Chapter 3

Sustainability as Contingent Balance between Opposing though Interdependent tendencies; A Process Approach to Progress and Evolution

Edmond Byrne

Sustainability is a property of the complex system of which our species is only a part. We have come to know a great deal about that system, but still understand little about it. All of these ranking systems come from our knowledge, but fail to represent the kind of understanding critical to guiding our actions in such a way as not to undermine the security and coherence of the system. The more we try to expand and rely on our knowledge, the farther from understanding we tend to go. Such is the fundamental context of our modern age where science rules the roost.

John Ehrenfeld (2009)

Introduction

Popular conceptions of sustainability typically envisage it in terms of competing or overlapping requirements of respective economic, social and ecological domains. Representational models of sustainability therefore incorporate these domains for example, by the intersection of three interlocking circles, or as an entablature which rests on three supporting pillars, or in terms of the rather more nebulous accountancy inspired concept of 'triple bottom line'. None of these abstractions recognise the presence of physical limits which define a finite world inhabited by an increasingly globalized human society. As Herman Daly (1992, p.225) put it: 'The economics of an empty world with hungry people is different from the economics of a full world, even when many do not yet have the full stomachs, full houses, and full garages of the "advanced" minority'. Thus if sustainability is to be envisaged in human terms using these respective domains, then only the concentric circles model, with the outermost circle representing fixed (hence finite) environmental and ecological limits, within which human society must operate, and within which again the economy exists, is the only physically or scientifically plausible one.

The popularity of the aforementioned representations do however present an insight into the worldviews and values which underpin them. While they provide a nod in the direction of unsustainability in recognising that there is, or may be a problem, they do this only in a way that can at best facilitate a *reduction* in unsustainable practices while maintaining the continuation of 'business as usual', as opposed to encouraging the mobilisation of any radical or transformative change. In envisaging the three domains as essentially *separate* orthogonal dimensions, this allows for any amount of wriggle room and a concurrent shifting the burden between domains in the guise of 'externalities', that is, non-economic entities whose values are inherently normative and are subject to arbitrary weightings to suit the occasion/framer. Such narratives represent a dangerous delusion; acting as soothing lullabies aimed at drowning out the background cacophony of unsustainability. They thus 'do not constitute genuine accounts of sustainability, but powerful fictions; fairy tales to help the children sleep at night.' (Gray, 2010, p.50).

Nevertheless such narratives constitute the dominant conception of sustainability, or of sustainable development concepts which, in this context are often conflated. Dominant models of sustainability remain not just subservient to the imperative of growth inherent in the dominant model of economics which pervades our ever more globalized world, but help promote and maintain it. In practice, this entails that people are *always* encouraged to consume more. This is regardless of whether they might go for the 'ready-to-consume guilt-free sustainability imbued best-in-class' product or choose a 'sustainability free' option, or elect for something in between. The market, framed in this manner, caters for all consumer tastes! In reality it is this growth necessitating model of economic reality that is in fact striving to be sustained, above all else.

An analogy might be drawn with Angela McRobbie's conception of how feminism has been 'taken into account' in contemporary twenty-first century culture and society. This has been promoted in the name of 'modernisation', she contends, and manifests itself as a 'new hyper-visible feminine consumer culture' (McRobbie, 2009, p.26), a 'liberal, equal opportunities feminism' (p.12) centred around 'career success, glamour and sexuality' (p.28). This however has occurred as part of a process McRobbie suggests, which has disarticulated feminism, so that it is expected to conform to an 'unaltered social order', and certainly has no purpose in being a 'radical feminism concerned with social criticism' (p.14). The result is an unthreateningly disempowered ideology which can readily align with, and indeed support, the implied freedoms of market driven consumerism. In this way, feminism in contemporary culture, she argues, is accordingly both 'at some level transformed into a form of Gramscian commonsense, while also fiercely repudiated, indeed almost hated' (p.6). Essentially what passes for feminism McRobbie argues, could be characterized as 'post-feminist individualism', an ideology characterized by an 'aggressive individualism' and an 'obsession with consumer culture' (p.5), and thus primarily oriented towards serving the global imperative for growth based consumerism. Thus instead of feminist politics we have a politics of the feminine, a depoliticized, deradicalized conception of gender equality.

A similar critique can and has been applied to dominant conceptions of sustainability and sustainable development. On dominant conceptions of 'corporate sustainability', Ehrenfeld and Hoffman (2013, p.53) propose that:

> *No matter how many times someone talks about what they are doing for sustainability – using green, sustainable, or sustainability to describe a product or new program to inform their customers – they are still in the world of BAAU [Business Almost As Usual]. It is different from BAU, but it is not the kind of paradigmatic or transformational shift that is necessary to address health, well-being, community building, interconnectedness, and all the other parts of the vision of sustainability-as-flourishing.*

The current chapter strives to frame sustainability in a way which coheres with reality in a way that it is not just 'taken into account' within the dominant narrative, but that it actually challenges this narrative and hence facilitates the transformational change required in the wake of contemporary global and societal meta-challenges. It will seek to demonstrate that a *process* informed approach to progress and sustainability is required, one encapsulating a transdisciplinary approach and ethos, as a prerequisite for addressing issues emanating from an unsustainable societal construct.

A Paradigm of Reduction and Separation

John Ehrenfeld would claim that dominant narratives around sustainability simply use (and abuse) the concept in a way that has nothing to do with the promotion of flourishing but everything to do with increasing material consumption and looking after the financial bottom line: 'the way they advertise and publicise their [green] programs lulls the public into believing that the firms are taking care of the future. … [but] almost everything being done in the name of sustainability entails attempts to reduce unsustainability. But reducing unsustainability, although critical, does not and will not create sustainability.' (Ehrenfeld and Hoffman, 2013, p.53). 'Reducing unsustainability' here manifests itself as the concept of 'sustainable development', resulting in projects aimed at eco-efficiency, which in turn only serve to drive further consumption and growth, and hence in and of itself, like the quick fix of an addict, it is an approach which can never hope to wean society off its unsustainable habit of growth based consumerism.

Dominant models and conceptions of sustainability emanate from and cohere with the dominant societal paradigm. This is the modern neo-Cartesian paradigm which has obtained and developed over the past four centuries or so. 'Paradigm' here is considered after that described in Thomas Kuhn's seminal work on the *'Structure of Scientific Revolutions'* (Kuhn, [1996] 1962). Kuhn describes paradigms in terms of scientific understandings, whereby periods of 'normal science' characterized by prolonged periods of consolidation through 'puzzle solving' are ultimately superseded by emerging anomalies and discontinuities which eventually lead to crisis. This leads to questioning on the margins of science and ultimately to a gestation period for a new paradigm (a 'pre-paradigm period'), which eventually supersedes the old and by now discredited paradigm 'by a relatively sudden and unstructured event like the gestalt switch', oftentimes through 'flashes of intuition' having reached a certain tipping point (Kuhn, 1996 [1962], p.123). Henceforth this new conception of the world around will be (to the scientist) utterly transformed, 'seem[ing], here and there, incommensurable with the one he had inhabited before.' (Kuhn, 1996 [1962], p.112). In the context presented here, paradigm is taken in the broadest socio-cultural-scientific domain (as opposed to for example, a narrower focus on say, physicists' historically different (paradigm shifting) conceptions of the atom) and is taken to incorporate what Edgar Morin has called respectively the 'old paradigm of disjunction/reduction/simplification' (Morin, 2008, p.29) (i.e. the characteristic neo-Cartesian paradigm of modernity) and an emerging paradigm of 'complex thought' (Morin, 2008, p.5).

The current dominant (though increasingly threadbare) neo-Cartesian paradigm of reduction and separation would reduce the concept of sustainability to *separate* domains of environment, society and economy, and envisage that they can each be dealt with as part of a larger *reductive* zero sum game where overspills from one domain can be conveniently accounted for as quantifiable 'externalities'. This exercise in atomism, a key axiom of the underlying metaphysic, is thus envisaged as a 'value free' endeavour, stripped of normativity, whereby an ethical domain can neither be envisaged nor accommodated. This is primarily due to another key paradigmatic axiom, that of reversibility, and in reversible systems directionality is impossible[1]. Everything therefore is replacable, nothing is sacred. It is similarly assumed that 'all else is equal', using this as a mechanism to simplify complexities and effectively 'bracket' the social (and its accompanying baggage of *values*). The result is a belief in ever increased efficiency as a quick fix, but when the recursive consequences of complex, iterative (and ever) evolving systems inevitably emerge, we simply label these 'unintended consequences'. The dominant conception of 'sustainability' is thus aligned with the dominant conception of 'progress'. Sustainability and progress, thus viewed through the lens of the reductionist paradigm of modernity represent the ultimate (ideal) destination on a directed linear causal (deterministic) path. The journey along this path is fuelled by the ideologies inherent in reductionist science, including blind faith in efficiency, the suppression of risk and uncertainty, positivistic and materialistic conceptions of science and reality, and a hopeless techno-optimism.

Thus when Ehrenfeld speaks of 'science' in the opening quotation what he actually means is 'reductionist science'. By this doctrine, the broader scientific reality, import and paradigm shifting implications of the likes of the second law of thermodynamics (Prigogine

[1] With thanks to Robert Ulanowicz for pointing this out.

and Stengers, 1984), or the radical implications of the uncertainty principle and other developments in quantum physics (Heisenberg, 1927) are either conveniently ignored or implicitly rejected. So too is the Gödelian uncovering of incompleteness/unprovability in logic (Gödel, 1931) and hence of irreducible uncertainty, and the double edged nature of technology, including its inherent increased propensity for disruption and vulnerability (Naughton, 2012, 2014; Hommels, Mesman and Bijker, 2014). Essentially our modernistic goal of controlling the uncontrollable only serves to exacerbate the problems we have created, or as Ehrenfeld (2008, p.20) put it: 'The root cause of unsustainability is that we are trying to solve all the apparent problems of the world, large and small, by using the modernistic frame of thinking and acting that has created the metaproblem of unsustainability'.

So how then might sustainability be best conceived if we are to venture beyond reductionism and embrace what Morin would call a 'paradigm of complexity' (Morin, 2005, p.6)? Again Ehrenfeld steps into the breach and proposes a definition which envisages sustainability in qualitative terms as an emergent system property. If the term 'sustainability' invites the question around what it is that one is hoping to sustain, he proposes in response the property of 'flourishing': an emergent and 'dynamic quality changing as its context changes' (Ehrenfeld and Hoffman, 2013, p.17). Sustainability therefore can be expressed as 'the possibility that humans and other life will flourish on the planet forever.' (Ehrenfeld, 2008, p.6). 'Flourishing', in this context is defined as 'the realization of a sense of completeness, independent of our immediate material context'; it is 'the result of acting out of *caring* for oneself, other human beings, the rest of the "real, material" world, and also for the out-of-the-world, that is, the spiritual or transcendental world' (Ehrenfeld and Hoffman, 2013, p.17) (italics added).

This conception of sustainability (or 'sustainability-as-flourishing') firmly (and deliberately) places it beyond the reach of reductive quantitative definition and instead within the realm of values, ethics and philosophical discussion, an entity built 'not just on technological and material development, but also on cultural, personal and spiritual growth' (Ehrenfeld and Hoffman, 2013, p.7). How does this sit ontologically with contemporary scientific conceptions of reality? Well, quite comfortably in fact, once one recognises a complexity informed conception of science which extends beyond a narrow reductionist materialism.

Sustainability and Complexity; Contingent Conceptions

Some key questions remain outstanding though: If sustainability, as a property of complex (economic/social/environmental) holarchic systems, on a relatively small and finite planet of which humankind is only a part, cannot be reduced to and optimized in terms of a hard quantity or metric, how then can it be conceived? Moreover, how can it be done on a sound scientific as well as a theoretical/philosophical basis?

Advances in science posited within a complexity framework have proved highly instructive in this regard. While in classical Greece, Heraclitus could conceive of the contingent, unique and ever changing *'process'* nature of reality, bounded by necessary opposite tendencies, as described by his observation Πάντα ῥεῖ (panta rhei): 'everything (continually) flows', a good many scientists, philosophers and philosophies throughout the ages since have largely subscribed to this framing of reality ahead of the neo-Cartesian antagonistic dualistic worldview, which would by contrast envisage progress as a linear directed pathway by modern humans towards the type of certainty and control achievable by a traditional, remote (controlling) puppeteer-like God: 'as soon as I had acquired some general notions respecting physics … for by them I perceived it to be possible to arrive at knowledge highly useful in life … and thus render ourselves the lords and possessors of nature.' (Descartes, 1638).

Proponents of the process view include 16th century French humanist philosopher Michel de Montaigne who (with more than a hint of prescient postmodernism) is said to have suggested that the only thing certain is nothing is certain. This reflected the thinking in an era of general prosperity across Europe which Toulmin (1990, p.25) describes as representing the first (literary humanistic) phase of the origin of modernity, characterized by an 'urbane open mindedness and skeptical tolerance', whereby uncertainty was embraced while recognising the inherent complexity, vulnerability and unpredictability of the human condition. The literary and scientific giant that was Johann Wolfgang von Goethe (1749-1842) would concur with this approach, reflecting that 'science is as much an inner path of spiritual development as it is a discipline aimed at accumulating knowledge of the physical world … [and one which incorporates] the spiritual dimension that underlies and interpenetrates the physical: faculties such as feeling, imagination and intuition' (Naydler, 1997, pp.92-93), an approach reiterated by the chemist and philosopher of science Michael Polanyi in the 20th century (Polanyi, 1973). In the twentieth century too, mathematician and philosopher Alfred North Whitehead proposed, with almost Gödelian perception that 'there is a quality of life which lies always beyond the mere fact of life; and when we include the quality in the fact, there is still omitted the quality of the quality.' (Whitehead, 1926). While days before his death in a typed correspondence to his wife, the Irish poet W.B. Yeats would further distil the (Gödelian) essense of this ontological construct: 'We can express truth but cannot know it' (Yeats, 1938). Great minds, in mathematics and literature it seems, are wont to think alike!

The question remains however. If the dominant models and conceptions of sustainability, based on reductionist conceptions of reality are inherently flawed and ultimately dangerous, what might a model of sustainability which coheres with complex reality resemble?

Ulanowicz's Sustainability Model

Robert Ulanowicz, a systems ecologist with (like Ehrenfeld) a background in chemical engineering has developed a quantitative model for (complex) ecological networks. This model represents a radical departure from the tradition of ecosystems modelling based on simulation. Ulanowicz postulates that the reason 'nature thwarts attempts to model ecosystems accurately' can be explained by understanding that 'the conceptual framework that supports the simulation process is itself flawed' (Ulanowicz, 2004, p.322). Consequently, he takes a complex systems or metabolic approach to ecosystem modelling which focuses on '*process*' (i.e. flows (of material or energy between nodes/agents/species/contiguous systems) or as (second law of thermodynamics implied) dissipation into the surrounding environment) as opposed to a singular focus on '*objects*' (i.e. system nodes). Accordingly, Ulanowicz proposes that processes can be represented by pathways within networks, and in this way the quantification of network properties may provide a vehicle for the quantification of process philosophy[2]. This leads him to the consideration of a middle way, as contemplated by Popper (1990), between respective antagonistic extremities of pure stochasticity (chance) and pure determinism/constraint (Ulanowicz, 2004). Pure deterministic (Newtonian cause and effect) 'forces' (which are nothing more than idealizations, dependent on stripping away context) and pure random stochasticism are thus replaced by context dependent (non-deterministic and non-random) 'propensities'. Consequently an atomistic approach is shunned in favour of 'a third

[2] With thanks to Robert Ulanowicz (personal correspondence). See also Chapter 4 for discussion on how process philosophy coheres with this broader context/framework.

window' (Ulanowicz, 2009a) which would consider that which lies *between*, in a way supported by the logic of the included middle (Nicolescu, 2010). In this way, truly novel knowledge and understanding concerning the system can progressively *emerge* in ways that cohere with a transdisciplinary philosophy of 'unity amidst diversity and diversity through the unity' (Klein, 2004, p.524), or by Morin's 'unitas multiplex' (Morin, 2008, p.4).

Ulanowicz's ecosystem network model has been used to compare nodal flows (of energy or material) throughout various ecological systems and hence produce aggregate quantities which correspond to what are in effect agonistic (opposing, though mutually obligatory) dualistic entities of system efficiency ('ascendency') and resilience ('overhead') (Ulanowicz, 2009a; 2009b). Intriguingly each of the seventeen[3] (non-simplistic) ecosystems chosen to model were shown to cluster non-randomly around a 'window of vitality' within a discernible range located *between* the points representing the respective agonistic extremities of (1) order/efficiency/constraint and (2) inchoateness/resilience/freedom (Zorach and Ulanowicz, 2003; Ulanowicz, 2009a; Ulanowicz, 2009b) as demonstrated in Figure 3.1. This state represents, what Carsetti (2013, p.1) describes as 'the intermediate state', that is, 'an intermediate situation between a complete absence of constraints, on the one hand, and the highest degree of redundancy on the other. In this sense, optimal organization should be considered an effective compromise between the greatest possible variability and the highest possible specificity.' Ulanowicz quantitatively measured this state among respective ecosystems in order to discern such a window of 'optimal organization', or as he would put it, (eco)system sustainability (Ulanowicz, et al., 2009). By this measure sustainability is recognized as a contingent and context dependent *balance* between opposing though necessary interdependent tendencies (Ulanowicz, et al., 2009).

This framework has added ontological significance when one considers that the model (shown in Figure 3.1) is based on the product of an expression proposed by the Austrian physicist Ludwig von Boltzmann (1844-1906) to formally estimate the second law concept of entropy (s) (characterized as the *absence* of an event), multiplied the probability of that event occurring (p). von Boltzmann defined entropy by the following relation: $s = -k \log(p)$, that is, in terms of the probability of a given microstate occurring (p), where k is a constant (Boltzmann's constant). Ulanowicz, et al. (2009) thus identify this product (i.e. s times p) as a means of ascertaining the *indeterminacy* (h) of some event i such that:

$$h_i = -k\, p_i \log (p_i)$$

By this model, the capacity of a system for change or evolution (a function of its indeterminacy, h_i) is zero at both extremes of $p_i = 0$ (zero chance of an event happening) and $p_i = 1$ (event guaranteed; fully (100%) controlled/determinate), but is maximized at a point in *between* these two extremes[4]. A 'window of vitality' extends around this maximum point, a sweet spot wherein systems operating within this contingent space not only flourish but are capable of exhibiting creativity, adaptation and emergent evolution. Studies (Zorach and Ulanowicz, 2003; Ulanowicz, 2009a; Ulanowicz, 2009b) have quantitatively demonstrated that flourishing 'sustainable' ecosystems operate within the 'window of vitality' as demonstrated in Figure 3.1, which represents a graphical representation of the expression [$h_i = -k\, p_i \log (p_i)$],

[3] Forty eight ecosystems were examined originally, but when simplistic ones ($n<12$) were eliminated seventeen remained (Ulanowicz, 2009b)

[4] An equivalent version of Boltzmann's model can be obtained which incorporates a normalised function which represents the degree of order, a, such that $F = -k\, a \log(a)$, whence the extremes are at $a = 0$ and $a = 1$ and the function is maximized at a point between these two extemes at $1/e$ (≈ 0.37) (see Ulanowicz, et al. (2009) for detail)

and which while the same as that presented in Goerner, Ulanowicz and Lietaer (2009) is here constructed *de novo* (and to scale).

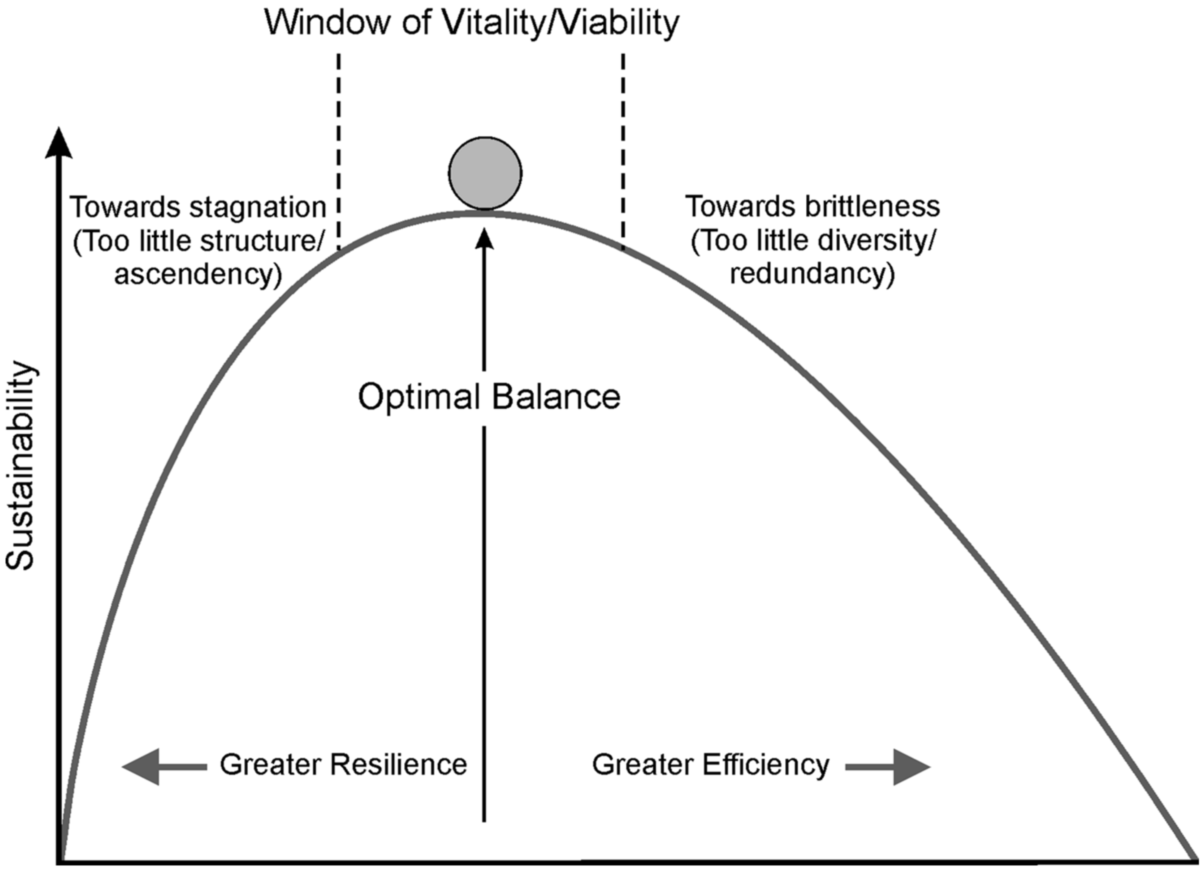

FIGURE 3.1 A model of sustainability as contingent balance between agonistic tendencies of overhead/resilience/uncertainty and ascendency/efficiency/control, after Ulanowicz, et al. (2009) and Goerner, Ulanowicz and Lietaer (2009)

Formalising indeterminacy in this way has far reaching implications. It goes where reductionist and positivist conceptions of science cannot go in 'reckoning the nonexistent' by providing 'a relative measure of what is missing' (Ulanowicz, 2014, p.23). This conception of reality is mirrored in the realm of dialectical critical realism where there is recognition of a requirement for consideration of the negative as well as the positive (Bhaskar, 2010, p.15):

> *..absence is constitutively necessary for being. A world without absence, without boundaries, punctuations, spaces, and gaps between, within and around its objects would be a world in which nothing could have determinate form or shape, in which nothing could move or change, and in which nothing could be differentiated or identified.*

Moreover, sustainability (and indeed a conception of 'progress') modelled in this way, as a contingent dialectical *balance* between opposing though complementary agonistic tendencies of order and inchoateness represents a Heraclitan paradigm rather than the neo-Cartesian antagonistic and separate dualism that has characterized modern linear conceptions of progress (towards ever increased efficiency and ascendency) and indeed sustainability which dominate to the present day. Such ontological differences have far reaching implications.

Indeed Hans Carl von Carlowitz (1645-1714), who is generally credited as the originator of the concept 'sustainability' (nachhaltigkeit) through his early 18th century writings on forestry management would have held to this singular and separate dualistic conception within a Europe in which 'the genesis of an unsustainable, growth based, industrialized society' (Caradonna, 2014, p.24) originated. This has since remained the dominant conception of sustainability and in particular 'sustainable development', which Ehrenfeld (2008) describes as merely 'reducing unsustainability', a quantifiable reductionist approach from which sustainability (as human and non-human flourishing) can never be realised.

Ulanowicz's model is thus a powerful construct for two reasons. Firstly, because not only does it disavow the dominant modern conception of sustainability in terms of it being a linear monist directed advance towards some unique (and context free) fabled 'optimized' state (towards the extreme right of Figure 3.1), but instead promotes the idea of it being characterized as an evolving, contingent and emergent property of a (flourishing) system (within the 'window of vitality' on Figure 3.1). It thus ventures 'beyond classical either/or alternatives' as Morin puts it, such that 'alternative terms become antagonistic, contradictory, and at the same time complementary' (Morin, 2008, p.33):

> *It also applies to holism/reductionism. In fact, reductionism has always provoked an opposing holistic current founded on the preeminence of the concept of globality or totality. But the totality is never anything more than a plastic bag enveloping whatever it found any way it could, and enveloping too well: the more the totality becomes full the emptier it becomes. On the contrary, what we want to draw out, beyond reductionism and holism, is the idea of the complex unity, that links analytical-reductionist thinking and global thinking, in a dialogic …*

The upshot is that sustainability has no pre-determined end point, but is best viewed as a range of possible states (which lie between opposing yet mutually obligatory extremes) which facilitate system flourishing. It also replicates (and is essentially identical to) Jantsch's model of complex self-organising systems whereby a middle way must be steered between the agonistic tendencies represented by 'conformity' (corresponding with ascendency) and 'novelty' (chaos) in order to self-referentially become self-transcendent through 'the creative overcoming of the *status quo'* (Jantsch, 1981, p.91). Moving to either extreme merely results in equilibrium and either stasis or chaos respectively, both representing collapse and death.

The second reason for the power and import of Ulanowicz's model is that critically, because it is not based merely on some abstract conceptual construct but represents a quantifiable (and experimentally tested) manifestation of the second law of thermodynamics, through incorporating the concept of entropy, it quantitatively provides a visual map which demonstrates the ongoing tension between the universal tendencies towards entropy generation (and energy dissipation) and the opposing though complimentary tendency towards system ascendency and structure. It thus also provides a compelling conceptual basis for both progress and evolution, rooted in the real in the guise of actual ecosystems.

By this model, systems can be characterized as exhibiting sustainability (with the potential for flourishing) when they operate within the 'window of vitality' (Figure 3.1). Operating in this (non-equilibrium) space also facilitates system evolution over time (in the presence of available free energy), in the direction of increased system complexity (Chaisson, 2001), as opposed to system collapse, which is more likely to occur the closer to the extremes (and equilibrium) that the system operates at. For example, systems that are too constrained, structured, efficient and/or inflexible are not able to respond to changing environmental context and are thus lacking in resilience. Succinctly put, this implies 'systems can become too efficient for their own good' (Ulanowicz, et al., 2009, p.34). Conversely, systems which are too diffuse, inchoate or disparate may also be unable to respond to changing contexts or to lack the necessary coherence to take advantage of available free energy and harness this to develop/evolve.

This is of course all posited within a (dialectical and process) Heraclitan framework, whereby contingency, change and evolution are enduring system characteristics. It fits in with broader conceptions of sustainability as an evolving and contingent quality, rather than as some ultimate point destination entailing optimisation around a unique endpoint located at the (right hand) extreme of Ulanowicz's rainbow, a sort of crock of gold exemplified by the mirage of 100% efficiency.[5] As Petersen (2013, p.2) puts it, sustainability in light of constant (internal and environmental) change and evolution can more accurately be conceived of in a broader sense as:

> *a heterogeneous and contested set of perspectives that are continually defined and redefined through social, cultural, and political practices. A central implication of this perspective is that sustainability cannot be viewed as a finite goal or destination we can work towards as a global community. Like the pot of gold at the end of the rainbow, sustainability is more of a moving target never quite to be reached. Using a navigational metaphor thus captures the concept more comfortably: sustainability discourses help us steer in a sea of future challenges and navigate around the rocky patches of undesirable solutions. In this capacity, as a navigational device, the specific sustainability discourses are also locally defining the legitimacy of new socio-material arrangements, such as technological systems.*

There are a number of additional discernible traits experimentally evident in Ulanowicz's model of complex ecosystems. One is a general tendency towards increased ascendency (in accordance with Holling's model (Holling, 2001)), essentially a move to the right on Figure 3.1 (towards 'greater efficiency'): 'In the absence of major perturbations, ecosystems have a tendency over time to take on configurations of greater ascendency' (Ulanowicz, 2009a, p.88). Ascendency here is quantitatively defined by Ulanowicz (2009a, p.87) as 'organized power', specifically the product of a measure of system structural organisation and aggregate system flows (of energy, material, information) or throughput. It is thus indicative of order, structural organisation, performance, coherence, homogeneity, control and efficiency. Systems exhibiting increased system ascendency and efficiency moreover, while having enhanced capacity for energy dissipation, are also at enhanced risk of collapse in the wake of external change due to reduced reserve capacity/resilience: 'A requisite for the increase in effective orderly performance (ascendency) is the existence of flexibility (reserve) within the system' (Ulanowicz, et al., 2009, p.30). In this way ascendency and overhead (or redundancy) are complimentary opposites operating in a dialectical Heraclitian fashion as 'two countervailing tendencies … at play in the development of any dissipative structure' (Ulanowicz, 2009b, p.1889). 'Conversely, systems that are highly constrained and at peak performance (in the second law sense of the word) dissipate external gradients at ever higher gross rates' (Ulanowicz, et al., 2009, p.30; see also Schneider and Kay, 1994). Thus balance is quite literally, vital.

In more general terms, Ulanowicz (2013, p.253) notes with respect to the development of complex ecosystems that 'the common experience is that natural systems tend to increase in complexity up to a point, after which they either fall apart due to lack of coherence or simplify at a larger scale under the aegis of some synchronous dynamic'. Initial system development and growth from an original state of high indeterminacy and overhead can thus help facilitate

[5] As ordained by the second law of thermodynamics; no system can be 100% efficient

system sustainability and evolution (as with the growth of a child), but only up to a point (characterized by a move to the right *towards* the 'window of vitality'); thereafter further ascendent growth is associated with system unsustainability, senescence and ultimately disintegration. Coffman and Mikulecky (2012, p.134) describe this process in the broader global societal context:

> *... development is a teleological process of (self) - actualisation via growth and self-organisation, which when continued past a certain threshold of maturity causes senescence and thence the demise of the specific system or thing being developed – [this] constitutes a model whose realization we are now witnessing at the level of global civilization.*

Moreover Coffman and Mikulecky (2012, p.125) point out that 'development of a system naturally leads to senescence *unless* the system is periodically disturbed (shaken up) by external interactions'. Systems which are too highly constrained and lack sufficient diversity and indeterminacy are therefore less resilient and less sustainable.

Extending the Context

While Ulanowicz's quantitative model (underpinned by that most profound and fundamental of scientific laws, the second law) has been developed for, and successfully applied to systems ecology, it carries far broader resonance. It echoes Bateson's characterization of (ecological, social) systems as requiring a degree of flexibility as well as specialization in order to achieve health and survival (Bateson, 1972, p.492), while it has also been applied to complex systems in the realms of economics and global financial systems (Goerner, Ulanowicz, and Lietaer, 2009; Lietaer, Ulanowicz and Goerner, 2009). This framework of irreducible duality (as opposed to exclusive (Cartesian) dualism) has carried broader resonance throughout the history of human thought as well as within contemporary complexity thinking (Jörg, 2011, p.79).

Table 3.1 highlights some of the opposing though complementary dualistic tendencies recognized across disciplinary bounds which are analogous to the extremes in Ulanowicz's model. It should be noted that in contrast to Cartesian antagonistic duality which would seek to singularly promote 'modern' tendencies such as order, control and efficiency over 'alternate' tendencies, this conception requires a dialectical synthesis of *both* extremes in a manner which might be described by Morin's concept of 'unitas multiplex', essentially a unity of opposites through 'the conjunction of the one and the many' (Morin, 2008, p.4). This is the essence of what Morin calls 'complex thought' (Morin, 2008, p.5; Montuori, 2013). The contingent properties in the central column reflect this scope for emergent 'greater than the sum' progressive/process evolution, whereby as Coffman and Mickulecky (2012, p.126) point out '(contra Marx) the dialectic can *never* be resolved-there is no ultimate synthesis of thesis and antithesis, because that would be a developmental dead end, and the world never stops changing'.

Modern conceptions of progress are essentially fundamentalist (and hence ultimately dangerous), since they are underpinned by a paradigm of separation and reduction which has identified progress in monist terms as a *singular* drive of optimisation directed towards the extremes represented by the 'modern tendencies' listed in Table 3.1 (equivalent to striving for the extreme right on Figure 3.1). The emerging paradigm of integrative and complex thought would radically extend this vision by recognising the need for *balance* between *both* sets of necessary tendencies in order to achieve respective emergent properties such as progress, evolution, sustainability and flourishing. The result of complexity informed understandings and scholarship has been a surge in interest in many of the 'alternate' tendencies in Table 3.1, such as for example, resilience, diversity, holism and autonomy, as well as more practically, more localized and artisan means of production and consumption. This has in turn facilitated a broader and more balanced and contingent conception of sustainability, as elucidated for example by Fiskel (2003, p.5330):

> *The concept of "resilience", borrowed from the field of ecology, enables sustainability to be viewed as an inherent system property rather than an abstract goal. ... sustainability is often misinterpreted as a goal to which we should collectively aspire. In fact, sustainability is not an end state that we can reach; rather, it is a characteristic of a dynamic, evolving system.*

Table 3.1 Opposing though complementary dualistic (agonistic) system tendencies required for emergent properties such as sustainability

Modern tendency	Emergent contingent (dialectical) property	Alternate tendency
Development	Sustainability	Equilibrium
Organization		Inchoateness
Ascendency	Progress	Overhead
Efficiency/Information		Entropy
Certainty	Innovation	Risk
Concentration		Diffuse
Conservation	Flourishing	Adaptability
Intensification		Diversification
Order	Coherence	Chaos
Certainty		Uncertainty
Efficiency	Sufficiency	Redundancy
Stability		Resilience
Control	Trust	Flexibility
Durability		Robustness
Constraint	Emergence	Freedom
Structure		Spontaneity
Competition	Evolution	Cooperation
Conformity/Homogeneity		Diversity
Determinacy	Creativity	Indeterminacy
Globalisation/Interconnection		Localisation/Self-sufficiency
Reductionism	Integrative /('Unitas	Holism
Totalitarian	Multiplex')	Individualistic
Managerialism		Autonomy
Unchallengeable Orthodoxy		Undirected Dissent
Specialisation (division of labour)	Community	Artisan
Productivity		Fastidiousness
Quantitative	Quality	Qualitative
Autocracy		Anarchy
Centralization		Decentralization
Modern absolutism	'Complex thought'	Postmodern deconstruction
Directed		Stochastic
Objective	Relational	Subjective
Conformity		Novelty
Law	Propensity	Chance
Instrumental Knowledge		Reflective Understanding

Another Contingent Sustainability Model; Stirling's Temporal Model
Quite independently, and unaware[6] of Ulanowicz's work in quantifying sustainability as it relates to ecosystem dynamics, work by Andy Stirling and colleagues focussing on the socio-technical sphere has led to the proposition of other qualitative contingent models of sustainability. These models are presented with no ontological claims but instead more modestly seek 'an heuristic and analytic apparatus for further discerning – and opening up – more nuanced and robust approaches' to conceptions of socio-technical vulnerability and sustainability (Stirling, 2014, see also Leach, Scoones and Stirling, 2010). In addition, the models resolve environmental change in complex socio-technical systems into sudden large (but transitory) system disturbances ('shocks') and more long term enduring disturbances ('stresses') (Figure 3.2). Possible responses to each of these temporal changes are then considered on orthogonal axes. The result is a not dissimilarly framed map of sustainability to that presented earlier, one governed by constant change and ineliminable contingency[7]. (It might be noted however that as presented here (Figure 3.2), the model represents an inverted image of Figure 3.1, when read from left to right.)

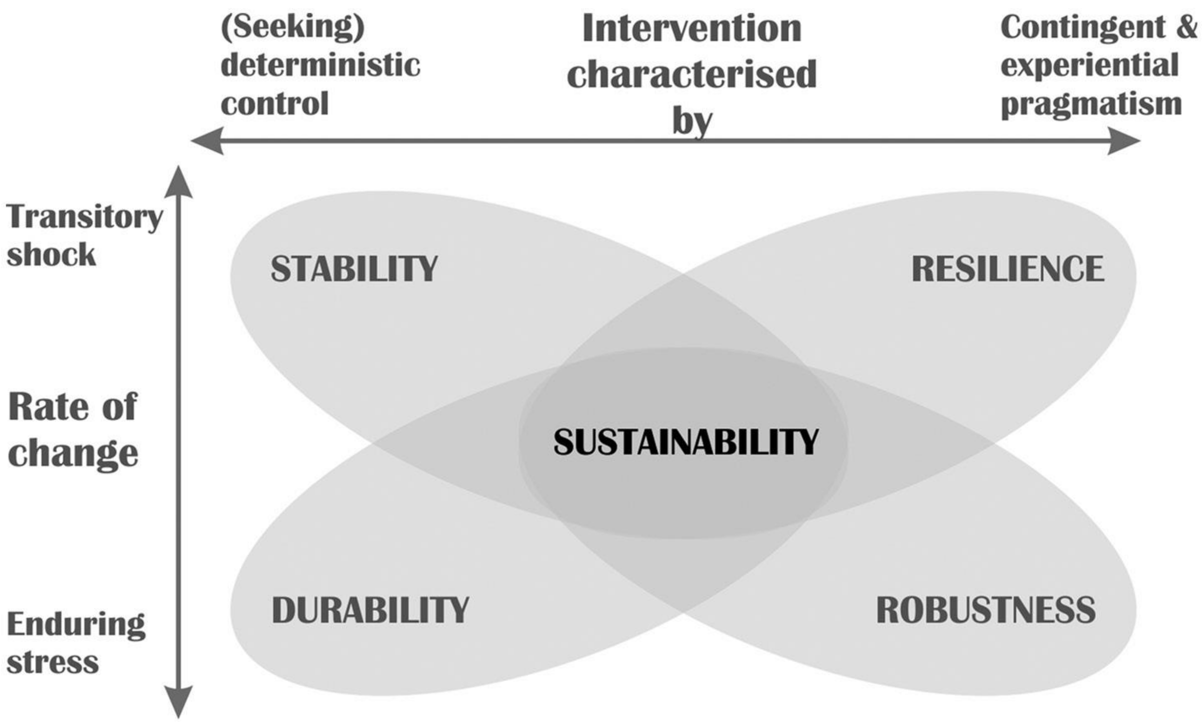

FIGURE 3.2 Model of seeking system sustainability in terms of contingent and context-dependent interventions in response to temporal change, after Stirling (2014)

Possible responses to shocks and stresses range from interventions characterized by modernistic approaches which would seek to achieve system control to more integrative approaches which would act in a more responsive fashion through contingent pragmatism based on experiential learning and ongoing accumulated context dependent system knowledge. Ehrenfeld (2008, p.182) characterizes these respective styles of action as respectively seeking system 'management' and 'adaptive governance', suggesting that the latter is better able to

[6] Learned through personal discussion around the 'transdisciplinary conversations' conference which preceded this book (see Chapter 1)
[7] This could be termed a '"dynamic properties" framework' for describing system sustainability, a characterisation employed by Stirling himself (personal correspondence)

effectively respond to change in complex systems, since it 'seeks to maintain some emergent system property such as resilience', while the former 'tends to focus on some quantitative outcome, such as sustainable yield'. Despite the deterministic control 'management' approach being most suited only for simple deterministic systems (as opposed to the complex emergent ones that typically pertain in socio-technical, economic or ecological domains), it is nevertheless the dominant approach taken for all manner of complex indeterminate systems, as promoted by the modern paradigm of reductionism.

This 'management' (stability/durability) style of action represents a feedforward approach driven by forces of conservation whereby control and system *status quo* is sought through strategies aimed at complete system characterisation, risk reduction and deterministic forecasting (Figure 3.2). When applied in the political sphere this represents autocratic or technocratic tendencies aimed at managing the system through control. By contrast the 'adaptive governance' resilience and robustness approach is characterized by a less hubristic contingent feedback intervention strategy which is accordingly more comfortable with change, disruption, evolution, novelty and re-organisation, and seeks to both exploit and respond to these in promoting and enhancing system sustainability. In political terms this approach would embrace ongoing participatory bottom-up engagement, social-ecological experiments in new ways of living and governance, and enhanced network connectivity as a response to ongoing change. By this model, Stirling proposes that sustainability in complex (socio-technical) systems can only be achieved (to a greater or lesser extent) as a contingent and context dependent *balance* between feedforward (expert driven 'risk reducing') interventions aimed at achieving system control, and concurrently on appropriate responsive feedback interventions which concentrate more on building resilience and robustness. This serves to reemphasize the conception of sustainability in dialectical terms and as an ongoing evolutionary never-ending *process* as opposed to some sort of 'permanent solution' (Barry, 1999, p.34, p.125). Indeed this is a common framework found throughout literary history, where there is recognition that relevant agonistic tendencies 'as anthitheses … are in fact intimately tightly bound together in a spiral dialectical dance' (Keohane & Kuhling, 2014, p.12), as exemplified for example by the twentieth century Irish writers Joyce and Yeats, who would reflect on 'the recusive movement of history - history as recurrence, repetition, rather than linear progresss' (Keohane & Kuhling, 2014, p.15).

If sustainability could be described as the ability of systems (whether these be social, ecological, economic, or some combinations of these) to endure, particularly in the wake of significant system perturbation or disruption, then the question may well be asked: what is it that one is trying to sustain/endure? If it is accepted that the current (socio-economic-ecological) system, which promotes limitless ongoing consumptive growth, is on an unsustainable trajectory, then there is a good basis to argue that this particular societal construct *itself* requires disruptive change. Thus rather than seeking perseverence of an unsustainable construct, the aim would be to *disrupt* unsustainability – and corresponding socio-technical lock in. Stirling (2014, p.325) addresses this by drawing out a third orthogonal axis reflecting 'normativity of framing'. In seeking to *disrupt* (unsustainability) rather than *sustain* (i.e. maintain) the *status quo*, a new set of trajectories are called upon. By this model, 'transition' and 'transduction' are proposed when there is an envisaged endpoint in a system which can be reasonably well characterized/controlled or where some specific intervention and/or outcome is envisaged in order to precipitate system disruption (Figure 3.3).

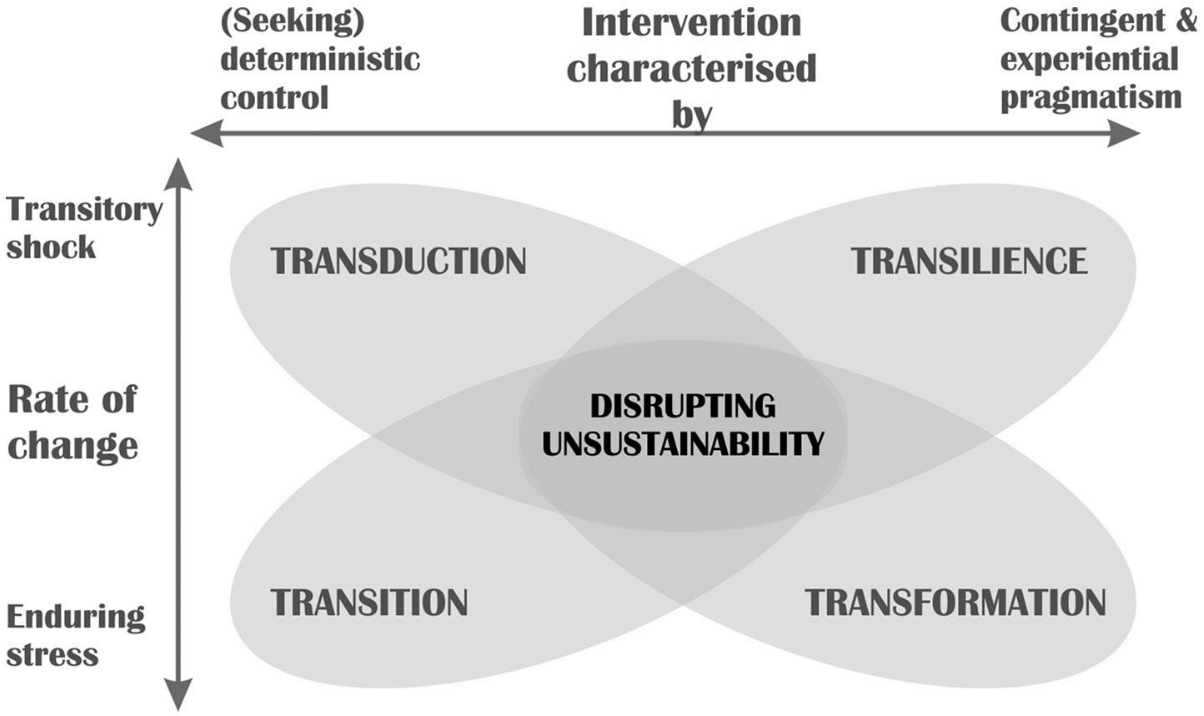

FIGURE 3.3 Model describing intervention styles in systems subject to temporal change aimed at seeking sustainability through disruption of unsustainable trajectories, after Stirling (2014)

The concept of backcasting; 'designing a "future system"' (Stasinopoulus, et al., 2009, p.88) could represent an example of transition in this context. For less determinate more uncertain futures with open ended outcomes, interventions seeking 'transformation' and 'transilience' are more appropriate. In general movements such as 'transition towns' and other non-governmental organisations which would 'seek more exclusively to create change around discourse concerning long-term, large-scale secular stresses' would target transformational change since 'the potentially transformative consequences are also more distributed, diffuse, and diversely oriented than a single transition, opening a more indeterminate array of possible alternative trajectories' (Stirling, 2014, p.330).

More generally, the overall thrust of Stirling's sustainability/changeability model suggests that in any real complex system, a contingent and context dependent set of interventions are appropriate, whereby 'the context, style, and orientation of governance interventions can all be seen to vary quite radically, depending on the prevailing circumstances'. Thus emerges a topography of sustainability/vulnerability which reveals 'more plural, complex, nuanced and recursive – but also precise – forms than is often acknowledged' (Stirling, 2014, p.330).

Broader Complexity Informed and Integrative Conceptions of Reality

The models of sustainability outlined above, which envision it as an emergent property rooted in contingency, context, propensity and dialectical balance align with what might be called an integrative worldview (Hedlund-de Witt, 2013a, 2013b, 2013c). Such 'approaches are characterized by attempting to move beyond 'either/or' thinking and instead plead for an inclusive 'both/and' approach' (Hedlund-de Witt, 2013a, p.240). They would also 'position themselves as alternatives to both positivism and constructivism, building forth on some of their most important insights, while simultaneously aiming to transcend their widely perceived shortcomings.' (Hedlund-de Witt, 2013a, p.301). Such thinking is incorporated into a number of epistemological models and theories including complexity theory (Morin, 2008; Cilliers, 1998), transdisciplinarity (Nicolescu, 2008), integral theory (Wilber, 2007), integrative pluralism (Mitchell, 2003), critical realism (Bhaskar, 1975, 2015), process philosophy (Whitehead, 1929) and postformal and planetary futures studies (Morin, 1999; Montuori, 1999; Gidley, 2013). This 'new meta-level field' (Gidley, 2013) is underpinned by contemporary scientific understandings which go beyond the narrow utilitarian and reductionist conception of science that underpins the modern worldview. These developments include twentieth century advances in respective fields of mathematics and logic (e.g. Gödel, 1931), physics (Heisenberg, 1927), thermodynamics (Prigogine, 1997), biology (Kauffman, 2000) and ecology (Schneider and Kay, 1994; Gunderson and Holling 2002; Ulanowicz, 2009). Post-normal science (Funtowicz and Ravetz, 1993) and concepts such as the new engineer (Beder, 1998) and wicked problems (Rittel and Webber, 1973) are examples of practical manifestations of this broader more explicitly normative approach when applied to the practice of science and engineering.

Table 3.2 is based on Annick Hedlund-de Witt's Integrative Worldview Framework (IWF), which provides a useful model for comparing this integrative and complexity informed conception of reality with earlier epistemological models and worldviews and their respective paradigmatic underpinnings (Hedlund-de Witt, 2013a). Pluralistically oriented, integrative worldviews (bottom right quadrant) differ from earlier conceived counterparts in that they are both transcendent (emergent from) and integrative with respect to earlier worldviews associated with pre-modern ('traditional') (bottom left), modern (reductionist) (top left) and postmodern (relativist and deconstructivist) (top right) conceptions of reality. The integrative worldview thus recognizes dialectical necessity and has the capacity to recognize (at least partial) truth within each of the preceding worldviews. It is in this context that Hedlund-de Witt (2013b) can assert for example, that 'several authors speak of the emergence of an "integral" or integrative worldview in our contemporary cultural landscape, which is characterized by its tendency to bring together and synthesize perspectives that from the perspective of other worldviews tend to be considered mutually exclusive and polarized, such as rationality and spirituality'. Such conceptions open up opportunities for an easy and productive rational-spiritual dialogue, amid an integrative humanism which parallels Toulmin's (1990) first clear eyed phase of modernity, as cited earlier. Indeed, to quote Pope Francis[8] (2015, para. 141) while delivering a devastating critique of reductive market driven economic growth: 'We urgently need a humanism capable of bringing together the different fields of knowledge, including economics, in the service of a more integral and integrating vision'.

Hedlund-de Witt and Hedlund-de Witt (2015, p.28) provide an example of how an integrative approach can achieve this by incorporating elements of the other worldviews in the case of organic and slow food movements. They report that:

> *individuals associated with these movements tend to be inspired by a pluriform value-palette, which ... ranged from more 'traditional' values (such as an emphasis on and appreciation for family-owned farms; local livelihoods; traditional production methods; simple, seasonal, artisanal foods produced and prepared according to 'grandmother recipes'; strong social ties between producer and consumer), to 'modern' values (flourishing economies; pleasure of taste; high quality foods; abundance and variety; experimentation and innovation; health and nutrition), to 'postmodern' values (environmental well-being; animal welfare; pure, natural foods and mindful eating; food choices as expression of one's individuality; vitality and holistic health).*

[8] A spiritual authority with a technical formative background (in chemical engineering)

Table 3.2 Paradigmatic characteristics of the Integrative Worldview Framework (after Hedlund-de Witt, 2013a; Hedlund-de Witt and Hedlund-de Witt, 2015)

	Seeks Certainty/Control	**Recognizes Inherent Uncertainty**
Materialistic	**Modern (Reductionist)** *Associated with:* Neo Cartesian Separate Dualism Positivism Scientism Directed Change (towards optimum: progress) Instrumentalism Technocratic techno-optimism Disenchantment Self contained logic/literalist Secular materialism Seeks revealed certainty through reason *Progress through:* Reductionist Science	**(Deconstructionist) Postmodern** *Associated with:* Social constructivism Relativism Deconstructivism Poststructuralism Skepticism Constant decentred change (in space and time) Ineliminable Uncertainty Nihilism 'Death of God', seeks to go beyond Rejects generalizations, abstractions, absolute truth *Progress through:* Pluralistic tolerance
Beyond Materialism (spiritual, transcendent, emergent)	**Premodern (Traditional)** *Associated with:* Singular and comprehensive view of universe Conservation Immutable Fixed hierarchical structure/order Irreducible Mystery Mythos as well as Logos (myth-metaphor/logic-literalist) Sacred *Progress through:* Interpretations and insights into the unique divine created order based on sacred texts/scriptures, particularly as mediated by religious authorities.	**Integrative (Dialectical balance between control and uncertainty, and between material and transcendent)** *Associated with:* Recognition of irreducible complexity; Complexity Theory (Complex unity; unitas multiplex) Transdisciplinarity Critical Realism Integral Theory Process Thought Post-normal, Postformal and Planetary Futures studies Ongoing Change and Emergent Evolution Interconnectedness, Recursivity & Reflexivity Creativity Re-enchantment e.g. 'our Sister, Mother Earth, who sustains and governs us' (Armstrong, 1999, p.113)/'Reinventing the sacred' (Kauffman, 2010) *Progress through:* Integrative science and philosophy; characterized by an ongoing relational dialectical balance between agonistic extremes of control and uncertainty. Progress recognized as contingent, context dependent, emergent and qualitative (e.g. 'sustainability-as-flourishing', whereby 'flourishing' emanates from care for both the material and non-material/spiritual (Ehrenfeld and Hoffman, 2013, p.17)).

At the same time, the extreme (and linearly directed) tendencies of the other worldviews are discarded in favour of contingent Heraclitian (or equivalently, the Oriental concept of yin and yang) balance between necessary opposites. So while the pre-modern has been characterized by a quest for ordained order, principally through religious authority, the modern has promoted similar autocratic societal structures in the form of respective twentieth/twenty-first century afflictions of statist communism, fascism and the ultimately ubiquitous regime of market controlled globalized consumerist capitalism (each of these seek out optimisation at the extreme right on Ulanowicz's model (Figure 3.1), representing a totalizing desire for order and control – by states and/or markets). Meanwhile, a deconstructivist postmodern agenda would (at its opposite optimized extremum) seek a society characterized by chaos and discretization in the form of post sturcturalist anarchism, market driven individualism and/or rejection of modern technological ascendency (as it seeks optimisation on the far left of Ulanowicz's model (Figure 3.1)). Indeed Cilliers (2007, p.160) points out that 'if relativism is maintained consistently, it becomes an absolute position. From this we can see that a relativist is nothing but a dissapointed fundamentalist'. Nevertheless, he cautions that this 'should not lead on to conclude that everything that is called postmodern leads to this weak position' (p.160); by this he means the post-deconstructivist dialectical type of 'post-modern' worldview that we are here calling 'integrative', of which he cites critical realism as an example.

An integrative approach would therefore envision 'progress' and 'sustainability' through ongoing contingent dialectical balance between opposing (but necessary) extremes of ineliminable uncertainty and control. It thus represents, as Pope Francis puts it in his ecologically inspired Encyclical Laudato Si', 'liberation from the dominant technocratic paradigm' to reveal 'another type of progress, one which is healthier, more human, more social, more integral.' (Francis, 2015, para. 112). The resulting context dependent property is therefore both emergent and qualitative. Because it cannot be reduced to a simple quantitative metric (e.g. monetary value), it goes beyond the purely materialistic and thus by necessity also incoporates the axis of materialistic-non materialistic (i.e. normative/ethical/spriritual) in addition to the previously encountered uncertainty-control axis of Ulanowicz's model.

This facilitates its candidature as a suitable and appropriate worldview for both understanding and addressing contemporary emergent 'nexus' crises around global unsustainability (Hedlund-de Witt, 2013c; Hedlund-de Witt and Hedlund-de Witt, 2015; Stirling, 2015), each of which are of course, merely outcomes of the ongoing dominance and application of the modernist reductionist paradigm and its associated worldview.

Addressing our Blindness; Process Reality over One Eyed Quantitative Outputs

Such nuanced and contingent visions of sustainability, rooted in the agonistic tendencies of complexifying ascendency on one hand, and dissipative entropy generation on the other, offer a credible prescription for a mode of adaptive system governance (over one seeking ultimate control) that is required in order to help guide open and far-from-equilibrium complex adaptive systems towards sustainability, progress and evolution. This contrasts with modern conceptions of progress and sustainability, which cloaked as they are in a closed linear neo-Cartesian paradigm of separation and reduction are blind to the need for system redundancy and overhead. By this conception, the attainment of sustainability is simply to be achieved through a one way path via initiatives which would facilitate for example, ever increased efficiency, greater quantitative and predictive knowledge, technological ascendency and quantitative risk management approaches to seeking control. Morin (2008, p.6) is thus moved to conclude that 'we are blind to the problem of complexity. This blindness is part of our barbarism. …only complex thought will allow us to civilize our knowledge'. This blindness enables modern society to ascribe to 'the myth of progress', a story which rejects the ascendency fuelled premise that 'if there is a foundation on which all environmental degradation rests, it is entropy generated by the ever-increasing transformation of energy by humans' (Wessels, 2006, p.51). It also ignores the implications and evidence around Jevons's paradox (Jevons, 1866; Princen, 2005; Herring and Sorrell, 2009) in a world exhibiting ever increasing socio-technical ascendency with systems/technologies exhibiting a corresponding increase in energy dissipation rate per unit mass (W/kg) (Chaisson, 2010), culminating in ever increasing biospheric entropy (Wessels, 2006), and perhaps ultimately, the inevitability of long term catastrophic consequences in the form of longer term 'global heating' (Chaisson, 2008).

The danger inherent in this mismatch between the modern conception of progress (as an exercise in linear optimisation towards ascendency and dissipative entropy generation) and evidential increased reality of falling into what Wright (2005) calls a 'progress trap': a state where (societal and other) systems become too efficient and constrained for their own good and thus lack necessary resilience in the wake of (ongoing) temporal change. A complex system which is governed primarily on the basis of *feedback* in the form of quantitative *output* metrics rather than a focus on *process* (thus necessitating a reliance on accumulated experiential learning and relational aspects which facilitate pragmatic contingent action), is one which is dangerously poised; apropos the financial rating agencies ahead of the 2007 global economic crisis.

Conclusion

The current chapter has sought to outline a vision of progress and sustainability encapsulated by a process approach to reality as elucidated by Heraclitus and bolstered by contemporary scientific understanding around irreducible complexity and ineliminable uncertainty. This is advanced through the lens of a dialectical, relational and integrative model of reality which envisages sustainability as a contingent and emergent property resulting from respective agonistic tendencies of control and disorder, between the forces of attraction and dissipative entropy. Robert Ulanowicz's model has fundamental scientific and mathematical import, based on the concept of entropy inherent in the second law of thermodynamics, while demonstrating in a quantitative manner the contingent balance required for ecological systems to sustain, flourish and evolve. The upshot is that the dominant modernistic paradigm of reduction and separation, which has held sway for over the past four hundred years is today not only unfit for purpose, but is demonstrably dangerous, as it coaxes us onto an existentially unsustainable trajectory which is manifestly divorced from reality. The result is contemporary crisis; ecological, social, economic and ethical. Transdisciplinary approaches to knowledge integration and generation are required if we are to, as Edgar Morin (1999, p.146) puts it, get beyond our 'fragmented thinking' and in doing so 'no longer strive to master the Earth, but to nurse it through it sickness, and learn how properly to dwell on it, to manage and cultivate it.'

The author would like to sincerely thank Robert Ulanowicz for his valuable feedback and insights on both this and the following chapter, as well as to colleagues who reviewed respective chapters.

Bibliography

Armstrong, R. J., 1999. *Francis of Assisi - The Saint: Early Documents.* New York: New City Press.

Barry, J., 1999. *Rethinking green politics.* London: Sage.

Bateson, G., 1972. *Steps to an ecology of mind.* New York: Ballantine Books.

Beder, S., 1998. *The New Engineer.* Melbourne: Macmillan.

Bhaskar, R., 1975. *A realist theory to science.* Brighton: Harvester.

Byrne, E. Mullally, G & Sage, C. (2016) Transdisciplinary Perspectives on Transitions to Sustainability. Routledge.

Bhaskar, R., 2010. Contexts of Interdisciplinarity. In: R. Bhaskar, C. Frank, K G. Høyer, P. Næss and J. Parker, eds. *Interdisciplinarity and climate change.* Oxon: Routledge.

Bhaskar, R., 2015. *Metatheory for the 21st Century: Critical Realism and Integral Theory in Dialogue.* London: Routledge.

Caradonna, J. L., 2014. *Sustainability: A history.* Oxford: Oxford University Press.

Carsetti, A., 2013. *Epistemic complexity and knowledge construction.* Dordrecht: Springer.

Chaisson, E. J., 2001. *Cosmic evolution: the rise of complexity in nature.* Cambridge: Harvard University Press.

Chaisson, E. J., 2008. Long term global heating from energy use. *Eos, Transactions American Geophysical Union,* 89(28), pp.253-254.

Chaisson, E. J., 2010. Energy rate density as a complexity metric and evolutionary driver. *Complexity,* 16(3), pp.27-40.

Cilliers, P., 1998. *Complexity and Postmodernism: Understanding Complex Systems.* London: Routledge.

Cilliers, P., 2007. Knowledge, Complexity and Understanding. In: P. Cilliers, ed. *Thinking Complexity: Complexity and Philosophy.* Mansfield: ICSE Publishing.

Coffman, J. A. and Mikulecky, D. C., 2012. *Global insanity.* Litchfield Park: Emergent Publications.

Daly, H. E., 1992. *Steady-state economics: with new essays.* London: Earthscan.

Descartes, R., 1638. *Discourse on method.* [online] Available at: <http://www.gutenberg.org/ebooks/59> [Accessed 11 February 2015].

Ehrenfeld, J. R., 2008. *Sustainability by design.* New Haven: Yale University Press.

Ehrenfeld, J. R., 2009. *Unintentional Greenwashing.* [online]
Available at: <http://www.johnehrenfeld.com/2009/10/unintentional-greenwashing.html> [Accessed 12 February 2015].

Ehrenfeld, J. R. and Hoffman, A. J., 2013. *Flourishing A frank conversation about sustainability.* Redwood City: Stanford University Press.

Fiskel, J., 2003. Designing Resilient, Sustainable Systems. *Environmental Science and Technology,* 37, pp.5330-5339.

Francis, I., 2015. *Encyclical Letter Laudato Si' of the Holy Father Franics on Care for Our Common Home.* [online]
Available at: <http://w2.vatican.va/content/francesco/en/encyclicals/ documents/papa-francesco_20150524_enciclica-laudato-si.html> [Accessed 4 September 2015].

Funtowicz, S. O. and Ravetz, J. R., 1993. Science for the post-normal age. *Futures,* 25(7), pp.739-755.

Gidley, J., 2013. Global Knowledge Futures: Articulating the Emergence of a New Meta-level Field. *Integral Review,* 9(2), pp.145-172.

Gödel, K., 1931. Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I. *Monatshefte für Mathematik und Physik,* 38, pp.173-198.

Goerner, S. J., Ulanowicz, R. E. and Lietaer, B., 2009. Quantifying economic sustainability: Implications for free-enterprise theory, policy and practice. *Ecological Economics,* 69, pp.76-81.

Gray, R., 2010. Is accounting for sustainability actually accounting for sustainability and how would we know? An exploration of narratives of organisations and the planet. *Accounting, Organizations and Society,* 35(1), pp.47-62.

Gunderson, L. H. and Holling, C. S., 2002. *Panarchy: understanding transformations in human and natural systems.* Washington, DC: Island Press.

Hedlund-De Witt, A., 2013a. *Worldviews and the transformation to sustainable societies.* [online] Available at: < http://dare.ubvu.vu.nl/handle/1871/48104> [Accessed 2 June 2015].

Hedlund-De Witt, A., 2013b. *An Integral Perspective on the (Un)sustainability of the Emerging Bio-economy: Using the Integrative Worldview Framework for Illuminating a Polarized Societal Debate.* [online] Available at: <https://foundation.metaintegral.org/sites/default/files/Hedlund-de-Witt_Annick_ITC2013.pdf> [Accessed 2 June 2015].

Hedlund-De Witt, A., 2013c. Worldviews and their significance for the global sustainable development debate. *Environmental Ethics,* 35(2), pp.133-162.

Hedlund-de Witt, A. and Hedlund-de Witt, N. H., 2015, in press. Towards an integral ecology of worldviews: Reflexive communicative action for climate solutions. In: S. Mickey, S. M. Kelly and A. Robbert, eds. *Integral ecologies: Culture, nature, knowledge, and our planetary future.* New York: SUNY Press. [online] Available at: <http://www.academia.edu/1978213/Towards_an_Integral_Ecology_of_Worldviews_Reflexive_Communicative_Action_for_Climate_Solutions> [Accessed 1 October 2015]. pp.1-36

Heisenberg, W., 1927. Über den anschaulichen Inhalt der quantentheoretischen Kinematik und Mechanik. *Zeitschrift für Physik,* 43(3-4), p.172–198.

Herring, H. and Sorrell, S., 2009. *Energy efficiency and sustainable consumption: The rebound effect.* New York: Palgrave Macmillan.

Holling, C. S., 2001. Understanding the complexity of economic, ecological, and social systems. *Ecosystems,* 4, pp.390-405.

Hommels, A., Mesman, J. and Bijker, W. E., 2014. *Vulnerability in technological cultures.* Cambridge: MIT Press.

Jantsch, E., 1981. *The evolutionary vision: Toward a unifying paradigm of physical, biological and sociolcutural evolution.* Boulder: Westview Press.

Jevons, W. S., 1866. *The Coal Question.* 2nd ed. London: Macmillan and Co.

Jörg, T., 2011. *New thinking in complexity for the social sciences and humanities.* Heidelberg: Springer.

Byrne, E. Mullally, G & Sage, C. (2016) Transdisciplinary Perspectives on Transitions to Sustainability. Routledge.

Kauffman, S., 2010. *Reinventing the Sacred: A New View of Science, Reason, and Religion.* New York: Basic Books.

Kauffman, S. A., 2000. *Investigations.* Oxford: Oxford University Press.

Keohane, K. and Kuhling, C., 2014. *The Domestic, Moral and Political Economies of Post-Celtic Tiger Ireland: What rough beast?.* Manchester: Manchester University Press.

Klein, J. T., 2004. Prospects for transdisciplinarity. *Futures,* 36, pp.515-526.

Kuhn, T. S., 1996 [1962]. *The Structure of Scientific Revolutions.* 3rd ed. Chicago: University of Chicago Press.

Leach, M., Scoones, I. and Stirling, A., 2010. *Dynamic sustainabilities: technology, environment, social justice.* London: Earthscan.

Lietaer, B., Ulanowicz, R. E. and Goerner, S. J., 2009. Options for managing a systematic bank crisis. *Sapiens,* 1(2), pp.1-15.

McRobbie, A., 2009. *The Aftermath of Feminism: Gender Culture and Social Change.* London: Sage.

Mitchell, S. D., 2003. *Biological complexity and integrative pluralism.* Cambridge: Cambridge University Press.

Montuori, A., 1999. Planetary culture and the crisis of the future. *World Futures: The Journal of General Evolution,* 54(4), pp.232-254.

Montuori, A., 2013. *Complex Thought: An Overview of Edgar Morin's Intellectual Journey*. MetaIntegral Foundation Resource Paper [online] Available at: <https://foundation.metaintegral.org/sites/default/files/Complex_Thought_FINAL.pdf> [Accessed 4 September 2015].

Morin, E., 1999. *Homeland Earth.* Creskill: Hampton Press.

Morin, E., 2005. Restricted Complexity, General Complexity. In: *Intelligence de la complexité: épistémologie et pragmatique Colloquium.* Cerisy-La-Salle, 26 June 2005. Translated from French by Carlos Gershenson. [online] Available at: <http://cogprints.org/5217/1/Morin.pdf> [Accessed 12 February 2015]

Morin, E., 2008. *On Complexity.* Creskill: Hampton Press.

Naughton, J., 2012. *From Gutenberg to Zuckerberg: What you really need to know about the internet.* London: Quercus.

Naughton, J., 2014. *It's no joke – the robots will really take over this time.* The Guardian, 27 April 2014. [online] Available at: <http://www.theguardian.com/technology/2014/apr/27/no-joke-robots-taking-over-replace-middle-classes-automatons> [Accessed 12 February 2015].

Naydler, J., 1997. *Goethe on Science: A Selection of Goethe's Writings.* Edinburgh: Floris.

Nicolescu, B., 2008. *Transdisciplinarity: Theory and Practice.* Creskill, New Jersey: Hampton Press.

Byrne, E. Mullally, G & Sage, C. (2016) Transdisciplinary Perspectives on Transitions to Sustainability. Routledge.

Nicolescu, B., 2010. Methodology of Transdisciplinarity: Levels of Reality, Logic of the Included Middle and Complexity. *Transdisciplinary Journal of Engineering and Science,* 1(1), p.19-38.

Petersen, R. P., 2013. The Potential Role of Design in a Sustainable Engineering Profile. In: *Engineering Education for Sustainable Development (EESD13)*, University of Cambridge, 22-25 September 2013. Cambridge: EESD.

Polanyi, M., 1973. *Personal knowledge: towards a post-critical philosophy.* London: Routledge and Kegan.

Popper, K. R., 1990. *A world of propensities.* Bristol: Thoemmes.

Prigogine, I., 1997. *The End of Certainty.* New York: Free Press.

Prigogine, I. and Stengers, I., 1984. *Order Out of Chaos: Man's New Dialogue with Nature.* New York: Bantam Books.

Princen, T., 2005. *The Logic of Sufficiency.* Cambridge: MIT Press.

Rittel, H. W. J. and Webber, M. W., 1973. Dilemmas in a general theory of planning. *Policy Sciences,* 4, pp.155-169.

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.

Stasinopoulos, P., Smith, M. H., Hargroves, K. and Desha, C., 2009. *Whole System Design An integrated approach to sustainable engineering.* London: Earthscan.

Stirling, A., 2014. From sustainability, through diversity to transformation: towards more reflexive governance of technological vulnerability. In: A. Hommels, J. Mesman, and W. Bijker. eds. *Vulnerability in technological cultures: new directions in research and governance.* Cambridge: MIT Press. pp.305-332.

Stirling, A., 2015. Developing ‘Nexus Capabilities’: towards transdisciplinary methodologies. In: *Transdisciplinary Methods for developing Nexus Capabilities Workshop,* University of Sussex, 29-30 June 2015. Sussex. [online] Available at: <http://www.thenexusnetwork.org/wp-content/uploads/2015/06/Stirling-2015-Nexus-Methods-Discussion-Paper.pdf> [Accessed 4 September 2015].

Toulmin, S., 1990. *Cosmopolis: the hidden agenda of modernity.* Chicago: University of Chicago Press.

Ulanowicz, R. E., 2004. Quantitative methods for ecological network analysis. *Computational Biology and Chemistry,* 28, pp.321-339.

Ulanowicz, R. E., 2009a. *A Third Window: Natural Life beyond Newton and Darwin.* West Conshohocken: Templeton Foundation Press.

Ulanowicz, R. E., 2009b. The dual nature of ecosystem dynamics. *Ecological Modelling,* 220, pp.1886-1892.

Ulanowicz, R. E., 2013. Circumscribed complexity in ecological networks. In: M. Dehmer, A. Mowshowitz and F. Emmert-Streib, eds. *Advances in Network Complexity*. Hoboken: Wiley, pp.249-258.

Ulanowicz, R. E., 2014. Reckoning the nonexistent: Putting the science right. *Ecological Modelling,* 293, pp.22-30.

Ulanowicz, R. E., Goerner, S. J., Lietaer, B. and Gomez, R., 2009. Quantifying sustainability: Resilience, efficiency and the return of information theory. *Ecological Complexity,* 6, pp.27-36.

Wessels, T., 2006. *The myth of progress: Toward a sustainable future.* Vermont: University of Vermont Press.

Whitehead, A. N., 1926. *Religion in the Making Lecture II: 'Religion and Dogma.* King's Chapel, Boston, February 1926. [online] Available at: <http://www.mountainman.com.au/whiteh_2.htm> [Accessed 12 February 2015].

Whitehead, A. N., 1929. *Process and reality: an essay in cosmology.* Cambridge: Cambridge University Press.

Wilber, K., 2007. *The Integral Vision.* Boston: Shambhala.

Wright, R., 2005. *A short history of progress.* Edinburgh: Canongate.

Yeats, W. B., 1938. *Letter to George Yeats from Hôtel Idéal-Séjour,* [letter] Cap Martin, France. [MS 30,280]. 23 December 1938. Dublin: National Library of Ireland.

Zorach, A. C. and Ulanowicz, R. E., 2003. Quantifying the complexity of flow networks: How many roles are there?. *Complexity,* 8(3), pp.68-76.