GLOBAL OVERSHOOT :

CONTEMPLATING THE WORLD’S CONVERGING PROBLEMS

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PREFACE AND OVERVIEW

We shall not cease from exploration
And the end of all our exploring
Will be to arrive where we started
And know the place for the first time.
TS Eliot[1]

Myself when young did eagerly frequent
Doctor and Saint, and heard great Argument
About it and about: but evermore
Came out by the same Door as in I went.
Omar the Tentmaker[2]

This book has its origins in a handful of questions and perceptions which has been niggling me since the publication in 2003 of *Deep Futures*,[3] my attempt to equip myself with an evidence-informed set of beliefs---working hypotheses---about humanity's prospects for surviving, and surviving well, through the centuries and millennia ahead.

Writing *Deep Futures* cheered me up no end. While present knowledge condemns our species to eventual extinction in one way or another, I concluded that we could well have a long Indian summer before us, provided that we keep learning, stay lucky and don't turn what is promising to be a particularly difficult century into a full-blown catastrophe.

I was seeing the 21st century as one where the people of the world might, through hard work, shrink the overarching problems of war, poverty, injustice, environmental degradation and sociopathy; or, more positively, creep up on the goals of peace, material wellbeing, social justice, environmental protection and sociality (goodwill). The challenge, as I saw it then, could be expressed in terms of how to most effectively improve quality of life for most people. However, the perspective I have come to hold as I write the present book is, not quite that humanity is fighting for survival, but, plausibly, *we are threatened with a large and rapid drop in quality of life (e.g. fear and hunger) across the world; and that humanity's primary task for the foreseeable future should be cast in terms of defending the status quo, not improving on it.* More colloquially, our challenge is one of sandbagging the levees, not irrigating the desert.

[1] From his *Little Gidding* (Number Four of the 'Four Quartets.') http://www.tristan.icom43.net/quartets/gidding.html (Accessed 19 Jan 2011)
[2] Edward FitzGerald, Rubáiyát of Omar Khayyám, 1859, http://ebooks.adelaide.edu.au/o/omar_khayyam/o54r/ (Accessed 19 Jan 2011)
[3] Cocks, D., 2003, *Deep Futures: Our Prospects for Survival*, University of New South Wales Press and McGill University Press, Sydney

There is nothing particularly novel about my updated perspective; perhaps I am just catching up. The world is awash with premonitions that global society is on the brink of being massively disrupted by global-scale processes associated with, for example, global warming and the depletion of fossil fuel deposits. There is probably general agreement on the need for international cooperation to address such global-scale problems, and a recognition that achieving such cooperation is always difficult. Working from within this mainstream world view---call it *Interventionism*---there are thousands of policy analysts and scientists, mostly from first world countries, documenting and modelling global change---economic, social and environmental---and developing social and material technologies for responding to the threats and opportunities it presents.

My own response to global-scale problems is somewhat different. As when writing *Deep Futures*, my humanistic (humanitarian) starting point is a wish to contribute to the *achievement of high quality of life for most people into the indefinite future,* the goal I call *quality survival.* But I do not want to write yet another treatise on how to set up a carbon trading scheme or recycle water or, indeed, any aspect of the mechanics of tackling the world's many problems; I want to produce a philosophy, a way of looking at things, not a recipe book. My plan is to understand what is happening, not to suggest solutions.

My starting point is to build up an historical and pre-historical understanding of how humanity and the human ecosystem came to be as they are (Chapters 1-4) and, from there, in Chapter 5, explore how people of different temperaments might respond to a suggestion, a diagnosis rather than an assertion that a global-scale *Overshoot Crisis* has already begun. A system is in *crisis* when it is moving quickly towards a highly uncertain future. It is in *overshoot* when one or more processes of cumulative change appear to be approaching limits (sometimes called tipping points) where a major reorganisation could well be triggered. My scenario of an *Overshoot Crisis* rests on the perception that the converging effects of four momentous human-made trends---towards overpopulation, global overheating, overextraction (of resources) and over-connectedness[4] between nodes of activity, e.g. an increasingly interdependent world economy---will, unless actively averted, impact pervasively on quality of life via destructuring processes such as deurbanisation (abandoned cities), deindustrialisation (shattered economies), depopulation (megadeaths), and deglobalisation(e.g. currency wipe-outs, declining trade, declining internationalism). That is, an Overshoot Crisis could turn into an *Overshoot Catastrophe.*

In addition to the conventional wisdom of Interventionism in some form or other, Chapter 5 discusses tough-minded *Empiricism* and tender-minded *Reconstructionism* as other legitimate ways of responding to the diagnosis of an Overshoot Crisis. Empiricists have a 'wait-and-see' perspective while Reconstructionists have, metaphorically, a 'Noah's Ark' perspective. More directly, *Reconstructionism* is the belief that it is already too late to stop a massive disorganisation and simplification of the human ecosystem. As of now, we are committed to passing through a dystopic bottleneck and the Reconstructionist suggestion is that we should be concentrating on how we might best help our great-grandchildren (or beyond?) regain some quality of life as they emerge on the other side where, if they are lucky, they will toil their days away in agricultural villages. Because

[4] Connectivity is the ability of one element in a network to influence another.

Reconstructionism is all too easily labelled as defeatist and sanctimoniously dismissed, I have felt it useful to explore the puzzles it throws up. As for the Empiricists' perspective, it suffers from being too easily hijacked by vested interests wanting to use caution as an excuse for inaction.

Assuming that a global-scale Overshoot Crisis is indeed coming into view, how realistic is it to believe, as many mainstream Interventionists do, that global society can and will, rationally and comprehensively, intervene to forestall a large and rapid drop, a plunge, in quality of life across the world? My answer is 'quite unrealistic.' All that can be hoped for is a collation of uncoordinated interventions by various protagonists---from international organisations to individuals---each acting within their own sphere of influence to 'fix' some facet of the total problematic as they see it.

There are two elephantine reasons why the Interventionist perspective has to be judged naïve, both so fundamentally at odds with the way problem-solving is conceptualised in 'enlightened' societies that neither can be readily admitted to the public consciousness. First, in no sense is there a collective 'We,' united around achieving or defending quality survival as a primary task. Next, even if there were, the Overshoot Crisis has been generated from within the human ecosystem, this being what scientists call a *complex dynamic system*. That label means, first, that the speed, size and duration of the Overshoot Crisis cannot be predicted and, second, that humanity's knowledge of how such systems work is insufficient to allow them to be confidently steered in some preferred direction, such as defending global quality of life. I will return to these two difficulties presently.

Chapter 5 concludes that while humans will survive their self-made Overshoot Crisis, it won't be because of any remarkable capacity to adapt to major challenges in ways that protect quality of life. It will be because the Crisis wasn't as bad as some thought it might have been; that is, the species had not been really tested. Or, it will be that while the Crisis was highly destructive of quality of life for most, it spat out a post-bottleneck population which, scattered and much-reduced, retained sufficient social and material technologies to begin rebuilding stable sedentary societies and improving quality of life once again.

This conclusion will be unwelcome to many people, particularly those with an exaggerated view of humanity's ability to know its goals and to manage itself and the world to achieve them. It has not been done deliberately, but we need to acknowledge that humanity has brought a crisis on itself, one which it is not yet ready to deal with. We are confronted with a knot of spillover problems of a type which we have not yet learned how to avoid, much less solve. This is despite the fact that our material and mental capabilities have increased sharply in the last three thousand years. While every generation has its world view(s), recent generations have acquired a dramatically improved understanding---plausible, coherent, and naturalistic---of most (?) of the world's physical, biological, social and psychological processes. Each year we know a little more. Strange as it sounds, it is an enormous achievement of consciousness to recognise that, as a species, we face great problems which are of our own making and which, for the moment, we are unable to solve.

It is not judgmental to recognise that, metaphorically, *H. sapiens* is an adolescent species whose emotional development has been slower than its cognitive development, e.g. not yet having learned to empathise and collaborate with others, and being, on occasions, thoughtlessly cruel or abusive; impulsive; still unduly bewitched by material technology; unconcerned about the species' life expectancy, or even with planning life a few generations into the future. Indeed, likening the life story of the human species to the life of a human individual is a rich enough metaphor (an allegory perhaps) to not only suggest ways of understanding where we have arrived, but also alternative directions we might take in search of enhanced quality of life. For example, taking a whole-of-life perspective might lead the species to conclude that what is now happening, namely an Overshoot Crisis, is no more and no less than the next challenge to be survived, as best we can, so that we might return to constructing quality lives for the lineage.

Conversely, thinking of the species as living out a life story offers the individual an insight into his/her own identity, namely, as someone playing a role in their species' Overshoot Crisis, e.g. as an Empiricist, an Interventionist, a Reconstructionist, a pawn, an opportunist; and so on.

Just as any individual's life story takes shape within the 'life story' of its species, so is the species' life story embedded in the successively larger and longer 'life stories' of the ecosphere (Earth's surface film of plants and animals and their environments), the planet and the cosmos. Chapters 1-4 attempt to build up a basic awareness---I term it *Eco-awareness* or, more briefly, *Ecawareness*---of how well-recognised evolutionary and ecological processes (physical, biological and cultural) have given rise to a temporal sequence of increasingly complex energy-degrading systems, from the early universe to today's world-wide human ecosystem.

In Chapter 6, 'Ecohumanism and Other Stories,' I argue that an Ecawareness of the processes underlying the *Story of Global Overshoot* provides an initial framework and a succinct language for formulating and debating what-to-do responses to the perception of Overshoot. Building on this conclusion, I proffer the philosophy of *Ecohumanism*---a bundling of Ecawareness and the Quality Survival goal---as a useful *tool* for thinking about the Global Overshoot Crisis. Definitionally, humanism is a philosophy which puts human progress at its centre, and Ecohumanism is a humanism which is informed by an extended awareness of ecosphere processes, both ecological and evolutionary. Metaphorically, Ecohumanism views global society as being like an evolving ecosystem in which a plethora of human interest groups are the 'virtual species' and the social and material technologies these groups repeatedly create are the 'mutations' which selectively change the quality-survival prospects of the adapting groups.

The value of Ecohumanism to those confronting Global Overshoot cannot be 'proved,' but it can be demonstrated in various ways, and this is what Chapter 6 essays. It shows how Ecawareness can be helpful, for example, in shaping attitudes towards threatening trends (like population growth); or in the identification of issues which need to be widely debated, e.g. choice of an overarching societal goal.

Further, the Chapter's section on 'Practical Ecohumanism,' presents a sample of indicative guidelines to bear in mind when addressing, not the proximate causes (overpopulation, overheating, overconnectedness, overextraction) of the Overshoot Crisis, but several of its underlying causes (root causes) as these emerge from the Story. One of these is the aforementioned difficulty which human groups have in cooperating for their common good, what I call the *virtual-species problem*. The other is the *complexity problem*, a recognition that complex situations, those characterised by networks of causes rather than simple sequential causes, can only be steered adaptively, i.e. by some strategy of incremental and continuously monitored trial-and-adjust operations.

The question of what-to-do in the face of complexity is not going to be answered by simply subscribing to some abductively plausible 'origin' story leading up to Global Overshoot. Nevertheless, the choice of what strategies to trial and, equally, to avoid trialling, does depend on the way in which the past is understood---an understanding which recognises the role of luck, the role of natural events, the role of morality, the limits of reason, the arbitrary nature of emotions, what worked, what failed…The list goes on. There is a presumption here that while no strategic choice can ever be more than intuitive, that intuition can only be improved by a conscious elaboration of the principles and insights one would like to see influencing that choice. For the moment this is the pragmatic best we can do about complexity.

I close my case for Ecohumanism by recapitulating some of the qualities which I believe are likely, on balance, to make people *emotionally* inclined to accept it as a platform from which to contemplate the possibility of global overshoot. These include: an understanding of cultural differences; naturalism; a non-religious spirituality; inclusiveness; an opportunity for personal responsibility; a flexible and evolving narrative; an acceptance of the species' strengths and weaknesses; and an understanding of death. Ecohumanism is proclaiming an origin story, which, not being exclusive to any national or religious group, and which, because it does include all people at all times, has the emotional pull to bind people everywhere into an empathizing global family or tribe. It is a story which, of itself, can help individuals meet three of their fundamental quality-of-life needs simultaneously---for belonging, for meaning and for identity.

Ecohumanism is an invitation to outgrow belief in such shackles as 'the iron laws of history' or 'the fixity of human nature.' Or, more generally, it is an invitation to question adherence to 'truths' and authoritarian behavioural rules inherited from earlier times, sometimes from earlier origin myths. The old stories do not have to be abandoned, simply recognised as having had a function at a particular moment in cultural history.

Freed from the dogmatism and fixedness of traditional origin stories and world views, the Ecohumanist doctrine being developed in this book, based as it is on an appreciation of scientific method, is always open to both extension and re-interpretation. Thus, each generation has to re-interpret history, or, more generally, the knowledge stock, in terms and concepts that are relevant to the time; and as each generation continues to learn in its own way, its new knowledge will become part of the story its descendants will live by and learn from.

So, have I, as Omar Khayyam put it, come out by the same door as in I went? Or, have I, as TS Eliot put it, returned from my exploring with a clearer view of where I started? I certainly have not found practicable cause and effect mechanisms which will protect or enhance global quality of life. Some will judge this unfortunate in a milieu where most people feel they are unable to discuss a problem publicly unless they have a solution to offer. There is every prospect that the people of the world are going to struggle and suffer enormously over coming decades. Perhaps that can and will be avoided, or perhaps it just won't happen. For those of us who are aware of these 'scenario' futures, several questions arise. Do I care? Which scenario will I adopt as my working assumption? Do I want to help protect global quality of life? How can I best help?

I find the prospect of plunging quality of life, world-wide, very plausible and very distressing but doubt if there is anything practical I can do. What I do know is that writing this book has increased my understanding of and empathy with my own species and sharpened my sense of the joy and pain of living. I very much want this species to seek and find quality survival. We may be about to endure a great setback but, if so, we will surely rise like the phoenix. And I realise that we will rise that much more easily if we can protect the knowledge stock that has been accumulating, with ups and downs, for several hundred thousand years. Nor do we want to have to struggle for centuries or millennia to regain the heights of joy and pain that a great poetic consciousness can express:[5]

Once and once only for
each thing-then no more.

For us as well. Once.
Then no more... ever.

But to have been as one,
though but the once,
with this world,
never can be undone.

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One pleasure of writing any book is the sparse flashes of insight that come as, mostly, one struggles to say things well enough, a somewhat grittier pleasure. Some of those insights come from within but more are triggered by arguments, or even phrases, in the books one reads. Once discovered, ideas tend to keep reappearing but there is something special about those who first open doors for you. I want to acknowledge, with particular affection, nine books and authors who have sharply expanded my understanding of the world:

[5] Rainer Maria Rilke (from his Ninth Duino Elegy)
http://www.hunterarchive.com/files/Poetry/Elegies/Duino_Elegies.html (Accessed 19 Jan 2011)

Julian Jaynes (1976) The Origins of Consciousness in the Breakdown of the Bicameral Mind[6].

Walter Ong (1982) Orality and Literacy: The Technologizing of the Word[7]

Gordon Childe (1936| 1981) *Man Makes Himself*[8].

Eric Fromm (1942), *Fear of Freedom*[9]

Eric Chaisson (2001), Cosmic Evolution: The Rise of Complexity in Nature[10]

Karl Polanyi (1944| 2001), The Great Transformation: The Political and Economic Origins of our Time[11]

Zoltan Torey (1999), The Crucible of Consciousness: A Personal Exploration of the Conscious Mind[12]

Peter Berger and Thomas Luckmann (1966), The Social Construction of Reality: A Treatise in the Sociology of Knowledge[13]

George Gaylard Simpson (1949), *The Meaning of Evolution*[14]

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[6] Jaynes, J., 1976, *The Origin of Consciousness in the Breakdown of the Bicameral Mind*, Houghton Mifflin, Boston

[7] Ong, W., 1982, *Orality and Literacy,: The Technologizing of the Word*, Methuen, London
[8] Childe, G. 1936|1981, *Man Makes Himself*, Moonraker Press, Bradford-on-Avon, England
[9] Fromm, E. 1942, *Fear of Freedom*, Routledge & Kegan Paul, London
[10] Chaisson, E., 2001, C*osmic Evolution: The Rise of Complexity in Nature,* Harvard UP, Cambridge, Mass.
[11] Polanyi, K., 1944| 2001, The Great Transformation: The Political and Economic Origins of our Time, Beacon Press, Boston
[12] Torey. Z., 1999, *The Crucible of Consciousness: A Personal Exploration of the Conscious Mind*, Oxford University Press, Melbourne
[13] Berger, P., and Luckmann, T. 1966, *The Social Construction of Reality: A Treatise in the Sociology of Knowledge*, Doubleday New York

[14] Simpson, G.G., 1949, *The Meaning of Evolution,* Yale University Press, New Haven

CHAPTER 1 THE DEEP PAST: A STORY OF PERVASIVE CHANGE

> The fate of individual human beings may not now be connected in a deep way with the rest of the universe, but the matter out of which each of us is made is intimately tied to the processes that occurred immense intervals of time and enormous distances in space away from us. Our Sun is a second- or third-generation star. All of the rocky and metallic materials we stand on, the iron in our blood, the calcium in our teeth, the carbon in our genes were produced billions of years ago in the interiors of a red giant star. We are made of star-stuff.
>
> Carl Sagan *The Cosmic Connection*, 1973, pp.189-90

This is a book about the plausible possibility that world society is entering an Overshoot Crisis which, within the next few decades of this twenty-first century, *could* produce widespread social disorganisation and plunging quality of life for a majority of the world's people. My chosen task in this opening chapter is to argue and demonstrate that a knowledge and causal understanding of what happened in the *Deep Past*---between the beginning of the universe and the advent of primates and mammals on Earth---is a valuable resource for those looking to respond, practically and attitudinally, to such a dystopic scenario. In the next several chapters I will extend the same approach to the more recent past.

As told by science, the step-by-step narrative of what happened in the Deep Past gets better by the year as researchers collect and interpret more and more data about the natural world and the universe, using ever-better measurement and experimental methods and organising frameworks. *Consilience* is making an important contribution here, i.e. insights from different scientific disciplines are, more than ever, being brought to bear on common puzzles; ecology, for example, is as important as genetics for understanding biological evolution. So, while there is much debate over the 'best' interpretation of particular events, concepts and sequences (dates of past events are particularly subject to revision), there are no glaring contradictions in the story in its outline form; it is eminently plausible. Many excellent books tell parts of this story,[15] and some further attempt to tell the larger story of both the distant and the more recent past.[16]

In this chapter I propose to make (selective) use of the story of the Deep Past in two ways. One, more general, is to use it as a vehicle for explaining what science has asserted about change processes *per se.* The other, more specific, is to use it to identify particular material changes in the Deep Past which might inform the way in which 'what-to-do' questions and 'what's happening?' questions are answered in the contemporary world.

With respect to these specifics, the story of the Deep Past is a source of provisional but rational information about how the Earth system has behaved over geological time and *might* hence behave into the future; in terms of, for example, volcanism, temperatures, sea levels, biological extinctions. For example, over geological time, the globe has been largely ice-free when atmospheric CO_2 levels have been above 500 parts per million.[17] The story brings an awareness of how the universe and the solar system are passing through their life cycles and what this means for the future of the Earth, including humans. Thus, it gives contemporary humans an initial 'fix' on the extent to which the bio-physical world's behaviour might be susceptible to human intervention versus the extent to which its various behaviours might have to be accepted and adapted to (or happily ignored).

On *change* as such, the story of the Deep Past, when it is listened to carefully, has the potential to bring home to people that it is often more productive to think of reality as a process of ongoing, ubiquitous change, punctuated by periods of relative stability, rather than the other way round.[18] Change is normal. Under this *world view*, 'things' are simply standing waves (attractors) in a continuous dynamical process and have no inherent absolute properties--- like eddies on a river. As Heraclitus said, 500 years before the Common Era (500 BCE)),'You can not step twice into the same river.' Even a stone is a

[15] Chaisson, E., 2001, *Cosmic Evolution: The Rise of Complexity in Nature*, Harvard UP, Cambridge, Mass.; Rees, M.J., 2003, *Our Final Century*, Heinemann, London
[16] Lloyd, C., 2008, *What on Earth Happened?* Bloomsbury, London; Southwood, R., 2003, *The Story of Life*, Oxford University Press, Oxford; Christian, D., c.2004*, Maps of Time: An Introduction to Big History*, University of California Press, Berkeley, London
[17] Glikson, A., 2010, Good Planets are Hard to Come By, Online Opinion, http://www.onlineopinion.com.au/view.asp?article=10033 (Accessed 29 Dec 2010)
[18] Whitehead, A.N., 1933, *Adventures of Ideas,* Free Press, New York

slow-moving dynamic process! For present purposes, a good reason for preferring *process thinking*[19] as a perspective to one which focuses on the behaviour of 'things' is that it is change, not stability, which brings threats and opportunities to human societies. Thus, the Global Overshoot Crisis is important because it embodies a threat of destructive change.

The more general insight that I am seeking to take advantage of is that abstract concepts that have been developed by generations of scientists for understanding the emergence and persistence of stars, planets, organisms and ecosystems can be remarkably useful for understanding, or just priming speculation about, change in today's global society, including the role of the human mind.

Consider the concept of *evolution,* the cornerstone of process thinking. At its simplest, evolution is any process of piecewise or bit-by-bit change over time. Understood at this level, evolutionary change pervades nature in all its forms. Charles Darwin and Alfred Wallace are rightly famous, not just for documenting evolutionary change in various animal and plant forms, i.e. change in their inherited characteristics, but for arguing convincingly that it has been a slow process of *natural selection* that has produced the unity and the diversity we can see in the tree of life. As Theodore Dobzhansky observed, nothing makes sense in biology except in the light of this process.[20]

Subsequently, since Darwin's time, the basic idea behind natural selection, namely, the *selective (non-random) retention of variation,* has been co-opted to explain evolutionary change in all manner of *systems*. Under the banner of *Universal Darwinism* or, to be less biological, *Universal selection*,[21] change-sequences in various physical, chemical, psychological, cultural (including economic and technological) and other types of systems have been 'explained' using one or another version of this powerful idea. For example, solving problems by 'trial-and-error' involves generating a variety of potential solutions until one which works is found and adopted (retained).

Another powerful and related idea for understanding change, one which I will show to be well-represented in the story of the Deep Past, is that reality is made up of nested layers of *dissipative* or *energy-degrading* systems[22]---smaller, faster-running systems nestling inside larger, slower-running systems. The fundamental property of dissipative systems is that they continuously take in energy, physical materials and information (a patterned form of energy with special properties) from their environment and continuously excrete (dissipate) materials, information and degraded energy---energy of a lowered quality in terms of its capacity to do work---back into the environment. For example, the multi-species assemblages which ecologists refer to as *communities* or *ecosystems* can, in some sense, be considered as energy-processing systems which are transforming high-quality

[19] http://plato.stanford.edu/entries/process-philosophy/ (Accessed 30 Dec 2010).
[20] Dobzhansky, T., 1967, *The Biology of Ultimate Concern*, Rapp and Whiting, London
[21] Hull, D. L., 1988, Science as a Process: An Evolutionary Account of the Social and Conceptual Development of Science, University of Chicago Press, Chicago; Nelson R.R. and Winter,S.G.,1982, An Evolutionary Theory of Economic Change, Belknap Press, Cambridge, Mass.
[22] Salthe, S.N., 1985, *Evolving Hierarchical Systems: Their Structure and Representation,* Columbia University Press, New York

solar energy into chemical energy and then distributing this to all of the community members to be dispelled, eventually, as heat, a low-quality (useless) form of energy. The link here to evolution is that evolution is a process which creates, maintains and destroys dissipative systems.

Apart from its value for exemplifying the generic nature of change and for indicating something of the future world's behavioural possibilities, I have a third reason for presenting some extracts from the story of the Deep Past: It is my belief that some (enhanced) version of this narrative will have to be an important part of the emotional capital, the system of beliefs and attitudes, that humans will need to call on to encourage and guide them, if and when they conclude they are facing a massive crisis which perhaps can be averted but, otherwise, has to be endured.[23] While I cannot expand that rationale here, I do return to it in my final chapter. Hinting at the flavour here, the quote from Carl Sagan at the head of this chapter not only introduces the material story of the Deep Past, but captures something of its evocative and energising power. 'Fancy that!' I say. It is wonderful and amazing that the breath I am now drawing probably contains gas molecules once breathed by Charles Darwin, to pick an historical figure whose spirit permeates this book. Equally wonderful is Sagan's pithy reminder that the hydrogen and helium which condensed out of the rapidly–cooling pulse of photons (packets of energy) produced in the first second of the life of the universe soon coalesced, gravitated, into 'furnace' stars where, for the first and last time, molecules of all the heavier elements would be 'forged.' Some of these, billions of years later, would end up in Darwin, long after being dispersed around the universe as their parent furnace-stars first imploded and then exploded, i.e. as they became *supernovae*. Planets, life and human intelligence can all be regarded as by-products of the stellar epoch. As a 'memory' which we all share, we are truly children of the stars.

EVOLUTION BEFORE LIFE

Formation of matter

The best available non-supernatural story of the evolution of the universe begins 13.7 billion years ago (Bya or Ga), soon after a postulated explosion (the 'big bang') projected incomprehensibly large quantities of super-hot high-quality radiant electro-magnetic energy outwards, taking the 'envelope of space' with it. According to the standard theory, the universe inflated from being a 'bubble' of space smaller than an atom, and a container for all the energy in the universe, to something larger than our solar system in less than a second---and has been expanding and (therefore) cooling down ever since.

Everything that has happened in the universe since that 'local density fluctuation' (and everything that will happen in the future) has been an instantiation, an expression of just one pervasive conversion process or equilibration process, namely, the ongoing conversion of that original high-grade (also called low-entropy) locally-concentrated energy into low-grade (high-entropy) locally-dispersed or spread-out energy. Call it the *cosmic equilibration process*. And *everything* means just that. It includes the formation, persistence and destruction of matter, galaxies, stars, planets, plants, animals, brains,

[23]Salthe, S.N. and Furhman, G., 2005, The Cosmic Bellows: The Big Bang and the Second Law, *Cosmos and History,,* **1**(2), pp.295-318.

ideas (minds??) and societies. Nature abhors disequilibrium! The cosmic equilibration process is spontaneous in the sense that whenever conditions allow (and such are many) the conversion process proceeds at the maximum speed compatible with those conditions. Or, putting this another way, for every set of conditions under which conversion is possible, conversion proceeds at a characteristic speed. It is a necessary condition for the occurrence of a spontaneous process that *entropy*, low-quality energy, should be produced.

Before going on, a word about energy, in particular about its quantity and quality. Like many abstract things, we have, to quote the great physicist Richard Feynman, 'no knowledge of what energy is.' A standard definition such as 'energy is the capacity to do work' is seen to be tautological when it is realised that 'doing work' means that the amount of energy in one part of a system of interacting entities is increased (we then say that *work* has been done on that part of the system) at the expense of the amount of energy stored in some other part of that system. For example, when Galileo supposedly carried his weights up the Leaning Tower, the weights acquired gravitational potential energy and Galileo lost chemical (metabolic) energy. What we most importantly do know about energy is that it exists in various forms (e.g. heat, light, gravitation, invisible radiation, kinetic, mechanical work, chemical, potential, nuclear, electrical etc) and that it can be converted (within limits) from one form to another without any loss in quantity---but with an inescapable loss in quality.

That last sentence is an informal statement of both the first and second laws of thermodynamics, this being the science of energy (a much better name would be energetics). The first law of thermodynamics says that energy can be neither created nor destroyed, only changed from one form to another. So the total quantity of energy in the universe is the same now as it ever was. The second law says that each time a quantity of energy of a particular quality changes from one form to other forms, there is a loss in the amount of energy subsequently available for and capable of participating in similar kinds of energy conversions in the future. A system's *entropy* is simply the amount of energy in it which is unavailable to do further work.

This pervasive process of converting or dissipating (useful word) low-entropy energy into high-entropy energy is equivalently called entropy production or 'loss of free energy'. From a human perspective, a common example is the conversion of high-quality chemical energy in the form of petroleum plus oxygen into low-quality 'waste' thermal (heat) energy and simple 'tailpipe' chemicals which have few high-energy bonds e.g. water and CO_2. After being converted into the kinetic energy of a moving vehicle, the chemical energy of petroleum is unavailable for further 'useful' tasks. The second law is simply saying that the cosmic equilibration process clicks over another notch whenever (and only when) energy is converted from one form to another. In this context, the cosmic equilibration process is the tendency for higher quality locally-concentrated energy to spontaneously dissipate into lower quality less-concentrated energy, i.e. it does so if it is not blocked (as it commonly is) by chemical, physical or psychological barriers/ constraints.[24] The reason that the evolution of the universe as a whole is irreversible is because its energy mix contains ever more entropy, never less. Thus, it can never return

[24] http://entropysite.oxy.edu/students_approach.html (Accessed 30 Dec 2010) has a good simple discussion

to last week's energy mix! The universe would be in equilibrium if it contained no pockets of relatively high-grade energy.

The famous Einstein equation reminds us that matter (that which has mass and occupies space) and energy are interconvertible under the right conditions. As the early super-hot universe cooled, conditions became suitable for matter in the form of, first, heavy particles (e.g. neutrons, protons and antiprotons), then successively lighter particles (e.g. electrons and positrons) to 'condense' from colliding photons (packets) of radiant energy. High-quality high-temperature photons were being converted into particles of matter plus lower-quality lower-temperature photons, an entropy-increasing process consistent with the cosmic equilibration principle and the second law of thermodynamics. As cooling continued, temperature-conditions necessary for the formation of matter came to an end and the amount of matter in the universe has remained approximately constant since that time.

The gradient or 'difference between locations' which is being increasingly eliminated by the cosmic equilibration process was originally created when, shortly after time zero, the universe was expanding and cooling so rapidly that the equilibrium proportions being successfully maintained between matter particles and energy particles (photons) during the first 100 seconds was destroyed. How? There is a different equilibrium ratio between numbers of matter particles and energy particles for each combination of mass density (gms of matter per cubic centimetre (cc) of universe) and temperature in the cosmic medium. But, after 100 seconds, density-temperature conditions were changing too fast for such equilibrium to be maintained. In an expanding universe, radiant energy was cooling faster than matter was cooling. Putting this another way, the reason that the amount of matter in the universe has stayed approximately constant is that since conditions cooled well below the temperature of matter formation, there has not been any energy source sufficiently concentrated to energise particles to the point where they would 'evaporate' back into radiation.

Formation of atoms and molecules from elementary particles

Between 10 000 and a million years after time zero, and with further cooling to 4000 degrees Kelvin (4000 degrees above absolute zero), elementary positive and negative particles could begin assembling into neutral atoms without being constantly broken up again by high energy photons.[25] Hydrogen (90%) and helium (10%) accounted for most of the atoms formed.

Radiation does not interact with neutral atoms as it does with a gas of charged particles. It simply passes through. So, as the neutral atoms formed, and with no free electrons left to scatter the photons of light, the universe steadily became transparent to radiation. It was as though, after 300k years from time zero, a great fog blanket had lifted. Once the radiation born in the Big Bang stopped interacting with (decoupled from) the matter it had given birth to, it became the cosmic background (microwave) radiation which can be observed today and which constitutes over 99% of the universe's total energy complement.

[25] Chaisson, E., 2004, Complexity: An Energetics Agenda, *Complexity*: (Journal of Santa Fe Institute), **9** (3), pp.14-21

Without charged particles to maintain thermal equilibrium (i.e., matter and radiation being at the same temperature and behaving as a single fluid) the temperatures of the matter and the photons went their separate ways. The rate of photon cooling was inversely proportional to the size of the universe, while matter cooled at a faster rate, inversely proportional to the square of the size of the universe. So, for the first time in the history of the universe, two temperatures were needed to describe things. As the temperature of the universe's hydrogen atoms (and hence their thermal energy) dropped below the dissociation energy of molecular hydrogen, they paired to form the first molecules.[26]

Formation of galaxies and stars from molecules

After the end of the molecule formation epoch, matter began clustering into galaxies, with the initial locations of embryo 'protogalaxies' corresponding to locations where a few molecules had strayed together by chance and stayed together long enough to begin collecting other molecules through gravitational attraction. Once started, such a process is self-reinforcing. It is also an entropy-producing process. Gravity is a weak force and only starts to have this gathering-in effect when molecules have insufficient thermal energy to keep them apart, i.e. after cooling below 100 degrees K. The phrase *thermal determinism* captures the powerful generalisation that there are a number of major transitions which can be readily explained as the result of the universe's decreasing temperature.[27]

As such emerging clouds of gas became ever denser, after 180 million years say, stars began igniting inside them, and clusters of stars began to form the large scale structures now known as galactic regions. While still continuing, galaxy formation (500 billion of them) was largely over after a billion years, by which time the cosmic temperature had plummeted to 100 degrees Kelvin or –173 degrees centigrade. An idea is now growing that the gross structure of the universe is that of a more-or-less flat 'mesh,' with long 'filaments' of galaxies criss-crossing each other. Particularly dense clusters of galaxies are found where filaments intersect. Despite the enormous size of this mesh, galaxies have been calculated to contain only 2-3 per cent of the matter in the universe. The rest, called *dark matter*, has not been explained. Taken together, dark matter and an equally mysterious *dark energy* are thought to make up most of the universe.[28] Dark energy appears to oppose the self-attraction of matter and to cause the expansion rate of the universe to accelerate.

While few new galaxies have formed in, perhaps, the last ten billion years, star formation (and destruction) has been a commonplace within galaxies, right up till the present. A typical star forms as ever-more hydrogen (mostly) atoms come together under the

[26] Lineweaver, C.H., and Schwartzman, D., 2004, Cosmic Thermobiology: Thermal Constraints on the Origin and Evolution of Life. In J. Seckbach, (Ed.) *Origins: Genesis, Evolution and Biodiversity of Microbial Life in the Universe* Kluwer Academic Press, Dordrecht, pp.233-248

[27] Lineweaver, C.H., and Schwartzman, D., 2004, *ibid.*

[28] Bahcall, N.A., Ostriker, J.P., *et al.,* 1999, The Cosmic Triangle: Revealing the State of the Universe, *Science,* **284**, pp.1481-1488.

influence of gravity, eventually packing together at a density at which nuclear fusion begins, creating a hydrogen-burning ‘stellar furnace’ in which, as described by Sagan, conditions are suitable for the nuclei of all the heavier elements to be synthesised from hydrogen and helium. So stars are dissipative systems which extract nuclear energy at high core temperature (~ 10^7 K) and discard it at low surface temperature (~10^3-10^4K). As an example of the contingent (but for…) nature of evolutionary processes, it can be noted that if the nuclear force that holds protons and neutrons together were any stronger, fusion of hydrogen to helium in the Sun would have finished long ago and if any weaker would not be delivering solar radiation at a level sufficient to sustain life.

Eventual demise of galaxies, stars and matter

Cosmological theory suggests that, in the fullness of time, galaxies and matter, as well as stars, will disappear from the universe. Massive ‘black holes’ dwell in most galaxies. These super-massive collapsed stars are called ‘black’ because gravity is so strong inside them that not even light-rays can escape from them. Over time they capture more and more of a galaxy’s matter. Viewed from the right position, Earth’s galaxy, the Milky Way, looks like a catherine wheel with trailing arms of stars spinning around a central ‘black hole’ every 250 million years or so. The star called the Sun is well out towards the edge of this galaxy and hence relatively safe from various nasty fates, such as being sucked into this black hole.

Long after the Sun has exhausted its fuel supplies and died down to a dim *white dwarf* star, and then a *black dwarf* (a non-radiant star), the Milky Way and other galaxies will move into what has been called the *Degenerate Era*. The only stellar objects remaining by then will be white-black dwarfs, brown dwarfs, neutron stars and black holes.

White dwarfs are the dying embers of standard hydrogen-burning stars. Their lives may be prolonged, somewhat but not indefinitely, by capturing and consuming ‘dark matter’---particles of several types that have so far eluded detection but which astronomers and high-energy physicists calculate must be present in the universe in enormous quantities. *Brown dwarfs* are failed stars, having insufficient mass to initiate thermonuclear, hydrogen fusion. Stars with a mass of about eight solar masses will complete their life cycle in a cataclysmic flare we know as a supernova. All that remains from such an event is a rapidly spinning *neutron star*, an object about the size of the Earth, composed exclusively of neutrons, with a density so great that a teaspoon of its matter is about the weight of the Earth. A star with a mass greater than eight solar masses may end up as a black hole rather than a neutron star.

Also during the Degenerate Era, galaxies will begin to unravel with some star-remnants moving out to the edge of their galaxies and others falling to the centres. Most remnants, including planets, will be adrift in intergalactic space, having been ejected from their galaxies.

What could possibly happen next? One suggestion is that the mass of remnant stars will begin to dissipate through a process called *proton decay*. For a long time, protons were believed to last ‘forever’, like electrons. It is now believed that even they have a finite lifetime, theorized to be between 10^30- 10^40 years. Since protons are a fundamental component of all matter, their decay into photons and positrons would mean the disappearance of all material structures.

That is, all material structures except black holes which, being made of neutrons, would be unaffected by proton decay, and would linger on. This is where the Degenerate Era ends and the *Black Hole Era* begins. But even black holes will not last forever. As long as they are being fed by captured stars, they will grow larger. But even these enormous masses must eventually dissipate into thermal radiation, photons and other decay products. Neutrons decay into protons, electrons and neutrinos. A black hole of one Solar mass may last for 10^65 years. A black hole with the mass of a typical galaxy may finally evaporate after 10^98 years. The era closes when all the black holes have radiated away and all that remains is a diffuse sea of electrons, positrons, neutrinos and radiation suspended in nearly complete and total blackness. The cosmic temperature will be a minute fraction above absolute zero. We will leave this plausible bur highly speculative story there, with the universe effectively dead.

The particulate, galactic and stellar epochs of cosmic history are all examples of the cosmic equilibration process. All involve processes in which some form of high grade freely-available energy is partly converted into other and different forms of high grade energy (e.g. matter, material structures, kinetic structures) and partly dissipated (dispersed, degraded) into lower-grade energy, including thermal energy, the lowest grade of all in terms of its availability for conversion to other forms of energy. For example, the clustering of matter under the attractive influence of gravity is a process of converting gravitational energy to potential energy and, as with all energy conversion processes, some of the energy involved is changed from a lower-entropy state to a higher-entropy state, e.g. changed to heat and light. In particle and atom formation, radiant energy is converted into the energy which holds those entities together. In fact, particle formation, atom formation, galaxy formation and star formation are all examples of dissipative processes taking place in dissipative or energy-degrading cum energy-transforming systems.

There is a degree of evidence to suggest that within the realm of what becomes possible (with cooling, for example), dissipative systems *self-organise* or spontaneously reorganise their networks of internal energy-conversion paths in such a way that the rate at which cosmic equilibration proceeds is maximised. This is called the *maximum entropy production or MEP hypothesis*.[29] It is an illuminating idea which is further discussed in an Appendix to this Chapter.

Formation of the Earth and Moon

Having summarised a plausible life story of the universe into a few pages, let us return to more local matters. The Earth's Sun was born as a typical star some 4.6 billion years ago (Ga), i.e. 4600 million years ago (Mya). It sustains itself by burning 150 000 tonnes of hydrogen a second, a rate of energy conversion which the Sun can sustain for perhaps another 5-7 bn years before swelling up 50-fold to become a 'red giant' star, incinerating the inner planets and then collapsing into a 'white dwarf' star and, ultimately, into a burnt out 'black dwarf'. Degrading free energy at such a rate sounds enormous but, on a per gm basis, the Sun's free energy rate density is 1/10 000 that of a human being.[30]

[29] Swenson, R., and Turvey, M., 1991, Thermodynamic Reasons for Perception-Action Cycles, *Ecological Psychology*, **3** (4), pp.317-348
[30] Chaisson, E., 2001, *ibid.*, p.139

The Sun and all its planets, i.e. the solar system, formed around the same time, i.e. 4-5 Ga. Beginning with a very hot, relatively homogeneous, rotating disc of matter, gravity and temperature differences caused materials with different masses and melting points to be pulled to different distances from the Sun where they eventually cooled enough to condense and accumulate. Dense materials with high melting points condensed and accumulated nearer the Sun, e.g. Earth, Mars. Less dense materials with low melting points condensed and, pushed outwards by particles ejected from the Sun (solar wind), cumulated further from the Sun, e.g. the gas planets.

Starting 4550 Mya as a relatively small pile of cosmic rubble drawn together by gravitational energy, the Earth grew steadily via accretion from a bombardment of various bodies including meteorites and comets, large and small. It is believed that much of Earth's water and carbon, both prerequisites for life to arise, arrived as cometary debris. There are no rocks surviving from that Hadean time because, under the heating effects of constant bombardment and radioactive decay, the Earth was molten. Indeed, the surface of the Earth was periodically vaporised and covered with an 'atmosphere' of rock vapour.[31]

High density elements like iron and nickel sank to the centre of this liquid globe to form an inner core of solid iron and an outer core of molten iron, both of which will probably remain so for billions of years. Calcium, sodium, potassium and aluminium silicates (feldspars) melt at temperatures as low as 700-1000 degrees C and when molten are relatively light. Early on, they would have risen to the surface by convection to become the most common minerals in the Earth's crust. This differentiation (separation) probably also initiated the escape of gases from the interior and led to the formation of the primitive atmosphere and the oceans. Flow of heat to the Earth's surface became more efficient (created more entropy) with the development of convection cells in the Earth's mantle (the layer between the core and the crust).

When a body we can call the *proto-Moon* struck Earth a glancing blow about 4.5 Bya and skidded back into space, it set the Earth spinning once every 17 hours or so.[32] Day and night were created but it took another 3.5 bn years for rotation time to slow to 20 hrs. Currently the Earth's day length is increasing by a second every 62 500 years, an hour every 360 megayears (million years). As the Earth rotates more and more slowly the Moon is spiralling away from the Earth at a rate of about 2.5 mm per lunar month. Eventually, under the influence of the Moon's gravity and the loss of rotational energy in the form of heat generated by the friction of tidal movements, the Earth's rate of rotation will fall below one revolution per 1100 hours.

As the Earth's rotation rate slows, its shape becomes more nearly spherical (less flattened), an ongoing process which creates tremendous dynamic pressures and stresses (stored energy) within the Earth's brittle crust as it endeavours to conform to the ever

[31] Hartmann, W.K., Ryder, G., *et al.*, 2000, The Time-Dependent Intense Bombardment of the Primordial Earth/Moon System. In Canup, R.M., and Righter, K. (Eds), *Origin of Earth and Moon*,, University of Arizona Press, Tucson, pp.493–512.

[32] Denis, C., Schreider, A.A., *et al.*, 2002, Despinning of the Earth Rotation in the Geological Past and Geomagnetic Paleointensities, *Journal of Geodynamics*, **34** (5), pp.667-685

changing mantle upon which its constituent tectonic plates (see below) float. Think of a wrinkling orange. Stresses from this and other internal processes such as shifts in the Earth's axis, and including convection currents in the mantle, are relieved (dissipated) by the triggering of volcanoes, earthquakes and mountain-uplift.

Evolution of the pre-life Earth

For perhaps 500 myrs after its formation, the Earth was a cooling but still molten sphere, too hot for life to emerge and survive---more thermal determinism. However, a few hundred million years later, with ocean temperatures still in the nineties, the first simple bacterial life forms had emerged.

Meanwhile, here is a brief description of how the Earth evolved and functioned as an integrated energy-processing, energy-degrading system in the pre-life era when conditions were becoming suitable for the emergence of the first organisms. My aim is to provide some background for later discussion of the processes by which life-forms and their physical environments (together called the *ecosphere*) subsequently evolved and co-evolved (i.e., evolved in tandem). A second aim is to discuss change and variability in the physical conditions of the pre-life Earth in a way which will inform later discussion of the conditions that life might have to adapt to in the future if it is to persist.

The main idea to be established and reinforced is that life emerged in a dynamic world where conditions were (and still are) always changing, slowly in some cases, rapidly but smoothly in others and, irregularly, there can be high-energy disturbance events emanating from space or from within the Earth. The latter have sometimes dramatically reconfigured (re-organised) the global pattern of energy dissipation associated with the cyclical movement of materials around the planet. Just as the universe as a whole can be viewed as a self-organising dissipative system spontaneously degrading energy at the maximum available rate by using that energy (plus materials) to form kinetic and static structures, so can the (pre-biotic) Earth. In Earth's case the kinetic structures are the networks of pathways along which various materials are cycled through the lithosphere, the hydrosphere and the atmosphere.

How does the planet dissipate energy?

The Earth has long been an interwoven network of co-evolving (jointly-changing) energy-dissipating sub-systems, drawing the energy which these sub-systems collectively degrade from two main sources, namely, the Sun and the planet's hot core.

<u>Solar energy</u> Step by step, incoming solar energy is degraded from high-grade (high energy per photon) short wave radiation to outgoing low-grade (low energy per photon) long-wave radiation as it drives many of the planet's surface processes such as wind patterns, precipitation, erosion, ocean currents, electrical storms etc. This applies in the biotic as well as the pre-biotic world, the difference being, as we will discuss, that there are many more pathways in the biotic world.

Remember that energy cannot be converted from one form to another without simultaneously converting part of that same energy to a low-grade form (e.g. waste heat in the form of enhanced molecular kinetic energy) which cannot be subject to further conversions. Thus, a portion of all incoming solar energy is irretrievably lost back into space with each successive conversion of that incoming energy to other forms. However, while all incoming solar energy is ultimately degraded, this does not happen instantaneously. It takes time, called *residence time,* for energy to move via various processes along pathways between different planetary ‘reservoirs’ where it is temporarily stored. For example, solar energy which produces clouds by evaporating water has a much longer residence time on Earth than energy which strikes polar ice and is immediately re-radiated back into space.

Geosphere energy In addition to the solar energy which drives surface processes, many of the planet’s geological processes continue to be driven by the original conversion of gravitational potential energy to, first, kinetic energy and then to heat during the coming together of proto-planetary raw materials.[33] Ongoing nuclear reactions in the planet’s lower mantle further boost temperatures there to something like that of the Sun’s surface, more than 5000 deg. Kelvin. This internal energy store creates and drives processes such as continental uplift, drift and collision, sub-surface magma (hot semi-fluid) flows, volcanism, magnetic-field formation, seismic activity and polar shifts. For instance, it is core heat which drives convection currents in the viscous mantle on which the more rigid crustal surface is ‘floating.’ Convection currents are probably the mechanism by which rigid plates of crustal rock (tectonic plates) are separated, pushed together or rotated, causing great rifts in the crust where the plates separate, or high mountain chains where they collide. Plate motions also give rise to earthquakes and a high heat-flow towards the surface, especially along the plate boundaries where volcanoes tend to be formed, e.g. the Pacific Ocean’s ‘rim of fire.’

All of these processes can be regarded as alternative pathways in a large *heat engine* which is simultaneously transferring heat energy from inner Earth to outer space and converting heat energy into the kinetic energy of various material flows and mass movements. A heat engine is a device which converts heat energy to the kinetic energy of mechanical work. Notwithstanding, the amount of internal heat reaching the Earth’s surface to be eventually radiated into space is very small compared with the amount of solar energy reradiated into space.

Not all outgoing geothermal energy is converted to mechanical work; some geothermal energy is also re-stored in static structures, e.g. the kinetic energy of a moving tectonic plate is converted to and stored as gravitational potential energy when used to push up mountain ranges.

Other energy inputs As noted, the Earth’s rotational energy is gradually being dissipated by tidal friction and its angular momentum transferred to the Moon---which means sending the Moon into a more-distant orbit. Earth-Moon and Earth-Sun gravitational forces are expressed as bulges in the Earth's land and sea surfaces. Tidal flows in the oceans are what happen as the Earth rotates beneath these bulges; the resulting ‘braking’ friction in both crust and oceans is Earth-warming.

Finally, there are several types of small (usually) but concentrated and localised energy inputs to be processed and dissipated by various Earth systems. Lightning is not one; it is an important high energy driver of atmospheric processes (e.g. ‘fixing’ nitrogen) but is generated within the Earth system. Asteroids and other occasional bodies from space have to be included here. For example, the asteroid which exploded above Siberia in

[33] Chaisson, E., 2001, *ibid.,* p.162

1908 had the energy of a thousand Hiroshima bombs. Simulation models suggest that an asteroid 5 km in diameter, if it landed in the Atlantic Ocean, would produce a tsunami high enough to inundate most of the world's coastal landscapes.

Overall, while still high today, the specific rate (i.e. rate per gm) at which the planet is processing incoming energy to other forms and radiating away the low-grade thermal energy this produces has fallen considerably over time, particularly in comparison with Earth's first half billion years. This observation is not incompatible with the idea that, in any time interval, the quantity of entropy (energy that has been degraded to heat) being produced by the Earth system is higher than it would be if no global material-energy cycles had emerged after the planet's initial cooling, i.e. whenever physically feasible, such cycles come into existence (spontaneously self-organise) as a way of better satisfying the *cosmic imperative* to degrade high quality energy into low quality energy as rapidly as possible. While energy-in must still equal energy-out if the Earth's temperature is not to change, the outgoing energy is of lower quality than it would have been in the absence of material cycling.

The mechanics of global material-energy cycles

The restless Earth is only able to continue dissipating solar and core energy as fast as it does because the sequences of global-scale energy conversion and transfer processes which produce dissipated energy are largely based on a 'circulatory system' of more-or-less closed material cycles. These include (see Box 1.1) climate-weather cycles, geological, geophysical and geochemical cycles and, more recently, the biological cycle. Let me explain.

A typical global material-energy cycle has three sorts of components:
(a) Reservoirs for storage of materials
(b) Transport paths which denote how material moves between reservoirs
(c) Fluxes (flow rates) which describe how much material moves along particular transport paths.

During any movement of matter between reservoirs, energy is used to convert materials (air, water, chemicals, rock, soil…) from one form to another (e.g. gas to liquid) and/or to do the work required to transport materials from reservoir to reservoir. And, in accordance with the cosmic equilibration process, the 'thermodynamic imperative', some of the available energy is converted at each stage into unavailable thermal energy which is then radiated out into the heat-sink of space. Labelling such an energy conversion processes as cyclical simply means that most of the materials which are transformed or transported at each stage eventually return to where, and in much the same form as, they started out. This means that these materials are being recycled, that, in some sense, they are being renewed and the system is *self-maintaining*. Self-evidently, if something like this does not happen, the chain of processes in a multi-stage energy conversion cycle will stop when the available stock of input materials is exhausted.

Box 1.1 Some important global material-energy cycles
Hydrologic cycle
Climatic and meteorological cycles
Oceanic cycle
Ice cycle and sea level cycles
Biological cycle
Elemental (geochemical) and nutrient (biogeochemical) cycles
Supercontinent cycle
Rock-soil cycle

Examples

In the *hydrologic cycle* for example, solar energy is used to evaporate liquid water, from the oceans say, into vapour and, simultaneously, to increase its (latent) energy content by 2.4 x 10^6 J per kg. This water vapour is carried upwards by atmospheric convection currents till it condenses at high altitudes where the air cools (due to its volume expanding as the air pressure falls) and, in condensing, releases, as heat, the energy it absorbed when first vaporised. The released heat is eventually radiated back into space and the liquid water is recycled back into the oceans as rain. So, as crudely described here, there are two stages in the hydrologic cycle. In the first stage, water is converted into 'high energy' vapour and lifted skyward. In the second stage vapour is converted back to liquid water, low quality thermal energy is released and the water falls to the oceans as rain. Thus, the cycling of water is completed and the stock of water available for evaporation is renewed. If most water vapour drifted into space on reaching high altitude, the hydrologic cycle would soon stop.

The *characteristic time* of a material-energy cycle is the time normally taken for materials to pass through every stage or reservoir of the cycle. One of Earth's longest cycles is the supercontinent (or Wilson) cycle, which has an average duration of about 500 myrs. Beginning about 3000 Mya there have been five or six cycles of breakup and reformation of one or more supercontinents. A supercontinent (the most recent ones, formed when Pangaea broke into two, were Laurasia and Gondwana) breaks up into smaller continents when *radiogenic heat* from relatively shallow internal radioactivity is trapped underneath it and builds up to the point where the 'lid blows' and the supercontinent ruptures into pieces. After being broken up in this way heat no longer accumulates and the smaller continents eventually drift back together again. It might be noted that if the planet's sources of radiogenic heat were any deeper in the core, the planet would periodically revert to a totally molten state.[34] As it is, the bulk of the

[34] Strahler, A., and Strahler, A., 1997, *Physical Geography: Science and Systems of the Human Environment,* 4th ed, Wiley, New York, p.169

geosphere has been comparatively stable for the past three billion years with unrest largely confined to the 'rind-like' crust and uppermost mantle. It is the boundaries of continental plates which are the sites of most earthquakes, volcanic activity, and exchanges of heat and volatiles between the interior and the oceans and atmosphere. Plate tectonics is one of the great unifying theories in geology. Virtually every part of the earth's crust, and every kind of rock and every kind of geology can be related to the plate tectonic conditions which existed at the time they formed. It has been said that 'Nothing in geology makes sense except in terms of plate tectonic theory.'[35]

More generally, the way in which the supercontinent process spews out new oceanic crust at mid-ocean ridges and destroys it beneath ocean trenches represents a major cycling of crustal material, water and chemical constituents between the Earth's surface and its interior. This fundamental tectonic (rock-forming) process plays a major role in controlling the chemistry (behaviour of matter at the molecular and atomic scales) of the ocean and atmosphere.

The *rock cycle* (see Box 1.2) is an example of a shorter, more localized material-energy cycle superimposed on the supercontinent cycle.[36] It involves the solidification, erosion, sedimentation, recompaction and re-melting of the mineral constituents of Earth's rocks.

Box 1.2 New rocks from old: An example of a global material-energy cycle

Simplifying, the rock cycle can be described as follows:

1. Magma cools and solidifies (crystallises) forming igneous rock;

2. Igneous rock weathers, gets transported, and is deposited as sediments;

3 Sediments, through cementation and compaction, lithify to form sedimentary rock;

4. Sedimentary rocks, through pressure and temperature, largely at margins of continental plates, become metamorphosed forming metamorphic rocks (igneous rock can also be metamorphosed without first becoming sediments);

5. Metamorphic rock gets melted, forming magma once again (alternatively, metamorphic and sedimentary rock can be weathered, transported and deposited to form new sediments).

Geochemical cycles are those planetary-scale material-energy cycles in which individual elements such as phosphorus, carbon, nitrogen, oxygen pass through a recursive sequence of chemical forms, each embodying a different level of chemical energy. However, because these cycles have been so dramatically influenced by processes associated with the emergence of life (e.g. nutrient cycles in ecosystems), making them

[35] http://csmres.jmu.edu/geollab/fichter/Wilson/Wilson.html (Accessed 27 July 2009)
[36] Strahler, A.N. and Strahler, A.H., 1973, Environmental Geoscience: Interaction between Natural Systems and Man, Hamilton, Ca.

biogeochemical rather than geochemical, we will delay their discussion until we discuss the evolution of biological cycles.

Interacting cycles

While it is convenient to describe Earth's pre-life global cycles as separate dissipative processes, there has always been a network of strong interdependencies, relationships of mutual influences and interdependent evolution (coevolution), among the main cycles.

The supercontinent cycle provides several illustrations of such interconnections. Each time a supercontintent is pulled apart, huge quantities of greenhouse gases are released and warm, wet greenhouse conditions come to prevail. When smaller continents recombine, mountain ranges and continental platforms are pushed up, soils form and assimilate CO_2 from the atmosphere as they erode; eventually this CO_2 is incorporated back into marine deposits, e.g. limestones. CO_2 levels in the atmosphere then fall, the significance of this being that glaciations and ice ages occur when atmospheric CO_2 is low. It seems then that supercontinent cycles create conditions that also produce very long climatic cycles. Various climatic cycles with much shorter characteristic times are then superimposed on these very long climatic cycles. Some of these shorter cycles, driven by various periodic changes in solar energy, are very regular (e.g. recent ice ages) and others (e.g. volcanic winters) are quite irregular.

Crustal landscapes provide another example. Under the influence of four interacting energy sources---geothermal heat, solar radiation, Earth's rotational energy and gravitational attraction---the evolution of Earth's physiography (landscapes) began with the formation of the primitive continents, oceans and atmosphere. For example, the momentum of the Earth's rotation and the gravitational attraction of the Sun, Moon and Earth led to the occurrence of tidal forces which are most noticeable in water bodies and which especially affect coastal landscapes. Gravitational forces provide energy less directly, but by attracting all earth materials towards the Earth's centre, impart a potential energy to rocks and soil.

Geothermal heat initiates the injection of new material into the crust and the spilling of molten magma onto the surface to form volcanoes and lava flows; and also the earth movements which produce large scale uplift, warping and folding. These processes are generally constructional in that they lead to an increase in elevation and relief. Subsequently, erosional and depositional sculpting, driven by gravity and the energies of the solar-powered wind and water cycles reduces the elevation of these primary landforms.

Lurking here we have a particularly clear example of the coevolution of dissipative landscape processes. The geological cycle produces mountain ranges which increase the rainfall they intercept by lifting rain-bearing winds to heights where they more readily precipitate their moisture as rain. Increased rainfall increases the rate at which the mountains erode and deliver sediments to the ocean where it will again be converted to rock. So, despite large differences in characteristic times, changes in the meteorological and geological material-energy cycles are mutually influencing each other in terms of how and where they are processing material and energy, i.e. they are co-evolving.

It was the long-term interplay between these internally-generated constructive and externally-generated deconstructive processes which guided the history of Earth's pre-biotic landscapes for a billion or so years. Then, as will be discussed presently, with the emergence and proliferation of life, a biological cycle began to interact with the physical cycles of the atmosphere, the hydrosphere and the lithosphere and, thereafter, strongly modify the history of landscape evolution. For example, we will reflect on a remarkable correlation between the supercontinent cycle, the long-term rise in atmospheric oxygen level and the increasing complexity of plant and animal life-forms.[37]

Kinetic and static structures

This is a moment to recapitulate, in quite general terms, the basic behaviours of dissipative systems (and their component dissipative structures) of the type represented by global material-energy cycles.

It bears repeating: dissipative systems are the processes through which the universe's spontaneous tendency to smooth out (eliminate) all potential energy gradients (differences in energy density between locations) works itself out. How do they do this? In their *closed form*, they are bordered collections of matter which receive energy of a particular spectral quality from the environment and return energy of a lower quality than that received. This is what *dissipation* means---the conversion of *exergy*, i.e. energy capable of doing work, into *entropy, i*.e. energy not capable of doing work. In their *open form*, they receive both matter and energy and give out both matter and energy. The Earth, our present example, is a dissipative system which has been effectively closed since the pre-biotic Earth stopped accumulating materials from space.

Delving a little deeper, the relatively-high quality energy entering a dissipative system is not dissipated until it does work on the materials residing in the system, either by moving those materials around or by changing their chemical or physical structure. When the energy which is moving materials around the system and imparting kinetic (motional) energy to them forms those materials into persistent observable forms it is creating *kinetic structures*. When the incoming energy is used to transform the system's materials, either chemically or physically, into forms with higher potential energy it is creating *static structures.* Both kinetic and static structures function as energy stores, with bigger structures storing more energy.

The important difference between kinetic structures (e.g. the global system of ocean currents) and static structures (e.g. landforms, mineral deposits) is that kinetic structures spontaneously collapse, i.e. lose their organised form and stored energy, when energy flow into the system stops whereas static structures do not. Kinetic structures are constantly being regenerated from materials being imported from the environment (open systems) or, in the case of global material-energy cycles from recycled materials (closed systems).

Static structures are usually formed by *associative processes* in which clumps of matter are brought together and held by molecular-bonding energies. This is why they do not break down and lose that stored potential energy (gravitational, chemical, etc) until an appropriate external pulse of bond-breaking *activation energy* is applied, e.g. heat energy,

[37] Campbell, I.H. and Allen, C.M., 2008, Formation of Supercontinents Linked to Increases in Atmospheric Oxygen, *Nature Geoscience*, **1**, pp.554-558

mechanical energy, chemical energy. Once a static structure has had its energy content raised to a critical level by a pulse of activation energy of some sort, it will spontaneously change its structure to one with less exergy (a state of ‘minimum free energy’) and dissipate the ‘lost’ exergy. Static structures, because they have no tendency to spontaneously change, are sometimes called equilibrium structures but this can lead to a confusion with thermodynamic equilibrium, meaning a system in which all exergy has been converted to entropy.

The natural variability of global cycles

Like all dissipative processes, the planet’s main energy-degrading cycles in the atmosphere, hydrosphere, solid crust and core-mantle (and, as we shall discuss presently, the biosphere) all had a beginning and, one day, either before or when the Sun dies down, all will end. First, the Earth had to cool sufficiently for its atmosphere to outgas, its oceans to condense and its crust to solidify. Only then could these novel material structures respond to the solar and core energy loads on them by self-organising from what might be called disordered dissipation into the sorts of material-circulating, energy-dissipating systems described above. Looked at over the time scale of geological eons, the rate at which energy has been and will be dissipated by Earth’s material-energy cycles will increase from zero, peak, and then decline back to zero.

But, looked at on shorter timescales, including the timescale of human affairs, the rate at which energy is dissipated in any of these cycles fluctuates around an effectively-constant trend value. Like true love, the course of Earth’s cycles does not run smooth. Even if there were no variability in the solar and geothermal inputs driving global cycles, there would still be a degree of intrinsic variability in cycle behaviour, i.e. in fluxes along the transport paths between reservoirs, droughts for example. For much of the time, each cycle will be similar to but not quite the same as the cycles preceding and following it. In the language of dynamic systems theory, as we shall see below, such ‘self-similar’ cycling is characteristic of the behaviour of a system which is being spontaneously drawn towards a *strange attractor*, also known as a *chaotic attractor*.

At other times, under the influence of somewhat larger disturbances in a cycle’s material-energy sources it will temporarily move away from this ‘normal’ dynamic-equilibrium behaviour. And, less frequently, under the influence of even larger disturbances, the cycle will breach its *homeostatic limits* and *self-organise* into a distinctly different network of fluxes between reservoirs, e.g. setting up new paths, new reservoirs (see below). As a general rule then, Earth’s dissipative systems are stable in the sense that when environmental conditions change, and stay changed, they transit to and then tend to remain in a new dynamic equilibrium, more or less different from their previous state.[38].

All sorts of disturbances

Both solar and geothermal inputs into global cycles exhibit random and periodic (oscillatory) variability. Oscillations in flow rates through global cycles caused by (entrained by) oscillations in insolation (radiation intensity) range from daily (e.g. sea breezes) and yearly (e.g. seasonal rainfall) to multi-millennial (e.g. ice ages). Indeed, linked to the rotation of the galaxy, there might be at least one 250 million year insolation

[38] Strahler, A.N., and Strahler, A.H., 1997, *ibid.*

cycle. At the other extreme, while sunspot cycles are periodic, solar flares (storms on the Sun's surface) appear to be randomly variable.

Variations in circulation rates can also be due to interactions between cycles, for example, their coevolution as described above. Throughput and circulation rates also vary when energy and materials leak from or are diverted from one cycle into another. For example, much water is removed from the hydrologic cycle when tectonic plates slide over each other.

Conversely, materials can temporarily accumulate in one or more reservoirs of a cycle, e.g. rising sea level. In a *strongly-buffered cycle* the rate at which material-energy is moving through the cycle is small relative to the storage capacities of the cycle's reservoirs. This usually means that changes in throughput in one part of the cycle take a long time to affect other parts of the cycle; the system is insensitive in the sense of being slow to respond to a given change in input rates.[39] For example, the oceans have a massive capacity to store thermal energy (heat) and, under contemporary global warming, are taking a long time to heat up to the point where their circulation patterns will change. Similarly, the planet's ice caps are buffers which can expand and contract enormously with variations in heat flow from the tropics. Or, another example, variations in river flow due to varying rainfall are smoothed out when large falls are temporarily intercepted and stored in the landscape's soils and waterbodies. Ultimately, a cycle can only proceed at the processing rate of its slowest link.

Importance of self-reinforcing and self-correcting feedback processes

Feedback processes have underlain much of the historical variation in processing rates exhibited by global cycles. They are processes which, at higher or lower rates than is 'normal,' either deplete or augment stocks of materials stored in particular reservoirs. Alternatively, they are processes which act to reverse some initial change. In a feedback process some initial causal disturbance (change) in a stock level is, subsequently, either amplified (positive or self-reinforcing feedback) or dampened (negative or self-correcting feedback) by the very effect that it produces. Positive feedback processes are also called *autocatalytic* or self-catalysing processes. In some cases of positive feedback the rate of change may keep increasing until it encounters a 'limit' of some sort. Negative feedback processes are also called *homeostatic* processes if they result in the system being returned to a previous steady state or *homeorhetic* when they return the system to a prior trend or developmental path, e.g. long-term increases (decreases) in sea level, atmospheric carbon dioxide, atmospheric oxygen. *Complex* is a useful term for describing systems containing multiple feedback processes.

All feedback processes are examples of *circular causation*, i.e. process A affects process B affects process C...affects process A. For example, in the positive feedback process which produces 'runaway' global warming, a small increase in greenhouse gases (e.g. from volcanic eruptions) allows the Earth to warm to the 'threshold' point where greenhouse gases trapped in ocean sediments, permafrost beds etc are released into the atmosphere.

[39] Strahler, A.N. and Strahler, A.H., 1973, p.16

A contrasting example of circular causation is the process which has occasionally led to an ‘icehouse Earth’: an initial disturbance which cools the Earth enough to increase its area of surface ice can trigger ‘runaway’ cooling when the newly formed ice reflects rather than absorbs solar energy, and that of course leads to further cooling and more surface ice. Over the life of the Earth, the most spectacular examples of positive feedback in global mass-energy cycles have perhaps been three occasions (600 Mya, 750 Mya and 2.3 Ga) when the Earth, including the oceans to a depth of at least a km, has been largely frozen. It is thought that, following an initial period of cooling triggered by declining CO_2 levels or increasing oxygen levels, glaciers and sea ice, which reflect solar energy back into space, expanded to the point where further cooling followed. Every movement of the ice front towards the equator reduced, at an increasing rate, the amount of solar energy absorbed by the Earth’s surface and so induced more glaciation. Each time this ‘runaway ‘ process had led to a ‘Snowball Earth’ the planet has remained frozen for 7-10 myrs until, plausibly, the steady release of CO_2 from volcanoes restored the atmosphere’s capacity to trap heat from the Sun and allowed the Earth to warm again----another good example of the coevolution of Earth’s material-energy cycles.

All positive feedback processes have a common mechanism in that they use the energy they are processing to create stable structures and kinetic processes which increase the likelihood that they will capture even more energy (or, in some cases, such as ‘snowball Earth’ scenarios, even less). A plant which uses light energy to make light-capturing leaves is a clear-cut example.

Another shared property of positive feedback processes is that they always come to an end. This might be because of energy or feedstock shortages or because cumulative change in the system experiencing positive feedback triggers ‘corrective’ feedback processes which halt or reverse the cumulating change, perhaps by diverting materials elsewhere.

In the runaway-warming example, the supply of trapped CO_2 could either be exhausted directly or the accumulation of atmospheric CO_2 might, in raising temperatures, speed up negative feedback processes which remove CO_2 from the atmosphere. Specifically, as temperatures rise, much CO_2 is removed from the atmosphere because CO2, as carbonic acid, is an agent in rock weathering and rock weathering takes place more rapidly at higher temperatures. So, under negative feedback, stock-accumulation processes trigger or enhance countervailing depletion processes. Or, conversely, depletion processes trigger countervailing accumulation processes. In either case, negative feedback processes decline as the system returns towards its pre-disturbance steady state.

Succinctly then, global cycles respond in different ways to small and large, temporary and ongoing, additions to and withdrawals from their material-energy supplies. Small pulses, whether internally or externally generated, are accommodated by variations in flow rates within the existing structure of paths and reservoirs, perhaps transmitting the pulse through a hierarchy of cycles superimposed on cycles. When the pulse is over, the cycles’ behaviours tend to revert to the self-similar dynamic equilibria in place prior to disturbance.

Large, but not disruptively large, pulses of additional material-energy which cannot be accommodated within existing structures tend to initiate the budding off of new dissipative structures which grow through positive feedback till all the additional inputs are being processed. If the flow of additional inputs persists however, the new structures tend to persist too. Conversely, if large quantities of energy and materials are withdrawn, then parts of the system's structure and organisation will necessarily close down, e.g. plant growth ceases during 'volcanic winters'.

Perhaps the more general point here is that while feedback processes within any global cycle always come to an end, they can open and close (activate) all sorts of dissipative paths on the way to that end. This is because whenever there is a change in the material-energy entering or leaving one cycle there must be a corresponding change in another cycle (or in another part of the same cycle). It is this reciprocal relationship which ultimately underlies interaction between and coevolution among global cycles. The metaphor that comes to mind is that of a great river cutting new channels while abandoning and silting up existing channels as it ineluctably descends to the sea.

Early Earth was a self-organising dissipative system

Let us now expand on the single most powerful idea available for explaining year-to-year and place-to-place variations in the circulation rates and kinetic (material flow) pathways of global materials (water, rock, magma, minerals, gases etc) in the pre-biotic world, namely, *self-organisation.* It is a concept which has much in common with, indeed subsumes, the idea of *emergence*, introduced above to describe how the pathways available for dissipating the universe's energy changed dramatically over the universe's first few billion years. Thus, we talked of the sequential emergence of matter, galaxies, stars and planets. While the term 'emergence' is sometimes restricted to describing only these sorts of major changes in system organisation, notably the rate of processing energy, it will be convenient for present purposes to regard any system which is the result of a dissipative system having spontaneously re-organised, wholly or partly, as being emergent, i.e. as having emerged from its previous configuration.

Think of the Earth as a single large (by our standards) energy-dissipating system. Like most, dissipative systems, the Earth has a capacity to cycle and dissipate the matter and energy passing through it in a variety of ways, depending on its current structure and organisation and on the form and delivery rate of the system's energy inputs. In practice, the Earth's material inputs from, and outputs to, space have been minimal since it was first formed and can be ignored, i.e. the Earth system is effectively closed to material flows but open to energy flows.

Any dissipative (energy degrading) system is said to *self-organise* when it spontaneously (i.e., without being obviously triggered or, more accurately, triggered by an extremely small fluctuation (noise) in energy flow) changes, wholly or partly, from using one set of paths and reservoirs for cycling energy and materials to using a somewhat different set of paths. That is, the system re-organises itself from one form of organisation to another. As its temperature fell below its melting point, the early Earth self-organised or, as I prefer, self-re-organised in a major way; it changed from being a homogeneous molten sphere losing thermal energy by conduction to being a hierarchical set of interwoven material-energy cycles, ranging from the 500 million year supercontinent cycle to daily weather cycles. Once the planet cooled enough to allow atmosphere and ocean to form, thermal energy could thereafter be transported by coherent (organised) convection currents as well as incoherent conduction to the planet's surface. In accordance with the principle of maximum entropy production (see Appendix to this Chapter), the cyclic mode, being the better entropy producer, was spontaneously selected as the planet's main mechanism for dissipating energy via the hydrosphere, lithosphere and atmosphere.

Very approximately, the self-organising Earth, taken as a whole, is, like a pan of gently simmering water, a *steady state system*. The two main ways of dissipating solar and core energy are the transfer of heat energy from the Earth's surface to the upper atmosphere and from tropical to polar oceans. Despite a history of fluctuating flows through these and the other global material-energy cycles of the lithosphere, hydrosphere and atmosphere, the Earth has stayed in approximate energy balance for four billion years. That is, despite variations in solar and core energy inputs, global surface temperature--- the most important characteristic of the climate--- has almost always remained in the comparatively narrow range of 10-20 degrees C; the present average is 15 degrees C.[40] For example, the Sun was less bright in the distant past and has since intensified by about 25 per cent.

There will always be some imbalance between energy being absorbed and energy being dissipated. Since 1850, for example, additional incoming energy (e.g. from fossil fuel use) has exceeded additional outgoing energy by 1-2 Watts per sq m of the Earth's surface, with a large fraction of this excess going into heating the oceans. Another example: some 250 Mya the Earth warmed to the point where the temperature difference between equator and poles was insufficient to create convection currents in the single global ocean surrounding the then supercontinent (Pangea) and, as this unstirred ocean stagnated, its oxygen level fell to the point where 95 per cent of all marine species died out. Many fear that this could happen again under contemporary global warming.

Whether or not the Earth would have stayed in such tight energy balance, maintained such a constant entropy content, if life had not evolved is an open question which will be explored presently. We will see that the global biological cycle has incorporated a number of powerful positive and negative feedback processes which did not exist in the period when all the planet's dissipative processes were purely physical, a period which started to end about four Bya.. One modelling exercise suggests that, without its biosphere, the global dissipative system would bifurcate, unpredictably, to one of two stable states with surface temperatures of -100°C or + 400 C respectively.[41]

An appendix to this chapter (More on Self-organising Systems) discusses how the quirky behaviours of self-organising systems can be better understood by using concepts from the theory of *non-linear dynamic systems*. It also expands on the relatively new idea that dissipative systems which are not confined to one steady state will tend to evolve to a state which maximizes the rate at which they produce entropy.

EVOLUTION OF LIFE AND THE ECOSPHERE

The story of the evolution of the physical universe up to the time when it became possible for Earth-style life to evolve has been cast in terms of flows of energy and matter through

[40] Gorshkov, V.V., Gorshkov, V.G., *et al.,* 1999, Biotic Control of the Environment, *Russian Journal of Ecology,*. **30** (2) pp.87–96.
[41] Gorshkov, V.V., Gorshkov, V.G., *et al*., 1999, *ibid.*

an evolving hierarchy of open systems. It is a perspective we will continue to draw on as we extend the evolutionary story to life and the ecosphere. It is a beautiful illustration of the concept of *path dependency* (where you can go depends on where you have been) that Earth-life as we know it could not have evolved in the absence of any of the following necessary physical conditions:[42]

A stable parent star (the Sun), not too close to the centre of the galaxy where radiation is high and not too far out where metals are not present in sufficient quantity for planet formation.

A 'right size' parent star (if the Sun had been 30 per cent larger, it would have burnt out in 4 billion years).

Earth being formed in a 'goldilocks' orbit around the Sun (neither too close and too hot nor too distant and too cold for carbon-based life).

Earth's moon being of the right size to stabilise its angle of tilt (and hence stabilise its seasons and ocean basins).

More debatably, Earth's location near a large planet (Jupiter) has provided it with a protective gravitational shield.

While physical conditions in the atmosphere, the hydrosphere (oceans and other bodies of water) and the lithosphere (solid outer surface of the planet) have changed continuously, markedly and variously since those times, and the conditions under which life can persist have also changed as life has evolved, it has, self-evidently, never become impossible for life to survive. The question we are not asking here is whether another form of life, different from the carbon-based, water-based, DNA-based form that we know, would have evolved if the above 'necessary' conditions had not been met.

By c.4400-4100 Mya the Earth had cooled sufficiently for the continental plates to form and for the oceans to condense from water vapour in the atmosphere. That is, conditions had become such that the evolution of carbon-based life was no longer impossible. And, in the event, life did evolve, presumably some time before the dates attributed to the oldest microfossils, namely c.3800 Mya. These newly-emergent types of dissipative systems, the first unambiguous life forms, were the *prokaryotes* (for simplicity. I will include the related group *Archaea* under this heading).These simple single-celled bacteria captured energy either (1) by fermenting[43] the ocean's stock of energy-rich organic compounds which had been accumulating naturally on an anaerobic (oxygen-free) Earth or (2) by a process of *anaerobic photosynthesis,* i.e. sunlight energy triggers the release of chemical energy locked up in hydrogen sulphide (H_2S) and then, by combining hydrogen and atmospheric carbon dioxide, storing that energy 'in-house' as carbohydrate (c.3200 Mya). Molecular-scale waste products (metabolites) from fermentation and photosynthesis processes would have accumulated in the environment until lines of cells evolved that were able to use these wastes for their own metabolism.

[42] Ward, P., and Brownlee, D., 2000, *Rare Earth: Why Complex Life Is Uncommon in the Universe*, Copernicus Press, New York

[43] Fermentation is the energy-yielding anaerobic (i.e, no net oxidation) breakdown of a nutrient molecule, such as glucose.

With this plausible-enough development, the first fermentation-based trophic chains (food chains) emerged, bringing with them the cycling of various chemical elements.[44] These were the first *ecosystems*, i.e. dissipative systems characterised by the re-cycling of matter between genetically-different groups of organisms. While there is some evidence of an additional process of aerobic (oxygen producing) photosynthesis (by *Cyanobacteria*) having evolved by, say, c.2700 Mya,[45] it was not until c.2200 Mya that oxygen levels in the atmosphere began to rise. The advent of aerobic photosynthesis, the process which uses light energy to split hydrogen dioxide (water) rather than hydrogen sulphide, allowed prokaryote populations to expand dramatically insofar as they were now independent of the ocean's relatively small feedstocks of hydrogen sulphide and fermentable organic molecules.

Just another global cycle?

From the perspective of seeing the globe as a single dissipative system, the emergence and proliferation of life can be viewed as an elaboration of the geochemical pathways by which various sorts of molecules were already being cycled through the pre-biotic global system. In particular, since organisms are largely made of molecules containing atoms of carbon, hydrogen, oxygen, and nitrogen, it is the dissipation of energy during the cycling of these, plus phosphorus, sulphur, iron and some 'trace' elements, which is of interest.

Since life has been described as 'just carbon chemistry', let us take the example of carbon. The main pre-biotic carbon cycle involved the movement of CO_2 from atmosphere to lithosphere (captured during rock weathering) and hydrosphere (by dissolution and precipitation) and then to the upper mantle (via subduction) from whence it was eventually returned to the atmosphere during volcanic activity. But, as suggested above, it can also be plausibly argued, from simple chemistry principles, that as the time of life's emergence approached, a wide range of carbon-containing (i.e. organic) molecules (e.g. polycyclic aromatic hydrocarbons, amino acids) could have been repeatedly synthesised and destroyed in the high-energy conditions of the then atmosphere and oceans, including perhaps the environs of undersea hydrothermal (hot water) vents. That is, carbon was being cycled on a molecular scale as well as a 'macro' scale. From a planetary perspective, fermentation of such compounds by prokaryotes is just a further way of dissipating the energy locked up in this stock of organic molecules.

Most sorts of complex molecules contain less free energy than is collectively contained in their components and so, in accord with the cosmic imperative (or the second law of thermodynamics if you prefer), they tend to form spontaneously when their components are all present and, once formed, tend to be stable. Any such molecule is said to be in a potential well or free-energy well, meaning that a pulse of externally applied *activation energy* is required to dissociate or break it up again. Such associative (coming together) reactions are called *exothermic* (heat producing, energy-releasing) and produce entropy in the form of heat. The stable products formed are building blocks for the static (cf.

[44] Guerrero, R, 1998, Crucial Crises in Biology: Life in the Deep Biosphere, *Internl. Microbiol.*, 1, pp.285-94.
[45] Knoll, A., 2003, *Life on a Young Planet: The First Three Billion Years of Evolution on Earth*, Princeton University Press, New Jersey

kinetic) structures produced, to some extent, by most of Earth's dissipative systems. Crustal minerals are a good example.

Other complex molecules contain more free energy than is collectively contained in their components and so do not form spontaneously. Their formation requires an *endothermic* (energy-absorbing) reaction, one in which the components are forced to bond together under the influence of an outside energy source. This can happen in various ways, none of which violate the second law---as would happen if there were no *net* production of entropy. For example, they can be formed directly in high-temperature high-energy environments. Thus, in the absence of an atmospheric ozone layer, ultraviolet radiation would have been intense in pre-biotic times. Or they can be formed with the help of catalyst molecules which allow the required energy to be provided in several small pulses rather than one large pulse. Or they can be formed in environments where the outside energy required to force the components together is drawn from a 'coupled' exothermic reaction proceeding in parallel with the 'thermodynamically forbidden' endothermic reaction. Here, entropy lost during the endothermic reaction has to be less than entropy gained during the exothermic reaction if the coupled reaction is to proceed. *Coupling* is the way CO_2 is converted into organic compounds in plants. It should be noted that knowing a reaction to be thermodynamically favoured says nothing about the rate at which that reaction will proceed; that is the province of *chemical kinetics*.

Once formed, such molecules tend to dissociate spontaneously or, alternatively, when energised sufficiently by a pulse of activation energy, can react with certain other molecules (commonly oxygen), to form low-energy products (commonly oxides). Most reactions which proceed spontaneously after being 'kick-started' do so because the reaction itself generates the very conditions which allow the reaction to continue, e.g. a burning candle produces sufficient heat to vaporise more wax and raise its temperature to ignition point.

To the extent that complex high energy molecules were being formed and broken down into component atoms or smaller molecules, these components were being cycled and were as much part, a small part though, of pre-biotic (pre-life) global cycling as other physico-chemical processes. Most importantly, to the extent that complex and high-energy molecules were being formed faster than they were being destroyed, the sort of rich molecular 'soup' from which, it is argued, life could have emerged was being accumulated. Remember that the pre-biotic Earth had a reducing atmosphere---hydrogen-rich and oxygen-poor. The Earth had evolved to contain an environment in which a new sort of self-organising system could emerge. The evolutionary stage was being set for a self-organised transition from chemistry to biochemistry and from geochemistry to biogeochemistry.

Biogeochemical cycles

Biogeochemistry is the study of how biological and geochemical processes affect the global-scale cycling of chemical elements. We are learning that there are few large-scale chemical reactions on Earth that are not somehow affected, promoted, or catalysed by living organisms. And that the physical, chemical, and biological processes responsible for the composition of the atmosphere, oceans, soils, and sediments are intricately linked. The overall reason for this, as we shall see, is that living organisms capture and store energy---the basic process in the biological cycle---in ways that allow it to be subsequently used to overcome thermodynamic energy barriers and to activate reactions. After life appeared, the Earth's geochemical cycles could begin to diversify into new pathways, including more rapid weathering,[46] and did so to the extent that this increased global entropy production.

Biogeochemists can reconstruct the history of the great carbon reservoirs in the crust of the Earth, the limestones and the coal deposits, as well as the distribution of nitrate and phosphate in the ocean. They find explanation for the composition of the atmosphere (nitrogen, oxygen, trace gases etc.) in bacterial action and photosynthesis. And they record the changes over evolutionary time in the fluxes of materials between the biosphere (meaning all of life), lithosphere, atmosphere and hydrosphere, e.g. the decay of organic matter in soils and the resulting release of gases into the air; the uptake of oxygen by the ocean and its utilisation at depth; and the leaching of nutrients from the soil and their transport into the sea.

The increase in atmospheric oxygen since life began suggests a corresponding increase in Earth's rate of entropy production and a progressive reduction in the planet's entropy content. Insofar as a more ordered system means one processing more energy, the latter two go together. Chemically speaking, atmospheric and oceanic conditions have changed from reducing (3.8 Ga) to mildly oxidative (2 Ga) to strongly oxidative today.

More broadly, biogeochemistry views the mix of dynamic systems near the surface of Earth as collectively self-maintaining---the outputs ('waste' products) from one sphere become the inputs for another. For example, as the ocean takes up oxygen (the waste product of plants) it releases an equivalent amount of carbon dioxide (the waste product of decay but the stuff of growth for plants). Overall, it seems clear that, for a long time, the Earth has been a dissipative self-organising system in a (slowly changing) dynamic equilibrium. Its behaviour suggests a system following the trajectory of a chaotic attractor or, very approximately, and depending on one's time frame, a system in a steady state where, plausibly, entropy is being produced at a maximum rate. As well as its roughly constant surface temperature, the Earth is stable with respect to atmospheric and oceanic composition and crustal acidity and chemical composition. On the other hand, while still small in energy processing terms, relative to Earth's other global dissipative systems, life has experienced great changes in energy throughput and standing biomass---the mass of Earth's biota (all its organisms) has increased perhaps 20-fold in the 600 myrs since the Cambrian period.[47]

While many of the feedback processes which maintain this stability are biological, this does not make the Earth a homeostatic living organism as posited by the 'strong' version of James Lovelock's 'Gaia hypothesis'.[48] For example, living organisms have a tendency

[46] Minik T., Rosing, D., *et al.*, 2006, The Rise of Continents—An Essay on the Geologic Consequences of Photosynthesis, *Palaeogeography, Palaeoclimatology, Palaeoecology* , **232**, pp.99–113

[47] Wesley, J.P., 1989, Life and Thermodynamic Ordering of the Earth's Surface, *Evolutionary Theory*, **9**, pp.45-56.

[48] Lovelock, J.,1995, *The Ages of Gaia: A Biography of Our Living Earth*, Norton, New York

to replicate. It suffices to say that life contributes massively to creating and maintaining environmental conditions under which it can and has evolved to survive.

Coevolution of the Earth and its ecosystems

Just as it is useful to expand the use of the term *evolution* beyond its familiar biological context, to encompass temporal changes in the atmosphere, the lithosphere and the sociosphere, it is useful to use the term *coevolution* to describe, not just the way in which biological species evolve in response to changing *selection pressures* from other species, but to encompass the variety of ways in which evolution in one dissipative system triggers evolutionary change in (a) another part of the same system or (b) in another dissipative system. Thus, coevolution also includes behavioural and genetic responses to changes in the abiotic (non-biological) environment. For example, animals adapting to a cooling climate also, through their adaptive behaviour (e.g.digging shelters), reorganise the abiotic environment, at least locally---a process called *niche construction*.[49] From this perspective, there are two causal processes in evolution---natural selection of the organism by the niche and ongoing construction of the niche by the organism. From their parents, organisms receive both a genetic inheritance and an environmental inheritance. And, as earlier noted, coevolution also includes physical interdependencies such as the interaction of the geological and meteorological cycles.

On early Earth, life and the physical environment coevolved in several ways which led, first, to accelerated global cooling and, second, towards an equilibrium global temperature which was also optimal for the rate of production of entropy by the biosphere.[50] One of these was the way in which marine plankton (drifting microorganisms) trigger extensive cloud formation which leads the Earth to cool by reflecting sunlight more effectively than the ocean's surface. This surprising effect is caused by the release of *dimethyl sulphide* molecules to the atmosphere by plankton populations. Derivatives of these molecules become nuclei around which water vapour condenses to form clouds. The coevolutionary feedback thereafter would have been an increased selection pressure on subsequent generations of plankton to adapt to the cooler temperatures, leading to higher levels of plankton, and even cooler temperatures!

A second form of large-scale coevolution, once continents had formed to a significant extent, might have been an amplification of rock weathering by bacterial action, leading to cooling associated with the removal of heat-trapping CO_2 from the atmosphere. At a later date, the biosphere-atmosphere cycle became connected to the rock cycle by the roots of plants. Roots deliver CO_2 deep into soil where its combines with water to make carbonic acid which attacks calcium silicate in rock to yield calcium carbonate and clay. The calcium carbonate can then be transported in solution to the oceans where it can be dumped out as limestone. Thus the rate and density at which plant roots penetrate soil is a major control of weathering rates and of the rate of CO_2 removal from the atmosphere.[51]

[49] Sterelny, K., 2005, Made by Each Other: Organisms and their Environment, *Biology and Philosophy,* **20,** pp.20-36.
[50] Staley, M, 2002, Darwinian Selection Leads to Gaia, *J. Theor. Biol.*, **218**, pp.35–46
[51] Falkowski, P.G., Fenchel, T.F., and Delong, F., 2008, The Microbial Engines that Drive Earth's Biogeochemical Cycles, *Science*, **320**, No. 5879, pp.1034-1039

The ideas of coevolution and evolution are important tools for imposing meaning (connections, generalisations, synopses) on the bewildering kaleidoscope of ceaseless change in the physical Earth and its ecosystems once the Earth cooled to the point where life could emerge. For the remainder of this chapter, my task is to provide a plausible-enough, albeit drastically-condensed, version of this story to serve as a foundation for appreciating the evolution of modern humans and their societies (Chapters 2-4).

Archean Eon (3.8-2.5 Ga) Emergence of life and genes

There is no standard model for the emergence of life as there is for cosmology**.** The chain(s) of spontaneous causes and effects and staging points which resulted in the appearance and proliferation of free-floating single-cell prokaryotic organisms of various ‘species’ in Earth’s hot (90 degrees C) and organically-rich Archean seas remains a matter for speculation and scientific debate. Notwithstanding, because of the presence of the same core biochemical pathways in all life forms, the idea that all life forms had a single common ancestor is accepted. For present purposes, we can also accept as a working hypothesis that the first recognisable prokaryotic cells were ‘self-assembled’ from various pre-existing components, including bacteria-sized *protocells*---vesicles with an aqueous core enclosed by a semi-permeable membrane---and self-replicating macromolecules of (plausibly) RNA (ribonucleic acid).

This is not the place to dissect either this or alternative hypotheses,[52] but it is worth noting that some version of RNA is found in all living and fossil cells, from the earliest bacteria to the human brain. The supposition is that once RNA had emerged, it was extraordinarily successful in assisting in the survival and replication of any protocell it occupied. In particular, it can be argued that the RNA molecule eventually catalysed the formation of the self-replicating DNA (deoxyribonucleic acid) molecule, this being the polymer (chain of molecules) which, in most forms of life, carries the templates, the *genes*, which guide the assembly of all the structural and enzyme proteins that cells have come to need to survive reasonably well.[53] Certainly it has been shown that some RNA sequences have catalytic capabilities and can act as *polymerases*, these being enzymes that can assemble a strand of RNA from its component nucleotides (monomers). Which is what self-replication means. Conceptually, any part of a self-replicating molecule which also catalyses the production of any sort of survival-enhancing molecule is, in effect, a gene.

Based on available evidence, a reasonable conjecture is that *liposomes*, bacteria-sized vesicles enclosed by phospholipid membranes, were naturally present in the prebiotic seas and that cyclical systems of replicating and catalytic macromolecules[54] could have become encapsulated in such vesicles. Membranes constructed from the ‘right’ lipids

[52] Segré, D., and Lancet, D., 2000, Composing Life, *EMBO Reports* 1 (3), pp.217-222.

[53] RNA would have been replaced by DNA because the latter is more stable, i.e. able to support longer genomes and, with that, more versatile organisms. It is possible that there was a phase, early in biological evolution, when the prokaryote genome (its pool of genes) consisted of unlinked RNA genes, each separately replicated..

[54] In such systems, called *autocatalytic sets*, every molecule is either 'feedstock’ from the environment or synthesised by reactions catalysed by species within the system.

allow ions from the external environment to permeate into the protocell at a sufficient rate to provide a supply of monomers for the vesicle's enzymes, the result being that nucleic acids accumulate in the vesicles, safe from dispersion. The physical chemistry of liposome membranes is also such as to control the ingestion of various nutrient molecules from the environment.

Then and now, prokaryotes reproduced through *asexual reproduction*, usually by splitting in two when they had grown to a critical size at which they became unstable.[55] Initially, each daughter cell contained a random share of the parent cell's genetic material, a share which would not necessarily be adequate to ensure the daughter cell's viability. Genetic recombination and exchange between organisms probably occurred, but in the form of *'horizontal' gene transfer*, e.g. when two small prokaryotes collide and merge. Indeed, this may have been the principal form of evolution before the 'invention' of *'vertical' gene transfer* in which a copy of the parent's DNA or RNA goes to each daughter cell. There may even have been a common global gene pool and a core global gene set[56] before vertical gene transfer allowed the early prokaryotes to evolve into different genetic strains, some of which reproduced more abundantly than others, depending on the characteristics of the ocean niche or habitat being occupied, e.g. its temperature, salinity, light regime, prevailing currents and available nutrients.[57] That is, natural selection, as first postulated by Darwin and Wallace, had begun.

Mutations were, presumably, a further source of genetic variability in the early prokaryotes. Sometimes, when self-replicating, a molecule can experience a copying mistake or mutation which, without destroying the molecule's tendency to self-replicate, does give it a capacity to catalyse the production of a new type of enzyme or protein which, in the right environment, improves the survival prospects of that type of prokaryote. Populations of cells that have successfully incorporated a new mutation will tend to expand relative to other populations

Respiration is the process by which cells convert the energy in the chemical bonds of ingested and/or photosynthesised food molecules (e.g. glucose, stored starch) into ATP (adenosine triphosphate), a multi-purpose energy-storing molecule that prokaryote cells use to grow and maintain themselves. For example, the phosphorylation by ATP of amino acids and nucleotides primes (energises) them for polymerization (chaining) into polypeptides (short proteins) and polynucleotides.[58]

[55] Swenson, R., and Turvey, M, 1991, *ibid.*

[56] Although there is enormous genetic diversity in nature, there remains a relatively stable set of core genes coding for the major redox reactions essential for life and biogeochemical cycles. Falkowski, Fenchel and Delong (*ibid.,* 2008) argue that this set is so widespread in microorganisms that if all higher life forms were to disappear, life would simply 'reboot' from the core microbial gene set.

[57] Woese, C.R., 2002, On the Evolution of Cells, *PNAS,* **99** (13), pp.8742-8747.

[58] Weber, B.H., 1998, Emergence of Life and Biological Selection from the Perspective of Complex Systems Dynamics, In G. Van de Vijver, S.N. Salthe and M. Delpos (Eds.), *Evolutionary Systems: Biological and Epistemological Perspectives on Selection and Self-Organization*, , Dordrecht: Kluwer, 1998, pp.59-66

At some stage, around the end of the Archean perhaps, the respiration process in prokaryotes underwent a giant evolutionary leap---from being anaerobic to being aerobic: It may have been in the cyanobacteria, the group which first (?) evolved aerobic photosynthesis, that a capacity emerged for incorporating oxygen (the by-product of aerobic photosynthesis) into a complex series of reactions which produced far more ATP per food molecule than anaerobic respiration (each molecule of oxygen also produced a molecule of CO_2). It was the acquisition of aerobic respiration and aerobic photosynthesis which ultimately provided prokaryote populations with the abundant supplies of food and energy that would support the eventual evolution of *eukaryotes*, the larger and more complex unicellular (single cell) organisms from which all multicellular plants and animals would eventually evolve.

The end of the Archean was also the time when cumulative photosynthetic activity was beginning to lift free-oxygen levels in the oceans and the atmosphere and, in the process, destroying essential enzyme systems in many types of anaerobic organisms. In oceans and freshwater lakes, until about 2.5 Ga, dissolved oxygen was triggering the precipitation of abundantly- available iron as the oxides which today constitute the world's iron ore deposits. In the atmosphere, until about 2.4 Ga, most free oxygen went towards oxidising volcanic hydrogen sulphide and methane. Thereafter, over about 100 million years, atmospheric oxygen levels rose to about two per cent, the beginning of a massive shift to the highly oxidizing conditions (21 per cent) that prevail today.[59]

Proterozoic Eon (2500-542Mya) Eukaryotes, colonies, sex, multicellularity

The rise in atmospheric oxygen around the beginning of the Proterozoic can be further explained, perhaps, by the 'supercontinent effect.' An elegant paper by Ian Campbell and Charlotte Allen in 2008 shows that, since the Archean, atmospheric oxygen has risen in steps or jumps and that these co-occur with amalgamations of Earth's land masses into supercontinents.[60] They suggest that the continent–continent collisions required to form supercontinents produced supermountains (sic) which eroded particularly quickly, flushing CO_2 from the atmosphere and releasing large quantities of growth-limiting nutrients such as iron and phosphorus into the oceans. This led, each time, to a proliferation of algae and cyanobacteria, and a marked increase in photosynthesis, and photosynthetically-produced oxygen. Conversely, enhanced sedimentation during these periods promoted the burial of a high fraction of iron sulphide and organically-produced carbon, thus blocking their reaction with free oxygen, and leading to sustained increases in atmospheric oxygen and decreases in atmospheric CO_2.

Snowball Earth is a vivid metaphor for a world where the oceans are deep-frozen and glaciation extends to the equator. It is also a canonical example of coevolution of the biosphere, the atmosphere and the hydrosphere. As noted earlier, the three occasions when this has happened in Earth's history have been attributed to a positive feedback process powerful enough to flip the global dissipative system from one 'basin of attraction' to another, a process initiated by a sufficiently large loss of 'Earth-warming' greenhouse gases from the atmosphere. For the Snowball Earth event at the beginning of

[59] Des Marais, D.J., 1997, Long-term Evolution of the Biogeochemical Carbon Cycle, In J. F. Banfield and K. H. Nielsen, (Eds.), *Geomicrobiology: Interaction between Microbes and Minerals,* Mineralogical Society of America, Washington, D.C., pp.429-448.
[60] Campbell, I.H. and Allen, C.M., 2008, *ibid.*

the Proterozoic (2.3 Ga) it is now thought that methane was the lost greenhouse gas, stripped from the atmosphere in the oxidising conditions created by the buildup of atmospheric oxygen generated during photosynthesis.[61] The fossil record covering the Snowball events at 750 and 600 Mya suggests that these did not affect the diversity and distribution of (unicellular) life[62] and we might hypothesise the same for the earlier event.

The name Proterozoic, from the Greek 'earlier life,' denotes a period preceding the first abundant complex (sic) life on Earth, where 'complex' is taken to mean hard-bodied multicellular organisms. Up to a billion years, yes, a thousand megayears, of the Proterozoic Eon had to pass before eukaryotes, large single-celled organisms containing a membrane-enclosed *nucleus* and other novel structures, particularly *mitochondria* and *chloroplasts*, appeared in numbers alongside prokaryotes in marine ecosystems.

Meanwhile, prokaryotes continued to evolve by natural selection. While continuing to reproduce asexually, many evolved to have their genetic material, their DNA as it had become, organised into a single circular chromosome containing a single copy of each gene and a little repetitive ('junk') DNA. Some types (e.g. spirochaetes) developed *flagellae* (propeller tendrils) and became *motile*, i.e. able to move towards food or more equable environmental conditions. This obligate linking of a motor (movement) response to an environmental stimulus has kept re-appearing in increasingly complex ways through subsequent evolutionary history, e.g. instinctive behaviour in animals, human agency.

Nitrogen, an essential component of the proteins etc. which all life forms must synthesise, was present in quantity in the Proterozoic atmosphere but not in a form which microorganisms could use. Sometime after the first Snowball Earth event, perhaps 2.2 Ga, prokaryotes, probably cyanobacteria, evolved a capacity to 'fix' atmospheric nitrogen into biologically available forms---such as nitrate and ammonia---and thereby decreased their dependence on the supply of these nutrients which had hitherto been produced as by-products of lightning discharges.

Notwithstanding, this development may have been much earlier. There is evidence that, early in the Archean, cyanobacteria evolved a capacity to form multicellular 'filaments' or strings of connected cells, some of which fixed nitrogen and were anaerobes while others were aerobic photosynthesisers.[63] If this is correct, cyanobacteria were pioneers of not just multicellularity (see below), but also of the use of differentiated cells to carry out specialist functions

The evolution of biological nitrogen fixation, an energy–intensive process, suggests that, at some point, the demand for fixed nitrogen exceeded the supply from abiotic sources; but the timing and causes of the emergence of biological nitrogen fixation remain unclear. Both the nitrogen 'drought' and life's nitrogen-fixing adaptive response may have been triggered by the unmet demands of a growing population of microorganisms

[61] Kasting, J.F., 2005, Methane and Climate during the Precambrian Era*, Precambrian Research* ,**137**, pp.119-129.

[62] Corsetti, F., 2006, The Biotic Response to Neoproterozoic Snowball Earth, *Palaeogeography, Palaeoclimatology, Palaeoecology*, **232** (2-4), pp.114-130.

[63] Bonner, J.T., 1998, The Origins of Multicellularity, *Integrative Biol.,* **1**, pp.27-36.

tied to a trickling supply of fixed nitrogen; or by declining production of fixed nitrogen in an atmosphere where CO_2 levels were declining and oxygen levels rising only slowly.[64] The point here is that the chemical reaction which fixes nitrogen in the atmosphere requires the splitting of a CO_2 molecule at high temperature. And, illustrating coevolution once again, the reasons CO_2 was being removed from the atmosphere at the time included its increasing use in photosynthesis and its increasing role in the weathering of freshly-exposed continental rocks. Rock weathering, accelerated by bacterial secretions (particularly from cyanobacteria) perhaps, was already producing the *soils* which, in time, would allow plants to migrate from lakes and oceans and colonise the land.[65]

Creation of a life-protecting ozone layer in the (upper) atmosphere was another far-reaching consequence of the buildup of free oxygen. Ozone, a three-atom variant of the oxygen molecule, absorbs high-energy ultraviolet radiation which would otherwise reach Earth's surface and destroy any biological molecules encountered. It is synthesised from oxygen by the very photons it dissipates. Without an ozone layer it is doubtful if terrestrial (land-based) multicellular life could ever have evolved. Putting this another way, coevolution between aerobic photosynthesisers and the atmosphere (and the lithosphere) had created a habitable niche, a platform, for a wide range of evolutionary possibilities.

It would seem that cyanobacteria (cyan means 'sickly green') have played a leading role in the evolution of each of the three most important adaptations by prokaryotes to the Archean and early Proterozoic worlds: aerobic photosynthesis, aerobic respiration and a capacity to fix atmospheric nitrogen. Introducing a term which will presently prove useful for understanding human cultural evolution, these adaptations are, metaphorically speaking, *technologies*--- 'recipes' which are perceived as contributing to the persistence of the system using them.

Even more, cyanobacteria have always been important *symbionts* (community members) within the *biofilm* and *microbial-mat communities* into which, from earliest times, most microorganisms have commonly self-organised. *Stromatolites* are colonies of, predominantly, cyanobacteria which form macroscopic mats by trapping passing debris in slime secretions and cementing it in place with a precipitate of calcium carbonate. Biofilms are formed when large numbers of single-celled microorganisms live together in a matrix of slime (mucilage) which protects the cells within it while allowing them to communicate through biochemical 'signals' and to obtain nutrients by diffusion along inbuilt water channels. While some organisms form single-species biofilms, most such films are ecosystems in which various species perform specialised biochemical functions.

Slime is a brilliant 'social' technology. It is sticky enough to anchor a community to something solid, protecting it from dispersal, keeping members close enough to interact (e.g. exchange genes) and develop a collective organisation; the first truly multicellular organisms may well have emerged in biofilm or mat communities. Slime acts as a barrier

[64] Navarro-González, R., McKay, C.P., and Nna Mvondo, D., 2001, A Possible Nitrogen Crisis for Archaean Life due to Reduced Nitrogen Fixation by Lightning, *Nature* **412**, pp.61-64

[65] Retallack, G.J., 1990, *Soils of the Past: An Introduction to Paleopedology,* Unwin-Hyman, Boston

to predators and as a buffer against sudden environmental changes, in salinity for instance. Indeed, because slime also protects against dehydration, microbial colonies in biofilms and mats may well have been the first life forms, long before plants, to live on land; in tidal zones perhaps.

Enter Eukaryotes

Convinced by some bold thinking from Lynn Margulis (formerly Sagan) and her predecessors, [66] it is generally accepted that unicellular eukaryotes did not evolve by natural selection alone but also by *endosymbiosis,* a concurrent process of self-organisation in which several prokaryotic 'partners' came together to form a minute ecosystem within a single cell. *Symbiosis* means 'organisms living together' and *endosymbiosis* implies one organism living inside the body of another. Specifically, the mitochondria found in all eukaryotic cells and the chloroplasts found in photosynthetic eukaryotic cells are similar in a number of ways to certain aerobic proteobacteria and cyanobacteria respectively. Even the enclosed nucleus (karyon) that characterizes all eukaryotic cells may have evolved in this way. It seems plausible that a host cell could have engulfed (enfolded) both types and that, in time, a close symbiotic relationship, including gene exchange, could have developed.

It was suggested earlier that whenever a radically new type of dissipative system emerges, it processes free energy/ produces entropy at a higher rate per gram of its constituent matter than the systems (platforms) from which it emerged. The emergence of life conforms to this principle too. Thus, primitive unicellular organisms have a higher *free energy rate density* than the pre-biotic oceans and eukaryotes and multi-celled organisms process free energy at a higher specific rate than prokaryotes.

Some 1.2-0.9 Ga, eukaryotes began to proliferate and complexify, lifted perhaps by their capacity to exploit Earth's rising oxygen levels (see below) to power the emergence of new energy-intensive behaviours, intra-cellular structures, molecular-scale processes etc. Most importantly, by the late Proterozoic many types of eukaryotes were able to reproduce sexually as well as asexually, a development which has been authoritatively called one of the 'major transitions in evolution.'[67]

In asexual reproduction, one parent cell divides into two daughter cells, two 'clones' which each carry the same genetic information (genes) as the parent; the parent cell's genetic information is first replicated and, thereafter, one replicate is assigned to each daughter cell. The process is rather different between prokaryotes, where it is called *binary fission,* and eukaryotes, where it is called *mitosis*, but the result is the same.

Unlike prokaryotes which evolved to hold their genetic information in a single circular chromosome, eukaryotes evolved to hold their genetic information (genotype) in multiple linear (threadlike) chromosomes inside a membrane-bound nucleus. In sexual reproduction, each 'daughter' cell is bequeathed a full complement of essential genetic information, half coming from each of two 'parent' cells. However, because a daughter-cell's parents are always genetically a bit different from each other, no daughter cell is

[66] Sagan, L., 1967, On the Origin of Mitosing Cells,. *J. Theor. Biol.,.* **14** (3), pp.255–274.
[67] Maynard Smith, J., and Szathmáry, E., 1997, The Major Transitions in Evolution, Oxford University Press, New York .

quite the same as either parent. This process of *genetic recombination* is a continuing reliable source of moderate genetic variability in populations of eukaryotic microorganisms (cf. intermittent gene mutation). Natural selection follows, i.e. genotypes (and hence genes) which reproduce more successfully in the prevailing environment become more common; the composition of the population's combined gene pool changes from generation to generation as the population adapts to (learns to better survive in) its environment. Observe that it is the capacity of sexual reproduction to speed up the rate at which populations adapt to environmental change that makes sex such a powerful technology. After all, populations (species, say) go extinct when rate of environmental change exceeds their capacity to adapt! Obversely, sexual reproduction prunes 'out-of–date' genes from a population's gene pool.[68]

Sexual reproduction in unicellular eukaryotes has taken several paths. As one example, consider *Chlamydomonas,* a green alga. This organism is *haploid* for most of its life cycle, meaning that, like egg and sperm cells in humans, it has just one copy of each chromosome (a *diploid* cell has two copies of each chromosome). Every cell can be described as either a 'plus mating type' or a 'minus mating type.' When a plus and a minus meet, their cell contents mix and their nuclei fuse to form a single diploid *zygote,* this being the term for a cell formed when two *gametes* or 'sex cells' come together, whether in unicells or 'higher' forms of life. This zygote, the only diploid cell in the life cycle, eventually undergoes meiotic divisions or *meiosis,* to form four new (haploid) *Chlamydomonas* cells. This is true sexual reproduction because (a) chromosomes are reassorted during the meiotic divisions and (b) new individuals are formed. Note that in this early type of sexual reproduction, the gametes are morphologically identical; the distinction between sperm and egg has not yet been made. Nor, being unicellular, can there be a distinction between body (*somatic*) cells and specialist sex cells.

Another particularly important way in which unicellular eukaryotes continued to evolve through the Proterozoic was to get bigger. Eukaryote cells are typically some ten times the size of prokaryote cells and necessarily have a smaller surface area per unit volume than prokaryotes. This reduces the eukaryote cell's ability, on a per volume basis, to exchange materials with the environment, and hence, ultimately, limits their maximum possible cell size. This is because, given an underlying biochemical similarity, all forms of living matter have roughly similar energy requirements per unit mass (volume) for their maintenance. It follows that, in parallel with growing body size, eukaryotes would have needed to improve their strategies for acquiring energy from the environment, as well as their cell-repair and regulatory technologies, in order to maintain the rate of energy supply to their operations at the required level.[69] One estimate is that it took 60 major innovations, including thousands of new genes, to convert prokaryotes to eukaryotes.[70]

To take a pervasive example, some eukaryotes became sufficiently large, flexible and mobile enough to be able to find and 'swallow' prokaryotes for food, digesting them

[68] http://en.wikipedia.org/wiki/Evolution_of_sexual_reproduction (Accessed 29 May 2010)
[69] Makarieva, A.M., Gorshkov, V.G., and Bai-Lian, L., 2005, Energetics of the Smallest: Do Bacteria Breathe at the Same Rate as Whales? *Proc. Biol. Sci.*. **272** (1577), pp.2219–2224.

[70] Cavalier-Smith, T., 2009, Predation and Eukaryote Cell Origins: A Coevolutionary Perspective, The International Journal of Biochemistry & Cell Biology, **41**, pp.307-322

internally rather than externally as prokaryotes do, i.e. by secreting digestive enzymes into the environment to break food particles into molecules small enough to diffuse through the cell wall. Internal digestion was not only more efficient (calories acquired per calorie expended) than external digestion, it freed these ‘protoanimals’ to become the first ‘predators,’ able to spend more time searching for food. We have here the beginnings of a *trophic strategy*---actively seeking prey for food---which has remained important ever since for many *heterotrophs*, i.e. organisms such as animals and fungi which, unlike *autotrophs*, cannot synthesise their own food. To take a remarkable example, some heterotrophs evolved a capacity to detect and home-in on the type of radiation absorbed by autotrophs during photosynthesis!

Other heterotrophs, ‘filter feeders,’ developed feeding strategies which relied, not on being mobile, but on capturing prokaryotes delivered to them in passing currents (a form of ‘energy subsidy’) or in currents created by the vibrating of the cell’s own *cilia*, these being hair-like protuberances from the cell surface. Photosynthesising *algae*, the unicellular eukaryotic ancestors of plants, did not have the same need for mobility and flexibility to ensure their food supplies, but some nevertheless benefited from being able to propel themselves towards sunlight and away from salty, acid etc. conditions.

How, more generally, do we explain the emergence and multiplication of eukaryotes in a world that had been dominated for two billion or more years by prokaryotes and which, in terms of their share of the world’s biomass, still dominate? The short answer is ‘size and sex.’

Increased cell size was the technology which allowed eukaryotes to exploit the unoccupied *ecological niche* created by the proliferation of prokaryotes. The chemical energy locked up in prokaryote populations could be degraded more rapidly inside eukaryotes than by death and decomposition. The seas and fresh waters of the late Proterozoic were certainly ecosystems, but not ones where prokaryotes and eukaryotes were competing for the same resources; nor ones where eukaryote predators were numerous enough to drive prokaryote numbers down in any significant way.

These were also ecosystems where *viruses*, a third form of life, were already important community members. A *virus* is a tiny microorganism consisting only of a DNA or RNA strand with a protein coat. A virus can only replicate by entering a host cell, either a prokaryote or a eukaryote, and coopting its genetic system into replicating the invader’s DNA or RNA, i.e. into making another generation of viruses. This may or may not kill the host cell. Contemporary research suggests that it has long been common for invading viruses to be ‘endogenised,’ i.e. incorporated permanently into the host cell’s genome. Such relationships are better seen as symbiotic rather than parasitic: while an endogenised virus gains by being assured of replication, its presence also seems to protect the host from attack by virus strains similar to itself. Second, when dissimilar genomes do manage to combine in a viable way, the evolutionary possibilities are greatly expanded.[71]

[71] Ryan, F., 2009, V*irolution*, Harper Collins, London

Multicellularity

Once established, complete with an efficient system of aerobic respiration (inside mitochondria), a disciplined system of sexual reproduction gave the eukaryote cell an enhanced capacity to (further) evolve internal structures (e.g. membranes, cytoskeletal scaffolding), which provided sites and compartments where various metabolic processes (e.g. synthesising particular proteins) could be localised (i.e. protected from dispersion) and separated from each other. Acquiring a capacity to isolate different, sometimes incompatible, operations inside a single 'multi-functional' unicell may have been a step on the way to the future development of special-purpose cells (e.g. for gamete production, for nutrient storage, for sensing food, for locomotion, for protection etc.) in multicellular eukaryotes. Indeed, by the time the first multicellular eukaryotes appeared in the paleontological record, some 1.2 Bya, the evolution of the modern cell in a form which has persisted till the present day, albeit in some hundreds of specialised variations, was largely complete. A platform on which all subsequent multicellular life---plants, animals, fungi---could develop had been established.

Metaphorically, strains of eukaryotic and prokaryotic unicells have relied on somewhat contrasting 'strategies' for surviving spatial variations and temporal fluctuations/shifts in their external environments. Prokaryote strains have relied for survival on, firstly, *culturability*, i.e. a population's capacity to multiply rapidly and regenerate quickly after near-destruction.[72] Being small and simple, prokaryotes have a shorter generation time and a higher rate of evolution than eukaryotes, advantages they would lose if they evolved to be larger. When environmental conditions deteriorate at a particular time or place, the local prokaryote populations simply die off or form hard-cased *cysts*, these being cells which remain inactive until conditions improve. Having numerous widely-distributed populations makes it unlikely that all members of a strain will be wiped out simultaneously.

By comparison, the basic eukaryote strategy for surviving environmental fluctuations has been one of slowly increasing *relative autonomy,*[73] a strategy based on trading-off culturability and opportunistic growth at the population level for better survival prospects at the cell level. That is, a complex eukaryote cell is less likely than a simple prokaryote cell to be incapacitated by fluctuations in the external environment; and eukaryote populations were probably more stable, numerically, than prokaryote populations. Nonetheless, it would be wrong to regard one strategy as 'better' than the other; and neither strategy is 'conscious' of course.

Relative autonomy is achieved in several ways. Simply because they are larger, environmental impacts are transmitted more slowly through eukaryote cells, a 'buffering' effect which smooths out changes caused by environmental fluctuations and allows time for a cell's homeostatic (counteracting) responses to kick in. Buffering is further increased to the extent that cell operations are compartmentalised in internal structures.

[72] Conrad, M., 1983, *Adaptability: The Significance of Variability from Molecule to Ecosystem*, Plenum Press, New York

[73] Rosslenbroich, B.,2009, The Theory of Increasing Autonomy in Evolution: A Proposal for Understanding Macroevolutionary Innovations, *Biol. Philos* . **24**, pp.623–644

Also, at the cost of being dependent on a larger energy flow, a larger cell provided space and sites for the evolution of other protective strategies such as storing food reserves, improving mobility, detoxifying poisonous chemicals, excreting wastes and manufacturing protective toxins.

Multicelled eukaryotic organisms, the next great transition in biological evolution after sexual reproduction, evolved independently many times and in many *phyla* (broad taxonomic categories of cell types based on similarity of body plan) of unicells but only a few went on to become plants, animals or fungi. However, being soft-bodied, the first multicellular eukaryotes do not appear in the paleontologists' record of fossilised shells, skeletons and other hard body parts. A somewhat puzzling exception is an *Ediacaran* fauna of animals comparable to jellyfish, polyps and worms which, while present in late Proterozoic sediments (700-545 Mya), appear unrelated to the plethora of clearly visible fossil types which 'suddenly' appeared 545 Mya at the beginning of the Cambrian period and the Phanerozoic eon.

While a detailed series of steps in the evolution of multicellularity cannot be presented with confidence, it is clear that there were several paths that could have been taken and that several platforms and plausible pre-adaptations had already evolved at least once and were 'in waiting' for this development. As noted earlier, some prokaryotes, notably cyanobacteria, had long achieved simple multicellular forms (e.g. cells connected in one-dimensional chains) and some differentiation of cell function (e.g. photosynthesising cells versus nitrogen-fixing cells). So, indicatively, it was clearly possible to evolve surface molecules which allowed cells to adhere (interlock) rather than remain separate.

The technologies which allow genetically identical cells to perform different metabolic tasks are based on activating or inactivating (silencing) particular genes in some cells but not others. Initially this may have been achieved by the evolution of hormones or other 'signalling molecules' able to diffuse between neighbouring cells. Later in the evolutionary story, as studied in the science of *epigenetics,* all cells with a particular function (e.g. liver cells) may have inherited, not only a genome (set of genes), but an *epigenome*, a set of *epigenetic marks*, these being groups of molecules attached to particular genes, allowing them to be turned 'on' or 'off.' [74] While epigenetic marks can and are routinely inherited, along with the genes they are marking, they can also be modified, or even removed, by exposure to environmental or other internal stimuli. It is becoming increasingly clear that the technology of 'epigenetic silencing' has long functioned as a powerful and subtle complement to genetic information in providing guidance for life's self-organizing physical/chemical/biological processes, notably its protein synthesis mechanisms.[75]

Meanwhile, it is reasonable to assume that the first multicellular organisms did not have specialised cells with different functions and that they arose within colonies of unicells, e.g. biofilms or microbial mats, where community members were already enjoying clear benefits (nutrition, protection etc.) from living in close association. It also seems plausible that all cells in the first multicellular organisms would need to be genetically identical, i.e. cloned from a single cell. This would ensure all of the organism's cells

[74] Grosberg, R.K. and Strathmann, R.R., 2007, The Evolution of Multicellularity: A Minor Major Transition? *Ann.. Rev. Ecol. Evol. Syst.* **38**, pp.621–54
[75] Grosberg, R.K. and Strathmann, R.R., 2007, *ibid.*

responding in the same way to any environmental stimulus or internally-generated chemical signal, i.e. there would be no 'rogue' or 'cancer-like' cells in the organism. Under this 'colonial' theory, a multicell can be regarded as a symbiosis between organisms of one 'species.'

What were the adaptive benefits of such a simple form of multicellularity? By reason of size alone, the first multicells would perhaps have been less vulnerable to predation than their predecessors. Conversely, if they were heterotrophs, they would have had access to larger prey. Those heterotrophs that were motile, and able to synchronise the wavings of their flagellae through chemical signals between cells, would have been able to move faster and further in search of prey. Those that were stationary autotrophs (photosynthesisers) would have been able to better resist being swept away and to capture more light energy by extending themselves (e.g. as branching filaments) into the surrounding environment. Thus, the earliest multicellular organisms, *protoplants* and *protoanimals*, were probably already using the two feeding strategies---extension into the environment and selectively searching the environment---that plants and animals, respectively, have continued to use ever since.

How did the first multicellular organisms reproduce? Perhaps they just broke into fragments when they reached an unstable size, with each fragment or bud resuming growth, through mitotic cell division. While this may have happened to some degree, and still does with, for example, sponges, sea anemones and plant cuttings, it is a method of reproduction which would have allowed damaged segments of DNA---*molecular lesions*---to accumulate in many of the organism's cells. Both normal metabolic activities and environmental stressors, such as ultraviolet light and cosmic radiation, can cause DNA damage, including gene malfunctions and mutations (which are usually harmful). It has been suggested, for example, that humans might incur as many as a million individual molecular lesions per cell per day.[76] Genes have evolved which allow many lesions to be routinely repaired,[77] but, equally, lesions can accumulate to the point where the cell dies or becomes non-functional. It is this problem of cumulative DNA damage which makes sexual reproduction almost a necessity for multicelled organisms. Apart from its value in generating the genetic variability which allows natural selection, sexual reproduction, including meiotic cell division, is a technology which produces distinct generations and which allows some-to-most members of each generation to begin life as a single cell containing relatively undamaged DNA.

While the precise evolutionary steps from unicells to multicells must necessarily remain speculative, what has been suggested as a transition from something like today's unicellular *choanoflagellates* to one early group of multicellular animals, namely the sponges of the phylum *Porifera*, is plausible and illuminating.

Sponges, which first appear in the fossil record for the late Proterozoic, do not have distinct circulatory, respiratory, digestive, and excretory systems. Rather, they rely on water flow to support these functions along with a filter-feeding system composed of flagellate cells, pores, and canals. Their bodies consist of two thin layers of cells sandwiching a gelatinous matrix which functions to both connect cells and carry chemical

[76] Lodish H., Berk, A., *et al.,* 2004, *Molecular Biology of the Cell*,. 5th ed., WH Freeman, New York, p.963
[77] http://en.wikipedia.org/wiki/DNA_repair#DNA_repair_mechanism (Accessed 23 June 2010)

signals between cells. They exhibit cell differentiation to the extent of containing non-feeding cells and specialist food–acquisition cells. Most sponges reproduce sexually, releasing sperm cells or, depending on species, sperm cells and egg cells into the water. Fertilised eggs develop into *larvae* which swim off in search of places to settle, grow and divide.

Choanoflagellates are a group of unicellular flagella-waving eukaryotes, living either individually or in colonies. They are considered to be the closest living relatives of the *metazoa,* i.e. multicellular animals. Genome sequencing (gene identification) suggests that today's choanoflagellates and sponges share a common ancestor. In particular, colonial-living choanoflagellates produce a surprising number of equivalents to the signalling and cell-adhesion molecules found in, amongst other animals, sponges. Morphologically too, choanoflagellate cells and sponge 'feeding' cells (choanocytes) are similar, e.g. both have 'collars.' which trap prey. We can speculate that that it was a small evolutionary leap from colonies of unicells like choanoflagellates to multicells like sponges. Recall that the prokaryote 'pioneers' of multicellularity, the cyanobacteria, had long before, evolved to be able to 'switch' genetically identical cells between the tasks of photosynthesis and nitrogen-fixing.

Humans cannot comprehend the three billion years it took for life to emerge and evolve into the handful of simple multicellular forms which mark the transition from a world of unicellular organisms to one with a wide variety of more complex multicellular organisms, organised into diverse ecosystems and characterised by, most obviously, mineralised (hard) body parts and diverse types of specialised cells and organs.

Notwithstanding, while evolutionary developments during the Archean and Proterozoic eons were unimaginably slow from a human perspective, most of the biological technologies and strategies that evolving life forms would subsequently utilise were in place in nascent form by the beginning of the Phanerozoic eon, meaning the geological eon of 'clearly visible fossils.' Mapping Earth's existence onto a 24-hour clock face, it was now 8.50 pm. Thus, by the beginning of the Phanerozoic, starting 542 Mya with the Paleozoic era and Cambrian period (eons contain eras and eras contain periods), the world's oceans comprised a rich dissipative ecosystem of unicellular autotrophs and heterotrophs, plus some minimally-differentiated multicellular organisms. Lichens (fungi and cyanobacteria living symbiotically) and mosses may even have been already present on moist shorelines. A long period of worldwide glaciation was coming to an end and the supercontinent Pannotia was breaking into four continents (Laurentia, Baltica, Siberia and Gondwana). The planet was primed for an era of (relatively) rapid bio-physical change.

Palaeozoic Era (542-251 Mya) Cambrian explosion to Permian extinction

Within a brief 20 million years of the beginning of the Cambrian, the period's opening complement of simple multicellular animals had diversified or, in evolutionary terms, *radiated* into early representatives (species etc.) of all the major groups (phyla) of animals present on Earth today---what is popularly known as the Cambrian 'explosion.' Shelly creatures such as the louse-like 'three lobed' *trilobites* and *brachiopods* (lampshells), of whose ancestors there is little sign in earlier rocks, are suddenly everywhere. Trilobites, for example, are *arthropods,* a phylum of animals without backbones (invertebrates), but with an external skeleton. The arthropod body plan, as seen in today's insects, spiders and crustaceans, consists of repeated body segments, each with a pair of appendages, e.g. claws, feelers, legs. Trilobites themselves however disappeared from the paleontological record after a *mass extinction* event at the end of the Permian period, some 250 million years ago. A mass extinction is a major drop in global diversity.

More generally, a variety of early Cambrian marine animals evolved to have hard (mineralised) body parts which provided protection for soft tissues and a firm base against which muscles could pull during grasping or swimming movements. The hard components were commonly formed from calcium carbonate, as in shellfish, while it was *chitin*, a complex carbohydrate, which provided crustaceans and insects with durable exoskeletons. Trilobites had remarkably functional eyes with calcite lenses; for finding prey and avoiding predators such as the giant (up to a metre) *Anomalocaris*. Indeed, this was a period in the fossil record marked by the rapid appearance of diverse trophic (feeding) strategies, including primary, secondary and tertiary carnivory; and of rapid *escalation* ('arms races'), meaning the adaptive improvement of multicellular species in coevolutionary response to the increased hazards of their biological surroundings---as competitors and predators and prey all improved their survival technologies.

Many immediate and background reasons have been offered for this elaboration of the marine ecosphere in the early Cambrian and, with hindsight, it was an unsurprising development. *Niche expansion* was pivotally important. Thanks to a population boom in marine plankton, the main energy source, directly or indirectly, for Cambrian animal life, emerging animal types were able to proliferate without having to compete too much for limited food. That is, selection pressures were low and 'experimental' body plans and 'tools' (teeth, claws etc) were not ruthlessly eliminated.

Equally though this could not have happened unless the early Cambrian's multicellular eukaryotes already had the genetic potential to reproduce rapidly and to generate a variety of body plans. For this, 'master' genes had to be in place to regulate the expression and interaction of other genes, particularly during the development process from zygote to adult, e.g. genes for controlling the number of modular body segments created. As happens throughout evolution, the paths that might be taken are narrowed down by the path that has already been taken.

Nor could the Cambrian radiation have happened without the conditions that favoured the proliferation of planktonic life forms. These included shallow warming seas on the shelves of the continents as these 'wandered' rapidly away from the South Pole. Atmospheric CO_2 could have been 15 times the present level and temperatures were 'greenhouse' high. Most importantly, the marine environment grew rich in phosphate, calcium and iron as Pannotia's 'supermountains.' eroded into the seas. As Pannotia was pulled apart, volcanism increased, further fertilising the seas with deposits of ash. Both the calcium and the carbonate needed to make animal shells and skeletons were now freely available.

Every rise in atmospheric and oceanic free-oxygen levels since Archean times has been associated with the emergence of new animal or plant groups, each characterised by having a higher metabolic rate per gm (free energy rate density) than pre-existing groups. For example, this holds true for the evolutionary sequence: crustaceans, amphibians, insects, rodents, primates. It is not so much that increased oxygen concentrations *cause* more complex life forms to evolve; it is rather that, for any nominated level of organismic complexity, there is a threshold concentration of oxygen above which it becomes *possible* for that level of complexity to evolve and persist---a necessary but insufficient condition. To take a simple example, body volume increases faster than surface area when organisms get bigger. Hence, one change which allows organisms to get bigger while remaining fully oxygenated is a higher dissolved-oxygen concentration, leading to a greater intake of oxygen per unit of surface area. More generally, because Cambrian organisms were, in some sense, more complex than their predecessors, they had a higher specific metabolic rate and, hence, oxygen requirement per gm. Presumably, the cost of having to take in more food and oxygen per gm of bodyweight is an 'investment' which is more than offset by allowing adaptations such as a reduction in body size, better access to food, higher reproductive rate or more efficient conversion of food into usable energy.[78]

Great Ordovician Biodiversification Event

Taxonomists group plant and animal life into increasingly inclusive categories, running from species through genus, family, order and class to phylum. The foundational nature of the early Cambrian explosion is indicated by the fact that not only have no new phyla appeared since then, but no new classes have appeared in 150 myrs and no new orders since the post-dinosaur radiations some 65 Mya.

During the Cambrian, the number of marine families peaked at nearly 200, declining thereafter and being replaced by a rapidly radiating Ordovician fauna. This so-called *Great Ordovician Biodiversification Event*[79] (c.485-460 Mya), much larger than the Cambrian explosion, introduced numerous new families. If the Cambrian period is thought of as producing the modern phyla, the Ordovician radiation can be considered as the 'filling out' of these phyla with the modern (and many extinct) classes and lower-level taxonomic groups. While Precambrian and Cambrian communities were mostly limited to the sea bottom, the Ordovician radiation filled the water column as organisms adapted to this previously unoccupied niche.[80] Bottom-dwellers too extended their constructive activities, building up and burrowing down. Ordovician seas kept rising to, perhaps, 200 m above present levels, the highest in Earth's history.

Notwithstanding, around the end of the Ordovician (c.430-440 Mya), as the number of marine families was rising above 400, an extinction of about 100 marine families occurred. This, the *Ordovician-Silurian mass extinction event*, was the first (and third largest?) of five such events that have occurred in the past half billion years.

Just as a changing geophysical environment primed the Cambrian and Ordovician radiations, it was changing environmental conditions (e.g. asteroids, glaciations, stagnant oceans, ozone depletion, atmospheric pollution) which precipitated this and subsequent mass extinctions. At the time, Gondwana was moving back towards the South Pole, triggering a period of intense glaciation, and hence cooling and falling seas, both on

[78] Conrad, M., 1983, *ibid.* p.256
[79] Servais, T., Harper, D.A.T., *et al.,* 2009, Understanding the Great Ordovician Biodiversification Event (GOBE): Influences of Paleogeography, Paleoclimate, or Paleoecology , *GSA Today,*, **19** (4/5) pp.4-10
[80] Servais, T., Harper, D.A.T., *et al.,* 2009, *ibid.*

continental shelves and in marginal seas, i.e. those not fully connected to the oceans. Widespread loss of habitat would seem to explain the Ordovician extinction. In the event, the Gondwanan ice sheet melted quite rapidly, for reasons not understood (volcanic activity possibly), and family numbers recovered within 15-20 myrs..

Smaller-scale extinctions have been commonplace throughout evolutionary history. Unlike mass extinctions, the reasons are as likely to be ecological as (physical) environmental (e.g. regional drought). That is, species can be wiped out by predators or parasites, especially small populations in isolated niches, and they can be wiped out by *competitive displacement*, as when a species is out-competed for a resource (e.g. food, shelter) by an invader or immigrant species.

Silurian-Devonian period 438-417-362 Mya

Although the union was not concluded until 275 Mya, the Silurian-Devonian time period saw Gondwana and Laurasia (Laurentia plus Baltica) beginning to come together to form what would be Pangea, the all-inclusive supercontinent. From their Ordovician high, sea levels slowly fell to about present-day levels, leaving extensive shallow seas around the continental margins. Day length crept up to 22 hours. About 16 per cent of the atmosphere was oxygen, sufficient to support a protective ozone layer that would allow complex life-forms to survive on land. The atmosphere's CO_2 level fell from c.5000 ppm (parts per million) to c.3000 ppm over the period. Climates were generally equable, even 'greenhouse,' and, after recovering from the Ordovician extinction, the number of marine families hovered around 400 until, at the end of the Devonian period, another mass extinction struck.

These were times of great change for the ecological stage and its evolutionary play, to borrow Evelyn Hutchinson's metaphor.[81]. In the sea, life evolved to more-fully occupy and exploit the *pelagic* or upper reaches of the water column. Calcareous coral reefs, built from algal skeletons and secretions, became a rich and quite new type of ecosystem. Elsewhere, both plants and animals evolved in ways which allowed them to occupy moist shorelines and, in time, drier landscapes; the first true terrestrial ecosystems began to emerge.

Ammonoids (the ancestors of squid and octopus) and fish, the first animals with backbones (vertebrates), evolved and quickly diversified. First came jawless fish (agnathans) which, while remaining filter-feeders, evolved from bottom-feeding to swimming freely through plankton-rich surface waters. Jawed fish evolved from and preyed on jawless fish, filling a 'vacant' niche and adding another trophic (food chain) level to an increasingly-elaborate marine ecosystem.

The first animals to occupy dry land---wingless arthropods such as insects, spiders and centipedes---did so in a period of rising oxygen levels in the middle-late Silurian, c.420 Mya. But moss-like plants, descended from green algae and living symbiotically with fungi, had reached water's edge well before. Such were limited in size though because they relied on diffusion to distribute water and nutrients through their tissues. The first plants with specialised *vascular tissues* for distributing water and nutrients were

[81] Hutchinson, G.E., 1965, *The Ecological Theater and the Evolutionary Play,* Yale UP, New Haven

descendants of mosses and appear in the paleontological record at 425 Mya. These were very simple---spiky green stems with no leaves, but with spore-bearing reproductive structures. It was vascular technology which, in time, would allow the evolution of large trees and a skyward extension of the ecosphere's envelope.

By 400 Mya, forests of *pteridophytes*, a group of shrub-like plants with roots and leaves, including lycophytes (clubmosses etc), horsetails and ferns had spread widely. Most importantly, *progymnosperms*, ancestors of seed-bearing *gymnosperms* now emerged. Unlike ferns, gymnosperms have the flexibility of not depending on free water for their fertilisation; they have air-borne pollen. By 380 Mya the continents were green with, for the first time, forests of woody trees. These forests were a 'sink' which lowered atmospheric CO_2 (storing it in peat swamps and sediments) and, in the absence of *herbivorous* (plant-eating) animals that might have recycled and oxidised this plant material, the source of a marked increase in atmospheric oxygen. Thus, the Devonian period produced an unoccupied ecological niche, along with an 'explosion' in plant groups and their growth forms.

About 380 Mya (late Devonian) the first land vertebrates appeared. Descended from fish similar to modern coelacanths and lungfish (living fossils!), these were large *amphibian tetrapods* (some up to five metres long) which had evolved four multi-jointed leg-like fins that allowed them to crawl along the sea bottom. Tetrapods have four legs and amphibians are animals that live both in water and on land. The *Tiktaalik*, for example, was an intermediate form, living in anoxic (low oxygen) swamps, where it was evolving to support itself on solid ground and, with the help of a lung-like air sac, possibly adapted from a swim bladder, to breathe air.

Early amphibians had to return to water to lay their shell-less eggs and to avoid 'drying out.' It was not till much later that some amphibians evolved into *reptiles* which had scales to minimise water loss and shelled eggs that permitted babies to be hatched on land. The egg, a small pool of 'water' inside a largely waterproof shell, is a brilliant niche-extending technology. Meanwhile, it was amphibians that were destined to become predators at the top of the food chain in this and following periods.

And then, over 20 myrs, starting 374 Mya, came the Eon's second mass extinction or, more correctly, a prolonged series of extinctions. However, while some 70 per cent of marine species, especially reef-dwellers, died out, land plants were little affected, notwithstanding a change in climate from mild maritime to harsh continental. Descendants of the aquatic organisms which survived would be the ones to rule the Earth for the next sixty million or so years. These included new types of corals, brachiopods, ammonoids, and a number of lineages of fish and tetrapods.

Various causes have been suggested for the *Late Devonian Extinction*, none totally compelling.[82] They include anoxic oceans, acidic oceans, cooling oceans, sea level changes, asteroid impacts, plate movements and combinations thereof.

Falling temperatures associated with falling CO_2 levels may have cooled surface waters by as much as 5 deg C, stressing tropical ecosystems in particular. These cooling waters may also have absorbed more CO_2, making them acidic enough to inhibit shell formation.

[82] Southwood, R., 2003, *The Story of Life*, Oxford University Press, Oxford, p.87.

Falling temperatures may also have produced a level of glaciation sufficient to lower sea levels in shallow marginal seas, leaving reef systems stranded. Equally when temperatures rose again for a time, triggered by a temporary CO_2 rise, sea level may have risen rapidly enough to 'drown' reef systems, which need to be in near-surface waters. The CO_2 rise itself may have come from volcanic emissions set off by asteroid impacts. Asteroids may also have brought anoxic, sulphurous deep waters to the surface where oxidation could have produced acidifying sulphate ions. Hydrogen sulphide may have been released in lethal quantities. Oxygen levels may have been further reduced as Laurasia and Gondwana came to together, blocking off 'conveyor belt' currents that had been important for keeping the oceans stirred and aerated.

A final driver in this complicated mix of possibilities might have been a surge in oxygen-capturing algal blooms in coastal waters. This could have been set off by a rise in nutrient runoff levels, a rise associated with an increase in soil formation and erosion as deep-rooted forests spread across the continents.[83]

Carboniferous-Permian period 362-290-251Mya

The early part of these periods was everywhere warm, but, as Gondwana moved polewards, it experienced a pronounced cooling and glaciation. Although the equatorial regions remained warm, wet and tropical, a vast ice sheet spread over what is now Antarctica, southern Australia, most of India, the southern half of Africa, and much of eastern South America**.** Pangea, the pole-to-pole supercontinent was fully-formed by 275 Mya, and stayed together for a hundred million years before beginning to break up, a process which continues to this day.

In equatorial seas, coral reefs and invertebrates flourished and diversified. Among the fish, groups which had dominated Devonian seas were disappearing and being replaced by an amazing variety of sharks. The equatorial lowlands were covered by swampy forests of large lignin-rich trees which eventually became great coal deposits (Carboniferous means 'coal bearing'). Lignin and cellulose are strengthening materials which decompose slowly. Some fern-like seed-bearing progymnosperms grew to 35 m. The drier uplands remained a sparsely occupied niche. Because the vigorously photosynthesising lowland forests were not being decomposed (oxidised) as fast as they died, atmospheric oxygen levels rose to an all-time high of 35 per cent and, correspondingly, CO_2 levels fell. Insects, spiders and other types of arthropods radiated rapidly in the forests' abundant leaf-litter. Some of these, capitalising on the oxygen-rich atmosphere, increased their metabolic rates to levels which would support the energy-intensive technology of flying. Some grew big; one dragonfly-like aerial predator was the size of a seagull. In waterbodies and water margins the tetrapods flourished and dominated, including various crocodile, eel, and salamander-like forms.

It is at this time that the first reptiles appeared. These, while well-adapted to live exclusively on land, remained ecologically insignificant until at least the very end of the Carboniferous. They developed larger and more powerful legs than amphibians, and were

[83] Algeo, T.J., and Scheckler, S.E., 1998, Terrestrial-Marine Teleconnections in the Devonian: Links Between the Evolution of Land Plants, Weathering Processes, and Marine Anoxic Events, *Phil. Trans. R. Soc. Lond. B,* **353**, pp.113-130

much more mobile because their legs sat beneath their bodies, not splayed, like amphibians, at their sides.

Meanwhile, under a cold dry Antarctic climate, the Gondwanaland continents evolved a distinctively different flora, one dominated by *glossopterid* (having tongue-shaped leaves) seed-ferns. It was from this group that the major plant groups of the coming Mesozoic Era (251-65.5Mya), and possibly (much later) even the flower-bearing angiosperms, would evolve. By the end of the Carboniferous-Permian periods, true gymnosperms (seed-producing plants whose seeds are not enclosed in an ovary) such as cycads and early conifers had appeared. Gymnosperms, equipped with the three technologies of seeds, fertilisation by pollen and efficient vascular systems, were adapted to become widespread in the drier continental climates of the early Mesozoic Era, conditions which more tropical groups could not tolerate.

From early Permian times (say, c.280 Mya) the global climate became steadily warmer and milder. Marine and terrestrial faunas which had been pruned back during the relatively cool Carboniferous diversified into new families. Gondwanaland's glaciers receded, and inland areas became drier. Far from the moderating influence of the global ocean, much of the interior of Pangea was probably quite arid, albeit with distinct wet and dry seasons. This drying tendency, along with alternating warming and cooling periods, continued through to the late Permian. A plethora of insects and reptilian herbivores and carnivores coevolved in step with the supercontinent's changing plant formations.

At the very end of the Permian, sea level, and hence the area of continental-shelf and lowland-swamp habitats, fell from its Ordovician maximum to an all-time low. This loss, an indicator of heavy glaciation, helps explain why there was a low rate of coal formation and a dramatic drop in atmospheric oxygen---to about 16 per cent---during the first five million years of the Triassic period. Giant firestorms too may have played a part, consuming oxygen and forests.

Permian-Triassic mass extinction c.260-245 Mya

The Permian-Triassic mass extinction, the most destructive on record, saw the loss of, perhaps 90 per cent of all multicellular species, including many amphibians and many trees, particularly pteridophytes which had flourished in the Carboniferous forests. Eight orders of insects became extinct. As with the Devonian extinction, this too was probably a series of extinctions over some 15 million years, albeit with a sharp 'spike' in the rate of loss around 251 Mya. That is, the end of the Paleozoic era was marked by both an extinction spike and a steady turnover (replacement) of older lineages by newer, better-adapted lineages in many niches.[84]

The spike in extinctions at 251 Mya is widely believed to have been triggered by massive volcanic activity in China and Siberia. The flood of lava released from the so-called Siberian traps, over about a million years, could have covered as much as seven million km^2. Looking for causes, this exceptional volcanism may have been related to the beginning of Pangea's breakup, or, more plausibly, it could have been associated with an

[84] Bottjer, D.J., Clapham, M.E., *et al.,* 2008, Understanding Mechanisms for the End-Permian Mass Extinction and the Protracted Early Triassic Aftermath and Recovery, *GSA Today*, **18** (9), pp.4-10.

asteroid strike directly opposite (antipodal to) Siberia on the other side of the globe (Wilkes Land in Antarctica?). On a sphere such as Earth, ‘shock waves’ from any large impact first spread and then converge on an antipodal point, generating large earthquakes and releasing lava there. Something similar may have happened during the Cretaceous extinction (65.5 Mya) when the Deccan traps, which are directly opposite the Chicxulub impact crater, extruded comparably large quantities of lava.

More specifically, how might the combination of an asteroid strike and megavolcanism have triggered the Permian extinction? Consider asteroids first. Even during periods of strong ocean currents, flowing as they do from warm to cool regions, the ocean deeps and bottom sediments are low in oxygen and home to anaerobic bacteria, busy producing large quantities of hydrogen sulphide and methane hydrates; more so when atmospheric oxygen is falling and ocean circulation is weak, as happens in a warm world. Should a large asteroid strike in an ocean basin, it will generate toxic, anoxic tsunamis, many hundreds of metres high perhaps. Methane-saturated waters may have ‘exploded’ when released from the pressures of the deeps. The potential for destroying life in coastal areas is great, not to mention the wider effects as atmospheric methane and H_2S move inland. An H_2S concentration of even 100 ppm will kill most animals.

Apart from the on-ground effects of megavolcanism, enormous quantities of CO_2, sulphur dioxide and particulate ash would have been spasmodically ejected; smaller ejections of chlorine and fluorine would have sufficed to destroy Earth’s life-protecting ozone layer. Sulphur dioxide in the atmosphere leads to acid rain, while dissolved CO_2 acidifies the oceans. Particulates block out sunlight and produce ‘volcanic winters,’ perhaps even persistent glaciation. Conversely, a CO_2 ‘blanket’ raises air and water temperatures, perhaps to levels that trigger extinctions. Warm and cold conditions might well have alternated during the Permian-Triassic extinction. Overall, one might wonder how *any* multicellular organisms could have survived this convergence of traumas in the late Permian.

Mesozoic Era (251-206-65.5 Mya) Dinosaurs, mammals, birds, flowers

For present purposes, the importance of the Mesozoic Era is that it was the ‘age of reptiles,’ hosting not just the radiation and subsequent extinction of a dominant *dinosaur* fauna, but the emergence of the reptilian lineage which gave rise to we mammals.

The Mesozoic Era, like Gaul, is divided into three parts: the Triassic (oldest), Jurassic and Cretaceous (youngest) periods. Archosaurs (‘ruling reptiles’) and synapsids (mammal-like reptiles) were two consequential reptile lineages, both descendants of large amphibians, which first appeared during the Permian period and survived into the Triassic. Thus, *Lystrosaurus* (‘shovel lizard’), a hippo-like burrowing and browsing synapsid, was pre-adapted to low-oxygen conditions and was the only largish (about a metre long) land animal to survive and, for a time, to thrive. It was such advanced synapsids (*theraspids*) that were evolving into true mammals by the end of the Triassic, even as they were largely disappearing and being replaced by archosaur lineages, particularly the *dinosaur* lineage.

In a short space of time, dinosaurs rose from being small, swift and bipedal, but ecologically unimportant, to a group occupying nearly all terrestrial niches. They were to increase in size and ‘rule’ the earth for the next 150 myrs (over twice as long as their successors, the mammals, have so far been predominant). Some herbivorous dinosaurs became huge, perhaps to keep warm (called inertial homeothermy), perhaps to accommodate the large guts necessary to slowly digest the nutrient-poor plants of the time.

Why were they so successful? Atmospheric oxygen declined sharply in the Triassic and archosaurs probably had comparatively advanced respiratory systems; being somewhat erect, they could run and breathe at the same time. Also, the early Triassic was largely arid; most of the earth's land area was concentrated in one supercontinent and the mountain ranges pushed up during Pangea's formation produced extensive 'rain shadow' deserts. Fibrous conifers and palm-like cycads, still gymnosperms, were becoming the dominant plant groups. Archosaurs were also probably better at conserving water than early synapsids because they had glandless skins and excreted nitrogen as a uric-acid paste (like today's birds) rather than as a watery solution of urea (like today's mammals).

End-Triassic mass extinction More generally, the end of the Triassic period marks the world's fourth mass extinction event, i.e. coming after the Ordovician, late Devonian, and Permian-Triassic events. This event, 200 Mya, lasted less than 10,000 years and occurred just before Pangea started to break apart. At least half of the species now recognised to have been living on Earth at the time went extinct. All large non-dinosaurian archosaurs, some remaining advanced synapsids and many of the large amphibians were wiped out. Niches were being emptied out, ready to be filled by diverse dinosaur lineages during the Jurassic period.

There is no widely agreed explanation for the End-Triassic mass extinction. Sea level fell and rose sharply at the time, suggesting the possible formation of an anoxic marine environment and a release of toxic gases. More suggestively, as Pangea began to rift apart, a flood of volcanic lava and CO_2, comparable in volume to the Siberian and Deccan traps events, was released in the Central American Magmatic Province (CAMP). Not only did this initiate greenhouse conditions that persisted through the Jurassic, the oceans may have been warmed sufficiently to become slow-moving and stagnant and primed to release large quantities of methane from bottom-sediments.

Pangea's continental plates continued to move apart throughout the Jurassic and Cretaceous periods, allowing plant and animal evolution to follow somewhat different trajectories on each relatively isolated continent. The present-day configuration of continents had been largely achieved by the time of the End-Cretaceous (fifth) mass extinction (65 Mya), the event which marks the transition from the Mesozoic era to the Cenozoic (recent animal) era.

In the late Jurassic period (c.140 Mya), angiosperms, i.e. flowering plants, evolved from a particular lineage of gymnosperms and a landscape dominated by ferns, cycads and gymnosperms gave way to one populated with seed- and fruit-bearing trees and other types of still-familiar angiosperms. By 100 Mya the angiosperms had diversified considerably and were widespread.

Fruits and *flowers* (petals are modified leaves) were the adaptations that allowed angiosperms to permanently displace gymnosperms as the dominant flora; over three quarters of all today's plants are angiosperms. Fruits (modified plant ovaries) facilitate seed dispersal and manuring by animals. Mobility is all-important to animal survival and the ability to spread provides plants with their own form of mobility, albeit in slow motion. Flowers facilitate pollen dispersal by animals, especially insects such as bees. But it was not just insects and angiosperms which were coevolving. The rise of the angiosperms as a food source triggered a burst of coevolution in both mammals and dinosaurs, including the dinosaurs we know today as birds.

During the Mesozoic era, mammals and some forms of dinosaurs (e.g. bird ancestors) evolved to be warm-blooded, i.e. able to generate body heat internally and control, through insulation, the rate at which that heat is lost, e.g. fur, blubber etc. While warm-bloodedness, or *homeothermy*, is energetically expensive, it allows instant mobility and nocturnal, cold-night mobility. It allows specialised organs (e.g. brain, glands) to operate independently of the outside temperature. Nocturnal mobility may have been particularly important for small insectivorous mammals trying to avoid dinosaur predators.

Sometime during the early Jurassic, two groups of reptiles gained the ability to fly and one of these groups later gave rise to the birds (the taxonomic class of Aves). Flying is energy–intensive but expands access to dispersed food sources. Apart from warm-bloodedness, birds developed a range of flight-assisting adaptations such as feathers and hollow bones. Bats became the only flying mammals. In Jurassic seas, apart from fish, the main vertebrates were marine reptiles, including ichthyosaurs ('fish lizards'), plesiosaurs, pliosaurs, and marine crocodiles. While the first true mammals appeared in the early Jurassic, the three extant mammal groups appeared, probably independently, in the early Cretaceous, say 120-130 Mya, these are the monotremes (egg-laying mammals), the marsupials (pouched mammals) and the placental mammals (others).

It was during the late Cretaceous that humanity's order of placental mammals, the *primates*, began coevolving with and adapting to an increasingly diverse angiosperm flora, including trees producing much larger fruits than their predecessors. Thus, primates began shifting towards a vegetarian diet and a largely arboreal lifestyle.

End-Cretaceous mass extinction

The end of the Cretaceous, about 65 Mya, is marked by a mass extinction which included all lineages of dinosaurs, save the birds. Up to this point mammals had been largely confined to nocturnal, insectivorous niches but, once dinosaurs were out of the picture, placental and marsupial mammals diversified, throughout the Cenozoic era, into many new forms and niches. Notwithstanding, 35 per cent of all mammal species died out at this time. It appears that the marine food chain based on photosynthesising plankton and the terrestrial food chain based on green leaves both collapsed for a relatively short, but catastrophic, period. Mammals and the other broad categories of terrestrial life that flourished in the wake of this extinction---birds, insects, flowering plants---are those that characterise the global ecosystem to this day.

Explanations are always contestable but what happened is consistent with evidence that an Everest-sized asteroid created the Chicxulub crater (170 km wide) off the coast of Mexico, throwing up a long-lasting (years?) sun-dimming dust cloud and, on the opposite side of the world, triggering tsunamis and the flood basalt event known as the Deccan traps. Vaporised limestone might have fallen as acid rain. Wildfires might have consumed much dead vegetation, adding a layer of soot to the already-opaque atmosphere. Vast quantities of toxic gases, e.g. methane and hydrogen sulphide, could have been released during the two antipodal events.

As with the four previous mass extinctions, the End-Cretaceous event was associated with a sharp fall in sea level, a fall not associated with an asteroid impact but, more probably, with the convergence of India and Africa on Eurasia which led to the Himalayas and the Alps being formed. Less probably, the cause might have been a period of aberrant glaciation in Antarctica. Either way, marine invertebrates were heavily depleted.

The greenhouse conditions which characterised much of the Cretaceous continued into the Paleocene and the Eocene, the first two epochs of the Cenozoic era. The *Paleocene-Eocene Temperature Maximum* (PETM) was a short spike of high temperatures associated with volcanism and lasting approximately 100 kyrs during the late Paleocene and early Eocene epochs (roughly 55 Mya). Sea surface and overland air temperatures increased by more than 5 deg C and a further round of terrestrial and marine extinctions followed. A few million years later came another particularly warm period, the *Eocene Optimum*---the world was ice-free and largely subtropical---but thereafter the Earth entered a fluctuating cooling trend which, in broad terms, has continued till the present day. .

It was then that the broad ecosystems (ecozones) which we have today began to take on their global pattern: tundra, coniferous forest, deciduous forest, tropical rainforest and grasslands. The last major group of plants to evolve was the grasses (family *Poaceae*), which became important from around 40 Mya. In areas of intermediate rainfall (500-900 mm per annum), grasslands and savannas (grasslands with some trees) replace forests---as happened in east Africa at the time our hominid ancestors were evolving. More generally, grasslands coevolved with new and diverse suites of grazing mammals.

IDEAS FOR A WORLD VIEW

This chapter is a brief version of science's story of the extended origins of our ancestors, the first primates, and the world into which they emerged some 60-65 Mya. Some may still be puzzled by the idea that this, the earliest instalment of the human story, could be a useful platform (among others of course) from which to contemplate the converging problems of the contemporary world; a bit like studying climate change before deciding to take an umbrella, perhaps? The puzzled may be right but, saying it again, and more explicitly, there are several ways in which a familiarity with this story stands to support and inform those responding to perceptions of an Overshoot Crisis in which primates are heavily implicated.

Overall, it is a story from which elements of a science-based, naturalistic *world view* can be extracted, a world view being *a coherent system of fundamental beliefs that describe reality*.[85] More specifically, it suggests various core propositions about our lineage's identity, about the way the natural world behaves and about processes which drive change in the natural world.

[85] Aerts, D., Apostel, L., *et al.,* 1994, *World Views: From Fragmentation to Integration*, VUB Press, Brussels; Internet edition 2007, http://www.vub.ac.be/CLEA/pub/books/worldviews.pdfInternet (Accessed 3 Jan 2011)

Humans are primates

An entity's *identity* is the characteristics by which it is recognised or known, such things as its history, its similarities-differences with comparable entities and its functional links inside some larger entity. This chapter is an invitation to envisage a wider-than-usual identity for the primate (and hence human) lineage:

Primates, including humans, are not only Sagan's 'children of the stars,' they are children of the Sun, the Hadean Earth, the first prokaryotes-eukaryotes, the first vertebrates, the first amphibians and the first mammals. And, for good measure, the big bang. All primates are 'cousins.' In terms of adapting to global change, the primate lineage should be recognised as having survived five mass extinctions, various icehouse and greenhouse regimes, 5-6 supercontinent cycles, oxygen poisoning , hydrogen sulphide poisoning, oxygen surges, nitrogen drought, great sea level changes, asteroid strikes, irradiation events, a slowing Earth and a slowly warming Sun. Adaptive technologies (survival–promoting ways of doing things) evolved by the primate lineage at different times include slime, aerobic respiration, endosymbiosis, mobility, sexual reproduction, heterotrophy, multicellularity, specialist cells and organs, air-breathing, warm-bloodedness, small litters, bipedalism, omnivory and group living.

Evolution and ecology are inseparable

None of these technologies is exclusive to primates of course. Biological evolution is a 'branching' process in which genetically similar populations begin to diverge (become genetically different) and, over time, become separate species, i.e. split into separate branches on the tree of life, to use an ubiquitous metaphor. When one lineage branches into several, each branch retains most of the technologies developed by their common ancestor. Over evolutionary time, the tree of life has sprouted innumerable twigs and branches only to have nearly all of these 'pruned' as species, families of species etc. have gone extinct. Still, despite a plethora of major and minor extinction events, the variety of life forms on the planet, its *biodiversity,* has increased, in saw-tooth fashion, since Archean times.

For example, an analysis by Robert May suggests that the number of orders of aquatic animals jumped in Cambrian, and Ordovician times, and remained more or less stable (at 80-100 orders) through the Silurian, Devonian, Carboniferous and Permian before dipping in the Triassic.[86] Orders of land animals only increased with the Silurian and reached a sort of plateau of about fifty by the Permian. A large increase in the number of mammal orders after the Cretaceous was because different orders arose to play similar ecological roles on different continents.[87] One of May's conclusions is that once all of a region's ecological niches are filled, the numbers of extant species tends to stabilise.

Lineages do not persist, radiate (branch), adapt (evolve without branching) or go extinct in isolation. While lineages come and go, those extant at any time coexist interdependently in ecosystems and coevolve with each other and with the physical environment. That, in a nutshell, is what was happening within the ecosphere from

[86] May, R.M., 1973, *The Stability and Complexity of Model Ecosystems,* Princeton University Press, Princeton, p.178
[87] May, R.M., 1973, *ibid.,* p.181

Archean times till the emergence of primates. Indeed, suitably elaborated and transformed, the same model provides a first understanding, of the contemporary human ecosystem, including its economic and political structures. Strange as it sounds, today's world is still very much the world of the first primates.

More explicitly, the history of the ecosphere can be understood as a dynamic (ever-changing) tapestry of niches and the lineages which occupy them. Since Archean times lineages have been organised into ecosystems of niches occupied, respectively, by primary producers (e.g. green plants, phytoplankton), or consumers (e.g. zooplankton, herbivores, carnivores; primates) or decomposers (e.g. fungi, prokaryotes). Most relationships between populations of species in ecosystems are based on the trophic niches they occupy as producers, consumers or decomposers, e.g. plant and herbivore, predator and prey, phytoplankton and zooplankton, parasite and host, scavenger and carrion. Equally important though are the many symbiotic and competitive relationships that develop within and between species.

Symbiosis and competition are both important

Competitive relationships usually involve organisms from one or more species seeking access to the same resource. This may mean direct competition for a limited food resource (as in overgrazing, overfishing), or less-direct competition as in technologies for allocating various 'instrumental' or 'positional' resources, e.g. living spaces such as nesting sites, forest plants seeking sunlight, males competing for females. When a contested resource is consistently scarce, natural selection leads to the preferential survival of the lineages and 'sub-species' which, in one way or another, capture relatively more of the energy and materials accessible from the niche. *Competitive displacement* is competition's extreme outcome, wherein one species, an invader or immigrant perhaps, crowds out a niche's incumbent species, e.g. the placental dingo displacing the marsupial thylacine.

Symbiotic relationships within and between species have been important in the ecosphere since the time of the earliest bacterial ecosystems. Broadly defined, such relationships are patterns of activity which enhance the survival prospects (e.g. make life more predictable) of the interacting partners or *symbionts*, and can take disparate forms under labels such as endosymbiosis, exosymbiosis (e.g. lichens, mycorrhizae), gene sharing (e.g. sexual reproduction), synergy, association, mutualism (e.g. pollination by insects), commensalism (e.g. tree orchids), cooperation (e.g. hunting in packs), division of labour (e.g. castes in beehives), information sharing (e.g. alarm calls). Indeed, persistent ecosystems are themselves complex multi-partner symbiotic relationships in that the 'stocking rate' (population size) in each species' niche is stabilised (within limits) by the stability (within limits) of the 'stocking rate' in all other niches, particularly those 'close by' in the food chain. Conversely, if the population in one niche crashes or booms, there will be a chain of repercussions through other niches; more so if the species involved is a highly-connected or *keystone* species.

Symbioses are emergent relationships, i.e. they are the opportunistic, largely unpredictable products of spontaneous self-re-organising interactions, and they persist for as long as both the partners and the conditions that induced the symbiosis persist. What then are the conditions necessary to bring forth and sustain symbioses? While every situation is different, a general answer can be given in thermodynamic terms.

Ecosystems are dissipative systems, components of the universe-wide thermodynamic process which degrades high quality energy into low quality energy as rapidly as circumstances permit. Diverting some of the energy flowing through an ecosystem into a new symbiotic relationship increases the rate at which the ecosystem is degrading energy, as well as making it more complex, i.e. having a higher free energy rate density. So, if the pre-conditions for a symbiosis are in place, it will emerge when sufficiently activated, e.g. when an appropriate immigrant species arrives.

When a symbiotic relationship persists over generations, it becomes a selective environment, a niche in which the symbionts evolve and coevolve, both genetically and behaviourally, e.g. angiosperm fruits become more attractive to primates and primate hands adapt to the fruit-harvesting task. As the lineages in a symbiotic relationship coevolve, their previously separable (though interacting) evolutionary fates move irreversibly together. They stand to become an 'evolutionary individual,' capable of entering new symbiotic relationships.[88] If such a new entity does become stabilised and persists, then it will, in turn, be able to participate in a similar process, one leading to the construction of a more stratified or hierarchical form of ecological organisation.

The ecosphere is vulnerable but resilient

Whether it be ecosystems or other forms of dissipative systems, the standout lesson is that every dissipative system persists only by courtesy of a stable-enough parent system from which a supply of free energy, and materials perhaps, can be drawn. Thus, every dissipative system has a dual nature: it is a whole in itself, and it is a part of some other whole. Energised by its high-temperature core and the Sun, the planet has, for four billion years, been a remarkably stable parent system for the global-scale material-energy cycles of the hydrosphere, atmosphere and lithosphere.

And, notwithstanding extinctions, for the emergent ecosphere too. The global life cycle, has abstracted increasing quantities of energy and materials from the Sun, Earth's core and pre-existing global material-energy cycles. From Pre-Cambrian times when it comprised only communities of bottom-dwelling species, the ecosphere has been drawn to expand spatially into previously unexploited environments, physical and geographical. Thus life has successively colonised the full depth of the marine etc. water-column, the water's edge, 'dry' land and, finally, airspace. Geographically, life has spread through a full spectrum of warm and cold, wet and dry, landscapes and seascapes; at all latitudes and altitudes. A 'quilt' in which the 'squares' are large ecosystems or *land systems* has been thrown across Earth's surface. It is a powerful idea that even complex landscapes are built up from a relatively few types of 'building blocks,' small open ecosystems called *land units*. These are repeated in characteristic patterns over large areas (perhaps hundreds of sq km) with each pattern being called a *land system* or *ecoregion*. Each type of land unit can be described as having (co)evolved a characteristic type of natural vegetation growing in a characteristic soil on a characteristic type of terrain.[89] For example, cracking-clay soils impose such expansion-contraction stresses on tree roots in seasonally wet-dry climates that only grasses can survive on these soils.

[88] Griffiths, P.E., and Gray, R.D., 1997, Replicator II: Judgement Day. *Biology and Philosophy,* **12**, pp.471-492.
[89] Cocks, D., 1992, *Use with Care: Managing Australia's Natural Resources in the 21st Century,* University of New South Wales Press, Sydney, p.46

When a mature land unit loses all or most of its trophic structure, and its constituent organisms, to a short-term exogenous (external) disturbance such as flood, fire, drought, pests or diseases, or to endogenous (internal) random fluctuations in lineage numbers it will begin to recover its previous structure once the perturbation passes or exhausts itself, e.g. the parent system's weather and landscape return to their 'normal' steady state. Recovery commonly takes the form of a temporal *succession* in which each lineage re-establishes itself, for a time at least, depending on which other lineages have already returned and what is available from outside 'reservoirs' (e.g. nearby land units) for recolonising the system's emerging niches.

Lineages come, stay and go. The dynamics of succession are such that many returning lineages enter symbiotic relationships with already-returned lineages, only to find themselves out-competed and eliminated as the succession proceeds and the extant mix of lineages changes, e.g. low-growing early colonisers get shaded out by later colonisers. Indeed, some lineages appear to depend on a periodic simplification of their environment to persist, e.g. grasses in a fire-prone shrub-savanna environment. More generally, if the physical environment (weather, landscape etc.) does not return to 'normal,' some returning lineages may prove to be so poorly adapted to the changed conditions that they become *locally* extinct.

The history of the ecosphere is graspable

Something comparable happens in mass extinction-mass diversification sequences, but on a grander scale in space (e.g. ecozones, clusters of ecoregions, continents, the globe) and time (e.g. millennia, megayears) than at succession's scale of land units-ecoregions and decades-centuries. Despite being ultra-slow by human standards, it is at this scale that the history of the ecosphere can be best grasped in the mind's eye.

From the Big Bang to the Hadean Earth, the pre-history of the ecosphere centres on the emergence at progressively lower temperatures of a succession of increasingly complex and energetic dissipative systems, each encased, like Chinese boxes, in a larger, slower 'parent' system. Since the Hadean Earth cooled to a temperature at which life could emerge in a form stable enough to persist, the planet's quilt of ecosystems has been constantly reworked at all scales. At global scale, this reworking can be explained in terms of processes which have led to habitat loss-degradation for suites of lineages over very large areas and, conversely, to broad-scale habitat creation-improvement for other lineages. While large niches can remain more-or-less unoccupied for a long time (up to tens of megayears) the quilt persists overall because what is niche-degradation for one lineage has commonly proved to be an upgrading for another. The supreme example, with gigayears of consequences, is the widespread replacement of anaerobic microorganisms by aerobes as free oxygen levels first rose in ocean and atmosphere.

Like progressive oxygenation, most of the processes which have initiated mass extinctions and/or afforded opportunities for mass diversifications have been relatively slow and progressive. Examples include oceanic and atmospheric warming and cooling; acidification, fertilisation, de-oxygenation and toxification of the oceans; sea level change; ozone buildup; supercontinent formation, erosion and breakup; and extensive glaciation.

A few, like asteroid strikes and the supervolcanoes whose ejaculates have occasionally produced 'volcanic winters' have been brief and highly energetic. In contrast, the slow buildup of CO_2 from long-lasting volcanism over extended areas has produced 'greenhouse' climates on occasions. More 'normal' patterns of volcanic activity and CO_2 production have, several times, proved sufficient to slowly reverse the very low CO_2 levels associated with 'Snowball Earth' conditions.

The ecosphere itself has initiated many processes which, sooner or later, have affected the broad-scale reworking of the ecosphere. Apart from the assimilation of CO_2 and the generation of oxygen by plants and algae, these include the production of H_2S and methane by anaerobic organisms in deep-water sediments; production of atmospheric aerosols; accelerated rock weathering-soil formation; and the accumulation of biological residues in coal and limestone deposits.

The history of the ecosphere can be likened to an incoming tide with each new wave taking suites of adapting, radiating and colonising lineages further up the beach and each retreating wave taking suites of declining and defunct lineages out to sea. The balance between lineages gained and lost varies between clusters of ecoregions (different 'beaches') depending on the particular broad-scale changes in the physical environment associated with each 'wave.'

Lineages and communities of lineages decline or die out as their reproduction rates decline or fall to zero. The reasons can be many and interlinked but, broadly speaking, changes in the physical environment destroy some lineages directly---their homeostatic limits are exceeded---and other lineages decline when their trophic niches shrink. For example, a predator dies out when its prey dies out; or a temperature rise which is tolerable for one coral may be intolerable for another. In a mass extinction all ecosystems in a very large area, a suite of ecoregions, stand to be drastically simplified, regressing to fewer lineages interacting via fewer trophic, symbiotic and competitive relationships. Whole trophic levels might disappear, e.g. top carnivores.

The following wave of diversification (if not interrupted) will see the remnant ecosystems evolving anew, both genetically and ecologically, towards a replacement set of mature ecosystems incorporating increasing numbers of lineages and linkages. But, unlike a local succession following a local extinction, the makeup of the incoming ecosystems here stands to be markedly different from the ecosystems being replaced. With local extinctions, the physical environment is less likely to have been permanently changed and neighbouring land units can seed the recovering ecosystem with plant and animal colonists similar to those eliminated in the extinction event.

So, what sorts of species stand to survive the forces of progressive extinction and become founder members of radically different ecosystems? They are more likely to be *generalists* as to their niche requirements (e.g. omnivores, rather than carnivores or herbivores) and not *specialists*, i.e. not obligatorily dependent on a few tight coevolutionary relationships for their survival (e.g. corals). And they are more likely to be genetically diverse, already existing as a number of *ecotypes*, any one of which might prove to have the physiological and behavioural flexibility needed to survive the threats to survival associated with the beginning of an extinction event. However, if they are to continue to survive cumulating extinction-pressures and initiate a wave of diversification, these founder lineages will need to keep adapting genetically and radiating genetically and geographically into their depleted and still-changing environment.

The Australian biota provides clear examples. Since separating from Gondwana in Cretaceous times, and since the End-Cretaceous mass extinction, the Australian flora has been dominated by just two genera, *Acacia* and *Eucalyptus*---wattles and gums. Both are now widely distributed and both are rich in species, collectively over 1000. And from an ancestral kangaroo-like creature there developed the big Red Kangaroos that live on the inland plains and the forest-dwelling Grey Kangaroos. Heavy-footed kangaroos, the rock wallabies, also evolved, as well as a variety of small swift things that haunt tussock and undergrowth. Two kangaroos, in tropical Cape York, have climbed back into the trees and eat fruit and leaves. Wallaby, Wallaroo, Tungoo, Paddymelon, Potoroo: these are all kangaroos springing from one or perhaps two kinds of ancestors.[90]

And, at any time, a mass diversification can be enriched or depleted by immigrants. Thus, immigrants from south-eastern Asia began arriving in Australia 30 million years ago, as it was 'colliding' with Asia.[91] These 'recent' arrivals include the bats, the ancestors of which were able to fly here. Then there are the true rats and mice, the forebears of which probably drifted here on floating debris. The small Asiatic wolf, the Dingo, almost certainly arrived recently (within a few thousand years), brought by the nomadic Aborigines perhaps, and so it has not differentiated, and now probably never will, into more than one of its kind.[92]

Adaptive technologies enhance survivability

Alongside a long-term erratic trend towards greater energy use (capture and dissipation) by the total ecosphere, there is a similarly extended trend for more recently evolved organisms (and their ecosystems) to be more complex than their ancestors, i.e., by Chaisson's measure of complexity,[93] they process more free energy per unit bodyweight.

How? Why? Once aerobic respiration had evolved, greater complexification became possible to the extent that oxygen was now available to better drive the conversion of food molecules into energy-storing ATP molecules. That is, additional energy could now be mobilised to allow and support new ways of cycling materials, which is what complexification means. Possible new ways for an organism to function, e.g. incipient symbioses and genetic mutations-reorganisations, would no longer be automatically rejected (selected against) on energy–shortage grounds. Any tentative new adaptive technology now stood to be incorporated if it enhanced the survival-reproductive prospects of the lineage.

More generally, the trend towards complexification in persistent lineages and ecological relationships has, for much of the ecosphere's history, probably been oxygen-limited. That is, each long-term rise in the atmosphere's oxygen content has seen a corresponding rise in the complexity of the ecosphere's radiating lineages and their associated

[90] Cocks, D., 1992, *ibid.,* p.24
[91] Flannery, T.F., 1988, Origins of Australo-Pacific Land Mammal Fauna, *Australian Zoological Reviews* , 1, pp.15-24.

[92] Marshall, J., 1966, *The Great Extermination: A Guide to Anglo-Australian Cupidity, Wickedness and Waste*, Heinemann, London

[93] Chaisson, E., 2004, *ibid.*

ecosystems, e.g. from eukaryotes to mammals. At times of falling oxygen levels, lineages which had become adapted to higher oxygen levels either re-adapted (e.g. became smaller, became air-breathers) or tended to be displaced by lineages which were less oxygen-dependent. By primate times, coral reefs and rainforests were well established as examples *par excellence* of highly complex ecosystems, characterised by long trophic chains and richly connected food webs; and by evolving and coevolving lineages and niches.

As illustrated through this chapter, complexification can take many forms, most of which can be understood in functional terms as adaptive (survival-promoting) technologies. Ecologically, these include adjustments which increasingly stabilise competitive and symbiotic relationships, i.e reduce their variability and increase their reliability. Once stabilised, such relationships become platforms on which a further hierarchical level of relationships can be established (if the requisite time and energy flow are available).

At the biological level, that of the individual organism, and grafted into an ever-changing mix of lineages, certain categories of adaptations keep re-appearing at all stages of ecosphere history. Thus, from prokaryotes to primates, we can identify how diverse adaptive technologies have been 'invented' which, in one way or another, enhance the organism's capacities for such generic tasks as:

Energy storage and mobilisation (e.g. ATP, fat cells, muscle)

Acquiring oxygen, food and water (e.g. gills, mobility)

Acquiring, storing and using information about the environment (e.g. sensory organs, DNA, instincts, memory)

Reproducing and dispersing offspring (e.g. breeding cycles, seeds)

Internal communication and transport (e.g. hormones, nerves, sap)

Regulating internal temperature (e.g. evapotranspiration, sweating)

Habitat modification (e.g. burrows, rock weathering)

Building protective structures (e.g. bark, shells)

Using limiting resources more efficiently (e.g. egg-laying, recycling nutrients)

The common theme behind these (and other) categories of adaptive technologies is not just that they are all survival-promoting, but that they all seek to improve a lineage's survival prospects in one way, and that is by reducing the impacts on the lineage of environmental variability of one sort or another, including fluctuations, shifts and shortages at various space-time scales. Attempting a further generalisation, such adaptations are achieved by either avoiding impacts or by absorbing them without losing functionality. Thus, the closing leaf-stomata on a hot day or migrating with the seasons are clear examples of *avoidance technologies.* Homeothermy and plants which can tolerate flooding for long periods are examples of *absorption technologies*. Risk-spreading (e.g. widespread seed dispersal), internalisation (e.g. egg production, implanted embryos), redundancy (e.g. multiple sensory channels) and anticipation (e.g. memory) are other terms used to understand how organisms counter environmental variability.

This completes my summary and explanation of the history and dynamics of Earth's ecosphere, up to the evolution of primates. The next chapter turns to the biological, ecological and early cultural history of the primate lineage, that which, in time, would spawn modern humans.

APPENDIX: MORE ON SELF-ORGANISING SYSTEMS

A mathematical analogue

What is happening when a system self-organises? And why? One way of explaining the behaviours of real-world dissipative systems is to map them into (draw analogies with) the behaviours of isomorphic (similarly structured) systems of mathematical relationships. For so *modelling* dissipative systems, the relevant mathematics appears to be the study of trajectories through time of solutions to systems of differential equations---what is known as the *theory of non-linear dynamic systems,* meaning systems which change through time but far from smoothly.[94] More popularly, this body of theory is called *chaos theory*. Drawing on this theory and its vocabulary, when a system self-organises (restructures itself) from one network of paths for cycling its component materials to another network, it is being pushed out of one *basin of attraction* and into another. Once inside such a new basin of attraction, the system spontaneously moves, under the impetus of (predominantly) positive feedback processes, along a trajectory towards a restricted part of the basin called the *attractor*.

Francis Heylighen defines an attractor as a region in state space (this being the set of all conceivable system configurations) that a system can enter but not leave; not leave easily perhaps.[95] Once a dissipative system enters an attractor region, its trajectory---the sequence of states it subsequently cycles through---will tend to stay inside that region. That is, it will be in a steady state of *dynamic equilibrium* and following an *equilibrium trajectory* from which, left to itself, it will show no tendency to depart. However, if it is nudged or pushed off this equilibrium trajectory by 'noise', meaning small random fluctuations in its material-energy throughflows, or by a modest change in rates of material-energy inflows to the system, negative feedback processes will start up and take the system back to the attractor trajectory. A system which returns to its former equilibrium after being thus moderately disturbed is defined to be in *stable equilibrium*. In contrast, a system which is in *unstable equilibrium* would continue to deviate from its equilibrium trajectory once such deviation is initiated. Unlike most human-designed systems, self-organising systems have a strong capacity to restore themselves after disturbance.

94 Abraham, R.A.., and Shaw, C.D., 1992, *Dynamics: The Geometry of Behavior*, 2nd edn., Addison-Wesley, Ca.

95 http://pespmc1.vub.ac.be/ATTRACTO.html (Accessed 4 February 2010)

The extent to which a dissipative system's trajectory can be displaced from an attractor-region and still return to the attractor when the disturbance ceases is a measure of the system's *resilience* or *homeostatic capacity* to absorb and recover from disturbance. Commonly, the larger the initial displacement, the faster the return to the dynamic equilibrium of the attractor.[96]

So, a *basin of attraction* can be looked at in two ways. One is to see it as the set of all initial system configurations such that, starting from any of them, the system will spontaneously move towards one specific attractor or sequence of states. The other is to see it as setting the limits to the system's homeostatic capacity, namely the set of states beyond which, after disturbance, it cannot move and still return to the basin's attractor.

The theory of non-linear dynamic systems recognises at least four types of state-trajectories that systems can follow once they have entered an attractor-region:

Point attractors are 'one-state trajectories'. That is, the system appears to remain the same even though its materials are continually turning over and it is degrading energy. A system reaching a point attractor is said to be in a stationary state.

Cyclic or periodic attractors (also called limit cycles or stable oscillations) are trajectories in which the system passes through a fixed sequence of states and then repeats the same sequence indefinitely.

Strange attractors (also called chaotic attractors) are trajectories which, without leaving a bounded region of the current basin of attraction, traverse an infinite number of states without ever returning to a previously visited state. A system following such a trajectory is said to be behaving chaotically and behaviour can vary from nearly periodic to apparently random.

Developmental attractors (also called homeorhetic attractors), are sequences of states (i.e. trajectories) corresponding to developmental stages in classes of systems which have well-defined life cycles, e.g. organisms. More generally, a homeorhetic system is regulated around 'set points' as in homeostasis, but those set points change with time, e.g. migrate across the basin.

When observing real-world dissipative systems, it is difficult to confidently detect point and cyclic attractors, partly because such only occur in simple systems with a few degrees of freedom (i.e. unlike global cycles) and, also, random (inherently unpredictable) disturbances obscure the underlying form of the attractor. More bluntly, cyclic and point attractors exist only approximately and for limited periods. It seems that global cycles and other physical dissipative systems are generally better described as having an underlying tendency to behave chaotically and, in the presence of frequent external disturbances, more or less randomly, at least within the confines of the attractor associated with the system's current basin of attraction. Developmental attractors, on the other hand, seem to be more the province of biological dissipative systems. A dynamic system will stay within its attractor, transporting materials, making static structures

[96] Schneider, E.D., and Kay, J.J., 1994, Life as a Manifestation of the Second Law of Thermodynamics, *Mathematical and Computer Modelling,* **19** (6-8), pp.25-48.

perhaps, and degrading energy, until it is pushed into a different basin by a sufficiently prolonged and sufficiently large perturbation or *disturbance,* meaning a change in the pattern of availability of energy/material inputs from the system's environment. The caveat here is that the disturbance should not be so large as to overload and destroy the system.

More completely, disturbances which trigger such self-organisation do not have to be *exogenous,* meaning 'from the outside'. They could be *endogenous*. What does that mean? An *endogenous disturbance* in a self-organising system is a fluctuation in the external environment of a component *sub-system* which is itself self-organising. That is, an endogenous disturbance is a fluctuation which is external to the reorganising sub-system but internal to the total system. A small change in one sub-system triggers a large change and, from there, a reorganisation in other sub-systems. The energy to drive this sort of reorganisation from inside will normally be energy which has been stored within the system itself after being captured from the energy flowing into the system from the environment. So, even though it is lagged, the reorganisation is still being powered by environmental energy flow.

If a dissipative system is located in an environment which is not variable enough to spill it out of its current basin of attraction, the system is said to be *stable*---at least in that environment. Putting that another way, stability in a real system means staying within some basin of attraction. As well as being a function of its environment's variability, a system's stability will also be function of its own resilience. Greater stability goes with a system's greater tendency to pull in (through positive feedbacks), concentrate and dissipate thermodynamic potential, i.e. organised materials and high quality (free) energy. Other things being equal, a system which is supplying its own feedstock materials through recycling is more likely to be stable, and hence persist. To take a global example, when the energy and moisture load of the atmosphere above a tropical sea of the appropriate temperature becomes too large to transport moisture aloft in the normal way, the transport system may spontaneously re-organise (self-organise) itself to include a new attractor called a cyclone. A cyclone, because it comprises fast-moving material, can dissipate a much greater quantity of energy per unit time for every gm of water it contains than the normal evaporation-rainfall cycle (doing things faster consumes more energy). When the energy load on the tropical sea drops back to more normal levels, there will no longer be a tendency for cyclones to form.

Recapitulating then, each of the global cycles, networks, through which energy and stuff passes, dissipating as it goes, reservoir by reservoir, link by link, is, in the language of non-linear dynamic systems theory, an attractor in a basin of attraction. It is to this state of dynamic equilibrium that the system returns, quickly or slowly, after disturbances from outside or noise from inside---provided, as noted above, these disturbances are not too large. If the degree of noise/disturbance is above some critical threshold level, part of the global cycle will shut down (collapse) through lack of feedstock. Alternatively, it will react to the changes by self-organising, by spontaneously jumping into another of the system's latent basins, one containing, perhaps, an attractor 'trajectory' that can successfully process the post-disturbance flows of materials and energy as they enter the global cycle in question.

A system which has been driven away from its dynamic equilibrium state towards a point, a *bifurcation point*, where it is close to undergoing a self-organising change is said to be in a *critical state.* A self-organising system which has reached a bifurcation point is unstable in the sense that it requires only a small pulse of energy to push it into one of several adjacent basins of attraction. Which of the available basins will be entered is quite unpredictable; the outcome is effectively random and, in this sense, evolving physical self-organising systems display the same 'blind variation' as biological systems evolving in accordance with the Darwinian 'variation and selective retention' model. To complete the parallel with natural selection, evolving physical dissipative systems are also *selected* in the sense that successive variations will be 'rejected' until the system reaches a basin where it is stable, i.e. where it can persist within its attractor trajectory without being rapidly nudged or jolted, endogenously or exogenously, into a new basin.

Maximum entropy production

Something which cannot be proven, but which is strongly suspected by many, and which can be mathematically modelled with some degree of confidence, [97] is that the global dissipative system, the stable self-organising Earth, is behaving in accordance with the maximum entropy production principle mentioned above (see p.17). That is, at all times and places, within the bounds of what is kinetically (materially) possible, the Earth is spontaneously attracted to that mix (network) of material-cycling energy-dissipating pathways which produces more entropy, dissipates more energy per gm, than any other feasible organisation.

There are normally many alternative pathways potentially available to the material-energy passing through any global cycle. To the extent that these alternative paths are incompatible, i.e. cannot proceed simultaneously, only one can emerge, can be selected. For example, a cloud can produce rain in Belgium or in England, but not both. Storms can blow up anywhere. At any time a particular path may be blocked or open, depending on what is happening in other global cycles or indeed in that same cycle, e.g. clouds can reduce evaporation. What is being suggested, at least in regard to the physical dissipative systems of the pre-biotic Earth, is that the particular mix of paths adopted for moving stuff around will always be changing in the direction of increasing entropy production. This capacity to spontaneously readjust the operating mix, the active network of paths, in a dissipative system in order to better meet, at least locally, the cosmic imperative to maximise entropy production is at the heart of the self-organisation-reorganisation process. Let me explain further.

Energy can only be degraded in the presence of matter, basically (but not exclusively) as a corollary of moving it around, which means doing work to overcome its inertia---matter's tendency to resist such movement. It is just not possible for a dissipative process to occur without producing some transient non-equilibrium structuring of its material constituents. What Rod Swenson has usefully observed is that, in such systems, ordered (internally-correlated) flows of disaggregated matter---kinetic structures---produce local entropy faster than disordered flows which rely mainly on friction and conduction to

[97] Dewar, R., 2009, Maximum Entropy Production as an Inference Algorithm that Translates Physical Assumptions into Macroscopic Predictions: Don't Shoot the Messenger, *Entropy,* 11, pp.931-944

produce entropy.[98] So, to the extent that different paths are feasible, the 'most ordered' mix of paths, the one which produces the largest amount of entropy and degrades the largest amount of *exergy* will be spontaneously selected. *Exergy* is a useful term for high-quality freely-available energy which when used to do work is degraded to a lower quality unsuitable for doing further similar work. Exergy lost always equals entropy produced.

This *thermodynamic selection* is the behaviour which locally satisfies the cosmological (thermodynamic) imperative, namely the universe's tendency to eventually eliminate all its own energy and material gradients. Distinguishing it from the additional sorts of selection processes which occur in chemical, biological, social and psychological dissipative systems, it is helpful to define thermodynamic selection as the process wherein a self-organising dissipative system 'gropes' its way towards the physically feasible set of kinetic paths which degrade energy at the maximum rate possible for that system.

In the language of non-linear dynamic systems, thermodynamic selection is the process whereby a dissipative system passes through a sequence of basins in each of which it is in unstable equilibrium until it reaches a basin-attractor where it is in stable equilibrium. It is stable because all the incoming exergy is being used to build and maintain kinetic structures rather than to perturb existing structures. And, in a situation where all the incoming available energy is being actively processed through kinetic structures, entropy production from that system-environment combination will necessarily be as high as it could be. Expressed in this way, 'thermodynamic rejection,' i.e. sequential rejection of the unstable, is perhaps more descriptive than thermodynamic selection. Of course both words have connotations of 'purpose' which are not intended.[99]

So, while energy can be degraded by moving material around in a disordered way, more energy can be degraded by moving the same material around in an ordered or structured way such as a convection current. For example, when a vortex forms around the plughole of an emptying bathtub, the rate of emptying accelerates. Moving any material faster uses more exergy and produces more entropy. From the observer's perspective, a structure here is a persistent macro-pattern of stuff, one in which the finer-scale material components in each part of the pattern are being turned over (imported and exported) incessantly, more or less regularly and more or less accurately in terms of reproducing the macro-pattern. The system will tend to be kinetically unstable (tend to keep changing) as long as a still more ordered structure, a new attractor requiring still more energy throughput to maintain it, can be constructed from the available materials. It is only

[98] Swenson, R., 1991, Order, Evolution, and Natural Law: Fundamental Relations in Complex System Theory, In Negoita, C., (Ed.), *Cybernetics and Applied Systems*, Marciel Dekker Inc., New York, pp.125-148. The degree to which a system is ordered or structured is measured, in principle, by the amount of information (usually measured in binary bits) required to describe how it is configured, molecule by molecule. More prosaically, order in a system means there are fixed relationships (correlations) between the parts of the system.

[99] Salthe, S.N., 2010, Maximum Power And Maximum Entropy Production: Finalities in Nature, *Cosmos and History,: The Journal of Natural and Social Philosophy*, **6** (1), pp.114-121

when this is no longer the case that the system will be kinetically stable, will be maximally ordered, will be producing entropy at the maximum feasible rate and will be degrading a maximum amount of usable energy.

Succinctly then, the more structure there is in a dissipative system, the more entropy it is producing, the more free energy (exergy) it is degrading, the more energy it is storing, the more outside energy it is using to maintain itself and the more rapidly the cosmological drive towards equilibrium is being satisfied. And, to complete the mutually causal loop here, the more energy it is degrading, the more structure it is producing and the further it is from equilibrium.

Not only is such behaviour illustrating Swenson's principle of maximum entropy production, it is consistent with Chaisson's view of evolution as a grand self-organising process in which 'islands' of increased complexity (increased structure) and increased *free energy rate density* emerge from a falling 'sea' of pre-existing less complex systems and persist when conditions are right, i.e. when constraints on what is possible are relaxed.[100] Free energy rate density is the rate at which, per gm of material, a system is processing energy. As we shall see, Chaisson's process is most dramatically illustrated by biological evolution but, as noted earlier, it is also evident in the pre-biotic universe. Self-reorganisation in the direction of maximum entropy production is also self-organisation in the direction of a system in which free energy rate density has been increased. Chaisson's work has focused on the jump in free energy rate density which occurs when a radically new sort of dissipative system emerges but, less spectacularly, the same is happening when any dissipative system self-reorganises in response to an increased energy throughput.

A final idea which neatly links the ideas of self-organisation and maximum entropy production is that a self-organising system which has settled into a strange-attractor region in a state of dynamic equilibrium is also, plausibly, producing entropy at the maximum rate possible for that system.

[100] Chaisson, E., 2001, *ibid.*

CHAPTER 2 STAGES IN THE EVOLUTION OF MODERN HUMANS

FROM PLACENTAL MAMMALS AND PRIMATES TO THE FIRST HUMANS

A convenient place to begin a brief history of the human lineage is with the placental mammals---hairy, sweaty, toothed, lidded, flap-eared four-limbed animals with lungs, four-chambered hearts and developed brains. They maintain a high constant body temperature. Their young are produced from embryos attached to a placental organ in a uterus and, after birth, are nourished by milk from mammary glands. The oldest fossil of a placental mammal, dated to c.125 Mya (million years ago), is a 'dormouse-like creature' 10 cm long.

Towards the end of the Cretaceous period (70-65 Mya), atmospheric changes, including cooling and reduced sunlight, caused, perhaps, by dust from a super volcano or by an Everest-sized asteroid led to the extinction of dinosaurs, plesiosaurs, ichthyosaurs, pterosaurs and much else. In fact no animal species weighing more than 10 kg survived this shock. Since this event, mammals and flowering plants have been the dominant groups of organisms.

Primates, distinguished by their good eyes and flexible hands and feet, are a taxonomic division (an *order*) of the placental mammals that includes the prosimians (primitive monkeys such as lemurs), apes, monkeys and humans. The earliest primates appear in the fossil record at the end of the Cretaceous (65 Mya) and become abundant during the Paleocene (65-55 Mya). They were small-clawed shrew-like quadrupeds living on the ground and in the security of trees. In the Eocene (55-38 Mya), primates finally took wholly to trees and developed many novel methods of coping with that environment. Through natural selection various innovations in body structure and function suited to an arboreal environment appeared.

These adaptations[101] included manipulative grasping hands (with opposable thumb and forefinger) and feet for leaping from limb to limb and stereoscopic vision for depth perception (enhanced by a rotation of the eyes to the front of the skull and a reduced snout). Parallel development of the cerebral cortex (cortex is Latin for bark) led to ever-better coordination of hand and eye (important for picking fruit rapidly). Sight and touch began transcending smell and hearing as the important senses. Primates began living in social groups in more-or-less 'fixed' territories and relying increasingly on socially-learned rather than instinctive behaviour. Being territorial included a willingness to expel trespassers, particularly of their own species. These adaptations can be plausibly traced to the tree-dwellers' diet of fruits from widely scattered trees. Large territories of scattered 'randomly flowering' trees can be better defended and better exploited by groups of primates with good colour vision for finding fruiting trees and fingers suited to picking the crop. The use of group 'scouts' is an effective way of amplifying the individual's senses.

Large litters are a disadvantage for mobile animals in an arboreal environment and primate reproductive strategy evolved towards more intensively caring for but one or two offspring. Also, being in a relatively tropical environment there was little need to limit sexual receptivity to certain periods of the year. Being able to mate throughout the year encourages pair-bonding and is helpful for increasing numbers in a species with a low birth rate. Having young with an extended dependency period and having a habit of living in groups for assistance, protection and food-finding were two developments promoting band cohesion and forms of social organisation that eventually led to human culture.

Throughout the Oligocene epoch (38-25 Mya), monkeys and apes, the 'higher' primates, flourished. By 25 Mya the short-tailed dryopithicene apes regarded as ancestors of humans and other extant apes were well established. Their evolutionary success was enhanced by a coevolution between the seed-distributing primates themselves and seed-producing trees, a symbiosis which led to seeds of high food value and an omnivore diet of seeds, insects and small reptiles.

During the Miocene epoch (25-5 Mya) the great ape family, the Hominoidae split into the ancestors of orangutans, gorillas, chimpanzees and humans. Some 17 Mya orangutan ancestors were the first group to diverge, with the gorilla-chimpanzee-human divergence coming towards the end of the epoch. Sarich and Wilson, drawing on molecular dating of DNA, suggested that gorillas, chimps and humans could have had a common ancestor as recently as 5 Mya.[102] Other more mainstream estimates have the gorilla splitting off some 8 Mya and put the chimpanzee-human split at 6-7 Mya.

The species *Ardipithecus ramidus* has a strong claim to being the earliest forerunner of modern humans to be identified. In 2001, a specimen found in Ethiopia was carbon-dated

[101] In biology, adaptation is a word used to describe both a process and its product. Adaptation is a process of natural selection (differential reproductive success of genotypes in a population) which produces adaptations. An adaptation is an unprecedented anatomical structure, physiological process or behavioural trait in a population of organisms which, at least in the short term, increases that population's capacity to survive and reproduce.
[102] Sarich, V.M., Wilson, A.C., 1967, Immunological Time Scale for Hominid Evolution. *Science,* **158**, pp.1200-1203

at around 5.2 Mya. Other specimens confirm that early hominines (human ancestors), including *Australopithecus afarensis,* walked upright on two feet 4.3-4.5 Mya.

CHAPTER 3 EMERGENCE AND EVOLUTION OF COMPLEX SOCIETIES

THE IDEA OF A UNIVERSAL EVOLUTIONARY PROCESS

Is there a sense in which the evolutionary process which has produced everything from elementary particles to the industrial age has always been the same process? And, if it is not just one process, how many processes is it?

At a very general level, all evolutionary changes are certainly expressions of a single universal process, namely one in which an existing dissipative system spontaneously reorganises all or part of its static and kinetic structures in a way which converts higher-quality energy (exergy) from one form to other forms at an increased rate and, in so doing, increases the overall rate at which low-quality energy (entropy) is being produced and dissipated into the parent environment. In this sense the evolutionary process is a spontaneous equilibrating process, satisfying a 'thermodynamic imperative' to reduce thermodynamic potential (flatten energy gradients) in the most effective available way. Inverting this, the principle, the law perhaps, to which the evolutionary process is conforming is that entropy spontaneously increases at the maximum available rate.

Newly-organised dissipative systems, singly or in combination, can behave in extraordinarily diverse ways and have diverse impacts on their surroundings. Much effort has gone into recognising recurring 'context free' patterns in such behaviours and impacts. For example, the theory of non-linear dynamic systems (see page 66) suggests various templates for the behavioural trajectory (e.g. cyclic, chaotic, point) of a system entering a new basin of attraction and clarifies concepts like thresholds and resilient behaviour (bouncebackability!). Some systems swing rapidly through a sequence of basins, others persist stably in one basin. Other well-recognised behaviours include the formation of hierarchies of systems (systems contained in or made out of other systems) and various symbiotic interactions between systems. We might also note, as pointed out by Stanley Salthe, that, from a self-organisation perspective, the distinction between evolution (moving between basins?) and development (moving within a basin?) becomes blurred.[103] They are overlapping historical processes.

Here, it is not our intention to attempt to abstractly and comprehensively classify what is a superabundance of dynamic behavioural possibilities for mixtures of evolving systems. Perhaps it is just semantics, but I find it more useful to think of these diverse behavioural possibilities as variations on one basic evolutionary process rather than as separate evolutionary processes.

Evolution Has a History

The history of evolution can be written in terms of the changing mix of products (types of dissipative systems) which the *evolutionary process* has created, maintained, destroyed. A broad–brush anthropocentric history of how the universe has evolved over time to produce contemporary humans and the world they live in falls readily into three overlapping 'eons', for want of a recognised word. These are the *Physico-chemical Eon*, the *Biological Eon* and the *Cultural Eon*---names chosen to suggest the advent and proliferation (and eventual decline in numbers) of what are, from the perspective of their human significance, three radically different types of dissipative systems. That is, they are radically different in terms of the types of energy and materials they take in and pass out and in the types of kinetic and static structures they use those inputs to create and maintain.

Central to understanding this temporal sequence is the 'piggybacking' idea of *path dependence*, e.g. that biological systems of the Biological Eon could not have evolved without the prior evolution of physico-chemical systems and cultural systems of the Cultural Eon could not have evolved without the prior evolution of biological systems. Nor could the systems of any eon persist without the survival of systems from previous eons, inasmuch as it is these which nourish that eon's systems with flows of materials and energy.

Just as the history of evolution can be subdivided into eons, the history of each eon can be subdivided into overlapping 'ages' identifying periods of emergence and proliferation of markedly dissimilar types of dissipative systems. Thus, in the Physico-chemical Eon, physical systems first emerged during the *radiation age* that followed the big bang and subsequently diversified over billions of years. Following the condensation of material particles in a cooling universe (the *particulate age*), this eon produced successive overlapping waves of galaxy formation (*galactic age*), star formation (*stellar age*) and planet formation (*planetary age*). Particles, galaxies, stars and planets are dissipative systems which come into existence and which, in time, 'die' in some sense. Each age signifies a major transition in the evolutionary process's reigning product mix.

It was only with the formation of planet Earth and its chemically-rich water bodies that the *chemical age*, a link between the Physico-chemical Eon and the Biological Eon, became possible. It was in the chemical age that life's precursors---sets of linked autocatalytic chemical reactions feeding (metaphorically) off each other---first emerged

[103] Salthe, S.N., 2010, Development (and Evolution) of the Universe, *Found. Sci.*, **15**, pp.357–367

from an environment capable of sustaining supplies of suitably energetic raw materials to these dissipative cycles.

The Biological Eon

The Biological Eon is conventionally, and adequately enough for present purposes, divided into a sequence of ages characterised by ecosystems that successively support unicells, multicells, fishes, reptiles, mammals and flowering plants ,and humans.

Living systems provide an early and important example of dissipation through the conversion of chemical energy to kinetic and thermal energy. Such systems depend for their survival on a process which is conceptually and operationally different from the process determining the survival of the physical and chemical systems which preceded them. At the heart of that novel process is the capacity of early life forms, namely single-celled prokaryotes, to grow (ie process energy at an increasingly higher rate) to a physically-determined 'maximum' size and then (approximately) self-replicate by dividing into two smaller, but otherwise still similar, physically-separate parts, each of which can disperse (e.g. drift away) and regrow to 'maximum' size, provided energy and material resources are not limiting. The fact that its parts are dispersed need not stop us regarding a population of single-cell sub-systems, formed by a cascade of divisions, as just one dissipative system.

Just as all dissipative systems take in energy and materials, they all produce outputs or products which can be described in terms of energy and material fluxes. The terms *autopoietic* (literally, self-creating) and *allopoietic* are a recognition that the outputs of living and non-living systems are fundamentally different. Non-living systems are allopoietic, meaning that they produce things different from themselves, e.g. volcanoes do not produce more volcanoes. Living systems, being autopoietic, produce outputs which, following growth, will be very similar to themselves; a population of unicellular organisms outputs small unicellular organisms, each of which stands to produce a population of unicellular organisms!

Non-living systems rely for their survival on the energy-materials fluxes that drive them staying within certain 'fixed' tolerance limits, limits which can be thought of as defining that system's *niche* in environmental space. If the system's environment keeps changing in any particular direction it will eventually move beyond the environmental limits defining the system's niche and the system will necessarily reorganise. Thus, if energy gradients are flattening, the system will tend to collapse, disaggregate, simplify or shrink and, if energy fluxes are rising, the system will tend to grow or complexify.

Early living systems, e.g. dispersed populations of similar unicellular organisms, were somewhat different. They relied (a metaphor) for their survival in a changing and spatially-variable chemical 'soup' on two attributes which followed from their tendency to bud off imperfect copies of themselves (imperfect in terms of the molecular 'species' feeding and participating in the cell's autocatalytic cycles). One attribute was a tendency to occupy (drift into) all accessible parts of the niche. The other was a tendency to extend the niche to include environments where occasional imperfect copies proved able to survive and replicate more reliably than their parents. Both tendencies improved the population's survival prospects. For example, a small catastrophe which wipes out part of the occupied environment will still leave part of the population to survive and perhaps multiply. Or, if the environment changed so that more of it was favourable to some particular sort of 'imperfect copy', then that particular component of the population would expand in numbers to fill the 'new' environment.

For this two-pronged survival strategy (another metaphor) to work, each part of a dividing organism has to reliably 'inherit' a spread, a starter kit so to speak, of all of the chemical resources needed for autocatalytic growth to proceed. But not too reliably; a *population* of cells which all have exactly the same capacity as their parents to process environmental materials through an autocatalytic growth process may be less able to survive a change in the availability of environmental materials than a *population* in which individuals vary to some extent. Conversely, if the inheritance process is too unreliable then most offspring cells will be unable to continue growing and dividing and the population will remain small and at risk from local catastrophes. The optimum degree of reliability in this 'divide and bequeath' strategy will depend in some complex way on the variability of the environment.

Even though there are, at this early stage in life's history, no genes being transmitted between generations, a form of natural selection is nonetheless operating. When individuals vary in terms of their autocatalytic chemistry, some will grow faster and divide more frequently than others, i.e. they will be selected. Genes and chromosomes evolved subsequently, functioning as a mechanism which reliably transmitted, not so much the molecules required for autocatalytic growth, but encoded information which triggered the construction of all necessary molecules from the raw materials diffusing into the cell. In time it would be the occasional imperfect replication of genes (not of the molecules participating in the cell's autocatalytic cycles) that would generate unicellular organisms of differential fitness and hence create the possibility of natural selection. Gene-based natural selection would, in more time, lead to adaptations such as a capacity for directed mobility or for photosynthesis.

While gene-based natural selection is most commonly thought of as a process which leads to speciation, it is, more fundamentally, a process which increases the survival prospects of multi-organism dissipative systems located in a heterogeneous and changing environment. Just as gene-based natural selection led to populations of organisms of various species being more likely to survive for a time, so did the emergence of *cultural inheritance* and *cultural selection* in populations with a capacity for individual learning and imitation.

The Cultural Eon

When it comes to the Cultural Eon, there is, again, a well-recognised sub-division of history's passing parade of human societies. While culture, in the sense of transmitting learned behaviour to others, could well pre-date the age of mammals, it suffices here to divide the Cultural Eon into a *hunting-gathering (or foraging) age*, a *farming-herding age*, an *urban age* and an *industrial age*. And while the seeds of a *post-industrial age* have no doubt germinated, the paramount feature of the dissipative systems that will characterise that next age is not yet clear enough to give it a specific name.

Of these several ages nominated as comprising the Cultural Eon, this book has so far looked only at hunting-gathering. We have particularly explored how cultural innovations in the hunting-gathering age, including material, social, cognitive and communicative technologies, co-evolved with such consequential biological transitions as those in brain size and organisation, the vocal apparatus, body size and maturation rate.

After the end of the last glacial, as energy flows through the biosphere increased and climates changed, the stage was set for the next major re-organisation of the Cultural Eon, namely a shift to a farming-herding age. It is to the evolution of farming-herding and later societies that we now turn.

CHAPTER 4 THE ROAD TO HIGH COMPLEXITY

This chapter continues our selective cultural history of *H. sapiens*, the animal species which, more than any other, has influenced the quantity of energy flowing through the global ecosystem and the paths which those flows take (war, population growth, monument building etc). The best single indicator of the complexity of any energy-degrading system is the rate at which it processes free energy---as more and more energy flows through a system, degrading and converting to other forms as it goes, additional pathways made up of flow and storage structures are created and, usually, existing pathways are restructured. In the case of the human ecosystem, such thermodynamic changes come to be seen as cultural change-cultural evolution.[104]

[104] Nils Bohr's Principle of Complementarity says two descriptions of nature are complementary when they are both true but cannot both be seen in the same experiment. In quantum mechanics, the wave picture and the particle picture of an electron or photon are complementary. Similarly, one can have a picture of cultural evolution couched in thermodynamic terms or in behavioural terms. Both may be true but descriptions from one perspective leave no room for the other perspective. But, as seems useful, one can switch between perspectives; also each description constrains what the other can say.

Considering the human ecosystem as a whole, there has been a more-or-less monotonic increase (ie no significant reversals) in the amount of energy it has captured and processed in the last 12k years. Both the Neolithic and Urban revolutions can be viewed as having been triggered by the adoption of new more-productive technologies for acquiring food energy, technologies which appeared when the niches for previous technologies disappeared or degraded. Both revolutions relied (largely) on human and animal power to convert solar energy to food energy and both were accompanied by significant coevolution between food production and social and other technologies. The mid-Holocene's third revolution, the consciousness-cognition revolution, flowered only briefly in response to the failure of the 'cannibalistic' survival strategy of the Bronze Age.

Now we look to understand an era in which non-biological energy sources start to play an increasing part in powering cultural evolution. Good examples, energy-extraction technologies which, over extended periods, have led to cascades of technology change elsewhere and to a changing cast of virtual species, include:

Capturing wind energy using sailed vessels

Capturing the chemical energy contained in gunpowder

Capturing the chemical energy contained in fossil fuels

Of the biological sources of energy playing expanded roles in the Common Era (CE), horse power stands out (perhaps camel power too?).

More generally, my guiding principle for reducing what I know of the enormous history of the Common Era to an organised précis will be to try and identify trends, events discontinuities and processes---such things as population growth, new technologies, human-made and natural disasters---which, on the back of trends in energy use, appear to have had the greatest consequences for the well-being of large numbers of people, either immediately or over time. Later, with the hope of getting a better idea of what we need to understand about contemporary societies if we are to pursue a social goal of 'quality survival', we will reflect on what has been selected.

THE LAST TWO THOUSAND YEARS

> Away, for we are ready to a man!
> Our camels sniff the evening and are glad.
> Lead on, O Master of the Caravan:
> Lead on the Merchant-Princes of Bagdad.
>
> Have we not Indian carpets dark as wine,
> Turbans and sashes, gowns and bows and veils,
> And broideries of intricate design,
> And printed hangings in enormous bales?
>
> We have rose-candy, we have spikenard,
> Mastic and terebinth and oil and spice,

And such sweet jams meticulously jarred
As God's own Prophet eats in Paradise.

And we have manuscripts in peacock styles
By Ali of Damascus; we have swords
Engraved with storks and apes and crocodiles,
And heavy beaten necklaces, for Lords.

James Elroy Flecker
The Golden Journey to Samarkand[105]

Trading networks

One of the Common Era's first consequential cultural shifts was a sharp expansion in long distance trade and communication between the four agricultural civilisations then containing a majority of Eurasia's (and hence the world's) people, i.e. the Roman, Parthian (Persian), Kushan and Han empires. Movements, particularly of luxury goods, increased over both land and sea routes between east and west Eurasia. On land, the most famous of these trade routes was the Silk Road which split to skirt north and south of the hostile Tibetan Plateau. And at sea, ever-bigger sailing vessels plied the coastal waters of South and East Asia, venturing in time into the Indian and Pacific oceans. The regular seasonality of the north-south Monsoon winds was discovered some hundred years before the Common Era. Sailing vessels powered by wind energy would eventually supplant the technology of the pack animal (camels and dromedaries), and in the process change power relationships (Who controls trade?) between maritime and non-maritime states.

The linking of Eurasia's largest cities in a long-distance trading network brought material benefits primarily to consumers of high-value low-volume goods, i.e. to ruling groups. Trade is a technology which allows transport costs to be balanced against the benefits of regional specialisation and the savings which come from producing a product on a large scale. But that is only part of the story. Cities in the trading network became places where populations could and did grow, consolidating a trend towards urbanisation which continues to this day. Also, while trade provided the impetus, trade routes were increasingly conduits for the spread of learning, technology recipes, religions, art, genes and disease. Thus, an early consequence of this first drive towards a globalisation, a single world-system of commerce was epidemiological disaster as the separate disease pools of each empire (Plague, smallpox, measles, syphilis) mingled together. For example, drastic depopulation from disease in parts of the Roman Empire contributed to its disintegration. By the time the Western Roman Empire fell (476 CE), Buddhist missionaries, originally from north India, had already spread their influence as far as Japan and Java. Christianity too had spread, with the Roman Empire, through Europe and into Asia Minor where, in later centuries, Anatolia would become a shifting frontier between Islamic forces and Christian forces of the Byzantine or Eastern Roman empire. And, in India, Brahmanism and Hinduism were nurtured in the bosom of the Gupta Empire.

[105] Flecker, J.E., 1913|1926, *The Collected Poems of James Elroy Flecker*, Secker, London

CHAPTER 5 CONFRONTING GLOBAL OVERSHOOT

THE WARM GLOW OF UNDERSTANDING

> The unbroken history of the human lineage can be traced back to the origins of the universe but more recently, meaning the last few million years, we have become, and remained, animals called mammals, then primates, and then a branch of the great ape family. Primates evolved to live in groups in territories from which they attempted to exclude trespassers, a behavioural tendency which persisted as the first humans evolved into modern humans and spread across much of the planet. During the last Ice Age, as *Homo sapiens*' rate of biological evolution (e.g. increasing brain size) slowed down, its rate of cultural evolution (e.g. tool-making skills) speeded up. That is, humans began to create and use an expanding and selectively changing range of behavioural 'recipes' (what I have adventurously called technologies) which through learning and imitation within and between groups, could remain available from generation to generation. By making the further assumption that groups and individuals are purposive agents (i.e. constrained to behave in an emotionally acceptable and rational way) when choosing between technologies, one can, in hindsight and in principle, construct a plausible story (a scenario) of how the species has survived, multiplied and thrived (or not) since, say, cultural 'liftoff.' The fact that technologies have become more elaborate and collectively more energy-intensive over time does not change the basic process; nor does the fact that the rate of cultural change has varied over time.

Before contemplating the future and its difficulties let us bask a moment in the warm glow of understanding that a knowledge of history's interweavings confers. The cameo recapitulation above is a confident assertion that, subject to accepting several methodological premises (groups as purposive agents, the species' capacity for technological innovation), and assuming a sufficiency of raw historical facts,[106] an abductively plausible world history should be possible, i.e. a history which is consistent with the facts. To make this happen, one has to not only assume that individuals are rational, albeit subject to emotional taboos, but that they have a fairly standard mix of motivations;[107] for material gain, access to women,[108] power, acceptance, self-preservation... Virtual species too have to be understood by assuming them to be selecting behaviours (what Graeme Snooks calls dynamic strategies[109]) which are variants on a few generic social technologies such as trade, conquest, colonisation…

In the event, every history, from world to local, is limited by factual gaps and a necessarily imperfect understanding of protagonists' mental models. There is also the inescapable limitation that the historian has to find a way of simplifying the warp and weft of the historical tapestry, its many parallel and cross threads, so that it can be presented as a linear narrative of a size that can be absorbed. Thus, the perspective of the present exercise is that history can be viewed as a succession of fundamentally important turning points or discontinuities. These are clusters of events which start wherever and which trigger (cause) extended chains of events, of ongoing and spreading adjustments, many of which will themselves be 'minor' discontinuities.[110] The challenge in applying this approach is to identify a manageable number of major discontinuities such that one can yet say something of where each came from and where it led. The complexity of history comes with the interweaving of multiple cascades of adjustments to multiple diachronic discontinuities.[111]

The present exercise centres on a macrohistory which culminates in the beginnings of a major discontinuity. It purports to explain how the human lineage went from being a small population of well-adapted tree-dwellers in Africa to being an erupting worldwide population relying on fossil-fuels and an ever-elaborating suite of material, social, communicative and cognitive technologies for meeting people's material etc. needs, albeit with starkly varying degrees of success. Whatever that success, it is hard not to feel a sense of wonder (fancy that!) at how these 'hairless apes' have created, survived, exploited, absorbed, magnified and built on history's environmental, biological and cultural discontinuities. Think of ice ages, the Toba eruption, language, cultural liftoff,

[106] 'By facts we usually just mean "data," that is, everything we count as not part of the particular problem before us, but as what is safe enough to be taken for granted in solving it, and needed to do so. But facts are never confined to the raw data of sense, and seldom to "physical facts" (the kind that can be stated in terms of physics). It is a fact that this is food or poison, that it is dangerous, dirty, unique, or legal, that it is an ancient totem pole or the flag of my country. Yet standards quite alien to physics must be grasped before we can "see" these facts. They are thus never logically isolated from some kind of "evaluating."' From Midgley, M., 1978, *Beast and Man*, Cornell University Press, Ithaca, p.178

[107] Midgley, M., 1978, *ibid.*, p 14 suggests that 'we badly need new and more suitable concepts for describing motivation.'

[108] Gottschall, J., 2008, *The Rape of Troy: Evolution, Violence, and the World of Homer,* Cambridge University Press, Cambridge

[109] Snooks, G.D.,1998, *The Laws of History*, Routledge, London and New York

[110] Minor discontinuities in macrohistory become the major discontinuities of microhistories.

[111] Salthe, S.N., 2010, Maximum Power and Maximum Entropy Production: Finalities in Nature, *Cosmos and History,* **6** (1), pp.114-121

the Holocene climate-shift, agriculture, cities, writing, consciousness, sail, plague, printing, industrialisation… The list goes on.

Wonder is not admiration

Having said that, wonder is not necessarily admiration. People tend to admire (approve of) contemporaries with talents and character traits they would like for themselves, talents and traits which are believed to enhance quality-survival prospects in today's world. By imitating parental behaviour, children learn what to admire and what to disapprove of. Furthermore, discretionary behaviours which are consistently admired (or denigrated) acquire a *moral character* which goes beyond approval-disapproval, i.e. non-conformity incurs physical or psychological (e.g. shame) punishment.

To the extent that people admire-denigrate other life forms, and that includes their own ancestors, it comes from projecting contemporary human qualities onto such, e.g. the tree that, metaphorically, 'strives' to reach the sky, the 'faithful' dog. Similarly we are tempted to admire and denigrate, and to pass moral judgements on what appear to be contemporary traits in our ancestors. But ancestral behaviours which we judge to be cruel, honest, honourable, cooperative, combative, exploitative, and so on, may not have existed in the sense that, at that time, the *concepts* of cruel, honest etc. may have not yet emerged. After all, cruelty (say) is an idea which had to be invented and given a name. Or, they may have existed but not had any moral character.[112]

So, we can say that the cruel conduct of, say, the Bronze-Age Assyrians was immoral by contemporary standards, but does anything useful follow from that observation? It is, potentially, more useful to ask if the Assyrians made an adaptive mistake by choosing to be cruel. Did they even perceive that they had a choice, consciously or unconsciously? Would they have achieved more of what they valued if they had chosen not to use the social technology of cruelty to produce conforming behaviour? Certainly their victims would have been better off. But, would the quality of life and survival prospects of today's humans be better if the Assyrians had foregone cruelty? These are unanswerable questions. If we are to reserve admiration for discretionary behaviours we judge to have improved the achievement of, and prospects for, quality survival, then much of history will be beyond that judgement.

In the event, scholars have found it more productive to study the history of values, i.e. how people in the past have thought about values. What did historical peoples value in terms of ends and means, of behavioural standards? Answers here have contributed, first, to understanding how it really was to live in, say, times of global transformation and, second, to understanding the diversity of people's values, not only in the past but, by extension, in the present, e.g. today's fundamentalist Christians appear to exhibit a religiosity comparable to much of medieval Europe.[113]

[112] Williams, B., 2006, *Philosophy as a Humanistic Discipline*, (A.W. Moore Ed.) Princeton UP, Princeton, Ch.8
[113] Muller, H.J., 1952, *The Uses of the Past: Profiles of Former Societies*, Mentor, New York, pp.244-50

Some ineluctable realities

Contemplation of the macrohistorical record yields several foundational conclusions about humans and the world they now face which cannot be forgotten if we are to think realistically about the quality survival task; recall the suggestion in the Preface that a suitable peak goal for humanity might well be one of seeing its lineage surviving, and surviving well. The three realities to be now recapitulated as impediments to achieving quality survival are: the what-to-do problem; the virtual-species problem; and the global overshoot problem.

1. Purposive behaviour is necessarily experimental---the what-to-do problem

Cultural and genetic evolution over millions of years has produced, in the modern human, a layered behavioural-guidance-system under which, depending on the information being received, activates particular biological, cognitive or emotional responses. Thus an immediate direct threat might trigger a genetically-programmed *instinctive* response of greater or lesser specificity. A more nuanced what-to-do situation might trigger an emotionally-directed response in the form of an impulsive choice from a limited range of previously-learned behaviours. And then, late in the evolutionary story, came the choosing brain, as we earlier called it. Here, the brain imagines the consequences of alternatives to impulsive behaviour and chooses the first imagined alternative to generate sufficiently positive feelings. That is, feelings act to limit the enormous range of alternatives that would otherwise have to be explored cognitively before a behavioural choice is made.

Language-based conceptual thinking was the technology which dramatically increased the range and effectiveness of cognition for guiding behaviour. In reasonably stable environments humans learn to behave in accordance with the slowly-evolving customs, habits, roles and traditions of their own societies. But in non-routine, and hence stressful, situations, leaders, and other decision-makers have come to increasingly rely on mental models of reality to guide their choice of what to do. And in some areas, most notably in science, people have learned how to upgrade such models in the light of experience.

Having said that, it needs to be recognised that all attempts to make rational decisions (those based on ends-means thinking) in what-to-do situations are less than ideal for reasons which include limited time, limited knowledge, pervasive complexity, illogicalities and misperceptions. Given the difficulties of thinking critically and comprehensively, decision-makers commonly resort to using ‘short cut’ heuristics or seeking the advice of authority figures.

What the above means is that all behaviour, whether instinctive, emotionally-directed or highly rational is, to some degree, experimental. The outcomes of an individual’s decisions, particularly in novel situations, are never certain---hence the ‘law’ of unintended consequences. So, when trying to solve a what-to-do problem rationally, one must be routinely prepared to respond further as one’s actions prove inadequate for the problem as initially conceived. Unfortunately, many what-to-do problems are also ‘wicked,’ an eye-catching word meaning that they have no definitive formulation (What sort of problem is this?) and no criteria for identifying a conclusively ‘best’ solution. For example, over what time horizon does one compare the costs and benefits of alternative actions? Moreover, the family of issues that underlies each problem is itself likely to be evolving. It is easy to conclude that most problems will never be solved, only managed by cautiously ‘muddling through,’ or overtaken by events. Notwithstanding, these difficulties are poorly recognised.

2. There is no We---the virtual-species problem

From early hunter-gatherer times, human groups have used the technologies of division of labour and territory-protection for improving their security and productivity. It was through the evolution and elaboration of these technologies---plus their coevolution with some related adaptations and with environmental changes---that the species came to be organised into a loosely connected and dynamic (ever-changing) network of hierarchically-stratified, territorially-based societies.

Unlike better-armed group-living species such as wolves, Paleolithic humans were never strongly selected for a capacity to self-inhibit aggressive behaviour towards trespassers of their own species. This is consistent with the perception that before developing energy-concentrating weapons---and then it was too late---human groups had little capacity to inflict lethal violence on each other. Thus, the untrained fighting style of (modern) humans consists largely of shoving and overhand blows to the bony head/shoulders/ribcage area.[114] While few individuals are highly aggressive, most conform when their group or society initiates aggressive behaviour; ordinary soldiers can be trained to kill when ordered, but most are still reluctant. In brief, humans tend to be aggressive towards strangers but, without weapons and appropriate training, rather ineffectively so.

In those Holocene societies that learned to produce surplus storable food, both population size and task specialisation increased; as did the use of social dominance (e.g. by coercion, manipulation, deceit) far beyond that which had existed in subsistence societies. And it is from these times that it becomes increasingly useful to describe humanity as being organised into virtual species, meaning coherent groups that engage in periodic competition, conflict and cooperation. In the broadest terms, these groups were, and still are, political states and, within each state, a ruling class and a working class. Beyond that breakdown, the hierarchy of virtual species extends upwards to associations of states and downwards to factions and functional groups within classes. In complex hierarchical societies, each individual is normally associated with multiple virtual species and may move between such, e.g. between social classes, political parties, professions, football clubs. In particular, ruling elites are almost always divided into vigorously-competing virtual species with shifting memberships.[115]

Every virtual species behaves, in several respects, like a separate hunter-gatherer group. In particular, group members are predisposed to feel friendly towards those within and enmity towards those outside the group (not just trespassers). And from Paleolithic to modern times, the sharing of amity and enmity emotions has repeatedly been at the heart of the individual’s success in satisfying his or her psychic needs, notably for bonding (the need to ‘belong’[116]), for identity (being an autonomous individual) and for meaning in

[114] Morris, D., 1977|2002, *Peoplewatching*, Vintage, London
[115] Hassan, F., 2005, The Lie of History: States and the Contradictions of Complex Societies, *Dahlem Workshop Reports*, MIT Press. Mass.

[116] Koestler, A., 1967, *The Ghost in the Machine*, Arkana, London

one's life (being part of 'something larger than oneself'). For example: I am a Greek and proud to be a Greek, not a thieving Trojan. We Greeks will conquer the Trojans, no matter how long it takes.

This amity-enmity dichotomy is also the source of the dual standard of morality which most people unconsciously hold, namely judging 'strangers' differently (moral alchemy!) from one's own 'tribe', be it a gang, class, ethnic group, nation or football club. In extreme form it leads to a failure to recognise other virtual species as conspecifics, as fellow humans; abominations such as ethnic cleansing, mass extermination and unimaginable cruelty follow easily. Somewhat less immoderately, other virtual species are seen as humans but, because of their 'dangerous' beliefs or their presumed past behaviour, they are humans who have 'foregone the right' to be treated as 'we' aspire to treat our own.

Armed conflict between groups or societies is a commonplace of history[117] but aggression, or hostility at least, between virtual species *within* hierarchical societies has been equally pervasive. Thus, the majority of humans have been oppressed by their own ruling classes for most of post-glacial history. A society of any complexity requires that some of its members coordinate and direct the activities of the majority. With few exceptions, these elite minorities have used their power to advance and protect their own interests at the expense of majorities. Reforms and concessions which have improved quality of life for the majority have most commonly come only in response to the threat of civil unrest from the 'dangerous classes.' During quieter times the elites seek to reclaim such concessions. The prime example of modern times is the creation of welfare states after the Second World War as a response to fascism and communism; and their winding back with the demise of communism. [118]

From Neolithic times, elites (soldiers, priests, bureaucrats, politicians etc.) have regularly taken their peoples to war in search of resources coveted by the elites themselves---land, slaves, women, converts, bullion, tribute etc. Notwithstanding this coercion, a state's elites and its masses generally come together to temporarily form one virtual species in times of war or external threat..

Burdened with rising populations or falling food supplies, elites have often been willing to let their people slowly and surreptitiously starve (Let them eat cake); or, indeed, to use war and conquest as technologies for culling their own populations. The link between hunger and attacking the neighbours weakened with the coming of hierarchical societies. It is only in the last few thousand years, starting with limited democracy in the Greek city states, that humans have moved somewhat from seeing societies as naturally divided into all-powerful rulers and masses with minimal rights. In some modern industrial nation-states, elites have managed to convince the majority of ordinary people that their political decisions do not favour elite interests. But, even in a strong democracy, every new issue of concern spawns a new mix of self-interested virtual species and a what-to-do problem that cannot be solved in a demonstrably efficient and equitable manner.

Nonetheless, in societies where people are not hungry, think they are being treated reasonably fairly (justly) and feel reasonably secure psychologically, amity and sociality

117 Le Blanc, S., with Register, K., 2003, *ibid.*
118 Wallerstein, I., 1995, *After Liberalism*, The New Press, New York

come to displace enmity and sociopathy (regarding others as enemies to be mistrusted and exploited if possible). People develop an expectation that their interests will be favoured acceptably often. Decisions get made and coordinated activity proceeds; people do what is expected of them. So-called competitive societies, those where egoism is admired (Greed is good!), run the risk of squandering those putative reserves of goodwill and helpful friendliness which might buffer against social unrest.

This brings us to the point of accepting that there is a *virtual-species problem,* namely the difficulty that autonomous virtual species have in collectively agreeing (We agree…) to work in a coordinated way towards ends judged to be mutually beneficial, ends which could not be achieved by one group acting alone---the amplification effect.

Often, it is the virtual-species problem which becomes the major impediment to the inventing of a new social technology. It may be of course that not every relevant virtual species construes the proposed behaviour as beneficial to them or they see it as less beneficial than some other more-independent behaviour (its opportunity cost). Or doubts may be felt as to what exactly is being agreed and what exactly will be achieved. This last is where the virtual-species problem and the what-to-do problem intersect. As discussed above, outcomes of proposals for addressing what-to-do problems are always uncertain and carry the risk of unintended consequences. It is understandable that groups already living on the edge of survival might be averse to risking experiments with novel behaviours, no matter how promising, and prefer to continue with 'safe' traditional behaviours.

The virtual-species problem is more conventionally known among political scientists as *agonism,* a term borrowed from biologists. For biologists, agonism is that combination of aggressive, defensive and avoiding behaviours which allow members of a species to regulate its spatial distribution; and, probably, access to food and mates. Amongst political scientists, agonists are sceptical about the capacity of politics to eliminate, overcome or circumvent deep divisions within societies, e.g. of class, culture, gender etc. They find many models of political behaviour, including liberalism and communitarianism, to be far too optimistic about the possibility of finding an harmonious and peaceful pattern of political and social cooperation.[119] Agonists prefer to start their theorising by asking how societies might first deal with such irreducible differences. It is a question to which we shall return.

In most circumstances, it is much harder to achieve the benefits of coordination when the virtual species involved are large collectives such as nation-states. Compared with domestic agreements, there are several reasons why this should be so. First of all, trust is scarce in international relations where, for centuries, 'realist' doctrines have prevailed, namely, that the essence of foreign policy is to make yourself as militarily powerful as possible, alone or through alliances.[120] Cooperation becomes even more difficult between nations that are already in conflict or have a history of conflict. Negotiators from different countries are more likely than negotiators from the same country to

[119] http://en.wikipedia.org/wiki/Agonism (Accessed 27 Nov 2008)

[120] Morgenthau, H., 1948, *Politics Among Nations: The Struggle for Power and Peace*, Alfred A. Knopf, New York

misunderstand each other's values and to disagree about 'facts' and about what is a fair distribution of costs and benefits.

Notwithstanding, states have been forming military alliances and making trade agreements for millennia. It is in situations where the shared threat or opportunity is not immediately obvious, or where the flow of benefits is not immediate, that international cooperation proceeds slowly. Examples are plentiful in the fields of international law, financial institutions and protection of the environment.

To claim 'There is no We' is just an extravagant way of making the point that it is normally difficult, and often impossible, for two or more virtual species to find and take coordinated actions that will benefit all. Part of that difficulty is the same difficulty as that facing a single virtual species, or an individual for that matter, in any what-to-do situation---all intentional behaviour is inescapably experimental. This is why virtual species that see themselves in an ongoing cooperative relationship must be prepared to revise their joint plans frequently. Even then, even when a degree of trust has been achieved, all such relationships are probably best recognised as intrinsically fragile.

Cooperation within the existing system of virtual species is but one strategy for a virtual species to advance its own interests. Conflict and coercion are other possibilities which, in their own ways, are as problematic as cooperation. Sometimes there is a place for competition in the sense of different virtual species seeking access to the same resources but without trying to thwart each other's efforts directly. Another less direct strategy, one which does not take the prevailing order for granted, might be to try to reshape the attitudes of 'neighbouring' virtual species so that the level of goodwill between virtual species is more conducive to future cooperation, e.g. through cultural exchanges, gifts, arms reduction...

Overall, the ineluctable realities we have identified as the what-to-do problem and the virtual-species problem are major constraints on what humans can achieve through collective action. They greatly reduce the range of options from which a choice of (joint) actions might eventually be made.

3. Overshoot---the accumulation of spillovers

We come now to recapitulating the third of the ineluctable realities which, it is being suggested, must be viewed unblinkingly, not forgotten or bypassed, if one is to think critically about the quality survival task as it presents at the beginning of the 21st century of the Common Era (and that is what we hope to do).

In my earlier book, *Deep Futures*,[121] the 21st century was foreseen to be a difficult century for humanity, one in which the successful pursuit of quality survival would require the species to work doggedly to ameliorate the problems of war, poverty, injustice, environmental degradation and sociopathy; or, more positively, pursue the goals of peace, material wellbeing, social justice, environmental protection and sociality. The virtual-species problem (pervasive disagreement) was assumed to be soluble (e.g. through

[121] Cocks, D., 2003, *Deep Futures: Our Prospects for Survival*, University of New South Wales Press and McGill University Press

a strong United Nations) and, while the presenting problems were great, they too were not to be treated as insoluble.

I am now convinced, just a few years later, that this scenario, call it *strong intervention*, is highly implausible. That is, one would be surprised in the extreme if it came to pass. For me, it is a much more plausible scenario that this will be not just a difficult century, but a disastrous one! Almost irrespective of anything that large numbers of well-intentioned people might do, the existing problems of war, poverty, injustice, inequity, environmental degradation and sociopathy will grow, not shrink. Under the combined effects of drought, famine, war, mass migration, poverty, disease, resource exhaustion and economic disruption, the world's population will start falling well before current estimates that global population will peak 'naturally' around 2070. Many indicators of quality of life, including life expectancy, will slump. In all countries, but especially in an increasing number of failed and war-torn states,[122] it will become much harder for most people to meet their everyday needs. Women and children, the old and the sick will be most affected. Jobs will be few. Supply chains for basic commodities (e.g. food, fuel, medicines) will break. Barter will become normal. Inflation will escalate. Health, education, transport and police services will degrade. Power and water supplies will become unreliable or worse. Roads and other infrastructure will be poorly maintained. Crime and group violence will escalate. Violent protest and looting will be commonplace. Ordinary people will live in fear. Mental illness will be endemic. People will turn to authoritarian regimes for respite. In brief, cities everywhere will struggle to avoid becoming giant lawless slums. Rural populations will be vulnerable to marauders and incursions from displaced persons. Life will be an exhausting wretched struggle.

Such a dark-age 'future' has already arrived in parts of the world---most obviously in parts of east and west Africa, the Middle East and South America. But it is also appearing in parts of large cities in first world countries, e.g. France, Britain, USA. The further questions surrounding this basic scenario of a world descending into Hobbesian dystopia, a shambles, are How far and How fast? And what makes it plausible?

But how far? How fast?

If quality of life is going to degrade globally, one might expect it to degrade more slowly in first world countries with their established institutions and the technological skills to divert resources being used for discretionary purposes into essential services. On the other hand, first world societies have directed very large, and now problematic, energy flows into the construction and ongoing maintenance of networks of relationships between virtual species. Resources such as labour and capital have been progressively locked into specialised functions (tasks) on which other functions are highly dependent, so-called long-chain dependency. This means that if the material-energy-information flows along a link gets disrupted, and there are no contingency plans for restoring that link's function (as in a competitive just-in-time economic system), the disruption spreads to other links. Just how far such malfunctioning spreads depends on the architecture of the network, its patterns of connections between nodes of activity. In general, as networks of functions become ever more tightly connected, they move towards transmitting shocks rather than absorbing them, i.e. they become unstable. If a highly-

[122] Stewart, P., 2007, 'Failed' States and Global Security: Empirical Questions and Policy Dilemmas, *International Studies Review*, **9,** pp.644–662

connected node, a 'hub', a power grid for example, is knocked out abruptly, whole populations stand to suffer dramatic falls in their quality of life. If the same power grid degrades slowly, people may have time to adapt and the impacts will be less dramatic; but still ultimately destructive of people's options. The 2008 global credit crisis, and its subsequent transmission to the real economies of many countries, is a text book example of how disruptions can spread in a highly connected (globalised) system. Russia's descent into chaos in the winter of 1991-92 did not spread globally but did illustrate how an organised, albeit repressive, society can break down in just months.[123]

In the world's rich countries, where most people have a high standard of living compared with second and third world (less developed) countries, people rely largely on markets, including the employment and stock markets, for satisfying their daily needs; and they rely on government to provide personal and property security. When markets and governments fail to meet normal expectations, not only does quality of life drop for most people, but they do not have coping and survival mechanisms and skills for meeting their needs in more basic ways, e.g. using more labour, simpler technologies and less capital and energy to grow food. More than that, their societies are not organised to facilitate extra-market adaptations (e.g. providing vegetable plots in cities) or, indeed, to switch to providing goods and services appropriate to changed lifestyles, e.g. wind-up radios, more public transport.

By contrast, people are more self-sufficient, less dependent on markets, in poorer countries. The exception to this is that the urban poor in such societies are particularly vulnerable to rising food prices. Poor people's lives invariably contain more hardship and physical labour, more disease and early death, more hunger and violence; but the collapse of markets around them does not cause them to fundamentally restructure their lives, not if their only purchases are, say, cooking oil, salt and matches. Having said that, the current global recession-depression is already hurting poor countries in several ways, including falling capital inflows (including aid), falling commodity prices and job losses in both export industries and in numbers of overseas guest workers.[124]

The happenings which do have relatively greater impact on the poor than on the rich are natural disasters, epidemics and organised violence. When they are spared such shocks, subsistence farmers, gardeners, fishers and herders can usually keep their societies intact, as evidenced by, for example, the maintenance of habits, customs and rituals. It is when such imposts turn people into refugees and displaced persons, or, indeed into marauders and pirates, that their quality of life plunges. Forced migration, including the return of desperate slum-dwellers to their villages, is doubly bad. Not only are the migrants traumatised, but the areas they descend on become instantly overpopulated, with all the possibilities which this creates for conflict between migrant and resident virtual species. As evidenced by the late Bronze Age, such 'knock on' discontinuities can spread over thousands of kilometres.

[123] Ferguson, N, 2010, Complexity and Collapse: Empires on the Edge of Chaos, *Foreign Affairs*, March-April, PDF Reprint, http://www.foreignaffairs.com/issues/2010/89/2 (Accessed 21 Jan 2011)

[124] Anon, 2009, The Toxins Trickle Downwards, *Economist,* 14 Mar 2009, pp.54-55

But none of the above constitutes evidence that, as of now, dystopic bottleneck conditions are festering and spreading across more of the world. Indeed, two important direct indicators of average (species-wide) quality of life, life expectancy at birth and under-five infant mortality, continue to improve, even as global population is rising by some 70 million per year. Nonetheless, while life expectancy at age 15 has increased by two to three years for most regions over the last 20 years, there are exceptions. Life expectancy in Africa decreased by nearly seven years between 1980 and 2001, and for the transition countries of Eastern Europe, in the same period, by 4.2 years for males and 1.6 years for females. On the other hand, the global child mortality rate declined by almost one quarter between 1990 and 2006, partly as a result of campaigns against measles, malaria and bottle-feeding, and partly from improvements in the economies of most of the world outside Africa. Gross World Income per head, which correlates strongly with health status, increased by 47 per cent between 2000 and 2007. Prior to the 2006 food crisis, living standards in the developing world had been rising dramatically for some decades.. The proportion of its population living in extreme economic poverty---defined as living on less than $1.25 per day (at adjusted 2005 prices)---fell from 52 percent in 1981 to 26 percent in 2005.[125]

While such global trends conceal marked differences between regions, and the quality of the underlying data is questionable anyhow, they are *prima facie* evidence that, world-wide, quality of life is probably still rising. The UN Human Development Index for the world, which is a crude amalgam of indices for income, literacy and life expectancy, has risen monotonically over its 20 year history.[126] Having said that, and recognising that falling child mortality is a major contributor to rising life expectancy, one suspects (there is no direct data) that the species-wide figure for *years of healthy life expectancy at age 15* might be stagnant or declining. The word 'healthy' here means 'without disabilities that constrain core activities.'

But, consider the debit side of the quality-of-life ledger:

Between the start of 2006 and 2008, the average world price for rice rose by 217 per cent, wheat by 136 per cent, maize by 125 per cent and soybeans by 107 per cent.[127] Suffering amongst those who spend the bulk of their income on basic food has been immense and food riots have occurred in dozens of the world's cities. Concurrently, these soaring *grain prices* have forced a sharp reduction in food aid, putting the 37 countries that depend on the World Food Program for emergency food assistance at risk of social breakdown. The UN Food and Agriculture Organisation's (FAO) provisional estimates are that, in 2007, 75 million more people were added to the total number of undernourished relative to 2003–05.[128] This represents an increase in the proportion of hungry people in the world from 16 per cent to 17 per cent. It is true that over the past

[125] http://web.worldbank.org/WBSITE/EXTERNAL/TOPICS/EXTPOVERTY/EXTPA/0,,contentMDK:20153855~menuPK:435040~pagePK:148956~piPK:216618~theSitePK:430367,00.html (Accessed 22 Dec 2008).
[126] UN Human Development Report, 2010, http://hdr.undp.org/en/countries/ (Accessed 5 Nov 2010)
[127] http://en.wikipedia.org/wiki/Food_crisis#cite_note-cyclone-5 (Accessed 12 Dec 2008)
[128] UN Food and Agriculture Organisation, 2008, *The State of Food Insecurity in the World 2008,* United Nations, Rome

half-century grain prices have spiked from time to time because of weather-related events (e.g.the 1972 Soviet crop failure) but the situation today is entirely different.[129] New and established trends are coming together which make it probable that real food prices will keep rising in coming decades, and keep rising faster than real incomes.

Demand for grain will continue to increase as a result of population growth and, less probably, as a result of the diversion of grain crops to ethanol production and meat production. On the supply side there is little new cropland coming on stream to balance ongoing losses to urban land uses and land degradation. In this century, irrigated agricultural land per capita has been falling by one per cent per annum. This will accelerate if Eurasia's glaciers continue to melt. Climate change, as currently foreseen, may allow cropping to expand in Canada and Russia but this stands to be offset by crop-area contractions in the 'breadbasket' countries of the Southern Hemisphere. A trend that may not be permanent but is worth noting is that grain consumption has exceeded production in seven of the last eight years; the world's stock of carried-over grain (2008) has fallen to 55 days of world consumption, the lowest on record. The world's grain markets are only one poor harvest away from panic.

Between 1950 and 1990, energy-dependent technologies (fertilisers and machinery) and new plant varieties allowed the world's farmers to increase *grainland productivity* by 2.1 percent a year, but between 1990 and 2007 this growth rate slowed to 1.2 percent a year. Technological advances, encouraged by higher grain prices but discouraged by higher oil-energy prices, could reverse this slowdown. However, there are no obvious candidates for this role at the moment.

In 2009, with the economic crisis impacting most societies, the Global Peace Index, as calculated by the Institute for Economics and Peace,[130] has actually slipped. However, contrary to popular belief, the world in the last twenty years has become more peaceful. The frequency and lethality of wars has been declining since the end of the Cold War in 1989. Since 1990 more wars have ceased than have started and the number of negotiated settlements has steadily increased.

Notwithstanding, according to one source,[131] there were 31 significant military conflicts in the world in 2008 compared with 25 in 1998. Apart from the direct suffering caused by civil and international conflicts, these, along with hunger, are a major cause of *forced migration*, a further indicator of declining quality of life. One partial measure here is the number of people under the care of the UN High Commissioner for Refugees (UNHCR), including both internally displaced people and international refugees. In 2007 this number rose by 2.5 million to 25 million.[132] Refugee numbers dropped dramatically when people returned home after the Balkans conflicts of 1992-1995, but have been rising again since then.

[129] http://www.Earth-policy.org/Updates/2008/Update72.htm (Accessed 12 Dec 2008)
[130] START HERE *Peace, its Causes and Economic Value*, 2009, Discussion Paper, Institute for Economics and Peace, www.visionofhumanity.org, (Accessed 3 June 2009)
[131] http://www.warscholar.com/Year/2000.html (accessed Dec 11 2008)

[132] UNHCR, 2008, *Global Trends: Refugees, Asylum-seekers, Returnees, Internally Displaced and Stateless Persons,* Annual Report

Environmental degradation in the forms of drought, desertification, erosion, deforestation and, most recently, sea level rise, has become an increasingly important source of the hunger that triggers migration. One might guess that the proportion of the world's people experiencing a reduction in quality of life as a result of being forced to relocate is continuing to rise but data to support that hypothesis is not available. While they are suppositional and not factual, scenarios have been imagined which foresee a massive increase in the number of environmental refugees in coming decades. For example, one of Gwynne Dyer's climate change scenarios[133] has Italy being overwhelmed by environmental refugees from a blighted North Africa by 2036.

Living in a society where civil and political rights are poorly established and protected is a pervasive obstacle to the achievement of high quality of life. Between 2004 and 2007, some 43 countries, or more than 20 percent of the world total, saw their scores for freedom-of-association decline---according to the calculations of Freedom House, a somewhat-conservative non-government organisation.[134] While the number of *people in prison* worldwide is a relatively small nine million, the rate per 100 000 people jumped from 117 in 1992 to 154 in 2004.[135] In quality-of-life terms, these figures are more likely to be indicative of declining social cohesion than anything else. Authoritarianism does seem to be on the rise again following the post-Soviet remission.

Mental and behavioural disorders affect more than 25 per cent of all people at some time during their lives. They are present at any time in about 10 per cent of the adult population. They are also universal, affecting people of all countries and societies, individuals of all ages, women and men, the rich and the poor, from urban and rural environments. They have insidious economic impacts and crippling impacts on the quality of life of sufferers and their families. The World Health Organisation estimated that, in 1990, mental and neurological disorders constituted 10 per cent of total *disability adjusted life years* (DALYs) lost due to all diseases and injuries. This rose to 12 per cent in 2000 and was projected to further rise to 15 per cent by 2020, partly due to a decline in the incidence of childhood infectious diseases.[136] Common disorders causing severe disability include depressive disorders, substance-abuse disorders and schizophrenia.

Data is not available for judging whether a global citizen's lifetime risk of developing a mental disorder is increasing or decreasing; some predisposing factors are declining (e.g. incidence of poverty) and others are increasing, e.g. the per capita use of psychoactive substances, including opioids, stimulants, tobacco and alcohol. Suicide rates would seem to be a good partial indicator of mental illness and, globally, from 1950 to 1995, suicide rates increased by approximately 35 per cent in men and approximately 10 per cent in women in all age groups.[137] The reasons for the differences in rates among different age, sex, and ethnic groups, as well as the change in rates since 1950 are not known. A

133 Dyer, G., 2008, *Climate Wars*. Scribe, Melbourne

134 Freedom House, 2010, *Freedom in the World 2009*, http://www.freedomhouse.org/template.cfm?page=363&year=2009 (Accessed 22 Dec 2010)

135 World Bank, 2008, World Development Indicators, *Development Review*, worldbank.org/.../YR07_CH2_RP02_AFR.pdf (Accessed 24 Jan 2010)

136 World Health Organisation, 2001, *The World Health Report 2001*, Ch.2 http://www.who.int/whr/2001/en/index.html (accessed 22 Dec 2010)

137 *www.who.int/whosis* (Accessed 17 Dec 2008)

pointer from one study is that, across 27 nations, alcohol consumption predicts suicide rates.[138]

Over the last three decades, longstanding communicable diseases such as tuberculosis, malaria, and cholera have spread geographically and more than thirty previously unrecognized communicable diseases, such as Ebola, HIV, Hantavirus and SARS, have emerged as new threats to quality of life.[139] The slow-moving HIV/AIDS pandemic has already killed more than 20 million people and sickened between 34 million and 46 million; it is on the way to becoming the worst pandemic in history. A wide range of disease–producing microbes are becoming increasingly resistant to antimicrobial drugs, e.g. drugs for malaria, tuberculosis, pneumonia.

Given such predisposing conditions as globalisation, population growth and urbanisation, it can be argued that, for the fourth time in history, humanity is encountering a ‘great wave’ of epidemic disease.[140] The first of these came with the domestication of wild animals (10 kya) and the second with the linking of East and West Eurasia by trade routes (2500 kya). The third ‘great wave’ began during the era of transoceanic exploration and trade expansion in the fourteenth and fifteenth centuries, when Bubonic Plague arrived in Europe from Asia, and European explorers and settlers brought smallpox, measles, influenza, and other diseases to indigenous populations across the Americas and Australia.

The last decade has witnessed a decline in the share of the world’s working-age population (aged 15 years and older) that is in employment (known as the employment-to-population ratio). It stood at 61.4 per cent in 2006, 1.2 percentage points lower than ten years earlier.[141]

At the time of writing, many of the world’s major economies are contracting, i.e. they are producing goods and services at a lower rate than in the recent past. For very large numbers of people, this world-wide *recession-depression* is having a direct impact on their quality of life and, also, on their expectations or hopes for an improving quality of life. Not only does unemployment rise as economies contract, but government revenues (e.g. from taxes) fall, making the provision of government services (e.g. schools, hospitals, police forces) more problematic.

There are other whole-of-world statistics which could be included here as partial indicators of how quality of life has been changing in the last decade or so for the average global citizen (e.g. air quality data, work-hours data, data on the psychological impact of species extinctions and ecosystem destruction), but, on the basis of the grossly imperfect indicators presented, are there tentative conclusions to be drawn?

[138] Lester, D., 2001, Association of Alcohol Use and Suicide in 27 Nations of the World, *Psychological Reports,* 88 (3), p.1129

[139] Worldwatch Institute, 2005, *State of the World 2005,* http://www.worldwatch.org/node/1044 (Accessed 22 Dec 2010)
[140] Worldwatch Institute, 2005, *ibid.*
[141] International Labour Organisation, 2008, *Global Employment Trends 2008*, http://www.ilo.org/global/publications/WCMS_090106/lang--en/index.htm (Accessed 22 Dec 2010)

Yes. With the exceptions of clear improvement in child mortality rates, and a possible ongoing improvement in healthy-life expectancy for adults, the selected indicators are all consistent with a subjective judgment that, on a decadal timescale, the (hypothetical) average global citizen is experiencing slowly declining quality of life. As a whole, the species is experiencing more hunger, violence, mental illness, dislocation, communicable disease, political restrictions, unemployment and deteriorating collective services. The burden is not being equally shared of course. Behind the average experience, a small fraction of the world's population is probably experiencing rising quality of life, even as others are bearing a disproportionate share of the burden of these imposts. It is in populations where people's ability to meet their physical and socio-economic needs is already low that the present decline is most easily seen.

Four juggernauts

While our discussion is suggesting that gross quality of life is slowly declining rather than improving, it makes no claim that this deterioration will continue, even though I believe (nothing more) that it will. We have already concluded that predicting the future behaviour of complex dissipative systems is a vanity. We cannot see how far and how fast the present decline will go. Nevertheless, there is little to suggest that the *percentage* of the world's people that is hungry, traumatised, mentally ill, displaced, infected, fearful, unemployed or dying young will decline in coming decades.

On the contrary, there is considerable agreement that a number of global-scale processes, *endogenous trends* as unstoppable as *juggernauts* it would seem, are in train and which, if not reversed, will, at some 'tipping' point, push the human ecosystem past its resilience limits and trigger major reorganisation or disorganisation, perhaps on the scale of the Neolithic and Industrial Revolutions. These 'tectonic stresses,'[142] these ongoing high-momentum processes, which, on balance, stand to make life harder, not easier, for most people are:

Population growth

Depletion of renewable (e.g. fisheries) and non-renewable (e.g. oil, phosphorus) resources

Global warming

Complexification of world society and the global economy (carrying with it the threats of ungovernability, long-lasting global recession-depression and the further impoverishment of poor, but resource-rich countries[143])

It is this perception of an impending disorganisation, an unravelling, a bottleneck with pervasive quality of life implications which is being termed the Overshoot Crisis. However, the difficulty of seeing how soon and deep this bottleneck might become is

[142] Homer-Dixon,T., 2006, *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization,* Island Press, Conn.

[143] Bunker, S., 1985, Underdeveloping the Amazon: Extraction, Unequal Exchange, and the Failure of the Modern State, University of Illinois Press, Urbana

emphasised when one appreciates how internal driving processes can amplify or quieten each other, commonly in unintended ways. For example, the current (2008-9) global recesson-depresson is probably slowing population growth, global warming and resource depletion. Conversely, oil depletion is likely to slow economic activity and global warming; an indication here is that five of the last six global recessions were preceded by an oil price spike.[144] And, of course, contingent episodes such as pandemics, wars and mass migrations add further complication. It was in recognition of a similar perception---that the world faces, not just a set of large free-standing problems, but a 'metasystem' of global-scale interacting problems---that the Club of Rome coined the useful term *global problematique.*[145]

Where though, the question remains, did these juggernauts come from? One answer is to see them as *spillovers* or *externalities*, as the cumulative unintended consequences of the efforts which every virtual species, from individuals to nations, makes to improve its own quality-of-life prospects. Each virtual species chooses the technologies it will use to this end, usually taking little account of the quality-of-life implications for other virtual species. We might call Global Overshoot the tragedy of the invisible hand! It is the consequence of numerous individual virtual species choosing technologies which generate spillovers (or precursors to spillovers) in the form of population growth, resource depletion, complexification and global overheating. For example, an extra child might help the family but not the village. Narrowly rational people do not ensure a rational society.

THREE WAYS OF REACTING TO AN OVERSHOOT SCENARIO

> The history of philosophy is to a great extent that of a certain clash of human temperaments. Undignified as such a treatment may seem to some of my colleagues, I shall have to take account of this clash and explain a good many of the divergencies of philosophers by it. Of whatever temperament a professional philosopher is, he tries when philosophizing to sink the fact of his temperament. Temperament is no conventionally recognized reason, so he urges impersonal reasons only for his conclusions. Yet his temperament really gives him a stronger bias than any of his more strictly objective premises. It loads the evidence for him one way or the other, making for a more sentimental or a more hard-hearted view of the universe, just as this fact or that principle would. He trusts his temperament. Wanting a universe that suits it, he believes in any representation of the universe that does suit it. He feels men of opposite temper to be out of key with the world's character, and in his heart considers them

[144] Rubin, J., 2009, Just how Big is Cleveland? http://research.cibcwm.com/economic_public/download/soct08.pdf (Accessed 24 Dec 2010)
[145] Meadows, D.H., Meadows, D.L., Randers, J., and Behrens Jr., W.W., 1972, *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind*, Potomac Associates, London

> incompetent and 'not in it,' in the philosophic business, even
> tho they may far excel him in dialectical ability.
>
> William James (1907), *Pragmatism,*[146] Ch 1

My scenario of an *Overshoot Crisis* with a dystopic prognosis provides a reference point for developing and critiquing several contrasting attitudes (habitual ways of regarding issues) towards global change. This 'baseline' starting point is a loose acceptance that the world is indeed experiencing resource depletion, global warming, population growth and ramifying interdependencies; and that the paramount indicator, species-wide quality of life, is more-or-less stagnant, moving up a little perhaps, or down a little, depending on one's values. The several attitudes to be now explored accept this description of the contemporary world, but differ in the significance they attach to it in terms of where it might lead and what, if anything, should be done about this potentially overwhelming issue.

In the above quotation, William James is recognising that his fellow philosophers tend to come to beliefs that are compatible with their inherent temperaments. This insight, plus his famous distinction between two temperaments---tough-minded *Empiricists* and tender-minded *Rationalists*---provides a basis for understanding the sharp differences in attitudes towards the Overshoot Crisis which are to be found in today's public and academic discussions of these matters. From the many possibilities lurking therein, I have selected three contrasting sets of attitudes for comparison and have given them the colloquial names of:

Don't panic

Stop fiddling

Rise like a phoenix

While these alternative viewpoints span the spectrum from tough- to tender-minded, as will be explained, I have avoided perspectives which overtly draw their inspiration from religious beliefs, political ideologies, rent-seeking agendas or Panglossian technological optimism.[147]

Don't panic

'Don't panic' is the tongue-in-cheek advice on the cover of *Hitchhiker's Guide to the Galaxy*[148] by Douglas Adams. It is hard for Adams' hero not to panic when he realises that ours is an insignificant planet blocking an inter-galactic freeway in an unfashionable

[146] James, W., 1907|1981, *Pragmatism: A New Name for Some Old Ways of Thinking*, Hackett Publishing, Indiana

[147] Lefroy, E.C., and Hobbs, R.J., 1993, Some human responses to global problems, in *Nature Conservation 3: Reconstruction of Fragmented Ecosystems* (Saunders, D.A., Hobbs, R.J. and Ehrlich, P.R. (Eds..)), Surrey Beatty, Chipping Norton

[148] Adams, D., 1980, *Hitchhiker's Guide to the Galaxy*, Harmony Books, New York

part of the galaxy. Notwithstanding, the advice is good. One is likely to think more clearly and find a way out of trouble if the mind is not racing from one knee-jerk response to another.

The tough-minded Empiricists whose response to my dystopic scenario is ‘Don’t panic,’ are sceptics who find it hard to believe in anything other than well-established facts. In this, they are the heirs to a long line of thinking which goes back to the Greek sophists and leads eventually to such great empiricists as Locke, Berkeley and Hume. Unlike tender-minded Rationalists, they are slow to use induction, deduction and abduction to create bold working hypotheses, spurs to significant action. They are wary of conceptualisation and speculation, and that includes formal models. Their reason for warning against panic is that they cannot understand how the tender-minded can confidently foresee an ineluctably growing problem that must be tackled vigorously and at once. Indeed, they have little faith that humans have the cognitive ability or data to plan solutions to large what-to-do problems or to muster the cooperation this will normally demand. For some, this means that empiricists are pessimistic and fatalistic as well as sceptical. They would reply that they do not ‘cross their bridges before they come to them.’ That is, they are generally not too concerned about anything that is not an obvious threat.

Other tendencies which James finds in empiricists are that they tend to think analytically (look inwards rather than outwards) rather than synthetically and materialistically rather than idealistically. Among other things, the latter means looking to new technologies rather than new ideas as drivers of history.

What is the evidence?

More specifically then, given these tendencies, how might the tough-minded be expected to view the four global processes suggested above as having the potential, singly or together, to drive the human ecosystem towards a major reorganisation.

Global population growth is a well-studied process for which reasonably reliable and current data is available. Fertility rates and death rates change slowly and smoothly most of the time which means, other things being equal, that future population numbers can be predicted, decades ahead, more successfully than most other social indicators. Both Empiricists and Rationalists accept this and, on the basis of documented declines in fertility rates, accept that the rate of global population growth is steadily declining, meaning that world population will peak in 40-50 years. The Empiricists’ perception is that there is little evidence that the world is coping any less effectively with each passing year’s population increment (70 million but declining) and that there is therefore little reason to try and lower the rate of population growth below what is happening naturally. In any case it is not easy to see how that might be achieved, other than through making better birth control methods freely available.

Depletion of renewable and non-renewable resources is well enough documented and not to be denied *per se*. For discussion purposes, consider the non-renewable resources, oil and phosphate; and the renewable resources, native-forest timber and ocean fisheries. The available data is not incompatible with the idea that global production of both oil and rock phosphate has peaked and will now begin to decline, failing major discoveries. Indeed, prior to the current global recession, prices for both were beginning to rise and will again rise as the global economy recovers (see below). Such price rises, provided they are not too sharp, provide timely and manageable signals to the economy to reorganise. In the case of oil, which is important to all sectors of the economy, it is fortunate that a number of substitute fuels and industrial feedstocks (biofuels, natural gas, coal-seam gas, tar sands etc.) exist and are already being produced in increasing quantities. In time, as supplies of carbon-based fuels (and fossil uranium) peter out, the energy sector will again have to reorganise, probably around renewable-energy technologies such as wind, wave and solar power (there are a number of others).

The phosphate situation is somewhat different. Phosphorus is an essential plant nutrient for which there is no substitute. Global agriculture is massively dependent on phosphatic fertilisers. Current reserves of rock phosphate will last many decades at current rates of mining but, at some stage, triggered by rising prices, large-scale technologies for recycling the phosphorus being dissipated in sewage, soil erosion and runoff will have to be introduced. While that transition will further raise food prices (recycling is energy intensive), the tough-minded, while hoping that this will not cause widespread pain, accept that this is a transition which, in the longer term, cannot be avoided.

Over the 15 years from 1990 to 2005, the world lost 3 percent of its total forest area through clear-felling for logs and woodchips and agricultural uses. In the same time, timber and woodchips from single-species short-rotation plantation forests have increasingly replaced the supply of these products from native forests. While plantations now provide wood products more cheaply than native forests, the clearing of forests (tropical forests in particular) to grow crops remains a matter of concern to those who regret the loss of biodiversity that this entails. However, apart from the direct impact of forest clearing on a small number of indigenous people, there is no data to suggest that forest clearing affects, or will affect, quality of life for any significant proportion of the world's people. Conversely, the meat, palm oil and other products produced on cleared forest lands meet people's needs on world markets.

Ocean fish stocks have been massively depleted in recent decades with many fisheries around the world collapsing. Nevertheless, as a result of more intensive technologies, harvests of ocean fish have remained at around 85-95 Mt. Meanwhile, global production of farmed fish and shellfish has more than doubled in value and weight (29 Mt in 1997). Aquaculture now supplies more than one-fourth of all fish that humans eat. Notwithstanding, pressure on wild fish stocks has not declined with the introduction of aquacultural technologies. First, demand for fish has grown in line with population growth. Second, the farming of carnivorous species, salmon and shrimp for example, requires vast quantities of wild-caught fish to feed confined stocks — indeed, the norm is that two to five kilograms of wild-fish biomass (fishmeal) are required to produce one kilogram of these high-market-value species. [149] Even if the wild-fish catch can be maintained, a further change in technology will have to occur eventually---from farming carnivorous fish to farming herbivorous fish such as carp.

Global warming, meaning a permanent increase in the temperature of the global atmosphere and oceans, may or may not be happening and may or may not be anthropogenic, i.e. be caused by human activities which result in a net emission of

[149] Naylor, R.L., Goldburg, R.J., Primavera, J., *et al.* 2001, Effects of Aquaculture on World Fish Supplies, *Issues in Ecology*, No.8

greenhouse gases into the atmosphere. Certainly the upward trend in atmospheric CO_2 since, say, the beginning of the Industrial Revolution is real enough, but whether this change in the atmosphere's composition is responsible for the large proportion of years in recent decades with temperatures well-above 'average' is not obvious. Perhaps this 'cluster' of warm years is simply a statistical fluctuation of the type which appears in all time-series of measurements of natural variables? Or, perhaps the world is experiencing a real upward tend in global temperatures, but not one due to the greenhouse effect? For example, have global temperatures been simply rebounding since the (ill-defined) end of the Little Ice Age towards those of the Medieval Warm Period?

The modelling work that has supported the conclusion, reached by the International Panel on Climate Change (IPCC) for example, that global warming is real and largely caused by human activity, is rich and commendable[150] but nonetheless contestable.[151] Some Empiricists are open-minded as to the truth of this conclusion, while others seize on recognised conceptual flaws and database deficiencies in the main models as grounds for rejecting those models' conclusions.

Empiricists who accept the reality of global warming may still be doubtful as to whether anything can or should be done about it. For those who cannot additionally accept that greenhouse gases are the cause and that reducing these will 'solve the problem,' there is not much that can be done. For example, alternative ways of cooling the planet, such as loading the atmosphere with aerosol particles or putting reflectors in space, have been suggested but, if anything, such are more problematical for sceptics than emissions-reduction.

Those Empiricists who can accept that the greenhouse gas hypothesis is plausible, albeit 'unproven,' may still be reluctant to advocate action to curb greenhouse gas emissions. This could be for any of several reasons. One is the difficulty of assembling a comprehensive range of alternative countervailing action-plans for consideration, together with the further difficulty of associating each plan with a reliable estimate of its costs and benefits or, more generally, its quality of life consequences. If attempted, such a study might even find the 'do nothing' option to be superior! And then there is the virtual-species problem. Global warming has to be tackled at a global scale. It would not suffice for Americans and Europeans to agree on what to do; the views of Chinese and Indians would have to be considered. To date, neither China nor India accepts that proposals for controlling global warming take sufficient account of their interests as major industrialising societies.

But there is a response to the perception of global warming, and its potential to disrupt billions of lives, which is compatible with tough-minded empiricism. Rather than attempting to ameliorate, to forestall the avalanches of change which would occur if 'worst case' models of climate change turned out to be correct (e.g. by reducing emissions), people might be able to cooperate sufficiently to monitor and give early warning of the emergence of shocks and abrupt impacts and help those affected to adapt to them, e.g. help people move to higher ground or relocate as sea level rises. While it is

[150] United Nations Intergovernmental Panel on Climate Change (IPCC), 2007, *Climate Change 2007, Fourth Assessment Report*, United Nations, New York, Synthesis Report

[151] For example, http://en.wikipedia.org/wiki/Richard_Lindzen (Accessed 27 Dec 2010)

true that this reactive or adaptationist approach would still require large-scale cooperation if large-scale impacts were to occur, the practical problems to be addressed, and responses to them, would be clear, and hence more readily agreed. The adaptationist approach has the further advantage that it does not require massive ‘up-front’ investment to ameliorate changes which may not even be the cause of global warming and its consequences; or to ameliorate changes which may never occur. It should not be taken as derogatory to label the adaptationist approach to global warming as ‘muddling through’ or reactive.

Global recession-depression is the fourth of the dark horsemen hypothesised to be presaging dystopia. The reality of the abrupt unravelling of the highly-connected global financial system and the global ’real’ economy which began in 2008 has been plain to the tough- and the tender-minded alike. It was of little surprise to the tough-minded that there was a near-total failure of ‘experts’ to foresee the onset of this bifurcation and equally unsurprising that there is much disagreement as to its causes and its prognosis. Historically, depressions have led to output falls of the order of 10-15 per cent over several years, but could the present reversal be much deeper and much more prolonged? The possibility that the global economy-financial system might never return to anything like its present size and structure is barely contemplated. What happens if the American dollar continues its 30 year slide and there is no ‘lender of last resort’? Could international currency markets collapse? The plethora of what-to-do remedies and rescue operations being tried by weakly-cooperating individual governments in their efforts to restore the *status quo ante*, attests to the limited understanding humans have of the monstrous non-linear system they have created.

Empiricists too have little confidence that the course of the current recession-depression can be predicted. Nor do they have much confidence in the ability of the global community to slow or reverse the present recession-depression. Indeed, they have doubts as to whether this is even desirable. As pointed out by Joseph Schumpeter, with his ideas of ‘creative destruction,’ the death of old enterprises releases ‘locked up’ resources for the establishment of new enterprises, better-adapted to an ever-changing world.[152] The same idea is found in Buzz Holling’s thinking about the processes of destruction, simplification and renewal in natural ecosystems.[153] If allowed to run its course (e.g. no bailouts), the present recession-depression will cleanse the economy of numerous activities with high opportunity costs. Notwithstanding, Empiricists who value the idea of high quality of life for most people, will still see it as important for governments to support people who have lost access to employment and publicly-funded services as this downturn spreads.

Summing up tough-mindedess

In terms of responding to a scenario of Global Overshoot ending in total social breakdown, the tough-minded are likely to have a reactive or wait-and-see attitude towards the four global-scale processes suggested as ineluctably increasing the

[152] Schumpeter, J.A., 1942, *Capitalism, Socialism and Democracy*, Harper, New York

[153] Holling, C.S., 1973, Resilience and Stability of Ecological Systems, *Annual Review of Ecology and Systematics*, **4**, pp.1–23.

probability of such an outcome. Reluctant as they are to generalise, the tough-minded have learned that when large complex systems are subjected to disruptive forces they tend to self-reorganise in ways which counter or negate the impacts of those disruptions. The tough-minded believe in closely monitoring these global-scale processes so that people know what is happening at any time; and, if and when quality of life can be seen to have been impacted, practical steps can be taken to redress those impacts. First put out the 'spot fires.' Their 'early warning' and 'first aid' attitude to the global problematique is understandable in light of their lack of confidence in the global community's ability to understand and manage population growth, resource depletion, global warming and economic complexification. They note the irony that a global-scale social breakdown will at once halt the very juggernauts that have supposedly caused that disorganisation. It worries Empiricists that many (perhaps most) of the relationships implicit in the reference scenario cannot be investigated via the methods of experimental science.

Two ways of being tender-minded

In terms of William James' distinction, a tender-minded rationalist is one who, in the spirit of the Enlightenment, is able to accept the Overshoot-diagnosis as a plausible working hypothesis. That is, in the absence of effective intervention, the unfolding consequences of global population growth, resource depletion, global warming and complexification of global networks will be, indeed, already are, highly threatening to species-wide quality of life. Rationalists, more so than Empiricists, have learned, from others, or from experience, to trust reason as a basis for action. More strongly, they *want* to use their reason to guide their behaviour. They are readier to come to inductive generalisations and to accept abductive explanations, i.e. those that are consistent with the facts. Compared to Empiricists, they are willing to accept lower levels of proof. Sometimes, because no reasoned position can ever be fully justified, Rationalists can be tempted to retreat into dogmatism when confronted with scepticism and accusations of naïveté. Normally though, Rationalists will recognise that their mental models of what is happening and what to do are likely to be wrong and likely to need correcting in light of experience and changing circumstances.

More generally, the 'how-to-intervene' problem is enormously challenging and has no truly convincing answer. In principle, Rationalists want the global community to address both causes and consequences of global Overshoot. This means, firstly, that they will be looking for ways to slow, reverse, modify or adapt to one or more of the 'big four' global trends.[154] Secondly, they will be looking to forestall or, if that cannot be achieved, mitigate (from mitigare: to soften) the adverse quality-of-life consequences, the suffering, lurking in these trends. In that last they are at one with the Empiricists.

This is the point where it is necessary to make a distinction between Rationalists who believe that effective intervention at the present stage of the Overshoot Crisis is possible and Rationalists who believe that the Overshoot Crisis is going to run its course, irrespective of the efforts of well-intentioned, knowledgeable humans, i.e. Rationalists who are 'immediate interventionists' versus Rationalists who are 'post-bottleneck reconstructionists.' The latter group's somewhat different perspective is that a well-prepared, forward-looking global community has reasonable prospects, after passing

[154] Füssel, H-M., 2007, Adaptation Planning for Climate Change: Concepts, Assessment Approaches and Key Lessons, *Sustainability Science*, **2** (2) pp.265-275

through an inevitable dystopic bottleneck, a great contraction, in which quality of life plunges, of rising, like a phoenix from the ashes and reconstructing a long-lasting human system in which quality of life steadily improves for most people. We will discuss these contrasting tender-minded attitudes under the admonitory headings, 'Stop fiddling' and 'Rise like a phoenix.'

Stop fiddling

Popular legend has it that Emperor Nero played the fiddle (lyre) while the Great Fire of Rome burned in 64 CE. The admonition of the immediate-interventionists to 'Stop fiddling and try to prevent the fire from spreading' is a metaphor for an attitude which sees the unfolding consequences of Global Overshoot as highly threatening to species-wide quality of life; and, furthermore, as a matter of urgency, the global community (the global 'fire brigade') should (and can) intervene vigorously to slow or reverse these processes.

Those who are looking to intervene at once to ameliorate or prevent a dystopic collapse over coming decades include governments, inter-government organisations, non-government organisations, enterprises and individuals. While each of these has its own capacities for intervention and its own sense of priorities, governments have a collective responsibility and inevitably carry much of the load. Our purpose here is not to discuss the many particular recommendations for immediate intervention that have been made. Rather, it is to highlight a handful of principles and priorities that might or should be guiding the making of such more-specific choices; and to ask what the proponents of immediate intervention hope to achieve in the longer term. .

For a start, it is clear that a comprehensive approach, a 'grand plan,' will never be possible and that a mixture of partial, heuristic and instrumental approaches will have to be used. At first sight, there is a body of ideas that has been developed to assist with making multi-faceted decisions under non-certainty.[155] That methodology would suggest searching for the mix of interventions with the highest expected quality-of-life benefits into the future; and then regularly revising one's plans as circumstances change. Unfortunately, the time, data, probabilities, values, resources etc for taking such an approach are not available. The rationalist ideal is again found to be constrained.

Just as comprehensiveness is not possible, its opposite, 'tunnel vision,' needs to be avoided, i.e. avoid addressing just one dimension (the global economy, say) of the global problematique while neglecting its other dimensions (e.g. resources, population, climate). Here, it is helpful to ask of any policy developed to address issues in one dimension what its implementation might mean for issues in other dimensions (all problems exist in the context of other problems). Or, more proactively, one should be looking for interventions which address multiple issues simultaneously. This can, in fact, be observed in current discussions on how to use government funding to revive a flagging global economy. Beyond lubricating the financial sector, government funding can play a useful role in, for example, improving infrastructure, and hence resource flows; or, supporting research into the mechanisms of climate change and population change; or improving quality of life directly by improving health and education services.

[155] http://en.wikipedia.org/wiki/Decision_theory, (Accessed 24 Dec 2010)

For the purpose of developing a suite of ‘high priority’ interventions, it is necessary to recognise which unwanted aspects of the juggernaut processes are mitigable and worth mitigating and which can be adapted to and are worth adapting to; the logic is that of medical triage. For example, sea level rise is one consequence of global warming which, given the high proportion of the world’s population living near the tidal zone, has major quality-of-life implications for the species; mid-latitude droughtiness is another. Many Interventionists think that the rate of sea level rise would be mitigated (slowed) if greenhouse gas emissions were to be reduced by 80 per cent by 2050. Or, more adaptively, those living in the coastal fringe can move to higher ground---if such is nearby and relatively unpopulated. But those so ‘invaded’ will simultaneously lose some of their quality of life, an illustration of how all mitigatory and adaptive responses to the stresses of overshoot produce both winners and losers. Such conflicts of interest between virtual species have to be resolved politically, often with great difficulty, or unsatisfactorily. That is why technological solutions, which are imagined to create fewer conflicts of interest, are so commonly promoted by politicians, e.g. building dykes against rising seas; capturing and storing carbon emitted from coal-fired power stations.

As the Overshoot Crisis broadens and deepens, conflicts of interest stand to consume much of the available political energy and that is dangerous for quality of life in the longer term---innovation becomes very difficult. More than that, Robert Heilbroner points out that in times of social crisis people often turn towards authoritarianism in the belief that it will be better able to cope than democratic structures can.[156] People will not tolerate a society where they are subject to periodic upheavals. A good example is fascism. In the 1930s fascism brought stability to fluctuating economies by reducing freedom at a time when there was a stalemate between democracy and what is nowadays called neo-liberalism.[157] Stability of expectations is clearly an important part of quality of life. Even in quieter times, many are willing, with help from the state, to sacrifice freedom and democracy for security. With the highest priority, the authoritarian threat must be held at bay. But how? Because the social technologies for strengthening democracy cannot just be taken off the shelf, it is important that adequate resources be found for generating and trialling ideas for improving democratic processes, e.g. making them less adversarial, more dialogic.

As a general principle, people can often adapt to large changes if such do not happen too quickly. So, even if the juggernaut processes cannot be stopped, all interventions which might delay their impact need to be evaluated. Moves to protect national economies from the vagaries of the global economy (e.g. via job creation schemes) would be an example. Using some form of taxation or rationing to slow the rate of depletion of oil and other minerals would be another. Measures to slow the rate of population growth, educating women for example, might take decades to bite but could mitigate social unrest in countries with high birth rates, e.g. in east Africa.

What of other principles for helping identify priority interventions? Some are self-evident, like attempting to mitigate-adapt to changes directly reducing quality of life for

[156] Heilbroner, R.,1993, *21st Century Capitalism*, Norton, New York, p.113

[157] Polanyi, K., 1944| 2001,*The Great Transformation: The Political and Economic Origins of our Time*, Beacon Press, Boston.

large blocks of people, especially those already disadvantaged, e.g. food and water shortages. Equally, attempts should be made to pre-empt 'high impact but low probability' contingencies such as large-scale resource wars, 'runaway' global warming and permanent global–scale depression..

A scenario for optimists

The more optimistic advocates of immediate intervention, subscribers to the dominant paradigm usually (see page **Error! Bookmark not defined.**) seem to think the global community can go a long way towards slowing, reversing and adapting to the juggernaut processes underlying the Overshoot Crisis; and towards ameliorating the accompanying negative impacts on quality of life. A scenario which would not surprise them might run something like this:

> Global warming and its downstream consequences will be mitigated and adapted to, albeit belatedly, using a mix of energy-saving measures, strategic retreat, renewable energy and carbon capture and trading. The global economy will recover from recession-depression more rapidly than otherwise through the use of public investment, redistribution programs and fiscal-monetary measures. Once recovered, the global economy will be reformed and proofed against further runaway disturbances through the use of measures for slowing capital transfers between currencies, stabilising exchange rates and regulating risk-taking market behaviours.[158]

Interventionists recognise that they can do very little about global population growth and, in any case, it is a juggernaut that is already slowing. Notwithstanding, there will be regions of the world where intervention to improve quality of life and to lower birth rates might be judged a priority, i.e. regions where rapid population growth has spawned hunger, disease and war. For example, outlawing the international arms trade would make war a smaller problem than it is. There will also be regions where mass movements of people will need to be managed. In the developed world, intervention to promote acceptance of simpler lifestyles will not slow global population growth but might be encouraged on the grounds that this will make it an easier task to feed the billions yet to come---the philosophy of 'live simply that others might simply live.'

As resources are depleted, the real costs (energy, labour etc) of delivering supplies to users rise which, if the economy is operating at capacity, means fewer goods and services will be available for final consumption. For example, if the energy required to extract and market a barrel of oil increases, that additional energy etc. is now lost to the rest of the economy. Alternatively, as such real costs rise, market forces which mitigate and adapt to this loss are likely to emerge. If the supply schedule of a resource rises, its market-clearing price will rise and ration what is available. Also, users of the resource will begin looking for cheaper substitutes, e.g. gas for oil. Recycling may increase where this is

[158] Solow R.M., 2009, How to Understand the Disaster, *New York Review of Books*, **56** (8) http://www.nybooks.com/articles/archives/2009/may/14/how-to-understand-the-disaster/ (Accessed 24 Dec 2010)

technically possible eg, for metals, phosphate. Technologies for improving resource-use efficiency (resource input per unit output) may be sought, e.g. fuel-efficient cars. In general terms, depletion of resources triggers a self-reorganisation of the product mix and the technology mix being used. If this self-reorganisation takes place fairly slowly, it will not necessarily be obvious that the reorganisation has reduced---or improved for that matter---quality of life.

If however a reorganisation takes place rapidly by human standards, people's lives will be disrupted and their quality of life will probably fall. In such situations Interventionists may look to introduce public programs which slow depletion (e.g. extraction quotas) or which speed up and improve the adaptive and mitigative responses generated by market forces, e.g. labour market programs, subsidies for recycling and for research into substitutes and efficiency–measures.

Resource extraction can trigger other side-effects (spillovers) which Interventionists may seek to mitigate or adapt to. Pollution in its many forms is a good example, e.g. air pollution from burning fossil fuels for transport and electricity generation. Resource use of itself can lead to resource depletion, e.g. loss of biodiversity through land clearing; degradation of poorly-managed arable land.

Finally, in the case of renewable biological resources such as fisheries and forests, Interventionists will probably seek to avoid depletion by having harvesting regulated to levels below maximum sustainable yields.

Managed markets

The tender-minded Rationalists who want the global community to 'stop fiddling' and intervene decisively in the Global Overshoot process have a characteristic approach to the how-to-intervene problem, namely a *managed markets* approach.[159] Under this perspective, the ordinary market processes of the economy are expected to spontaneously counter the advance of the various juggernauts to a considerable extent, e.g. bringing profitable new technologies to market. But it is equally recognised that a variety of collective actions will still be needed to address problematic aspects of the Overshoot process which are external to the market economy. For example, unmanaged markets will not provide goods and services for which there are no effective buyers, e.g. health and education services for poor people. Thirdly, the managed markets perspective recognises that some major threats to quality of life cannot be ameliorated by either governments or markets, at least not in the space of a few decades, e.g. global population growth.

Perhaps because it is too far off to have triggered consideration, it is not clear how Interventionists think the human ecosystem will be evolving and functioning after it has passed through a much less disruptive bottleneck than would have been the case without strong intervention. Implicitly, once effective measures have been taken to mitigate and adapt to the juggernaut processes of Overshoot, much of the human ecosystem's pre-

[159] Harris, J.M., 2009, Ecological Macroeconomics: Consumption, Investment, and Climate Change, *Real-world Economics Review* # 50, http://www.paecon.net/PAEReview/issue50/Harris50.pdf (Accessed 13 Sept 2009)

existing structures and processes will still be intact and poised to evolve further, free from the overhanging threats associated with economic complexification, resource depletion, global warming and the fallout from relentless population growth. While the evolutionary trajectory of this post-bottleneck ecosystem cannot be foreseen, it might well present as a world where fewer people are using less energy and social–cultural change is taking place more slowly than in today's world---a reformed world rather than a transformed world. It stands to be a more sustainable world, but one which would still seem quite familiar to postmodern people.[160]

We have now identified two contrasting attitudes towards the proposition that the human ecosystem has entered a global Overshoot Crisis which is funnelling into a dystopic bottleneck where quality of life will plummet for a large fraction of a much-reduced global population. One is a tough-minded 'wait-and-see' attitude whose advocates are empiricists. They are willing to implement adaptation and mitigation measures but feel they must wait till problems and damaging trends are (more) clearly evident.

The second [[[[???]]attitude is a form of tender-minded rationalism whose advocates believe that, in the absence of massive immediate reforms, the reference scenario with its vision of a rapid descent into 'tohu-bohu' is all too likely to come to pass. These immediate-interventionists are optimistic in the sense of being willing to act as though the global community, using a managed markets approach to intervention, can ensure that the dark future of the reference scenario will be briefer and less disruptive than would otherwise be the case. They have a level of confidence that the global community, governments and markets together, will mostly be able to make rational decisions on how to mitigate/adapt to foreseeable and emerging problems associated with overshoot. A depopulated, deurbanized, deindustrialised, deglobalised world awash with displaced people can be avoided. And they do not see the virtual-species problem, the difficulties that interest groups have in working cooperatively, as a towering barrier to successful intervention; theirs is not a world ruled by thugs and macroparasites.

Rise like a phoenix

We come now to our third selection from various possible attitudes towards the reference scenario, i.e. towards the idea of an *Overshoot Crisis* with dystopic consequences, including currency wipe-outs, depopulation, deindustrialisation and deurbanisation. It too is a rational tender-minded attitude, like that of those who would intervene strongly to minimise the entangled impacts of various juggernaut processes on quality of life for the world's peoples over coming decades. Differently though, it is an attitude which regards immediate-interventionists as far too optimistic, believing as they do that the global community can reform slow, mitigate and adapt to the momentous processes that are already reshaping and redirecting many elements of the human ecosystem. The alternative perspective now to be considered is that it is already too late to stop a massive

[160] Raskin, P., Banuri, T., Gallopín, G., et al., 2002, *Great Transition: The Promise and Lure of the Times Ahead,* A report from the Global Scenario Group, Stockholm Environment Institute, Boston
Mulgan, P., 2009, After Capitalism, *Prospect*, Issue 157, http://www.prospect-magazine.co.uk/article_details.php?id=10680, (Accessed 28 April 2009)

disorganisation and simplification of the human ecosystem from occurring, more-or-less as the reference scenario suggests.

However, while deeply pessimistic about the immediate trajectory of the world system, this attitude, tagged here as *Post-Bottleneck Reconstructionism,* is ultimately optimistic. How is that? The metaphorical admonition to 'Rise like a phoenix' is a reference to the mythic phoenix bird which self-immolates every 500 years only to rise anew, reborn from its own ashes. The implication is that after passing through an inevitable dystopic bottleneck, a great contraction in which quality of life plunges, it might be possible to reconstruct a long-lasting human ecosystem in which quality of life steadily improves for most people.

Is it totally preposterous, this scenario of a world experiencing a collapse in the social processes that allow daily life to continue meeting people's basic needs? It has happened before on a regional scale many times but perhaps not globally since the volcanic winter following the Mt Toba eruption 70 kya. Under the threat of a superpowers nuclear war, fear of such a scenario was widespread during the mid-20th century. Today, many respected scientists and academics, including James Lovelock, Martin Rees, Thomas Homer-Dixon and Ronald Wright[161] and respected science journalists such as Howard Kunstler and Paul Roberts[162] have concluded that they would not be surprised by the eventuation of some version of such a scenario. And to further help us to imagine what this looming bottleneck could be like, there is a long tradition of science fiction that explores life in apocalyptic and post-apocalyptic worlds.[163]

Having made the working assumption that the world system is sliding into an inescapable dystopic bottleneck, and given that the proponents we are talking of are tender-minded Rationalists who want to facilitate and expedite a post-bottleneck recovery in quality of life, what might Reconstructionists advocate? What is their strategy for helping global society rise like a phoenix? There are many possibilities, but let me elaborate one based on the 'Noah's Ark principle.' Faced with an inundation he could not prevent, the mythical Noah built a large boat which safely housed a variety of animals until the floods retreated. The animals were then released to repopulate the Earth. Transposing this 'be prepared' principle to the prospect of Global Overshoot, Reconstructionists argue that, before pervasive collapse arrives, there is a *window of opportunity* during which the global community should do as much as possible to prepare for reconstruction.

As with the Immediate-Interventionists, there is an elephantine assumption here that the global community's various virtual species (governments, enterprises, non-government organisations) will be able to agree on what should be done, and be able to cooperate to

[161] Lovelock, J.E., 2006,. *The Revenge of Gaia*., Allen Lane, London;.
Rees, M.J., 2003, *Our Final Century*, Heinemann, London; .Homer-Dixon, T., 2006, *The Upside of Down*,, Island Press, Conn.; Wright, R. 2004, *A Short History of Progress*, CBC Massey Lectures, House of Anansi Press, Toronto

[162] Kunstler, H.J., 2005, *The Long Emergency: Surviving the Converging Catastrophes of the Twenty-first Century* , Atlantic Monthly Press, New York; Roberts, P., 2004, *The End of Oil: On the Edge of a Perilous New World*, Houghton Mifflin, Boston

[163] http://www.empty-world.com/book_index.html (Accessed 10 Mar 2009) A fine example is Stewart, G. 1949|1999, *Earth Abides*, Millennium, London

attempt it. It would help here if Reconstructionists could convince people at large that an extreme-case scenario is plausible, although one imagines that most people will find it impossibly frightening to contemplate the destruction of their civilisation. And yet, a society that cannot and will not even consider the possibility of such a collapse cannot organise to better survive it. It would be ironic if collective action were to become an idea in good currency only after the organisational structures that would allow collective action had become dysfunctional! .

Just as Noah conserved biological capital, the Reconstructionists' task can be viewed as one of conserving and/or constructing an appropriate endowment of 'capital' to leave to the survivors of the bottleneck experience. This is where difficult questions start to suggest themselves---what to try to bequeath will depend on what the survivors' situation is assumed to be. For example, when will stable new patterns of social organisation begin emerging from the disorder of the bottleneck period? Are we talking decades or centuries? What form will those emerging societies take? Will they be anarchic, tribal or hierarchical? Will nation states exist? How will societies be energised? Will there be mechanical power, electric power, animal power? Irrespective of Reconstructionists' efforts, what cultural and physical capital will survive the bottleneck?

The aftermath: rolling backwards through history

While it is largely unpredictable, the behaviour of the global system as it is pushed into self-reorganisation by population growth, resource depletion, economic complexification and global warming, is not unbounded in its possibilities. For example, if people are to survive, and we can assume some will if there are no nuclear wars and winters, they will need to keep producing food by cropping, herding, fishing, hunting or foraging. If people persist, so must technologies for food consumption (e.g. fire, cooking) and production. It can also be assumed that people will try to live in intentional communities of some sort to secure the benefits of cooperation, e.g. physical security, food sharing. If so, language will also survive, perhaps with a degree of splitting and simplification, depending on which communicative and cognitive technologies also survive. However, other than supporting small populations of scavengers, large cities will not survive extended disruption to their food, water and energy supplies. And, as recently demonstrated in Baghdad, recommissioning degraded infrastructure is an enormous task, even with outside help.

It only takes a few such circumscriptions to create a space where one can think about the post-bottleneck world in a concrete way. For example, let us suppose that, come the 22nd century, our great–grandchildren or beyond have survived the worst of the bottleneck and are beginning to lead lives which are more settled and routine but still highly precarious. The Ecumene (inhabited world) might be somewhat smaller than it is today, but not dramatically so. Mid-latitude deserts may have expanded and coastal plains lost to rising seas but, elsewhere, one can imagine a thin smear of small subsistence villages distributed across the continents in patterns not dissimilar from today's food-growing regions; in total, the human, mostly rural, population is likely to be very much smaller. Crop yields per worker stand to be low and variable for reasons which include more climate variability, no mechanisation, no artificial fertilisers, no well-adapted management skills and plant varieties poorly adapted to new climate patterns. As in the early Neolithic period, or the early Middle Ages, any food surpluses will be insufficient to reliably support unproductive soldiers, priests and city-dwellers. Some villages might be able to support a blacksmith; others would need to trade precious surpluses for iron-tipped tools. With an anvil and a hammer a blacksmith can make everything else he needs; then he can make items needed for farming, building, cooking etc..

There will of course be some favoured areas, *refugia*, where food surpluses come easily. For example, as coastal waters penetrate inland they will become nutrient-rich and support larger fish populations. In general, renewable resources will be recovering from their pre-bottleneck exploitation; foraging prospects will improve. Communities capable of producing surpluses will have to trade off the security offered by stored food against the risks of attracting marauders and displaced people; or the risks of allowing their own populations to grow; or the risks associated with becoming a hierarchical society.

Creating an inheritance

Whether or not it actually guides their behaviour, these village communities could not but benefit from knowing how past societies have made these sorts of choices and what the consequences were. Indeed, just knowing that their forebears had to make similar choices is likely to boost a community's sense of identity. However, it is doubtful if the significance of surpluses and what happens to them would be appreciated by post-bottleneck villagers, at least not without assistance; few enough contemporary people understand how food surpluses have influenced history. Here then is a first task for the post-bottleneck reconstructionists---write a potted ecological-evolutionary history of the species, specifically for bottleneck survivors and with a focus on the adaptive consequences of major innovations in material, social, cognitive and communicative technologies. Perhaps an update of Gordon Childe's classic *Man Makes Himself* would suffice.[164] However imperfectly, we know much of potential value to our descendants---if we can but transmit knowledge to them across the discontinuity we are probably entering.

More generally, many ideas about what to try to bequeath flow from the modest starting assumption that the human ecosystem, as it emerges from bottleneck times, will be re-organising into numerous small communities of peasant farmers. Today, nearly half the world's people still live in villages of one sort or another. Given the Phoenix scenario, one can imagine most of these becoming dysfunctional, or even abandoned, under impacts such as crop failures, loss of government services, waves of refugees and loss of markets for selling cash crops and buying simple manufactures. Nevertheless, depending on how long the bottleneck lasts, sites of existing villages are likely to become the loci around which post-bottleneck societies begin to reorganise, places where people, extended families perhaps, come together for mutual protection, to share knowledge and meaning, to undertake collective enterprises, to feel a sense of belonging etc.

Assistance to these bottleneck survivors might be most useful if structured around the goal of helping them solve their immediate (cf. long-term) problems. Here, it seems plausible that these will be not dissimilar to the sorts of problems that modern scholars infer to have faced village-based farming societies as they have emerged around the world from the early Holocene onwards. For example:

[164] Childe, G., 1936| 1981, *Man Makes Himself*, Moonraker Press, Bradford-on-Avon, England

Managing food production and distribution under uncertain weather conditions

Managing population size and composition

Managing relations with neighbouring villages

Protecting themselves from marauders in search of food, women, slaves, valuables etc.

Protecting themselves from coercive self-serving-leaders

Improving technologies for routine tasks

Creating meaning and identity for themselves

These then are the sorts of problems the Reconstructionists might want to help with. Let us assume so for present purposes. If, and it does not seem very probable, Reconstructionism were to become an idea in good currency, resources might become available for assembling technology recipes and physical capital, either existing or imaginable, for the present generation to transmit to post-bottleneck generations; and for setting up ‘time tunnels’ for transmitting them. That is, Reconstructionists would be using the lull before the storm to create-document technologies and create-conserve artefacts specifically for the benefit of the present generation’s (great?) great grandchildren.

It may well be of course that, after living through several generations of increasing disorganisation, our descendants will have lost all understanding of a science-based world view and reverted to animism or theism. After all, look at how little impact Enlightenment thinking has today on a large majority of the world’s population. Perhaps our descendants might conclude it sensible to reject any help from those who triggered their discomfort!

It would be premature to make lists of specific technologies, artefacts etc which a Reconstructionist initiative might decide to transmit to post-bottleneck survivors. Ideally, the selection and construction of such a bequest’s components would emerge from an extensive program of dialectical discussions, consultancies and research involving numerous historians, contemporary villagers, anthropologists, sociologists, psychologists, technologists, scientists, sci-fi writers, futurists etc.(Why not degrees in post-bottleneck studies?). The best candidate institution for managing such a program might be something like a UN-based *World Commission for Post-bottleneck Reconstruction.* Or, in the absence of an international initiative, countries could still plan for the long-term survival of their own people.

What can be done here is to note, in relation to each of several challenges to post-bottleneck village-life, a few of the suggestions and observations likely to appear in discussions on just what cultural and physical capital has a good claim to be made available to the bottleneck survivors. These points represent the merest flavour of the many that might be raised.

<u>The food problem</u>

Urban refugees, in particular, will have little idea of basic agronomic practices including seedbed preparation, watering, weed control, plant nutrition (including recycling) and harvesting techniques. Well-designed implements, including wheelbarrows, will help. Making allotment gardens available to city dwellers now might help preserve cropping skills.

Growing food without the help of draft animals or machinery is physically demanding and for much of the year, totally time-consuming. Using draft animals increases output but such have to be fed and husbanded.

Survivors will need ways of diversifying and stabilising food supplies, including the use of mixed plantings, some hunting and gathering, trade with neighbours, raising domestic livestock. Any experimentation (e.g. plant breeding) will have to be on a small scale. Although survivors will need to supplement crops by foraging and hunting, it would seem almost impossible to transmit such landscape-dependent skills through manuals.

Technologies for sharing and distributing food can smooth out minor fluctuations in food supplies. Such practice will also contribute to group cohesion.

Survivors will need simple technologies for protecting stored food, including tubers and root crops, grain, flesh, fruit and nuts, from rodents and insects and decay. Good rat traps protect grain and capture food. Survivors will need technologies for protecting growing crops from birds and animals, e.g. birdlime, traps, fences.

<u>The population problem</u>

Depending on the productivity of the local environment, villages with populations smaller than, say, 50 or larger than, say, 150 are likely to encounter problems of, amongst others, achieving peaceful governance, sufficient defence capability and coordination of collective actions.

In principle, the population of an aftermath village and its surrounding farmland and other territory---the *stocking rate*---needs to be well below the long-run carrying-capacity of that territory. A low stocking rate confers resilience and security in the face of fluctuating food supplies. In practice, identifying that carrying capacity will be difficult, if not impossible, when local experience is limited and the local climate is not only variable but still changing perhaps.

Although it can be argued that quality of life is likely to be higher when numbers are more-or-less stable, history suggests that it is extremely unusual for human communities, whatever their size, to avoid population growth in good times and swift decline, through death or out-migration, in bad times. One reason is plain ignorance of population cycles. Reasons for a community allowing or encouraging population growth include fear of enslavement or massacre by a more-numerous enemy; or, conversely, an ambition in the community's own leaders for territorial expansion through military conquest. A large population may be seen (probably wrongly) as insurance against epidemic disease. For the individual, a large family offers some insurance against deprivation in old age.

Because optimal population size will always be context-dependent, Reconstructionists can do no more than warn survivors of the dangers of over-estimating carrying capacity and suggest a cautious approach to changing community numbers, whether up or down. More concretely, Reconstructionists should perhaps give high priority to bequeathing social and material technologies with the potential to ameliorate causes of population growth. Three of these causes, those stemming from the problems posed by marauders, coercive leaders and difficult neighbours, are dealt with separately below. Here, we can recognise the value for population management of technologies for reducing unwanted births and technologies for raising healthy-life expectancy at birth. Remember, we are talking of informing people who will have little historical memory of today's medical knowledge.

For a number of reasons, contraception is preferable to abortion and infanticide as a tool for population stabilisation. Unfortunately, condoms and sophisticated prophylactics such as contraceptive pills, emergency contraceptives and spermicides will not be available to post-bottleneck villagers. Research is needed now to locate and evaluate (and even breed) effective herbal abortifacients. The ancient Greek colony of Cyrene at one time had an economy based almost entirely on the production and export of Silphium, a powerful abortifacient in the Parsley family.[165] Research is similarly needed to develop intra-uterine contraceptive devices simple enough to be made by post-bottleneck villagers. It may also be possible to simplify and improve the accuracy of fertility-awareness methods (e.g. presence of cervical mucus) of avoiding pregnancy.

Reconstructionists may also be able to suggest behavioural guidelines which, along with more material technologies, might help survivor communities to keep their numbers stable. For example, women are more fertile and better milkers when well fed; the old can expect to be poorly fed when the stocking rate is too high; food rationing might improve survival rates in bad seasons; cannibalism is an option. An appreciation of the slow march of population dynamics would help.

Like people today, bottleneck survivors will want to lead long healthy lives. Simple technologies for raising healthy-life expectancy at birth include awareness of preventive behaviours such as avoiding contaminated water and washing hands with soap (which can be made from wood ash and animal fat). If large numbers of people could be trained to treat common illnesses and injuries ('barefoot doctors') before the world becomes too disorganised, theirs would be the sort of knowledge having a reasonable chance of being passed on till it became available to post-bottleneck villagers. As a bonus, to be able to understand the training manuals studied by these nurses would be a powerful incentive for people to continue learning to read. Ways of making simple medical instruments (e.g. tweezers, needles) would need to be developed too.

The neighbour problem

Throughout pre-history, humans and their extinct near-relatives lived in small groups in more-or-less fixed territories which they came to know well, and from which they attempted to expel trespassers. But, as noted earlier, lethal inter-group violence and

165 http://en.wikipedia.org/wiki/Abortifacient (Accessed 12 Mar 2009)

dispossession was probably a common response to overpopulation and hunger caused by runs of poor seasons.[166]

Under the phoenix scenario, it is easy to see how a culture of inter-group violence might grow up in a region as bottleneck survivors struggle to choose sites for villages, manage their group numbers and come to an understanding about boundaries with strangers in neighbouring villages. And it would not necessarily be an advantage to have this process of reconstruction being overlaid on a past pattern of occupied villages; not if the remnant prior populations wanted to cling to outdated practices and old enmities.

Once started, tit-for-tat violence seems almost impossible to stop. Still, while more than likely fruitless, it is important that Reconstructionists make a special effort to communicate this truth to post-bottleneck villagers. There may be a place for posturing and spear-shaking to clarify boundaries between territories but the risks of escalation need to be made crystal clear. A culture of inter-group violence has many costs and few benefits. Apart from the diversion of valuable resources into security operations and the creation of a permanent climate of fear, the big danger when fighting between neighbours becomes institutionalised is that it might trigger a push for population growth. Warring can then become a routine activity for culling excess population! What a trap.

Relations between neighbouring villages are more likely to be cooperative and friendly where villages are small and stocking rates low; and in frontier situations where new villages are founded by emigrants from nearby villages. Such arrangements are also conducive to 'balance of power' solutions to the problem of aggression, i.e. several of a region's villages can collaborate to discipline any single village which becomes aggressive.

When there is a degree of trust and interaction between the villages of a region, they will come to share a common disease pool (and hence similar immunities) and enough of a common language to be able to communicate on trade and other matters of common interest. Trade has the potential to improve life in many ways, allowing the acquisition of, for example, medicinal herbs, abortifacients, pottery, cloth, jewellery, pack animals, large and small domestic animals, seeds, minerals and scavenged metals.

History shows that intermarriage between people from neighbouring groups can promote cooperation and alliances between those groups. When those groups are extended families or clans, incest conventions can also serve as a technology for population control.

History reveals other ways in which neighbourly relationships can be improved, including inter-village gatherings to celebrate natural events (e.g. the passage of the seasons), song-and-dance 'corroborees.' feasts and sporting contests. Knowing others makes them less threatening, but such social technologies take time to evolve, even under stable conditions.

166 Le Blanc, S., with Register, K. 2003, *ibid.*

The marauder problem

The marauder problem is somewhat different from the neighbour problem. Like the Vikings and Scottish border-peoples of history, these are mobile groups which descend unexpectedly on sedentary peoples, take what they want by force and then depart the region. If a village's grain stocks, including grain reserved for planting, are stolen, the villagers might well starve---or turn to marauding themselves. In a post-bottleneck world, there could be hordes of displaced wanderers reduced to marauding to survive. It is clear that, above a certain level of successful marauding, a society organised into small villages could not survive and people would have to revert to a hunter-gatherer existence. An alternative would be for villagers to come together for protection in urban centres. Historically however, this 'consolidation' solution was only possible in special situations where output per field worker could be increased markedly by setting up large-scale irrigation projects, as in ancient Mesopotamia. Another solution, in situations where modest surpluses could be consistently achieved, would be *warlordism,* i.e. marauders become protectors in return for a share of each harvest.

It seems plausible that the Reconstructionist movement might judge it important to try passing down technologies which could help aftermath villages survive marauding. Of the many suggestions that might be considered here, we will note (a) some preparations that rely on a high degree of cooperation between neighbouring villages, (b) some preparations that make a village's assets less reachable, and (c) some preparations that increase a village's capacity to physically resist invasion.

Provided they are not too far apart, cooperating villages could warn each other of the presence of marauders using long-distance drums or gongs. Homing pigeons are another possibility. Research on the re-design of such signalling devices could be undertaken now. Agreements to come to the aid of a village being attacked are a possibility. Part of each village's food reserves could be stored in other villages, making it less likely that all would be stolen in a raid. If they could be developed, such arrangements might lead, in time, to a form of local government.

A village's food reserves and other portable valuables will be harder to steal if they are dispersed and hidden and protected with booby-traps (more research needed). A few caches could be poisoned. Food reserves in the form of live animals can be dispersed too. Hideouts for women and children and, perhaps, men can be established away from the village.

An alternative to evasion, depending on the size of the marauding group, is physical resistance. While Reconstructionists might want to help aftermath villagers protect themselves, transmitting technologies for better weaponry is problematic in that most defensive weapons can also be used offensively; and therein lies the prospect of arms races and endless war. Still, as Neolithic villagers found, palisades and ditches are (non-portable) structures which give defenders an advantage. It sounds strange but perhaps the design of palisades and ditches needs researching; or, given that there will be no cannon to bring them down, stone walls may repay the effort of constructing them.

If marauders are to be confronted, the value of dogs needs to be recognised. Not only do they have the senses and the instinct to be brilliant natural sentries, most dogs of reasonable size can be trained to become frightening, fearless attackers on command. In peaceful times, aftermath villagers will learn, as their forebears did but with some help from the Reconstructionists perhaps, how useful dogs are for hunting, carrying, protecting livestock and crops and, indeed, for eating.

The bully problem

The primate trait of being willing to conform to emerging dominance-submission relationships within the social group has adaptive value in terms of helping to maintain order without constant fighting and as a technology for coordinating group activities such as hunting, migrating and provisioning. It is a trait which perhaps co-evolved with the capacity of the young to accept parental authority in species where learned behaviour (culture) had become central to survival. While modern humans, primates all, are generally willing for their beliefs and behaviour to be guided by legitimate authority, they are less willing to submit to being frightened and coerced by bullies. For example, democracy is a recent social technology which derives its authority from the principle that each person has equal political power within a political unit that has a monopoly on coercive force.

In a post-bottleneck world, where technologies for conferring legitimate authority will have to be rebuilt, there will be space for violent bullies to emerge and claim the authority to make collective decisions on behalf of the community. Such developments have to be resisted because thugs generally make bad leaders. They tend to have poor impulse control and to be socially irresponsible, imposing selfish and self-interested decisions on the community. It is important that Reconstructionists attempt to convey this perspective to bottleneck survivors.

History shows that, once in control, sociopathic leaders are difficult to dislodge. They tend to form a virtual species around themselves by making decisions which favour an elite few (e.g. access to food) and by restricting access to weaponry.

There are various social technologies which, where they have become customary, help protect against the rise of coercive self-serving leaders. Thus, in many tribal societies, collective actions are agreed by reaching a consensus or agreed by tribal elders. Or, rather than a single leader, it might be customary for a duo or triumvirate of leaders to be selected by consensus (or by lot) and allowed to lead for a fixed period. The 'invisible hand' principle suggests the importance of harnessing self-interest to the pursuit of the public interest, e.g. leaders who are acclaimed as having served the public interest well might be invited to lead for a further period. These traditions have been traced back as far as Mesopotamian city-states c.2500 BCE.[167]

It is important that the powers of leaders be circumscribed in clearly defined ways. While hereditary leadership offers social stability at times of succession, the risks of getting a mad, bad or incompetent heir make this an unacceptable social technology. The group must be willing to kill or exile a bad leader or one who stays too long. Apart from an understanding of what leaders can decide, it is equally important for the powers of others in the group to be agreed, e.g. who is to predict the weather. In this way, doubts as to where a particular responsibility lies can be minimised. Leadership is an effective

[167] Bermant, C., and Weitzman, M., 1979, *Ebla: A Revelation in Archaeology*, Times Books, New York

social technology in many situations (e.g. simplifying communication and negotiation) and should not be abandoned just because it is so often abused.

Now is the time to do more research on the bullying personality. Are bullies treating people as they were once treated? Do leaders who are bullies inspire more confidence than others in times of conflict? Perhaps something of use to aftermath villagers can be discovered and bequeathed, along with what is already known.

The identity problem

Many post-bottleneck villages are likely to contain *ad hoc* assemblages of traumatised refugees with little sense of history of family, or the pre-bottleneck world or the human lineage. Without such knowledge, it is hard for people to acquire a strong sense of identity, meaning a feeling of belonging to various entities larger than oneself, such as one's family, village, region, species or, for some, the biosphere or the universe. Apart from each individual's psychic need for identity, villagers with a common or shared sense of identity will be able to more readily trust, communicate, collaborate and compromise with each other. It is obviously important for post-bottleneck villagers to understand the value of shared identity and hence for Reconstructionists to develop and transmit understanding of how shared identity can be fostered, e.g. through story-telling or simply through shared experience.

One can imagine that, within a few generations of 'the great breakdown,' people will have only a hazy idea of the history of the great cities that, for them, exist only as ruins to be mined for useful materials which are no longer being produced. If, as suggested above, the survivors can, with the help of the Reconstructionists, have access to a technological history of the species, it might help them understand something of what worked and what failed for their ancestors, and hence might improve their own choices. Rationality is a delicate plant and it is important that aftermath villagers do not revert to 'pre-critical' thinking.

It would not be possible, even for well-resourced Reconstructionists, to prepare and transmit a history of every local area which could become a site for a post-bottleneck village. What then might they be able to do to help post-bottleneck people to identify strongly with their local territories and communities? Not much probably, but one possibility would be to encourage localism and communitarian values at the expense of liberal values amongst today's rural communities. The hope here would be that these values might survive through any future social disorganisation. *Localism* (also called *regionalism*, *bio-regionalism*) is the movement to have more of people's needs, economic and social, satisfied within a local area (up to, say, half a day's travel) which, politically, enjoys significant autonomy under the nation-state. The bio-regional variant of localism looks for self-sufficiency for the residents of a bio-physically defined area such as a river catchment. Authority needs to be set in place now for future villages to assume emergency powers should higher levels of governance disappear.

A more concrete idea for creating a lasting sense of place would be to delineate today's local government boundaries with permanent markers and take the children out to 'beat the bounds.' Maps may well become rare, so knowing your territory's former place name and shape might be useful when negotiating boundaries with neighbours.

Humans tend to think in terms of binary divisions. But aftermath villagers must avoid identifying their communities by negation, i.e. by focussing on differences between 'them' and 'us.' This way lies prejudice, fear and, often, violence; shared enmity encourages a form of bonding that is ultimately self-defeating.

Identity through negation stands to be problem within communities as well as between communities. If and when village societies start to become more hierarchical, with a ruling virtual species and a labouring virtual species, differences between virtual species are more likely to be recognised than commonalities. Traditionally, ruling virtual-species have developed a range of social technologies for suppressing the potential for conflict. These include physical coercion, food rationing and the propagation of religious ideas which convince the underclasses to accept their lot in life. Such technologies work only up to a point before revolt emerges. The question for Reconstructionists is whether they can help aftermath villagers understand the importance of minimising differences between virtual species.

Technology issues

Darker versions of the reference scenario imagine a world of primitive subsistence villages where the elaborate manufactures and services (including electronic communications and motorised haulage) and food markets of today's urban industrial civilisation are no longer available. More than this, even in a world which has been disorganised for just several generations, it is likely that many of the skills which might have helped survivors to improve their quality of life will have been lost; along with physical capital such as buildings, tools, drainage systems and fences; and those inputs which are themselves made from the end products of various long chains of manufacturing processes (wood screws provide a simple example).

In a post-bottleneck world it will take time and luck to reconstruct village communities which have the material, social, communicative and cognitive technologies to survive the 'normal' range of threats to be expected from nature and various fellow humans. This is because complex technologies have to be built up from simpler technologies which are already established. You can't weave before you can spin, so to speak. The best that today's Reconstructionists can hope for is to speed up the rate at which some simple ideas, recipes and artefacts are 'discovered' by bottleneck survivors. There is no point in trying to transmit elaborate technologies through a time of rapid technological simplification..

Even as they learn to master village life, survivors will need to keep devising and modifying technologies for better dealing with changing conditions, if they are not to become increasingly vulnerable to disturbances. Apart from attempting to transmit various selected technologies, it might be just as important for any phoenix project to project and reinforce the optimistic perspective that humans have a long unbroken history of inventing new and improving old technologies.[168]

Equally, and it cannot be known in advance, survivors might benefit from being warned that most promising new technologies have a latent 'biteback' or 'fishhook' potential if adopted too enthusiastically, i.e, after a lag period, they come to be seen as having caused

[168] Childe, G. 1936|1981, *Man Makes Himself*, Moonraker Press, Bradford-on-Avon, England

new problems. The outstanding examples are better weapons, rapid population growth, and task specialisation leading to privilege. Recognising such 'technology traps' may be insufficient reason for not entering them of course.[169]

A technology which reduces inputs (e.g. a better plough) rather than increases outputs has several advantages. While saved resources (e.g. work hours) can be used to increase output, they may be better used to increase leisure time or to implement public works such as improved defences; or to improve social cohesion through group activities such as festivals. It is particularly important that time be found for educating the young in reading and writing, wherever these communicative technologies have survived.

History suggests that mutually beneficial trade is commonplace between the simplest of societies. Equally, post-bottleneck communities should probably be seeking technologies that produce tradeable goods. Apart from its direct benefits, trade can bring new ideas, an understanding of the outside world and improved relations with neighbouring communities. It is important however for communities to avoid becoming too specialised in the production of a few goods; outlets can disappear and specialisation often leads to exploitation.

Shouting down the time tunnel

Trying to transmit a message to one's great grandchildren has all the uncertainties of shouting down a metaphorical 'time tunnel.' One has to decide what to shout about and how to shout it; and then wonder Will anyone hear it? Will they listen? Will they understand it? Will they find it useful? Being a one-way tunnel, they can't shout back and tell you.

The Phoenix strategy can be thought of as having several prongs. One is to invest at once in the targeted development of new social and material technologies, which, if they survive the bottleneck tumult, promise to prove useful to post-bottleneck villagers. Another is to make contingency plans for 'mothballing' a small number of 'heritage' sites which incorporate vast amounts of concentrated information, especially the great libraries and museums. Remembering the fate of the Ancient Library of Alexandria and, more recently, the Baghdad Museum, such entities have to be recognised as vulnerable to social unrest. The third prong, as discussed above, involves collating a body of contemporary insights and procedural information and seeking to actively transmit this aggregate across a period of massive social disorganisation into the hands of post-bottleneck peoples. The thinking here parallels sci-fi writer Isaac Asimov's idea for an *Encyclopedia Galactica*, a vast compilation of the knowledge of a dying galactic empire; or Douglas Adams' *Hitchhiker's Guide to the Galaxy*.[170] Here, we consider some obstacles to and ideas for successfully transmitting an Earth-bound *Collation*.

[169] Heidegger, M.,1977, *The Question Concerning Technology and Other Essays*, (Trans. W. Lovitt), Harper and Row, New York

[170] Asimov, I., 1995,1996, *The Foundation Saga* (Foundation, Foundation and Empire, Second Foundation), Paperback editions, Harper and Collins, London; Adams, D., 1980, *Hitchhiker's Guide to the Galaxy*, Harmony Books, New York

One obvious principle is to use a diversity and redundancy of channels to deliver a Collation to as many post-bottleneck village-sites as possible. Electronic media will be unsuitable because they do not store well and become increasingly difficult to read. More to the point, the infrastructure which carries today's Internet (computers, servers, transmitters, fibres etc) will have been irreparably degraded by then. And, like other machinery from the industrial age, electricity generators will have disappeared.

What about books? Yes, the Reconstructionists' Collation can be thought of as a library of a few hundred books, manuals etc.. But they will have to be special books in a number of ways. Physically, they will need to be printed on some durable, fire-resistant medium (aluminium?), cheap enough to produce millions of copies in a number of contemporary languages. Their fonts will have to be large to allow reading by candlelight. In terms of presentation, they will presumably have to be written as though for people with a basic 800-word vocabulary and, like children's books, with lots of pictures. Also, they will have to be written as though for people with limited cognitive skills with respect to causation, induction, deduction, abduction etc.. It is well-known that, without practice, people tend to forget how to read and it probably has to be assumed that people who have been living precariously for several generations will also have trouble in making longer-term plans and investments when conditions begin to stabilise.

Much imagination will be needed to create a distribution system which has any prospect of reliably delivering Collations to post-bottleneck villages. How can each village's 'library' be protected from pilfering and wanton destruction until it needs to be accessed? Most suggestions have obvious flaws. One possibility is to house each village's collation in one or several shipping containers. But should these be padlocked or left open to be protected by local people? Would their contents be attractive to marauders? Should each village have multiple libraries? And so on. Perhaps each shipping container's walls could be covered, inside and out, with useful permanent inscriptions---like Hammurabi's Bronze Age steles which proclaimed the law for all to see.

Religious communities played an important role in keeping the flame of learning alive through the European dark ages. Might it be possible for the Phoenix project to encourage the establishment of ongoing communities of secular religious committed to, first, surviving the bottleneck and, second, mastering and passing on the Collation? For example, a contemporary group whose members might have perspectives and ideals suited to such a mission is the *deep ecology* movement founded by Arne Naess.[171] Simple agrarian societies are ecologically benign. And, continuing this high speculation, as more-orderly agrarian societies emerge from the bottleneck, these 'secular monks' could leave their 'monasteries' and become wandering story-tellers and teachers, helping villages make use of their inherited Collations. Plus ça change…

DISCUSSION

This chapter is organised around a dystopic scenario, an imagined future in which, world-wide, quality of life drops sharply over the next few decades. It is imagined that people in both rich and poor countries will find it much harder to satisfy their everyday needs

[171] Fox, W., 1990,. *Toward a Transpersonal Ecology: Developing New Foundations for Environmentalism,* Shambhala Publications, Boston and London

and to remain functional. Unthinkably large numbers will die from hunger, violence and disease. At the collective scale, nation-states will see the abandonment of cities, the disappearance of many industries and institutions and currency failures. It is argued that such a scenario is a plausible expression of ongoing cumulative change in four highly-consequential attributes of the human ecosystem---people numbers, stocks of natural resources, mean global temperature and the interconnectedness of the global economy-society. History certainly shows that human societies change markedly when any of these ‘control parameters’ shift. In a situation I have described as Overshoot, these four attributes have now, putatively, reached threshold levels, i.e. levels beyond which the global human ecosystem can only continue to function as a complex dynamic system if it spontaneously self-reorganises into a structure which is better-adapted to such changes.

It is because self-reorganisation is inherently unpredictable in speed, scope, onset etc. that different people can, quite legitimately, have quite different beliefs as to whether and how this reference scenario might eventuate; and different ideas as to what the collective’s response to such a scenario should be. The chapter suggests that, among those concerned for the well-being of the world’s people, it will be common to find tough-minded wait-and-see Empiricists and tender-minded Interventionists. The former have open minds as to when and how disorganisation might set in and spread but are willing to see generous aid offered to victim groups when it is clear that their quality of life is in decline. However, they have little interest or confidence in efforts to manage the juggernaut processes (resource depletion, population growth, global warming , economic complexification) lying behind declining quality of life.

Those I have labelled as (immediate) Interventionists are convinced that, if nothing is done, the reference scenario could very well come to pass. But, they also believe that, if there is strong coordinated intervention to manage the juggernaut processes and their impacts, average quality of life will decline but slowly for a generation or so and then begin to monotonically improve again. This is the idea that a ‘soft landing’ is possible.

As presented here, what is remarkable about the advocates of both these widespread attitudes, perhaps more so for the Interventionists because they are more ambitious, is that they are not overawed by either the virtual-species problem or the what-to-do problem In claiming to have a realistic perception of the reference scenario and how to best respond to it, they are equally claiming to have a reasonable working knowledge of the what-to-do options that are available, and their consequences, and whether or not the cooperation and coordination each option calls for can be achieved.

In addition to the Interventionist (Stop fiddling) and reactive (Don’t panic) responses, the chapter elaborates a third possible response to the reference scenario, that of the Reconstructionist or Preparationist. Here, the radical perception is that the reference scenario, or something much more dystopic, is not only totally plausible but largely unstoppable. That is, humanity needs to look to the future on the assumption that quality of life will plunge everywhere in coming decades, but most painfully in communities where there is a high dependence on trade and elaborate manufactures, where population density is high and where food and water are already scarce and further threatened by global warming. The Reconstructionists take this new dark age as given and ask what can be done now to help the village-scale communities that will be forming and looking for security and improved quality of life once the uncertainties of the bottleneck period begin to pass, in two or three generations perhaps.

As with the Interventionist and reactive responses, but probably more so, the ineluctable realities of the virtual-species problem and the what-to-do problem would make it very difficult for contemporary Reconstructionists to create and successfully deliver a genuinely useful inheritance to our post-bottleneck descendants. That is, an inheritance that would help them rebuild a technology mix and quality of life more quickly, while avoiding the reintroduction of some of the maladaptive technologies (behaviours) which have helped to create the present Overshoot Crisis.

Unfortunately, these descendants have no voice in today's world and diverting resources towards their interests in the face of today's pressing needs seems unlikely. Nor can one imagine players in today's political processes admitting that their working hypothesis is to assume an approaching massive breakdown of global society. So, as with the Interventionist and reactive strategies for responding to Overshoot, the Reconstructionist strategy is unlikely to evoke significant collective action.

A broader context

There are various other responses to the reference scenario which this chapter could have explored, but those selected, based on differences in respondent temperament, probably constitute a reasonable sample of the possibilities. Responses based on ideology, superstition or despairing nihilism were deemed unlikely to lead to productive discussion. Similarly, I could have selected a different reference scenario, one in which the speed and extent of breakdown in global society were either more or less than in the chosen scenario; or a scenario squeezed out of a different set of global-scale processes. Notwithstanding these matters of judgement, I will take my perception of the attitudes and responses outlined as a starting point for putting the Overshoot Crisis, and people's conceivable responses to it, into a broader context.

Despite the observably relentless progression of momentous juggernaut processes which appear to be more threatening than opportune, we will not know if we are now entering the early stages of a major discontinuity in the organisation of planetary society until hindsight allows us to look back at what happened, particularly what happened to average quality of daily life. If the Reconstructionists are making the right assumption, we have indeed entered a major discontinuity, but if the Interventionists' working assumptions are right, the global community will be willing and able to avert what would otherwise be such a breakdown. This would leave the global community free to resume building a more sustainable civilisation. So, unlike the tough-minded Empiricists, both groups of tender-minded Rationalists---the Interventionists and the Reconstructionists---agree that global society is approaching a major discontinuity; they disagree as to whether it can be averted.

Some Reconstructionists might further disagree as to whether it 'should' be averted, i.e. should a potential discontinuity, a sharp drop in average quality of life, be converted into a gentler transition to a post-overshoot world? Or, should global society be allowed to go through a harsh bottleneck so that it can be 'born again'? If there really were such a choice, history suggests that permitting or encouraging a sharp drop in quality of life in order to allow a more progressive replacement society to emerge would probably be a mistake. How many successful revolutions against oppression have quickly led to renewed oppression? In similar vein, starting from the assumption that average quality of life is about to drop sharply, it is a knowledge of history which suggests that

Reconstructionists' attempts to help post-bottleneck villagers should focus, not on improving their quality of life *per se*, but on helping them to avoid being brought down by various perennial threats.[172] More generally, it might be observed that the real tragedy of the Overshoot Crisis is that it has already redirected the global community's attention from the challenge to steadily improve quality of life for most people to the challenge of preventing a decline in average quality of life from present levels. People of goodwill are asking How much will quality of life decline in coming decades? They are not asking How much will it improve?

If the Reconstructionists' working hypothesis is correct, global society is entering a period of reorganisation at least as far-reaching as any associated with past periods of major reorganisation, including the flowering and transformation and disappearance of civilisations; and reorganisations triggered by climate shifts, natural disasters, shifts in cognition-consciousness and the emergence of transformative social and material technologies.

One thing that stands to be different about this 21st-century bifurcation, if it is that, is that it could engulf the whole world, something not experienced since the global warming at the end of the last ice age. Even the few remnant hunter-gatherer societies could be disrupted by climate change. More than this, apart from the sheer numbers standing to be killed or dispossessed, disruption could spread very quickly because of the density of high-energy links---economic, political, social, environmental---between large and small regions everywhere. When disruptions are being initiated in a variety of ways (through resource depletion, global warming, population shifts, economic linkages…) at multiple locations across the Ecumene, the potential for inter- and intra-regional domino effects, positive feedbacks, chain reactions, oscillations, destructuring etc is enormous. Breaking a link which carries or just directs a large energy flow (e.g. capital movements) is necessarily highly disruptive. Historically, endogenous and localised disruptions were more-or-less self-limiting in a world of loosely-connected regions; and, when it was a single region being disrupted, surrounding regions, being still organised, could both absorb the spill-over effects and initiate reorganisation in the disorganised region, e.g. the absorption of failed states by neighbouring states.

While the current Overshoot Crisis has the potential to be the most disruptive of the Holocene epoch, it pales beside various geophysical perturbations which scientists have flagged as plausible possibilities for the distant future. As discussed in my earlier book, *Deep Futures*, these include 'permanent total drought' in about 900 million years, large differences between daytime and night-time temperatures, and the extinction of the Sun in 5-7 billion years.[173] Also, once we begin thinking about futures measured in millions rather than thousands of years, scenarios such as volcanic winters, asteroid strikes and the loss of the geomagnetic field become plausible possibilities as distinct from possibilities which would be highly surprising if they occurred in the next millennium. Based on today's knowledge, it is reasonable to assume that the human species, or a successor

[172] Fagan, B., 2008, *The Great Warming: Climate Change and the Rise and Fall of Civilisations,* Bloomsbury, New York.. Fagan argues that village-based societies have, historically, been particularly resilient in face of climate and other change.

[173] Cocks, D., 2003, *Deep Futures: Our Prospects for Survival*, University of New South Wales Press and McGill University Press, Sydney, Ch 2

species, will be snuffed out at some time in the far future. We emerged from stardust and to stardust we will return.

In the nearer future, much less threateningly, the species will have the next ice age to contend with. Already, at 11-12 thousand years, ours is the longest inter-glacial on record and, well within a thousand years, we could be plunged into a world where, as in the last ice age, average temperatures are up to 10 degrees lower than today (although the cooling process commonly has taken much longer). Current greenhouse warming could delay this somewhat but is unlikely to permanently stall a process which, driven by recurring variations in the Earth's orbit, axial tilt and axial wobble, has operated with a basic regularity for a million years. In that cold, perhaps CO_2-deficient, dry, windy world, wheat could not be produced in the breadbaskets of Ukraine, North America and Australia and, in the absence of revolutionary technology, world population would plummet, if it had not plummeted already.

What will happen? Piecemeal intervention?

What has been achieved by having this discussion of various ways of reacting to a dystopic reference scenario? Are we any closer to knowing what will happen to global society over coming decades? The answer of course is No, once it is accepted that the global human ecosystem is a dissipative system which has been continually reorganising because it has been capturing energy at an increasing rate.

On the other hand, the possibilities as to what could happen or could not happen to the human ecosystem may be a little clearer, albeit wide-ranging. Thus, it seems highly unlikely that any of the three strategies suggested in the Chapter on behalf of Empiricists, Interventionists and Reconstructionists respectively will be adopted explicitly by the global community. Reconstructionists in particular would find it difficult to convince people or governments, who would prefer to not be convinced, that the reference scenario is plausible to the point where the species should act as though it will eventuate. Empiricists run the risk of being labelled 'just sceptics' and of being captured by those beneficiaries of the *status quo* who are advocating inaction in their own short-term interests.

On the other hand, the Interventionist position is likely to get a degree of support, but in a piecemeal way. That is, as early warning signs of particular threats to the quality of ordinary lives or the functionality of states appear in particular locations, those who stand to be directly affected will promote precautionary efforts to adapt to or mitigate the foreseen harm. Indeed, in a variety of ways this is already happening, from Kyoto to kerbside recycling, from bank bailouts to wind farms. A few of these efforts stand to be global in scope, tackling the juggernauts directly, but most will be national, regional, local or personal. Poor and failing states though will not have the resources to protect themselves or their people from Overshoot's shocks; and international assistance to such will be very limited.

But, to repeat, there is little chance of the Overshoot Crisis being tackled comprehensively. The understanding being suggested here is that the evolution of the global human ecosystem, and quality of life for many, are already being noticeably influenced by a process of *piecemeal intervention* in an Overshoot Crisis of unpredictable speed, size and duration. Like other wicked problems, the Overshoot Crisis is exhibiting itself as an evolving set of interlocking issues, constraints, objectives and options for action. Ends and means overlap. There are multiple protagonists, what I call virtual-species, and each will takes various actions, each of which is intended to be a partial solution, i.e. to improve some aspect of the total problem.

Faced with this emerging unscripted interplay between juggernaut trends and a patchwork of virtual-species' responses, it takes little to imagine that a sharp shift in community psychology, in social character, is also taking place. Recall that a society's social character is to be seen in the way that most people internalise, accept and support the cultural values implicit in their society's social and economic systems. But history shows that a society's social character can change quickly once it is commonly perceived that its socio-economic system is failing to deliver the values it professes to foster. As and if a failing socio-economic system is replaced by one seen as more progressive, so will the previous social character be replaced by one supportive of the incoming system. More precisely, this replacement process is coevolutionary in that change in either social character or the production system will induce further change in the other; social character both leads and follows social change. For example, Leonard Woolf's *After the Deluge* is largely concerned with the way in which, in 19th century Europe, the idea and practice of democracy replaced an unquestioned acceptance of inherited privilege as society's main organising principle.[174]

So, what is happening to social character now in, for example, First World countries? As noted in Chapter 4, support for the values and ideas underpinning economism and neo-liberalism has declined in recent decades, in line with the perception that the economic growth which these beliefs have fostered (at least until very recently) has failed to deliver increased prosperity and improved quality of life for the many. While there is no clearly apparent successor to either the capitalist system of production-consumption, or a besieged belief system, there is evidence of both being 'reformed.' Thus, the recent spread of 'interventionist' social-democrat governments in place of neo-liberal governments is best interpreted as a movement to reform, but not to replace, the dominant paradigm. That is, markets are still being seen as the core institutions of Western post-modern societies, but intervention to 'correct' widely-acknowledged widespread market failures has acquired a renewed legitimacy.

Much of that legitimacy rests on a growing approval within the community for the idea that *Sustainable Development* is an appropriate umbrella goal for the global human ecosystem. Building on the environmental movement that began in the 1960s, Sustainable Development is based on the proposition that all of the global community's projects can and should meet standards for environmental protection, economic development and social development in a balanced way.[175] Just as neo-liberalism was waiting in the wings to replace Keynesianism in the 1970s, Sustainable Development, has been emerging as the strongest aspirant to displace neo-liberalism as the centrepiece of First World social character. Support for this transition seems to have accelerated as the growing perception that there is a global Overshoot Crisis has joined the perception that economic growth alone did not and cannot provide high quality of life to most people. In this vein, *piecemeal intervention*, with its emphasis on managed markets as primary

174 Woolf, L., 1931/1937, After the Deluge: A Study of Community Psychology, Pelican, London
175 http://en.wikipedia.org/wiki/Sustainable_development (Accessed 26 Dec 2010)

instruments for responding to Overshoot, presents as a canonical example of the Sustainable Development philosophy.

Presumably, if this chapter's dystopic reference scenario does eventuate in the next few decades, the ideas of both Sustainable Development and neo-liberalism as grand organising principles will be consigned to the dustbin of history. People will then develop a new social character consonant with the society in which they find themselves. For example, if urban societies revert to a village-based mode of social organisation, one would be unsurprised by the emergence of a social character which is appreciative of the qualities of village life and supportive of customary approaches to addressing the problems that villages encounter.

Very sobering

To conclude, this is a very sobering chapter. It is suggesting that, while humans will survive their human-made Overshoot Crisis, it won't be because of any remarkable capacity to adapt to major challenges in ways that protect quality of life. It will be because the Crisis wasn't as bad as some thought it could have been; that is, the species was not really tested. Or, it will be that while the crisis was highly destructive of quality of life for most, it spat out a post-bottleneck population which, scattered and much-reduced, retained sufficient social and material technologies to begin rebuilding stable sedentary societies and improving quality of life once again. Nor does our analysis find any global collective will to consciously avert extended crises or to work systematically towards achieving high quality of life for most people into the indefinite future.

So, it has to be asked, if this is cultural evolution in action, is it a dead-end process, limping along until a somewhat bigger shock than the present crisis drives the species to extinction? For example, global warming during the Permian extinction produced sufficient deadly hydrogen sulphide gas to kill off 50 percent of animal families and 95 percent of marine species (see Ch 1). This is a largely unrecognised possibility which could happen again if, in a warmer world, the oceans' heat-transferring currents stop flowing.

For those hoping for a human ecosystem where prospects for long-term quality survival will continue to improve---call them *ecohumanists*---a better question to ask is whether cultural evolution is producing social, cognitive, communicative and material technologies which, other things being equal, could help this to happen. Growing out of our ever-increasing ability to conceptualise the world and its component processes, we have acquired a profusion of technologies, but no accompanying sense that prospects for quality survival are thereby improving. It may be that the quality survival challenge is not recognised as important by enough people, or is actively opposed by too many people or is just too difficult under present levels of cognitive skills and scientific knowledge, e.g. our limited understanding of the dynamics of complex systems; our inability to solve the virtual-species problem.

If ecohumanists want to convince enough people to believe in and progress the idea that quality survival is humanity's primary goal, they have to explain the world view (system of fundamental beliefs that describe reality) which leads them towards this conclusion. Thus, a great many ecohumanists view the world, including the human ecosystem, in terms of evolutionary and ecological processes, and find this to be a philosophy, a model of reality, which gives them a sense of meaning (What's been happening? Why are things the way they are and not otherwise?) and a sense of belonging---to the universe, the world and the human family. It is the feeling that all people, present and future, are one's 'brothers and sisters' or, at least, one's 'neighbours', that brings one to regard quality survival as a matter of ultimate importance. It is the ecohumanists' belief that feelings of loyalty to and solidarity with the 'other' blur differences between virtual species, foster cooperation and refocus the search for new technologies away from market reform and towards quality survival.

When a dominant world view emerges in a society it provides a set of constraints and guidelines within which both social character and social organisation will evolve, i.e. both will continue to change, but in ways which are not incompatible with the overarching world view. Because world views usually change much more slowly than social character and social organisation (centuries versus decades often), they are, most of the time, like a *medium* within which social evolution takes place. For example, if a world view inclines people to believe that humanity has been just plain lucky to have survived both large natural events and its own selfish, short-sighted behaviours, it may also incline them to behave with more concern for others and more presbyopically.

Unlike traditional societies where a single world view is the norm, today's connected world is one where alternative world views---religious, scientific, political, economic, psychological etc.---struggle for dominance, in the sense of each having their advocates, e.g. Samuel Huntington's 'clash of civilisations,' CP Snow's 'two cultures.'[176] What then is the likelihood that a world view based on a scientific understanding of reality will become widespread? And what are the shortcomings of such a perspective? Perhaps there are other world views which also constitute belief-environments where quality survival is readily seen as being humanity's paramount goal? Where concern for people everywhere is highly valued?

This then is where our project to understand the origins, nature and possible trajectory of the Global Overshoot Crisis has finally led us, namely, to a conclusion that the ways in which societies respond to existential opportunities and problems are broadly determined (macro-determined) by the world view or views prevalent in the society. This is a simple but important conclusion which, in the next and final chapter, to round out our analysis, we will look at in more depth. In particular, I will argue that *Ecohumanism*, understood as a science-based and humanistic world view cum philosophy, offers both a shareable understanding of the long trajectory of the human ecosystem and a variety of practical starting points for thinking about how to better manage both the proximate and root causes of Global Overshoot.

[176] Snow, C.P., 1959|1965, *The Two Cultures and a Second Look*, Cambridge University Press, New York; Huntington, S.P., 1996, *The Clash of Civilizations and the Remaking of World Order*, Simon and Schuster, New York

CHAPTER 6 ECOHUMANISM AND OTHER STORIES

STORIES THEN AND NOW

Storytelling is an old, old social technology with the potential to serve a variety of practical functions, especially in oral cultures. For present purposes, the term stories is a catchall for the myths, sagas, epics, fables, legends, plays, folktales, folk histories etc which members of religious, ethnic, political, tribal etc. virtual species tell and retell amongst themselves. Apart from being entertainment, allowing the listener to enjoy vicarious adventures etc., stories are a powerful socialisation and communicative technology which can mould and reinforce customs, belief systems, values and attitudes. For example, the Mahābhārata is a Hindu epic, the tale of a great dynasty, which supports a discussion of human goals (purpose, pleasure, duty and liberation) in terms of traditional understandings of the relationship of the individual to society and the world, including the nature of the 'Self' and the consequential nature of one's actions.[177] For individuals, stories can help satisfy their ever-present needs for a sense of meaning (e.g. understanding the past) and a sense of belonging to a group with a strong identity. In particular, religious stories, to the extent that they are believed, can console the grieving individual, allay her fear of death and help her endure great misfortune.

Cultural anthropologist Joseph Campbell is well-known for his thesis that many important myths from around the world, some having survived for thousands of years, share, in part or whole, a common structure. He summarizes same in a well-known quote from the Introduction to *The Hero with a Thousand Faces:* 'A hero ventures forth from the world of common day into a region of supernatural wonder: fabulous forces are there encountered and a decisive victory is won: the hero comes back from this mysterious adventure with the power to bestow boons on his fellow man'[178] Examples include Moses, Jesus, Mohammed, Buddha and Odysseus.

[177] http://en.wikipedia.org/wiki/Mah%C4%81bh%C4%81rata (Accessed 20 July 2009)
[178] Campbell, J., 1968, *The Hero with a Thousand Faces,* Princeton University Press, Princeton

Another helpful perspective on how stories are useful is that of Karl Kroeber in his book *Native American Storytelling:*[179] 'Storytelling was a recognised way of 'debating' solutions to practical personal, social and political contemporary problems' (p.2). Some stories were told for amusement and relaxation but most were active applications of historical tribal experience to specific current issues, individual and communal. Among others, the anthropologist Claude Lévi-Strauss has recognised that myths invariably introduce conflicting ideas about how the world works or should work and then show how 'thesis' and 'anti-thesis' can be synthesised or reconciled.[180] Thus, taking this book as an example, could my three different ways of reacting to an overshoot scenario be reconciled or synthesised?

Stories abound in contemporary society too. Some, survivors from the distant past, are still important for specific communities, particularly those stories which have survived as sacred religious texts. Because the stories in these texts cannot evolve, they can only remain relevant to contemporary communities by being continually re-interpreted. Alternatively, communities that believe in such a text attempt to hold on to the culture and social organisation which existed when their stories were young.

The bulk of 'new' stories are fictitious; they involve imaginary characters working through a plot-line of relationships and events, and are widely available through the media of film, television, radio, theatre and print. Most fiction is created for entertainment but, when vividly presented, it exposes people to experiences they can learn from and ideas they can use to expand their own behavioural options, e.g. by challenging or confirming conventional wisdoms, or by providing memes and role models.

Newspapers and electronic news media present the public with large numbers of 'non-fiction' stories every day. These provide people with a selective sense of what is happening and mould public opinion, sociality and social character as people exchange their responses to these widely shared experiences. While a majority of news stories are transient, many present as chapters in ongoing narratives; the state of the economy and progress in sporting competitions are examples here.

As discussed earlier, we live in a world where propagandists from one virtual species routinely distort non-fiction stories in order to persuade (cf. convince) other virtual species to come to beliefs and values which covertly advantage the propagandists. Governments which deliberately 'revise' history provide many examples---Stalin's and now Putin's Russia; Hitler's Germany; Japan's sanitised version of its atrocities in the Second World War Such rewritten histories find scapegoats and excuses for past failures or inspire populations to believe their forebears were great, creators of glories and triumphs, and never ignoble.

There may be circumstances in which the deliberate corruption of history can be justified---to motivate a shattered people perhaps---but people will react angrily and become indelibly suspicious when they eventually conclude they have been deceived. Or, if they continue to be deluded, they may well adopt dangerously unrealistic goals. A

179 Kroeber, K., 2004, *Native American Storytelling: A Reader of Myths and Legends*, Blackwell, Oxford

180 Lévi-Strauss, C., 1966, *The Savage Mind*, Weidenfeld and Nicolson, London

complication here is that corruption is not always a black and white matter. Even honest history has to be periodically rewritten to match contemporary understandings and to incorporate new data. With the best of intentions, historians may not be fully aware of their own world views, their unrecognised prejudices and assumptions; unconscious racism provides a good example. Or, quite genuinely, they may not regard their prejudices as prejudices.

And then there are 'true' stories, told by people who want to create meaning and understanding by linking available pieces of information together in a plausible, coherent way. Amongst others, scientists or, more generally, scholars, aspire to tell (provisionally) true stories; plate tectonics and evolution through natural selection are powerful examples.

THIS BOOK IS A STORY

This book is a story of course, albeit not one with a hero in Campbell's sense. It is a 'rock-hopping' story of how evolutionary and ecological processes have led, step by plausible step, from the early universe to a Global Overshoot Crisis which now threatens to massively reduce humans' average quality of life. At this point the *Story of Global Overshoot,* to give it a name, moves to discussing just how threatening the Crisis is perceived to be by people of different temperaments, how world society might respond and what might actually happen to quality of life. It recognises that some see no Crisis, that some see a Crisis that can and will be averted, and some a Crisis that will unstoppably turn into a disastrous bottleneck for humanity. My tentative conclusion is that reductions in quality of life over coming decades, whether they are to be large or small, are already determined and unlikely to be greatly altered by human intervention.

Why am I telling such an uninspiring story? It offers no solution to the Overshoot Crisis, no vision of steady improvement in average quality of life for the world's people. Notwithstanding, the story is offered as a useful response to perceptions of an Overshoot Crisis. This chapter recapitulates and reviews that claim.

Descriptive and prescriptive philosophies

Is it too grand to call my story a philosophy? Is it anything more than a 'philosophy' in the everyday sense of that word?[181] Its starting point is certainly an acceptance of the central idea of process philosophy, the assertion that reality is best understood by seeing it as a process of continuous change driven by the spontaneous dissipation of energy gradients set up when the universe began. It is a story which might equally have been called *Nothing is at rest*, a linked chain of questions and answers about how and why things have been changing; and what might have caused them to change otherwise. Each step in the evolutionary chain sees the creation of a more-or-less stable 'platform,' composed of material and energy flows diverted out of those already in existence. Each new platform then functions as an environment in which, for the first time, certain conditions necessary for the emergence and persistence of the next link (platform) in the evolutionary chain (hierarchy) are satisfied. It's platforms all the way up! This

[181] Wilson, J., 1966, *Thinking with Concepts*, Cambridge University Press, Cambridge, Ch.3

perspective is a *descriptive philosophy* in the sense that it is a quite general approach to understanding the Crisis---its origins, its present character and its possible future.

It is also quite abstract. For the story to have everyday meaning, it has to be told in terms of a mutually compatible (coherent) set of concepts, a *world view* or *belief system* which allows successive platforms to be described in terms of their own peculiarities. Thus, separate vocabularies are needed to describe and understand evolutionary change in, for example, the radiation era, the chemical era, the biological era and the cultural era. This book is based on, and intended to demonstrate, the naturalistic belief that, in general, the set of concepts provided by contemporary science and the humanities is a sufficient world view to allow the story of the Overshoot Crisis to be developed in a way that is both plausible and consistent with a core philosophy of understanding reality as a process of continuous change.

As told here, the story of the Overshoot Crisis is also an exercise in *moral philosophy*. [182] Thus, it prescriptively (normatively) proposes that *quality survival*, the achievement of high quality of life for most people into the indefinite future, be treated as global society's overarching goal. From this moral standpoint, the Overshoot Crisis is only a crisis because it carries a threat to average quality of life. It is only by embracing some such goal that alternative what-to-do proposals can be compared for expected effectiveness; or, likewise, that one can compare the expected impact of alternative Crisis trajectories. How do you know which bus to catch if you don't know where you are going!

Despite its fuzziness, I find the humanist goal of quality survival, perhaps more easily recognisable as *humanitarianism* or *cosmopolitanism*,[183] a more fundamental anchor point for thinking about the impact and management of the Overshoot Crisis than more conventional but instrumental alternatives such as economic growth, sustainable development, security or religious conformity; it is all too easy to confuse ends and means. Notwithstanding my own conviction, there is a broader injunction here---global society must recognise that goals are chosen, not revealed, and that they must never be closed to debate and revision. They are certainly not naturalistic in the sense of somehow being consequences of what is materially true. Apart from the adaptive value of this directive, humanity's image of itself needs to include the perception of being a species which, in an ever-changing world, is willing and able to keep questioning fundamental beliefs. For example, as noted earlier, it might suffice to judge a person's quality of life in terms of their success in satisfying Maslow's hierarchy of physiological and psychological needs[184] or it might be time to (say) rethink his concept of self-actualisation.

[182] Williams, B., 2006, *Philosophy as a Humanistic Discipline*, (A.W. Moore Ed.) Princeton UP, Princeton, Ch. 8
[183] http://plato.stanford.edu/entries/cosmopolitanism, Stanford Encyclopedia of Philosophy, (Accessed 26 Dec 2010)
[184] Maslow, A., 1968, *Toward a Psychology of Being*, Van Nostrand, New York

ECOHUMANISM: MY SUGGESTED RESPONSE TO GLOBAL OVERSHOOT

I have been advancing the idea that even if global overshoot were about to become widely recognised as a massive threat to average quality of life, world society would not have the social and cognitive technologies or the process knowledge to address this threat in a rational comprehensive manner. For a humanist, the best that could be hoped for would be a piecemeal response in which each virtual species, while acting primarily to protect its own quality of life, shows a degree of concern for the wellbeing of other virtual species.

But, beyond such a 'hope,' how might an individual, group, nation state, or other virtual species wanting to proactively improve global society's capacity to respond to the global problematique think and act? The suggestion I want to consider here is that such protagonists might choose to develop, promote and, as far as possible, within their sphere of influence, be guided by an ecohumanist philosophy or, if you prefer, belief system. Humanism is a philosophy which puts human progress at its centre, and *Ecohumanism* is a humanism which is *informed by an extended awareness of ecosphere processes*---call it *Ecawareness*---including both ecological and evolutionary processes.

For example, in the spirit of Ecohumanism, I have found it illuminating and a useful organising framework to view human history and pre-history as a pageant organised around the core ecological idea of a succession of interdependent (pseudo) species-populations and the core (cultural) evolutionary idea of selective retention (by virtual species) of (technological) variation. More generally, Ecawareness is a large idea, a world view, within which the universe's biological and pre-biological eras can be understood equally as well as its cultural era, e.g. trophic webs in biology are 'analogues' of economic systems in the cultural era.

Benefits of being Eco-aware

Whether an ecohumanist's focus and sphere of influence within the human ecosystem is local or global, he or she will try to understand what is happening in hir system of interest by, typically:

Identifying the main virtual species involved and how each is changing in terms of numbers, roles, material and energy use and acquisition, food supplies, technology mix, belief systems, quality of life. The task here may include the documentation of emerging and declining virtual species.

Identifying the main ecological interactions between virtual species (their niches), including, as well as conflictual relations, cooperative relations such as trade flows, joint institutions, and knowledge transfers.

Identifying processes in the focal system's parent platforms, both the social and bio-physical environments, which are affecting and being affected by virtual species activities, e.g. the anthropogenic hole in the ozone layer. This will include identifying interactions between these processes, and threatening-promising trends within them.

Identifying emerging and evolving technologies---material, social, cognitive, communicative---and their role in niche construction.

The example to hand is that this book's much-abridged story of the long slow rise of global overshoot has been written with the help of similar background guidelines. It is not being suggested that being eco-aware in this way automatically identifies the what-to-do behaviours that will best promote quality survival. Nor does it produce a canonical understanding of what is happening. What it does offer is an initial frame of reference and a common language (virtual species, platforms, social technologies etc.) which members of a virtual species can use for debating what-to-do/ how-to-intervene proposals and for moving towards a shared understanding of what is happening. More generally, having a heightened (eco) awareness of any complex system's components stands to improve one's *intuitive* capacity---all that one normally has---to make what-to-do choices in relation to that system.[185]

Identifying meta-problems

Especially when it extends back into the distant past, systematic Ecawareness can trigger and crystallise alternative perceptions of today's problems and opportunities. Thus, when writing the present history, it became apparent that the meta-problems of managing complexity and achieving cooperation and coordination have frequently blocked opportunities to improve quality of life or, worse, have reduced quality of life for sizeable numbers of people.

It can be suggested that, in the face of Global Overshoot, it is at least as important to find technologies for addressing these and other meta-problems---such as technological biteback, short-termism, parasitism, temporal myopia, pervasive deception, sequacity, etc.---as it is to manage the *proximate causes* of the Crisis (over-connection, over-depletion, overheating, overpopulation) and prepare for its consequences (depopulation, deurbanisation, deindustrialisation, decoupling). Indeed, it qualifies as a conceptual advance to perceive that a handful of meta-problems are the *root causes* of the Global Overshoot Crisis. Presently we will consider what might be done to overcome several of these.

Identifying issues which need to be widely debated

If Ecohumanists want their cosmopolitan philosophy and naturalistic world view to become more widely accepted as a valuable resource for managing global society, and they do, they have to be willing to constantly articulate, refine, question, debate and defend their views. Capitalist economics (more generally, economismic thinking) and, to a lesser extent, organised religion and nationalism are the dominant or privileged discourses in contemporary global society and it is with these that Ecohumanism must compete for influence over public policy. Perhaps *environmentalism*[186] too has become significant enough to be included here?

Most obviously, it is Ecohumanism's idea that *quality survival* should be an overarching goal for global society that needs to be closely examined and regularly re-examined.

[185] McKenzie, C., and James, .K., 2004, Aesthetics as an Aid to Understanding Complex Systems and Decision Judgement in Operating Complex Systems, *E:CO*, **6** (1-2), pp.32-39

[186] Environmentalism is the belief that an especially high priority should be placed on protecting ecosystems from direct and indirect disturbance by humans.

While there is no space to do so here, the quality-survival goal should be compared-contrasted with the broad social goals of the more privileged discourses. How should goals change with circumstances? At the next level down, debateable questions abound. Are simple, robust indicators of quality of life available? Should quality of life continue to be understood in terms of satisfying a hierarchy of needs? How does one balance quality of life today against quality of life tomorrow? How should one's understanding of quality of life change as society's issues of concern change? Earlier, a modest case was made for the claim that overshoot and declining quality of life are already realities and that, under the intertwined impact of several 'juggernaut' trends, a scenario in which global quality of life falls dramatically in coming decades becomes highly plausible. This was the reference scenario I used for exploring alternative perceptions of global overshoot and what should be done about it. However, while developed sufficiently for the purposes of this book, the implications of that reference scenario are so enormous that it needs to be questioned, challenged, re-worked and extended as competently and as fully as global society can manage. It is not that these efforts will reveal the future, rather that they will help us decide what to assume about it.

Shaping attitudes towards threatening trends

While it is doubtful if there are any 'laws of history,' viewing history and pre-history through the lens of Ecawareness does generate insights which, if more widely appreciated, might reconfigure conventional attitudes towards what is happening in global society today (attitudes are 'habitual ways of regarding issues'). Bernard Williams points out that the authority of such insights is vindicated or strengthened by the very fact that they have plausible step-by-step histories.[187]

Consider, as brief examples, the four juggernaut processes nominated as 'driving' global society towards a major self-reorganisation:

Population growth

History is crammed with examples of societies where, after a long period of growth, the population has crashed for one reason or another, bringing with it war, famine, disease and/or collapse of the social order. Surely it is up to those who read no threat to global society in present population growth to argue why 'things are different this time.'

Resource depletion

Another of eco-history's lessons is that humans commonly destroy the resource base on which they depend. Jared Diamond notes three situations in which human populations tend to wreak great damage on their environments:[188]

1. When people suddenly colonise an unfamiliar environment e.g. Maori destruction of megafauna in New Zealand, European settlers in Australia.

[187] Williams, B., 2006, *Philosophy as a Humanistic Discipline*, (A.W. Moore Ed.) Princeton UP, Princeton, Ch.16.
[188] Diamond, J.M., 1992, *The Third Chimpanzee: The Evolution and Future of the Human Animal*, Harper Collins, New York

2. When people advance along a new frontier (like the first peoples to reach America) and can move on when they have damaged the region behind.

3. When people acquire a new technology whose destructive power they have not had time to appreciate, e.g. New Guinea pigeon hunters with shotguns.

Societies come to rely on various renewable and non-renewable resources and when these run out, prove inadequate (e.g. for a growing population) or degrade faster than countervailing technologies can be developed, social reorganisation or disorganisation becomes inevitable. Particularly in arid and variable climates, deforestation, time and again, has led to soil erosion and the destruction of dams and terraces, e.g. in the classical Aegean civilization. As a rule of thumb, irrigation-based civilizations such as first arose in Egypt, Mesopotamia and the Indus Valley several thousand years BCE seldom last more than a few centuries before degrading the soil resource through salting and waterlogging. In general, it is intensification in resource use which leads to environmental depletion and, from there, to either sudden collapse of the cultural system or a shift to a new mode of production. Even when resource degradation has not been fatal, adjustment to it has usually been painful in quality-of-life terms for ordinary people.

Now we have the situation where global society has become highly dependent on a number of resources which are rapidly depleting or degrading or in shortening supply. Oil and arable land are the standout examples with rock phosphate, fresh water and marine fish stocks somewhat less so. Where Interventionists and Reconstructionists differ is on whether the human ecosystem is headed for reorganisation or disorganisation.

Global warming and after

In recent decades, historians have become increasingly aware of the recurring role played by environmental events (e.g. earthquakes, floods, droughts, tsunamis, cyclones and storms, volcanic eruptions) and transitions (e.g. climate change, sea level change) in guiding and channelling human history.[189] Earlier chapters provide many examples, most involving disruption of existing social organisation---migrations, invasions, dispersals---and some, like the Mt Toba eruption and the Holocene thawing having had world-wide (cf. regional) impacts on quality survival .

Now, the whole world is experiencing a period of rapid warming of unpredictable duration and magnitude. Environmental history allows us to see this in perspective. At one level, such an environmental transition is not unusual and humans will adapt to it as best they can---just as they will when, within the next few thousand years, another glacial age that will last 100 000 to perhaps 120 000 years will probably begin on Earth, reducing mean temperatures from current levels by as much as 10 deg C at times.

At another level, current global warming has the potential to be incredibly disruptive by historical standards. Most regions stand to be directly affected in terms of temperatures, rainfall, and storminess. Recent population growth means a billion people in coastal cities stand to be displaced as sea levels rise. The oceans stand to become stagnant biological

[189] Fagan, B.M., 2008, *The Great Warming: Climate Change and the Rise and Fall of Civilizations*, Bloomsbury, New York

deserts as they acidify and as circulatory flows slow. Note also that faster than anticipated warming will produce greater disruption than slower warming. Because most regions will be themselves disrupted, they are more likely to transmit disruption (e.g. uncontrolled emigration) rather than assistance to their distressed neighbours. This is what happened as a chain of societies collapsed across Eurasia in the late Bronze Age.

Unless something is to be done about them, the fact that global warming is being caused, to a greater or lesser extent, by humanity's greenhouse gas emissions is irrelevant. Nevertheless, if society's implicit strategy is adaptation, not mitigation, it will still be important to understand the trajectory of the warming process, and tracking emissions will be part of that.

Complexification

As noted earlier, Eric Chaisson has championed the useful idea that the complexity of a dissipative system is measured by its *free energy rate density*.[190] This is the extent to which, per gm of material in a system, the system is taking in and processing high quality (free) energy and excreting low quality energy (entropy). Consistent with the principle of maximum entropy production, he has further argued that the upper threshold of observable complexity has been rising since the beginning of the universe. For example, while stars have a free energy rate density of approximately 2 ergs per 0.1 gm per 0.1 sec, the figure for the human body is approximately 20 000 ergs per 0.1 gm per 0.1 sec.[191] Drawing the bulk of its energy supplies from the Earth's stock of non-renewable fossil fuels, the figure for a modern industrial ecosystem might be 20-30 times higher again.

The world-wide human ecosystem is continuing to become more complex as primary energy use rises. However, as fossil fuel supplies are drawn down, the system stands to spontaneously self-reorganise, in one way or another, to a multiplicity of simpler structures, e.g. with fewer links between nation states. Alternatively, if renewable energy sources come to be tapped in sufficient quantities, the system could retain its present complexity, or even self-reorganise to a higher level of complexity. Complex technologies (may) allow society to tap the large energy flows needed to maintain complexity!

PRACTICAL ECOHUMANISM

We now turn to a discussion of Ecohumanism as a source of *praxis*, a useful word meaning 'informed action.' It was suggested above that the Global Overshoot Crisis has proximate causes in the form of various juggernaut processes and root causes in the form of various meta-problems which are pervasive and which make the effective management of the juggernauts, singly or collectively, difficult in the extreme. Here, I present perspectives on two perennially intractable meta-problems, complexity and cooperation, and offer several exemplary guidelines, not for overcoming these, but for helping to better *cope* with them.

190 Chaisson, E., 2001, *Cosmic Evolution: The Rise of Complexity in Nature*, Harvard UP Cambridge Mass; Rees, M.J., 2003, *Our Final Century*, Heinemann, London
191 Chaisson, E., 2001, *ibid.,* p.139.

Some guidelines for coping with complexity

1. Acknowledging complexity

The first principle for guiding what-to-do decision-making in a complex world is to acknowledge that complexity and the need for complexity-sensitive thinking. Consider policy-making in the nation-state as an example. It has already been argued that all behaviour is more-or-less experimental (see p.84). So, when trying to solve a what-to-do problem rationally, a government must be routinely prepared to respond further as its actions prove inadequate for the problem as initially conceived. Things are nearly always more richly connected than is obvious.[192]

However, politicians in the developed world are locked into a convention that they should pretend to know with certainty how to respond to issues of concern (e.g. the juggernaut processes) and what the consequences of their confident policies will be. In adversarial societies, and that includes Western democracies, political conflict can enrich perceptions of issues, but the cost of coping with pretence and deceit is enormous. Seeking a balance here will be considered presently as an aspect of the virtual-species problem.

2. Deliberate experimentation

Once complexity and its uncertainties are acknowledged, a variety of other principles for improving decision-making under complexity emerge for consideration. One such is to explicitly treat each policy initiative as a deliberate (i.e. not unplanned) experiment, note its effects and, based on these, design a further policy experiment.[193] A refinement which might be possible sometimes would be to trial multiple policy 'treatments' simultaneously. There is a parallel here with the operation of natural selection on a genetically diverse population.

3. Monitoring societal change

Homeostasis (see p.27) is the ability of biological organisms (and ecosystems) to return to 'normal' functioning after being subjected to outside disturbance, e.g. regulation of body temperature. The effectiveness of homeostatic mechanisms depends on signals of environmental change (e.g. warming) being fed back rapidly from environment to organism, i.e.. via short unimpeded pathways.

In the same way, knowing what is happening in and to a human ecosystem as it is happening allows decision-makers to begin correcting problems before they get out of hand. If unemployment (e.g.) gets too high as measured (monitored), some countervailing action such as reducing interest rates can be taken even though the effects of such action cannot be accurately predicted. It is *monitoring* which then tells us if the countervailing action has worked or needs further adjustment.[194] To some degree, monitoring in real time can be thought of as compensating for humanity's limited ability

192 Levins, R., 2006, Strategies of Abstraction, *Biol Philos* **21**, pp.741-55
193 Walters, C., 1986, *Adaptive Management of Renewable Resources*, Macmillan, New York

194 de Groot, R.S., 1988, *Environmental Functions: An Analytical Framework for Integrating Environmental and Economic Assessment*, Workshop on Integrating Environmental and Economic Assessment, Canadian Environmental Assessment Research Council, Vancouver

to predict system behaviour. In practice, balancing the costs and benefits of developing monitoring programs will always be difficult.

As well as changing in response to outside disturbances (e.g. invasion), activity levels in human ecosystems, tend to go through *cycles* or *oscillations*, such being part of the 'normal' internal dynamics of any chaotic dissipative system. Many such cycles are the result of a time-lag between a causal trigger and its subsequent effect. For example, there is evidence that unemployment rates are driven by birth rates 15-20 years earlier.[195] Or, recall the earlier discussion of longer and shorter cycles of economic activity in mature economies (see p.**Error! Bookmark not defined.**). Without monitoring, the cyclical behaviour of socio-economic activity is unlikely to be understood and taken into account when deciding how to respond to change. The longer the period for which a socio-economic activity is monitored, the more valuable the accumulated data becomes in terms of being able to recognise if a recent downturn (say) in some indicator of interest is due to:

a downturn in a long-term trend

a downturn in a wavelike oscillation about that trend, or

a downturn in a (short-term) high-frequency fluctuation about an oscillation.[196]

4. Technology design and asssessment

New technologies are the raw material of eco-cultural evolution. Within a decision-maker's sphere of influence, problems and opportunities are putatively addressed by devising or collating a range of candidate technologies and selecting one for implementation. It is because so many technologies (material, social etc.) solve problems as intended, only to then 'bite back' and create new problems, that technology assessment and design should be an important part of coping with the uncertainties of managing contemporary socio-economic systems.[197] The guideline here is that technologies should be designed and 'pre-assessed' in a broader context than their immediate functionality.

When a society adopts a new technology, resources have to be diverted from other uses and, as well as the obvious beneficiaries, there will be those who, suffering from the disruption of the *status quo,* seek redress. But the bigger challenge in assessing a proposed technology is to foresee the ways in which the benefits of the technology might be eroded by the slow march of ancillary processes set in train by the new technology. For example, China's 'one child' policy, a social technology designed to slow population growth, has now led, after a generation, to problems of gender and demographic imbalance. Given our inability to develop formal predictive models of eco-cultural evolution, decision-makers can only rely on having an intuitive understanding of their focal systems to foresee strongly-lagged feedback effects and imagine how such might be

[195] Watt, K.F., 1992, *Taming the Future: A Revolutionary Breakthrough in Scientific Forecasting*, Contextured Web Press, Davis, California
[196] Watt, K.F., 1992, *ibid.*
[197] Tenner, E., 1996, *Why Things Bite Back: New Technology and the Revenge Effect*, Fourth Estate, London

circumvented. The more general advice here is to be aware that 'biteback' is widespread and to be looking for it.

5. Encouraging recycling and renewable energy technologies

In both human-free and simple human ecosystems (societies), materials tend to be used cyclically, passing from one use to another before returning to their original uses. Long-lasting ecosystems retain (hold within their boundaries) the materials (e.g. nutrients, substrate) on which their participants depend; or, at least, materials 'leak' from the ecosystem no faster than they are acquired from the parent system. Ecosystem participants (e.g. species, virtual species) are linked mutualistically (interdependently) through an intricate set of feedback relationships in which the well-being of any participant depends on the well-being of many other participants. These feedback loops, the so-called 'web of life,' are the paths over which materials are (re) cycled.

Under what conditions does recycling help a society cope with complexity? City ecosystems in particular recycle and re-use only a small fraction of their material inputs. Most becomes waste or dispersed pollutants. For example, many coastal cities lose most of their food-nutrient inputs offshore as sewage; petroleum is not recycled at all. If an input is abundant and readily acquired, the costs of establishing a recycling capability may well exceed the benefits, even including the external benefits of waste and pollution reduction. However, as pollutants accumulate or supplies dwindle, recycling, re-using and rationing of material inputs stand to become more attractive options. In terms of coping with complexity, these technologies extend the overshoot 'lead' time before disorganisation or reorganisation is rudely imposed on the society. This delay period can be used to develop and implement less problematic substitute technologies, paving the way for a minimally–disruptive reorganisation.

The 'unsustainable' use of fossil fuels associated with oil depletion and carbon dioxide pollution is the supreme example of our time. For more than a century, economic growth and the complexification of global society has been made possible, indeed 'subsidised,' by the ready availability of fossil fuels, notably oil, which have high *energy-profit ratios;* that is to say, a large quantity of usable energy in the form of oil can be captured by expending a small quantity of usable energy, e.g. drilling a hole. Renewable-energy technologies (solar, wind, hydro etc.) have much lower energy-profit ratios than fossil-energy technologies. While this greatly magnifies the rate of capital investment required to largely replace fossil-energy technologies with renewable-energy technologies over a period of a few decades, many Interventionists believe such to be possible and something to be encouraged.

6 Investing in resilience

Looking backwards, societies we think of as having been *resilient* or robust are those which pre-empted or recovered quickly from large and rapid falls in average quality of life (e.g. deaths, disabilities, diseases, hunger, fear) precipitated by large exogenous disturbances (such as floods, fires, droughts, invasions, epidemics); or, less often, internally-generated disturbances such as coups. In the Medieval Warm Period for example, comprehensively documented by Brian Fagan,[198] civilizations around the world

[198] Fagan, B.M., 2008, *ibid.*

survived repeated extended droughts before, resilience exhausted, most finally crumbled, e.g. the Mayans.

Can we judge the as-yet-untested resilience of contemporary global society, threatened as it is by the juggernauts of global overshoot---overpopulation, over-depletion, overheating and over-connectedness between social structures? My reference scenario postulates gross disorganisation of world society over coming decades, implying, not a resilient society, but a *brittle* or *fragile* one. In rejecting that scenario, Interventionists imagine that quality of life can and will be protected through the use of conventional collective instruments for coping with change in the stocks and flows associated with population, material resources, pollutants and trade, e.g. taxes-subsidies, cap-and-trade schemes and regulations.[199]

This may or may not be so. Our immediate interest is in whether complex dissipative systems have properties which suggest general strategies for making societies more resilient.[200] For example, as noted above, monitoring the advance of threatening change and designing forward-looking technologies are both approaches to countering the inherent unpredictability of such systems. Creating an educated, sociable society may be another (see below).

Unusually large oscillations in a society's activity levels may indicate that the society is near its homeostatic limits and at risk of disorganisation or reorganisation. Reducing current consumption to allow deliberate investment in (a) buffer stocks and (b) redundant pathways is a basic strategy for reducing that risk by, in effect, expanding the society's homeostatic limits. *Buffer stocks* of uncommitted capital (e.g. wheat stockpiles, American oil farms, stored vaccines) can be drawn down when supply chains are interrupted. Increasing resilience by investing in *redundancy* means building infrastructure which has spare capacity under normal operating conditions, e.g. power grids with alternative links and back-up generators; the Internet. Normal operating levels can then be maintained by calling on this spare capacity when other parts of the infrastructure complement fail or become unavailable in some way.

A brittle society is one where initial disturbances, rather than being buffered or diverted, spread rapidly, bringing widespread disorganisation. Such runaway change is more likely in societies where activities are connected in certain particular ways. For example, in strongly hierarchical societies where decisions flow down from a central authority, the inactivation or malfunction of the society's control centre, or its few communication links, can disrupt activities at all lower levels in the hierarchy. Or, more generally, societies where activities are grouped into a relatively small number of tightly-integrated sub-systems (hubs), each loosely linked to its neighbours, can be badly disrupted by disconnecting a single hub. In 2008, the global finance system proved to be such a hub in global society. Another source of brittleness is *long-chain dependency*, the situation where important activities can only be completed after a long chain of prior activities is first completed (see p.89), e.g. supplying component parts to the automobile industry.

[199] Cocks, D., 2003, *Deep Futures: Our Prospects for Survival*, University of New South Wales Press and McGill University Press, Sydney
[200] Walker, B.H., 2008, *Building Resilience: Embracing an Uncertain Future*, The Alfred Deakin Lectures, Deakin University.

Breaking any link disrupts all links. Conversely, modular societies, those organised into a large number of small but relatively self-sufficient sub-systems, only loosely connected, are more likely to prove resilient, e.g. tribal societies.

Note, finally, that investing in resilience always has an *opportunity cost*, one involving a trade-off between (a) saving the system from possible future failure and (b) foregoing beneficial output (e.g. immediate gains in quality of life) from the system in the short term.

7. Marginal incrementalism

The political scientist CE Lindblom has argued that very few situations can be changed other than marginally in democratic societies and that a philosophy of 'muddling through' by making frequent small changes in the `right' direction without particular reference to ultimate destinations is in fact an optimal strategy for managing society---not terribly effective but optimal.[201] Certainly better than deconstructing the system and having faith in 'market forces.' Recall that evolution works the same way. It must be accepted though that 'marginal incrementalism' is a slow business, not suited to tackling urgent problems such as global overshoot.

As part of 'muddling through,' intermediate goals themselves need to be regularly revised, even as progress towards those goals is being monitored. As noted earlier (see p. 84), many social problems are 'wicked' in not having any definitive formulation and it has to be accepted that ideas as to what is wanted from an intervention may well change as intervention proceeds. In the same vein, initial working goals should always be chosen from a sufficiently large pool of candidates.

8 Avoiding gridlock

It was suggested earlier (see p. **Error! Bookmark not defined.**) that human ecosystems which keep increasing in complexity as a consequence of processing more and more energy from the larger environment (e.g. an industrialising society) will, at some stage, begin to senesce or, metaphorically, to age. A senescent society is not necessarily brittle (subject to runaway change), but it will not be (as) resilient in face of large disturbances. Nor will it be (as) able to find ways of reorganising to improve quality of life significantly, e.g. Australia has great difficulty in changing its Constitution. These are the characteristics of a society entering *gridlock,* i.e. one where resources are increasingly unavailable for investing in either 'future-proofing' or progress. Causes can include the inertia of habitual behaviour, inertia from information overload and the self-interested locking-up of resources by elite virtual species, e.g. feudal estates.[202] As stock resources (e.g. accessible land) become scarcer in a growing society, existing activities have to be reduced to release resources for new activities. This may be difficult. *Pluralistic stagnation* (see page **Error! Bookmark not defined.**) is a form of gridlock found in mature societies where adversarial stakeholders with little concern for the public interest

[201] Lindblom, C.E., 1965, *The Intelligence of Democracy: Decision Making through Mutual Adjustment,* Free Press, New York, Ch.9

[202] Olson, M., 1982, *The Rise and Decline of Nations: Economic Growth, Stagflation and Social Rigidities*, Yale University Press, New Haven

continually nullify each other's attempts to improve their lot---even when the collective benefits exceed the collective costs. Pluralistic stagnation, so common in the politically stable societies of the developed world, is an excellent example of the virtual-species problem to be discussed below (see p. 143)

An increasingly senescent society can persist for generations in an unchallenging environment, but can the onset of senescence be delayed? Graeme Snooks argues that the rise and fall of societies is an outcome of their opportunistic development and exhaustion of the four dynamic strategies of family multiplication, conquest, commerce, and technological change.[203] In the present context, these are strategies for delaying senescence; they expand the availability of resources perceived to be limiting or, in the case of technological change, using a resource more efficiently makes it less limiting. In our globalised over-populated world it is technological change (the basis of economic growth) and trade which continue to be recognised---not explicitly as bulwarks against senescence, but as engines of 'progress.'

For societies which recognise and acknowledge that senescence and gridlock can happen, and which have the necessary cohesiveness and purpose, there exists a wealth of ideas that might be explored with the hope of delaying senescence. For example, societies can be kept simple by capping their energy use. This may confer the additional benefit of protecting long-term energy supplies. If an energy cap can be reduced slowly over time, it will allow the society to reorganise smoothly. And there are various ways in which the power of conservative elites to block adaptive change can be reduced, e.g. by strengthening democracy (see page **Error! Bookmark not defined.**).

While it is more difficult to coordinate strategic activities in a more modular society (e.g. one with strong local government), such organisation does allow resources to be re-assigned, module by module, without challenging the society's overall resilience. For example, sunset legislation (e.g. regular elections) allows a module to 'die,' in evolutionary terms, and to be 'reborn' without some of the shackles of previous arrangements. Given the implications for senescence, resilience, brittleness and adaptability (see below), balancing devolution and centralisation will always be a challenge.

9. Encouraging cultural diversity

A culturally diverse society is one which has a wide range of institutions and economic activities and a mixture of virtual species with a wide range of world views, occupations and lifestyles. For example, the coexistence of a broad range of political and religious opinions (John Rawls' 'reasonable pluralism'[204])) reflects diversity in a society's superstructure.

A diverse society stands to be more brittle than a theocratic or simple tribal society (see p. **Error! Bookmark not defined.**) but it is also more likely to generate policy ideas, not only for improving resilience, but, more proactively, for advancing mean quality of life. Just as genetic and trophic diversity allows biological systems (species, ecosystems) to

[203] Snooks, G.D., 1996, *The Dynamic Society: Exploring the Sources of. Global Change*, Routledge, New York
[204] Rawls, J.R., 1993, *Political Liberalism*, Columbia University Press, New York, p.134

survive and (pre) adapt to change, ideas and recipes for implementing ideas are the raw material of cultural evolution. It was suggested above that policy initiatives in complex societies be treated as experiments and that such need to be carefully designed to avoid unwelcome side-effects. It is around emergent ideas that such initiatives are constructed. If ideas are to emerge freely, it is particularly important that all individuals be supported (e.g. through the school system) in their efforts to develop their own individuality and, especially in a gridlocked society, helped to avoid being conformists. Radical ideas (e.g. questioning the value of prisons or of drug prohibitions) need to be properly debated, not dismissed.

Let us pause here on the grounds that space does not permit a fuller presentation of the many principles and on-ground options that societies might benefit from keeping in mind as they tackle what-to-do problems in a complex unpredictable world. We turn now to our second suggested root cause of the Overshoot Crisis, namely, the difficulty that groups of all sizes have in working cooperatively towards mutually beneficial ends.

Some guidelines for coping with the virtual-species problem

Recall that a (human) virtual species is a group of people who, mostly, interact cooperatively and who may sometimes have conflictual or competitive interactions with other virtual species (see p.**Error! Bookmark not defined.**). The concept is basic to understanding inter-and intra-group relationships---from war and class struggle to street gangs and 'partisan mutual adjustment'[205] in liberal democracies. Here, we will focus more on the virtual-species problem as it appears at the scale of the international community, namely, the problem of improving cooperation and reducing conflict within the existing system of nation states. We have in mind of course the Interventionists' goal of securing international cooperation in response to the perception of a Global Overshoot Crisis.

1. Towards a World Federation

From an Ecohumanist perspective, there can be no permanent answer to the question of how world society should be organised politically. Inevitably, as times change, so do political solutions. Nevertheless, the guideline suggesting itself here is that now is an appropriate time for moving towards a *World Federation* in which nations can both cooperate and develop individually.[206] Federation is a well-tried form of political union. The version being suggested here, like the Australian federation, leaves all responsibilities not specifically covered in the articles of association, to the individual state.

As noted earlier (see p.**Error! Bookmark not defined.**), it is difficult to envisage any scenario where a World Federation arises outside the platform of the United Nations. Despite being undemocratically controlled by Security Council members and their vassals in their own short-term interests, such a transformation is not inconceivable. It would probably have to start with another charter-making conference---San Francisco Two. Progress may also have to wait on prior federations in Europe, Africa and Latin

[205] Lindblom, C.E., 1965, *ibid.*
[206] Polanyi, K., 1944| 2001, *The Great Transformation: The Political and Economic Origins of our Time*, Beacon Press, Boston.

America. The magnitude of this task relative to the time that might be available before a contractionary bottleneck appears will seem unrealistic to many.

Membership of the World Federation would be open to any state accepting the UN's Universal Declaration of Human Rights, a remarkable document. Secession from the Federation would require a people's referendum to protect against self-serving leaders. Indeed, the people might need to be represented directly, as well as through their states, if the World Federation is to be seen as legitimate. Procedures for suspending states breaking the Federation's laws would have to be established, as would procedures for disadvantaging free riders. The massive funding required to run a World Federation would probably come in part from taxes on all international transactions including trade, capital and communications and in part from taxes on resource use (e.g. fossil energy, land clearing) and pollution (e.g. carbon emissions). International companies might be taxed on some mix of their profits, assets and dividends.

No state is going to act against its perceived national interest, so what would be the benefits of Federation membership? Given that the Federation's goal would be to seek quality survival there would be obvious immediate material benefits for disadvantaged third world countries pursuing modernisation. More broadly, the world's capacity to solve its trans-national problems (war, crime, pollution, trade, aid, migration, capital flows, espionage, terrorism, water flows…) would benefit from an enhanced sociality, stability and predictability in international relations.

2. War and conflict

To take a specific example, how might the World Federation move to reduce the scourges of war and armed conflict, destined as these are to worsen if the reference scenario eventuates? There may be 'just' wars but, given a goal of quality survival, the costs of war mostly outweigh any possible gains.

Let me start with a bright idea. Hazel Henderson includes a United Nations Security Insurance Agency in a list of desirable new global institutions.[207] Nations could buy insurance against potential aggression with premiums being used to fund peacekeeping and conflict-resolution contingents. Perhaps, to further boost the fund, those major powers that are heavily involved in arms sales and nuclear proliferation should be taxed on these activities. Other ideas with further potential to ameliorate the horrors of war include the International Criminal Court, disarmament negotiations and weapons conventions (e.g. banning anti-personnel mines). Community and international peace organisations should be given every encouragement. The prevention of war is a responsibility the world has to keep nibbling at on diverse fronts. The overarching guideline for preventing war and conflict is that the world, whether federated or not, should be run as a participatory and pluralist democracy.

[207] Henderson, H., 1998, Economics and Evolution: An Ethos for an Action Researcher, in Loye D (Ed) *The Evolutionary Outrider: The Impact of the Human Agent on Evolution*, Praeger, New York, pp.215–32

But what happens when conflict does appear? Traditional international relations models (e.g. Morgenthau and Thompson, 1985[208]) assume conflict (having incompatible goals) inevitably turns to war unless constrained by deterrence, i.e. the threat of deadly retaliation. Given the prevalence of war, it has to be assumed that deterrence is not applied sufficiently or that the theory is wrong and deterrence does not deter, e.g. Korea, Vietnam. The non-traditional view, my preference, is that inter-group conflicts can frequently be resolved without (further) deadly violence if the underlying frustrated needs of the conflicting virtual species can be teased out, through dialogue and if the parties then jointly search for political solutions satisfying both sets of needs.

Having said that, resource-based conflicts which are being driven by population growth do seem depressingly intractable. The conflict-resolution approach has some successes to its credit but, once spear–rattling, demonization, historical revisionism and counter-accusations have commenced, conflicting parties find it difficult to come together in this way. A period of violence seems, almost, to be first necessary. It may be that conflict-resolution methods will have to prove themselves at the domestic and community level (as is happening) before being accepted for use in international and 'tribal' conflicts. Nonetheless, conflict-resolution conferencing and dialoguing, conducted in secret, should be offered to all parties in actual or potential war situations.[209] The importance to a people of just having their group identity recognised by others cannot be over-emphasised.

3. Educating for sociality

As well as improving the political institutions and processes through which extant virtual species interact, there is a second broad approach to ameliorating the virtual-species problem. It is socio-psychological and centres on attempting to bring about widespread changes in people's attitudes towards others. Specifically, this is a strategy to develop societies in which *sociality* is high, i.e. where amicable relations between people predominate. In such societies, attitudes are *fraternal* or *sisterly*, meaning that people tend to regard others, even strangers, as their metaphorical brothers and sisters. Sociality is more than sociability. It implies social relationships marked by the expression of such behaviours as nurturing, fellowship goodwill, empathy, altruism, love, affection, concern, trust, agape, civility, collaboration, helpfulness, togetherness, belongingness, inclusiveness, mutualism, cohesion, loyalty and solidarity. Sociality can be contrasted with *sociopathy*, a set of attitudes under which most people tend to regard others as enemies to be mistrusted and exploited. Tribalism, territoriality and hostility-indifference to others characterise sociopathy.

Sociality is important for two reasons. In a society where sociality is the norm, many of the individual's higher needs which have to be met if a quality life is to be achieved will, to some extent, be automatically satisfied, including the needs for safety, security, belongingness and affection, esteem, respect and self-respect. The second importance of sociality is that it is indicative of a cooperative society, meaning one in which people

[208] Morgenthau, H., and Thompson, K.W., 1985, *Politics Among Nations: The Struggle for Power and Peace*, 6th edn, McGraw Hill, New York

[209] Burton, J.W.,1996, *Conflict Resolution: Its Language and Processes*, Scarecrow, London

easily and readily come together to exploit the synergies of collective action (see p.**Error! Bookmark not defined.**). More than that, a civilised society which has learned the benefits of amicable relations among its own interest groups will be open to extending these local attitudes to relations with other societies.

At this point, the practical question is whether sociality can be taught and learned. Both sociality and sociopathy have their roots in the behaviour of our hunter-gatherer forebears who evolved instinctive and useful appetencies for cooperation within the group and for hostility towards outsiders (see p.**Error! Bookmark not defined.**). It needs to be recognised that both appetencies still exist even though, apart from a limited role in stimulating social criticism and as an indicator of unmet needs, sociopathy has no apparent function in a complex society. Human behaviour is very malleable and children can be brought up to hate or to be fraternal-sisterly and cooperative. For example, children in lightly-supervised playgroups teach each other cooperation. Such socialisation is easy in a society which is already fraternal-sisterly simply because most behaviour is imitative. People treat each other much as they themselves have been treated. However, under conditions of stress, insecurity, crisis and declining expectations, sociality tends to be replaced by sociopathy. Along with meliorating those imposts, as part of restoring people's quality-of-life prospects, sociality has to be actively nurtured by teaching and example.

Experiential learning is one social technology with an important role to play in blurring the boundaries between virtual species. Children and young adults who are helped to spend time living outside their own societies (e.g. studying abroad) are more likely to recognise the essential similarity of peoples from different cultures. Familiarity breeds acceptance and, in conflict situations, perhaps empathy and respect for the other's position. By the same token, given the importance to sociality of being able to trust that one is not being deceived, educating people to understand and detect deceit would also seem to be a guideline for building or rebuilding sociality (see p.**Error! Bookmark not defined.**).

4.Constraining elites

History shows, in almost every society, that once elite groups have obtained control of energy surpluses and the social and economic privileges these support, they are loath to return to a society offering a more equitable distribution of life opportunities (see p.**Error! Bookmark not defined.**). And to the extent that the majority accept this order of things there is no 'virtual-species problem.' In modern democratic societies, persuasion, not coercion, is the instrument that elites use to maintain their position. This is done by controlling the institutions which reproduce the thought patterns of the state, namely the education system, the media, the churches and government itself.

To the extent that the majority are unhappily conscious of this imbalance, political democracy remains their most promising social technology for achieving change. What they need to first realise is that democracy itself is a generic instrument which can be used to support the search for and adoption of diverse social technologies which further improve democracy as a change instrument, e.g. through the elimination of privilege, the management of populism.

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The body of social technologies which may have a part to play in reducing the uncertainties caused by complexity and pervasive disagreement has only been touched on here. Also, it would be quite wrong to suggest that those mentioned are uniquely the products of an Ecohumanist perspective. The point remains though that this perspective is a promising source of ideas for overcoming the root problems that impede attempts to address the more proximate causes of global overshoot. We move on to asking if the Ecohumanist's story of the origins of global overshoot offers appropriate emotional inspiration to a global society facing the possibility of massive disorganisation.

BUT IS IT EMOTIONALLY SATISFYING?

In this Chapter, I have so far argued that Ecohumanism---a mixture of a story, a philosophy and a belief system---is a doctrine which people may find useful for rationally understanding how and why the human ecosystem has changed historically, is changing now and might presently change. Also, the Chapter is intended to illustrate that Ecohumanism contains sufficient ideas to spawn guidelines for better managing the processes that are driving changes in global quality of life.

But, beyond these virtues---praxis and factual understanding---we now ask if people will be *emotionally* inclined to accept Ecohumanism as a platform from which to contemplate the possibility of global overshoot. More specifically, does the ecohumanist's *Story of Global Overshoot* have qualities which are more rather than less likely to evoke positive emotional reactions in those exposed to it? This is important. Recall (see p.**Error! Bookmark not defined.**) that it is (only) ideas carrying a positive emotional tag which get accepted as input into decision-making processes. For example, is Ecohumanism likely to appeal to post-modern people, attuned to making their way in an individualistic marketised society? Can one be an ecohumanist while remaining loyal to one's ethnic, political, national, ideological, religious etc. virtual species? Will a fear that global society is about to be overwhelmed by multiple problems prompt people to look beyond their existing belief systems?

While people cannot be reasoned into switching from one belief system to another, and encouraging that is not my intention, I will recapitulate some elements of Ecohumanism which I believe are more likely, on balance, to evoke positive rather than negative emotions:

To start, Ecohumanism is a narrative for all humanity. No-one is excluded. It emphasises that we are all members of one species, the product of one continuous evolutionary process extending back to the beginning of the universe.[210] Science has demonstrated that physiognomic and physiological differences between peoples rest on minor genetic differences. From there, it is a small step to accepting that strangers have minds like one's own and, notwithstanding cultural differences, needs like one's own. Strangers lose their strangeness. For many people, once this common biological inheritance is accepted, the inherent concern they have for the wellbeing of their immediate relatives expands to embrace the species as a whole; and that is the humanist perspective.

[210] Christian, D., 2003, World History in Context, *Journal of World History*, **14**(4), pp.437-458

Ecohumanism recognises that any group of people living in a particular place for generations will evolve a place-specific culture which helps the group to persist; and that if the group is transplanted it will, to a greater or lesser extent, take its culture with it. Notwithstanding, when its environment changes, a culture can only evolve at a rate which does not destroy its overall coherence. Recognising the origins of cultural differences does not automatically preclude conflict and tension when cultures intermingle. But it may help. That is, knowledge offers an alternative to knee-jerk hostility.

Ecohumanism finds no need for a belief in the supernatural. Much that puzzled our pre-Enlightenment forebears can now be explained scientifically, while remaining puzzles such as biogenesis and the pre-universe are being slowly clarified. Religious beliefs in interventionist gods are best viewed as elaborations of the primitive animistic belief that everything is alive (see p **Error! Bookmark not defined.**). Such religions are social technologies which, *inter alia*, help people satisfy their need for meaning, for a model of the world. While Ecohumanism is not a religion, it is a 'spiritual' doctrine in the sense that understanding how the world and its people evolved is a precursor to feeling 'at home in the universe' and 'at home with humanity.'

Ecohumanism offers the individual the existential challenge of being responsible for hir own morality. Viewed as a moral philosophy, Ecohumanism suggests *quality survival* as an overarching goal for global society and hence as a broad criterion for guiding social and individual choices. Beyond that broad criterion, Ecohumanism is situational and pragmatic rather than prescriptive. For example, faced with multiple candidate interventions for addressing Global Overshoot, the ecohumanist does hir intuitive, aesthetic best to choose the one offering most in quality survival terms.

In inter-personal relations, the ethic which flows naturally from the Ecohumanist perspective is present already, in one way or another, in all the world's major religions, both theistic (e.g. Islam, Judaism, Christianity) and non-theistic(e.g. Buddhism, Confucianism, Taoism). Because every person's quality of life is equally important, because every person has an equal right to happiness, humans must take loving responsibility for the wellbeing of others.[211] The 'golden rule' or 'ethic of reciprocity' against which one's actions can be checked has been expressed in startlingly similar terms in a score of religions.[212] While Ecohumanism has no place for mythical and supernatural figures, it recognises educational and inspirational value in the stories of great human beings such as Mohandas Gandhi, Nelson Mandela, William Wilberforce and Paul Robeson. While Ecohumanism is not an optimistic doctrine *per se*, it recognises that optimistic individuals are often more successful than pessimists in finding solutions to problems..

Ecohumanism is an expanding and adaptive doctrine, not rigid. It is built around a revelatory and ever-richer story of an evolving cosmos. In the spirit of science, all its 'truths' are provisional and open to question. Notwithstanding, the authority of those 'truths' is strengthened by both their long intellectual history and a knowledge of their

211 Clark, M.E., 2002, *In Search of Human Nature* , Routledge, London, p.298
212 http://www.religioustolerance.org/reciproc.htm (Accessed 31 Oct 2009)

bio-physical evolutionary history.[213] Inescapably though, it takes curiosity, time, effort and opportunity to become eco-aware.

Ecohumanism is an honest doctrine, unbeholden to the interests of any particular virtual species. It tries to listen to and understand all points of view. It does not pretend to knowledge or authority it does not have. But it gives no credence to implausible hopes such as life after death or, indeed, implausible threats such as judgement day and eternal Hell.

Nevertheless, Ecohumanism recognises that fear of the future, particularly death, is a powerful, universal emotion and identifies insights which might help people accept their fear and not be paralysed by it. As Rilke's Duino Elegy muses (see Preface) muses, it is knowledge of death that makes life so precious. As individuals and as a species, we have emerged from a cosmic process and will be reabsorbed by it. Without the metaphorical 'deaths' of anti-matter and exploding 'furnace' stars, there would be no Planet Earth today. Without the deaths of innumerable plants in the Carboniferous era, there would be no oil to energise global society. In the economy, it is the deaths of old enterprises which unlock resources for the creation of new enterprises. In a finite world, it is human death which allows cultures and genomes to evolve. In general, death can be seen as a creative 'technology' which makes evolution---the selective retention of variation---possible.

Ecohumanism is non-judgemental. A simple but rich way of looking at people is to see them, whether by virtual species or individually, as rational agents, busily devising new technologies and applying received technologies (material, social, cognitive, communicative) to the end of meeting a spectrum of needs. People make their rational choices from sets of possibilities which are constrained in numerous ways, including being constrained by their values, their present technologies, their beliefs and their cognitive skills.(see pp.**Error! Bookmark not defined.**, 83). It is commonplace, but usually unproductive, to judge past behaviours from contemporary perspectives, e.g. as noble, altruistic, immoral, stupid, short-sighted etc.[214] Indeed, I am inclined to accept the argument of Jaynes and others that humans, prior to the first millennium BCE, did not experience consciousness as we understand it (see p.**Error! Bookmark not defined.**).

Ecohumanism has few illusions about the status of *Homo sapiens*. It should not need saying, but, given our appetency for self-deception (see p.**Error! Bookmark not defined.**), we may need to remind ourselves that we are not lords of the universe, destined for endless progress. Nor are we participants in some Manichean drama, fighting to secure the ultimate victory of good over evil. At this stage in our history we are more like impulsive adolescents, with limited foresight and self-discipline; notwithstanding, we are unlikely to wipe ourselves out yet awhile. We have been lucky in two important ways. One is with pre-adaptations, particularly the adaptations we brought with us when moving from a forest habitat to a savanna habitat (see p.**Error! Bookmark not defined.**). The other is that while the environment is always changing and threatening extinction, it has never changed fast enough to overwhelm our capacity to adapt.

[213] Williams, B., 2006, *Philosophy as a Humanistic Discipline*, (A.W. Moore Ed.) Princeton UP, Princeton
[214] Yardley, J., 2008, Review in *Washington Post* (16 Mar) of Wood, G.S., 2008, *The Purpose of the Past: Reflections on the Uses of History*, Penguin, New York

I have found the metaphor of the species as an individual, slowly learning to make the best of the finite life he or she has been granted, to be one which many people regard as illuminating and satisfying.

TAMAM SHUD: IT IS FINISHED

This book started with a perception that, in terms of people's quality-of-life prospects, the future of global society has become much more uncertain in recent years. While the data which might show average quality of life to be falling is inconclusive, the world is certainly being impacted by a number of accumulative processes which, considered jointly, give a degree of plausibility to a *Global Overshoot* scenario, meaning a scenario in which global quality of life falls dramatically in coming decades. This 'dark age' scenario, dégringolade, became the proposition from which I postulated three alternative perceptions of global overshoot processes and what should be done about them, viz.:

Not plausible at this time, not to the point of requiring pre-emptive action (Empiricists).

Plausible if ignored, but likely to be managed to the point of having a low impact on global quality of life (Immediate Interventionists).

Plausible, but unmanageable in any comprehensive way; better to focus on post-bottleneck recovery measures (Reconstructionists).

So, based on this span of reactions to the reference scenario, we have an emerging Global Overshoot Crisis which could have severe or mild or even insignificant consequences. My own working hypothesis, a provisional diagnosis perhaps, but increasingly supported as I have conceptualised and filled out my understanding of the deep origins of this Crisis, is that, for good reasons, something like the reference scenario will play out in coming decades.

Let me recapitulate those reasons. Humans, endowed as they are with a talent for technological innovation, have created a highly connected global society, a dissipative system which requires massive and increasing quantities of exogenous energy, and other inputs, to maintain it and to support its ongoing complexification. Should the normal operations of this system change rapidly (over several decades, say) and extensively, many people's lives will be disrupted and global quality of life may, likewise, fall rapidly.

In particular, if the four juggernaut processes I have nominated do not slow of their own accord, or are not mitigated in some way, they stand, singly and interactively, to trigger waves of rapid reorganisation in global society. Simple eco-aware reasoning is enough to produce plausible scenarios of how population growth, resource depletion, global warming and linkage proliferation might overwhelm global society's capacity to absorb change without disintegrating (see p.88). Conversely, I cannot find plausible scenarios which suggest that these proximate causes of the Global Overshoot Crisis might slow of their own accord (e.g. through value shifts) in coming decades or how they might be defused by purposive human action on a sufficiently large scale.

Why not? Didn't the Interventionist response to the reference scenario (see p.105) envisages a range of measures that global society could take to ameliorate/adapt to the proximate causes of the Crisis? Some such have already been implemented, albeit in a limited and piecemeal way, by governments and other virtual species. But, like the Reconstructionists, I see little evidence that global society has the cognitive ability or the knowledge base to devise promising solutions to such large what-to-do problems or to forge the required cooperation between the world's virtual species, particularly its nation states. I suggest that these two problems, managing cooperation and complexity, be viewed as root causes of the Crisis in that they are stopping its proximate causes from being successfully addressed---just as both are partly responsible for the development of those problematic trends in the first place.

This is an important conclusion. The implication for Interventionists is that developing social and other technologies for managing cooperation and complexity is at least as important as developing material and social technologies for slowing or reversing the momentous trends threatening global quality of life and, in the long term, quality survival. And Reconstructionists too need to be aware that unless humans can make considerable progress here, the post-bottleneck world they think we should be preparing for will once again begin creeping towards the next Overshoot Crisis.

Here then is my framework for thinking about the world's converging problems---a jostling set of hard-to-manage processes and lurking meta-problems which are threatening global society with massive disorganisation in coming decades. I recognise 'Wait-and-see' Empiricism, 'Noah's Ark' Reconstructionism and 'Stop fiddling' Interventionism as three 'not unreasonable' what-to-do responses to the suggestion of a dystopic future. While my own inclination is towards Reconstructionism, I do not think it can be argued that one of these is 'right' and the others 'wrong.'

However, while I find myself unable to recommend any step-by-step program for confronting the Overshoot threat, I am keen to see the global community continuing to search for and experiment with ways of avoiding a sharp drop in average quality of life;[215] or preparing for recovery from any such drop. Also, if Empiricists are not concerned as yet about falling quality of life, they always have the obverse option of working to raise global quality of life above current levels.

While this book has nothing to offer those who hate or those who have found the truth, the tool it is offering people of goodwill who want to think constructively about the world's converging problems is Ecohumanism, packaging it, metaphorically, as 'lodestar with travel-guide.'

Ecohumanism is a lodestar, a 'light on the hill,' in that it offers a reference point against which ongoing what-to-do decisions and choices can be checked, i.e. for which present and future groups, what are the quality of life implications of this choice?

When you arrive in a strange country, having a travel-guide allows you to understand what is happening around you, at various time-space scales, and how what you are seeing

[215] For example, Buzaglo, J., Global Commons and Common Sense, *Real-world Economics Review,* No. 51 (http://www.paecon.net/PAEReview/issue51/Buzaglo51.pdf (Accessed 2 Dec 2009)

got to be the way it is. It describes how the locals customarily behave and think. It suggests what-to-do activities, along with places to perhaps avoid. In more general terms, a good travel-guide primes your imagination with enough ideas to flesh out your mental model for an itinerary and, as required, provide a string of intuitively-generated what-to-do suggestions.

The Ecohumanist's 'travel-guide' to the 'strange country' which is the Global Overshoot Crisis is, similarly, suggestive-but-not-prescriptive. The story of this Crisis is the story of the human ecosystem, interpreted here as the working out of complex evolutionary and ecological processes going back to the beginning of the universe. Ecohumanism suggests that this story can contribute to humanity's short-term quality of life prospects and long-term-quality survival prospects in a variety of ways. At the risk of underplaying others, let me finish by recapitulating several of these contributions that I consider to be particularly important:

Ecohumanism provides a way of talking and thinking about the origins and tractability of the world's converging problems. It offers some hope that while we are confronted with problems we don't as yet know how to solve, we will, barring overwhelming setbacks, continue to mature in our ability to provide ever-more people, now and into the indefinite future with the opportunity to lead satisfying lives. But progress could be intermittent and glacially slow. For the Ecohumanist, it is Ecawareness, the coherent exposition of evolutionary and ecological relationships, which gives meaning to the world, i.e. confers a feeling of knowing what is happening, what has been happening and why things are the way they are.

Ecohumanism recognises that there is an inescapable need for intuitive judgement in the management of complex systems. To this end, it yields insights and guidelines for improving such judgements, e.g. guidelines for better managing the proximate and root causes of the Global Overshoot Crisis. At very least, these become opening theses for dialectic discussion.

Ecohumanism stands to strengthen and expand people's feelings of belonging to one human family; and their sense of identity---what it means to be human and a human. As individuals and as a species, humans are going through life cycles. We have evolved to a level of consciousness and understanding which can recognise that while life may be short or long, fulfilling or cruel, there is much that we can do to make it better than it would otherwise be, for ourselves and for others.

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