable to modern *Homo sapiens*. Qualitative analysis of facet configurations thus supports the result of the quantitative analysis that there is no clear way of explaining the results through recourse to a simple adaptationist model.

These results therefore suggest that we ought to view foot morphology as both emergent (not predictable from a knowledge of context, as neo-Darwinist assumptions suggest) and epigenetic (likely to be inherited via non-genetic means as well as genetic ones and comprising a blend of innate and acquired characteristics). Viewing such structures from a suitable perspective ought, therefore, to be a priority for those truly hoping to understand how primates came to be as we are and what the relevance of landscape is for our history.

Problem Solving in a context where Causality is Complex

We have now completed the problem-framing section of the project cycle. The problem of primate / landscape interactions has been opened up by taking fuller account of the complex co-dynamic interaction of genetic, epigenetic and environmental factors, including both geo-morphological and ecological pattern. This discursive approach to the problem so complexified the research domain that it became almost impossible to formulate a single, coherent problem-statement. We needed to close it down again. In policy-relevant research the effort of closing-down requires special attention to patterns of social exclusion and contested realities, but for present purposes the situation can be simplified greatly by focussing primarily on empirical data. The guiding principle of this closing down exercise has been that there is no point modelling causal factors separately in their empirical effects are indistinguishable. We have no prospect of distinguishing the effects of genetic from epigenetic factors except in circumstances where there is a clear empirical pattern to describe. The most promising feature of this empirical pilot study is the talo-calcaneal facet complex described above. Our next task in this section is to decide whether there is a well-posed problem to explore.

It would be easy, in this situation, to give way to anxiety and stress - *what am I to do if there is no well-posed problem to address? My project will collapse and I will fail.* This is not the case. In an agnostic universe of discourse there are many systems that are so strongly time-asymmetric that well-posed problems cannot be defined and a combination of discursive consciousness-raising and empirical pattern-searching is the best we can manage. There are also situations where problem ontologies are robust and ethically unimpeachable and the effort of problem-framing is frankly unhelpful. One may as well start at the problem-solving stage. There are also situations, particularly in social anthropology, where closing-down actions are ethically indefensible and a pure discursive approach is required.

Interestingly, there are many situations in which causal relations are reversed as one slips from one disciplinary perspective to another. Consider, for example, a limestone catchment. Viewed from the deep time perspective of geology, it is clear that water movement has cut through rocks to create limestone gorges, fissures and underground rivers. Surface water redistributed sediments to create new landscape features. Water movement ***causes*** landscape structures. When the same landscape is viewed on the meso-scale of hydrology, however, it is equally clear that persistent landscape structures - riverbanks, underground cave systems and flood plains, say - constrain the passage of water through the catchment. The shift of perspective seems to transform cause into effect and effect into cause. In such a system there is no need or reason to take sides in a paradigmatic argument about what causes what. Different types of feedback loop come into operation at different scales of observation. Coming down a step further to the micro-scale of events we see a time-asymmetric narrative chain of showers and sunshine, frost and animal migrations. Some of these events - a catastrophic spring melt, for example, can flip the system from one state to another, undermining boulders, destroying natural dams and so on. The water, which is normally constrained by landscape features, creates a catastrophic pattern of re-organisation that may leave traces in the geological record. The time-asymmetry of micro and deep-time dynamics are inter-related in a complex, *ex ante* unpredictable way.

The situation becomes much more interesting, at least from an anthropologist's perspective, when we introduce intelligent, co-operative mammals into the system that are capable of learning, forgetting, anticipating and intervening in the natural system. When humans become active in such a landscape, for example, we see that the system can flip from one set of causal structures to another in response to environmental perturbations and human action. Indeed, humans often manipulate causal structures by modifying a system's space-time signature, for example by building dams and harnessing hydro-power, by clearing forest or abstracting water from the aquifer. Complex causality, with its scale-dependent causal inversion, irreversible change and stick-slip dynamics, can be valorised wherever cultural and natural systems interact. Agnostic science is governed by Jonah's law. Even using statistical methods, we can only predict the course of history in respect of phenomena we are incapable of influencing and can only change the course of history in situations where innovation is possible and predictions potentially meaningless.

These agnostic constraints impose limits on human knowledge, but they need not prevent us from working. In integrative socio-natural science, for example, there are many viable combinations of discursive, empirical and analytic method, each of which corresponds to a different set of space-time scales. There are also inviable combinations. It is relatively easy to waste resources on data-gathering in archaeology or palaeoanthropology, dump the data in useless archives and write endless papers about taphonomic 'bias' or how terribly difficult it is to practice archaeology reflexively. If there is no operational link between the data and the conclusions, the research is scientifically sterile. If the taxpayer funds the work, there are also ethical questions to be answered about whether generating more data is a proper way of using those resources. You can write papers about sample bias, epistemic plurality and reflexivity without gathering new data.

In this closing section, then, we will outline protocols for testing the hypothesis that a worthwhile problem exists, a problem that is ethically defensible, justifies the cost of data gathering and seems interesting. This requires a brief introduction to conceptual modelling.

Conceptual Modelling

Imagine a sheet of paper as a 'project space'. Natural philosophers, when they think of spaces tend to think of them as collections of all possible locations. A geographical space is a collection of all possible geographical locations; a possibility space is a collection of possible scenaria, and space-time is a collection of all possible time-stamped locations. We are inviting you to consider the paper as a project space, a collection of all possible research projects. If you take a pencil and make a dot on the paper, that dot corresponds to a small collection of possible projects. If you make a closed loop, you have delimited a set of possible projects. That is what we are going to do here.

The discursive process of opening up requires us to form a set of *value-judgements* by considering all those *Why?* questions that might influence project design. *Why are you studying anthropological archaeology? Why are you initiating a research project on this topic?* Some of these *Why?* questions will refer to contested value-judgements. *Why are indigenous peoples interested in Western anthropology? Why did the Third Reich value Kossinna's approach to culture history?* These must be handled critically and with compassion. In large research projects, professional guidance may be sought from ethical advisors. However many of these value-judgements are ethically neutral. If you happen to love working with GIS or find Neanderthals fascinating, that is also a value judgement. Make a list of your own value-judgements, trawl the literature, consult other stakeholder communities and you will soon open the problem up, as we have in this paper.

Draw a closed circle on the space of possible projects and label it *Value*. This circle represents the set of all possible projects that is consistent with the value-judgements of the stakeholder community you have considered. Your next task is to close the problem down. You do this by asking a series of *What?* questions. *What is the problem-domain at hand? What things and types of things actually exist? What sorts of things might possibly exist in the future or might have existed in the past? What evidence is available?* Again, some of these 'boundary judgements' may be contested. Antagonised stakeholder communities often use boundary judgements as a pretext for promoting political and economic interests. If you bound your problem-domain as *the study of advanced western civilisations*, for example, some possible stakeholder communities are pushed beyond the pale. In policy-relevant systems practice, the study of *boundary critique* and the problem post-modernists sometimes call *othering* is an important tool in conflict resolution and management. However many boundary judgements are ethically neutral. Middle class neo-pagans may be frustrated by your decision to treat Neolithic religion and neo-paganism as independent cultural traditions, but you can disagree with them without bouncing the university ethics committee into action.

When you have answered all those *What?* questions, draw another circle on the paper to represent your boundary judgements. The intersection of boundary and value-judgements represents the subset of possible projects that is consistent with your stated values and with your understanding of systems ontology. It is almost a truism of socio-natural science that there will be three broad types of thing to be bounded. There will be material things like bones and land-forms; there will be ideational things like value-judgements and work-ethics, and there will be symbolic things like stylistic motifs and texts. Do not hesitate to include any or all of these three broad types of thing in your boundary judgements, but remember the exercise will not close down if you ignore material things. There must be concrete observables, data structures and empirical evidence.

The third type of judgement relates to those *How?* questions that determine your favourite choice of method. As we have seen, there appear to be three broad categories of method: discursive, analytic and empirical. Choice of method is largely personal. Some people love abstract algebra, others love poetics. Some people are turned on to data capture or electron microscopy. You should not ignore these aesthetic factors, but you should also consider unfamiliar methods. Bear in mind that choice of method can be ethically significant. Discursive method often draws our attention to personal experience and narrative. It is a very good indicator of how small groups of people feel. Empirical method usually deals with aggregates and analytic method with time-invariant processes. The processual approach to economics suggests we need to transfer the debts of private institutions like banks to national governments and from governments to ordinary citizens. Empirical research tests and winnows this hypothesis and discursive studies tell us what impacts those policies have on individual lives.

Draw another circle, this time to represent the 'operational judgements' you propose to make. Now look at the diagram (Figure 3). If the three circles intersect in the middle, then there exists a 'sweet spot' where value-, operational- and boundary judgements can be reconciled. It may be worthwhile contemplating a natural philosophy effort of problem-solving. If, however, the three sets do not intersect at all, or only intersect pairwise, your approach will be constrained and the scope for integrating natural history and humanism will be limited.

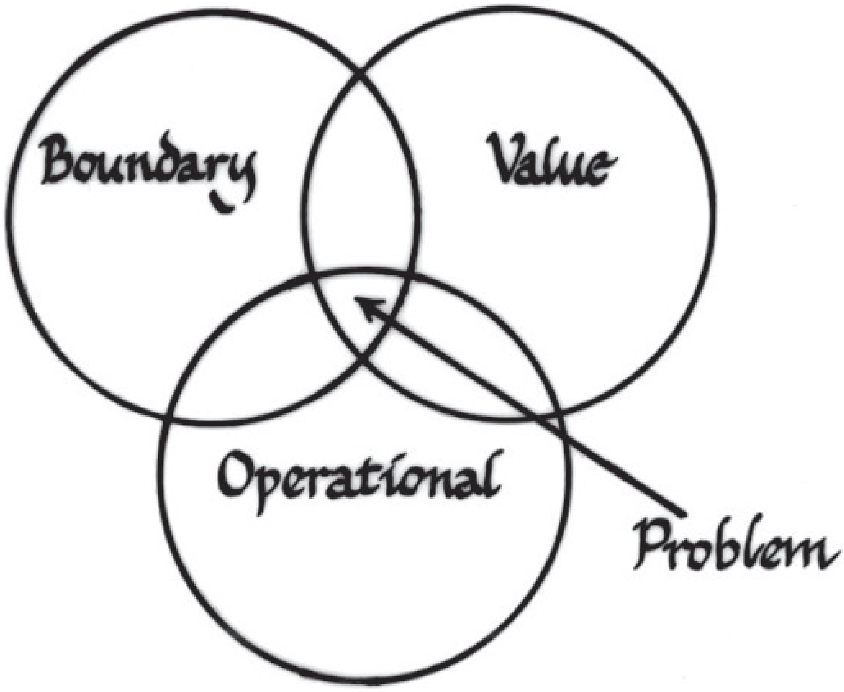

Figure 3: A schematic diagram of the conceptual modelling process. The problem is represented by the intersection of the sets representing three types of judgement.
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Complete project cycles are rare. Most projects tend either to the humanistic or natural philosophy end of the spectrum. In the case study we have just described, for example, it is unclear to what extent a well-posed problem can be defined. A further effort of closing down will be required to establish this. Our intention is to pursue three lines of research:

- We will study the morphology of captive and wild ape populations to see whether the effect of genetic (innate) and epigenetic (acquired) factors can be distinguished
- We will look at a range of modern human populations, to understand the range of variability in the recent past
- We will explore a range of analytic modelling strategies including GIS and dynamic modelling methods to see whether a coherent analytical problem can be developed.

The project whose design we have sketched here is now approaching completion. The first fruits of our research on complex causality have already been harvested (Winder 2012b; Winder *et al.* 2013). The purpose of this paper, however, is to introduce the key ideas of agnostic co-evolution and their extension into integrative socio-natural science.

The agnostic approach we have characterised here has much to recommend it, but comes as a considerable price. Since landscape science deals with contemporary phenomena and is shaped by scientific purposes and space-time scales defined in the present, we must accept that different scientific communities, working from different space-time perspectives will construct different explanations. Even when they seem mutually contradictory, we are under no obligation to make a choice between them. Causality is a complex phenomenon.

Viewed from a deep-time perspective, it is clear that genetic change can be used to explain changes in the morphology and physiology of biological organisms. The net effect of that evolutionary process is to enhance or at least maintain biological fitness. However, the meso-scale perspective of ecological process makes it clear that interactions between neighbours in a physical neighbourhood create a nexus of opportunities and threats that cause genetic drift. The dairy farmer is selectively co-operative with cows that give plenty of milk and the cows are selectively co-operative with farmers who treat them well. The genetic drift that enables dairying communities to digest raw milk and cows to produce enough milk to drown a calf is a by-product of this reciprocal co-operation. In this way, the shift of space-time perspective seems to transform cause into effect and effect into cause. Coming down a step further to the micro-scale of human agency, we see that the system can flip from one set of causal structures to another in response to environmental perturbations and human action. Indeed, humans often manipulate causal structures by modifying a system's space-time signature, for example by constraining the time-geography of their neighbours. If the sheep get into the cornfield or the dogs get into the sheepfold, the whole system can collapse. Complex causality, with its scale-dependent causal inversion, irreversible change and stick-slip dynamics, can be valorised wherever cultural and natural systems interact.

Although complex causality may seem daunting at first glance because it confounds conventional, enlightenment ideas about scientific rigour, the range of conceptual modelling techniques that allow us to characterise different causal structures and ontologies at different space-time scales and for different purposes provide considerable extra leverage. This leverage is particularly important in policy-relevant research because it can be used to define a range policy instruments that can be used to manage system resilience by flipping the system between one causal structure and another. Consider, for example, the case of the limestone catchment described above. Viewed from the deep time perspective of geology, it is clear that water movement has cut through rocks to create limestone gorges, fissures and underground rivers. Surface water redistributed sediments to create new landscape features. Water movement *causes* landscape structures. When the same landscape is viewed on the meso-scale of hydrology, however, it is equally clear that persistent landscape structures - riverbanks, underground cave systems and flood plains, say - constrain the passage of water through the catchment. The shift of perspective seems to transform cause into effect and effect into cause. Coming down a step further to the micro-scale of human agency, we see that the system can flip from one set of causal structures to another in response to environmental perturbations and human action.

This is where the policy instruments come into being. Humans often manipulate causal structures by modifying a system's space-time signature, for example by building dams and harnessing hydro-power, by clearing forest or abstracting water from the aquifer. We have become 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 change the world by changing our minds. That is too much work for a solitary monkey, of course, but we chatter until our minds and actions seem to be aligned, each with its neighbours, and we can act as a complex super-organism, perturbing resilient ecosystems by manipulating their space-time structures and feeding on the fluxes of energy and resources released as the system recovers from the system shock. Complex causality, with its scale-dependent causal inversion, irreversible change and stick-slip dynamics, can be valorised wherever resilience feeders like us are at work.

We think it likely that hominins acquired the ability to learn and to forget, to manipulate space-time structures and feed on resilience and to coerce their neighbours long before their cognitive skills had developed to the point where they could intellectualise these phenomena. What we call 'science' may be a co-evolutionary extension of cognitive intuitions and embodied aesthetics that guided early hominins to situations where they were able to thrive. They became fixed in our bodies as by-products of the co-evolutionary processes that shaped them. Even our tendency to gnosticism (scientific and religious) may have originated in this way. It allowed us to coerce our neighbours and be coerced by them in periods of co-evolutionary stress, when survival depended on social and behavioural coherence.

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