**Design for financial sustainability**

**Highlights**

- Define the general problem of design for sustainability
- Frame the inside-out design pattern for sustainability using axiomatic design
- Life on Earth as providing exemplars of the sustainable inside-out design pattern
- Critique the highly unsustainable financial system from an inside-out perspective

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**In brief**

Life on Earth is at least 3.4 billion years old. Across such an immense expanse of time, nature has evolved remarkably sustainable designs that have kept the flame of life alive. Design for sustainability demands that we learn from nature's adaptable designs and shift away from rigid, top-down deductive approaches to embrace a more bottom-up and inductive way. A case in point is our crisis-ridden, highly unsustainable financial systems. Studying nature, an inside-out design pattern emerges. Emulating such a design pattern might benefit the financial industry.
Article
Design for financial sustainability

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SUMMARY
The 1987 United Nations Brundtland Report established the vision of sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” How might we anticipate the requirements of future custodians of vast, continuously morphing socio-technical-ecological systems while addressing current pressing needs? An abstract, principled approach (such as axiomatic design) might help address such ambiguity. Such systems are composed of large numbers of information-processing agents/agencies that collectively form a complex adaptive system (CAS). The focus here is on financial sustainability: (1) what is a principled approach toward sustainable design? (2) What design insights might we obtain by studying financial crises forensically against sustainability successes in nature? (3) How to design for financial sustainability? This paper adopts the CAS framework alongside axiomatic design to help elicit design patterns and anti-patterns of sustainability. Inspired by nature, a promising inside-out design pattern emerges.

INTRODUCTION
The United Nations (UN) Brundtland report1 on sustainability evolved out of the need to harmonize human advancement (both current and future) alongside nature’s carrying capacity. The problem of design for sustainability reaches across time and therefore has unique challenges attached to it. In other words, it is unlike any other design problem.

In Future Design, Saito highlights the concept of seven generations: “Almost no person in the present generation, however, is in a position to reflect on their place in the universe between their ancestors and their descendants. The Iroquois tribe of Native Americans has arrived at a method to overcome this problem. … when members of the Iroquois tribe make important decisions, they must place themselves in the shoes of people seven generations ahead of them. The term ‘seven generations ahead,’ then, represents not a world in which one’s direct descendants live but a world that one cannot envision merely from the perspective of one’s own bloodline … Making decisions while considering a society that will exist seven generations from now is not simple.” The seven generations principle was articulated in the second half of the sixteenth century when five of the warring Iroquois tribes banded together to create a unified Iroquois Confederacy. While the “seven generations ahead” ideal is far-sighted, given the rapidity of change across all levels of our modern socio-eco-technical systems, our inability to imagine the kinds of problems and concomitant solutions that might lie ahead could be a limitation. Notice that nature also faces the
AD framework

Suh formulated the AD framework in order to bridge the gap between the practice of science and design. As he writes in Suh:3 “Just as there are many design solutions, there must be many diverse approaches to ‘design science.’ The axiomatic approach may be one of many possible avenues toward this goal. It is the hope of the author that the axiomatic approach at least illustrates how design can be made into a science.” In order to tease out the parallels between science and design, it might be worthwhile considering the parallels between the scientific method versus engineering design. Human knowledge has a specific structure that could help draw out the parallels between the two.

As indicated in Thomas and Zaytseva:9 “Human knowledge captures the sum-total of truths/facts gleaned from nature and accumulated across time. Given the relative abundance of concretes to abstractions, domain-specific human knowledge has a hierarchical shape.” This hierarchy is as shown in Figure 3A, which also maps the scientific versus the engineering-design problem-solving trace. Both traces follow stages a → f, although not necessarily in any particular order. During stage a, scientists engage in data exploration and analytics about a phenomenon within the socio-eco-technical system that interests them. In contrast, designers try to accurately perceive problems that will need an artifact design as a solution for themselves or their clients. In the vertical concrete to abstract scale shown at the left of Figure 3A, stage a is at the concrete end of the knowledge hierarchy. The foundation of the knowledge hierarchy (i.e., the breadth at the base) sets the inductive base for stage b. The richer the inductive base, the higher the inductive reach. Stage b is the inductive/statistical phase that both approaches (i.e., science and design) utilize in coming up with a competitive hypothesis (in the case of science) versus abstract design-problem.
statements (in the case of design). As indicated in Suh,3 “the ability to define the problem is the most important and difficult task in engineering.” Such is also the case for scientific problem statements. The design space is narrowed in scope if we do not capture the problem at a sufficiently high abstract level.

Stage c is either the creative inductive-leap (i.e., the eureka moment) or the deductive/mechanistic search for fit across a well-navigated design landscape (or a combination of the two, as captured in c1–c2).

As the design/proving activities proceed (from the abstract to the more and more concrete), stages a–c iteratively repeat in an abductive cascade (across stages d–e). The cascade could fail at any of these intermediate steps. The tail end of the abductive cascade is either the concrete design or the system-wide proof of the scientific theory (i.e., stage f), which will then need testing against the wider context.

The fundamental problem of DFS is the need for designing in the abstract. Most of the customers of such a design will be from generations that are yet to be born. The complete set of functional requirements of such a design is therefore unknown and unknowable. Moreover, given the pace of technological advancement, the design parameter space is also unknown and unknowable. In other words, not just the designer’s problem space is vague and fuzzy; it is also that the designer’s tool chest is rapidly evolving into hitherto-unknown dimensions.

The rate of change that one might expect is as depicted on the vertical axis of this graph. The motivation is to provide an abductive approach as it pertains to the problem of DFS. As shown in Figure 4, the act of design is partitioned across the paradigmatic customer, functional, design(n), and process domains with customer requirements (CRs), functional requirements (FRs), design parameters (DPs), and process variables (PVs) denoting the control variables from the respective realms. If we were to be designing for contemporary times, the requirements and designs that match these requirements would be reasonably well defined. However, as mentioned earlier, when dealing with the DFS problem that extends into the indefinite future, governing issues are ill-defined. Ordinary designs may also start as fuzzy. However, across multiple iterations, the fuzziness is effectively eliminated. Such an iterative elimination of the fuzziness is never the case for DFS. Given that the design pertains to future times, DFS will indefinitely remain fuzzy and ill-defined.

Figure 4 captures the critical elements of the axiomatic approach as it pertains to the problem of DFS. As shown in Figure 4, the act of design is partitioned across the paradigmatic customer, functional, design(n), and process domains with customer requirements (CRs), functional requirements (FRs), design parameters (DPs), and process variables (PVs) denoting the control variables from the respective realms. If we were to be designing for contemporary times, the requirements and designs that match these requirements would be reasonably well defined. However, as mentioned earlier, when dealing with the DFS problem that extends into the indefinite future, governing issues are ill-defined. Ordinary designs may also start as fuzzy. However, across multiple iterations, the fuzziness is effectively eliminated. Such an iterative elimination of the fuzziness is never the case for DFS. Given that the design pertains to future times, DFS will indefinitely remain fuzzy and ill-defined.

Various mappings between FRs and DPs are as shown in Figure 4D. At the abstract pattern level, the place-holder Xs in the design matrix relate the required set of FRs to the corresponding DPs. They denote the presence of a causal relationship indicating how the associated set of DPs aid or thwart a given FR at the left of the fundamental design-equation ((FR) = [DM] x [DP]), where DM is design matrix. As the design develops from the abstract to the concrete, these place-holder Xs become more concrete and quantifiable, as per the governing natural
laws. Across multiple iterations, even abstract design patterns may also attain quantification. Three seminal design patterns (i.e., uncoupled, decoupled, and coupled) have been extensively studied in Suh. The fully coupled design is merely an extension of the coupled design. Uncoupled design is the ideal, but hard to achieve. A decoupled design is more practical.

DFS involves both DITA and DFA (Figure 4B). As explained earlier, given how AD tracks the knowledge hierarchy, DITA is feasible by restricting the design to the higher echelons of the knowledge hierarchy (Figure 4C).

These patterns have relevance for DFA. For example, the uncoupled design pattern is infinitely adaptable as each element of the design is orthogonal from every other element, and therefore may evolve independently. However, many ill-conceived designs are coupled designs and pose unwanted side effects within the overall design. DFA may be achieved by judiciously composing the design elements using the decoupled-design pattern. By sufficiently atomizing and decoupling the FR-DP design elements (as shown in the practice of mass customization), product family architectures (PFAs) may be established to aid in the evolution and adaptation of the design to changing circumstances. As indicated by Tseng and Jiao, “it has been shown that individual products can be efficiently constructed on successful generations of underlying product architectures, commonly referred to as the product platform ... As the basic elements of a PFA, building blocks are referred to as various sets of DPs with their specific values corresponding to and satisfying different functional specifications.”

The fundamental design equation is not static in time; instead, it evolves for better FR-DP fit. This is especially true in the context of a decoupled design where FR dominance comes into play. In such a design, the FR-DP combination that may be chosen most independently of the rest of the design matrix may be considered to be in the dominant position. It is, therefore, the very first FR-DP that is related across the design matrix at the top left (see Figure 4D).

As discussed in Mantri and Thomas, biological designs in nature often start as coupled and over time evolve into the decoupled state. Also, highly conserved design elements (in the designs in nature and across vast evolutionary time scales) move up. As the decoupled design evolves, the most conserved FR-DP relationships migrate to the dominant top-left region of the design matrix. This is as shown in the last of the design patterns in Figure 4D.

The bottom panel (Figure 4D) is significant when attempting DFS, especially in the financial sector. DFS designers need to avoid coupled-design patterns; these are the anti-patterns that cause anti-sustainability. For example, the problem of increasingly coupled too-big-to-fail (TBTF) designs in modern finance could trigger unsustainable financial contagion via moral hazard. Furthermore, when it has migrated to the dominant position of the design matrix, it can result in system-wide unsustainability.

The fundamental difference between science and design is in the extra normative mandate that design has. While science explores what is, design explores what ought to be. Even so, the normative divide between these two practices is not absolute. For example, as shown in Figure 3B, Ockham’s razor (i.e., the constraint that “entities are not to be multiplied beyond what is required”) is a normative, designerly ought illustrative of
Sustainability

Systems contain systems and, in turn, are themselves contained by larger systems—unless of course, they are at the proverbial A or the Ω ends of existence (i.e., postulated preons as the point particles at one end, versus the all-encompassing universe at the other). The A end is conserved as it does not contain anything finer; it is conserved either individually or as a group. Likewise, the Ω end is the totality; it is therefore not contained by anything more encompassing.

Kalman10 highlights the invariance problem for quarks at the A end: “With the advent of the Standard Model in the late 1970’s, the guiding epistemology became and still is Atomism. The essential notion of Atomism was set out in 1750 by Rudjer Boskovic: atoms contain smaller parts, which in turn contain still smaller parts, and so on down to the fundamental building blocks of matter. These fundamental particles are indivisible bits of matter that are ungenerated and indestructible. The properties of quarks would fit the description of fundamental particles within a renewed bootstrap model (at the quark level), but are square pegs for fundamental particles as set out by Atomism. Quarks are not indestructible; some can decay into other quarks! … It is essential to the very atomicist underpinnings of the Standard model that quarks are composed of elementary particles: preons.”
At the levels that they exist, these two existents are not suffering change. They are eternally sustained. Everything in between evolves, adapts, and suffers change, and is therefore fundamentally unsustainable at all the constituent intermediate, B levels. As an abstraction, \( A \rightarrow B \rightarrow \Omega \) captures the totality of existents. Placing this in the philosophically historical context,\(^1\) \( A \) and \( \Omega \) are the unchanging Parmenidean existents, while the Bs are the unsustainable Heraclean fluctions. Here, uppercase Greek letters (A, B, and \( \Omega \)) are being used to denote the micro-meso-macro state of existents in a multi-scale system such as the universe (\( \Omega \)) at large.

In this section, as well as in sections stigmergy to CAS, we will introduce agents and artifacts that are denoted using lowercase Greek letters \( \alpha \) and \( \beta \), respectively.

The problem of sustainability only exists at all the intermediate B levels. B-level sustainability is, therefore, a holistic, emergent property of the system that pertains to its ability to maintain its state despite perturbing forces from within (endogenic) as well as from without (exogenic). As an emergent property, the sustainability of a system is not reducible to its constituent levels. The concept of emergence will be discussed further in the context of CASs.

Consider, for example, the Hokkaido super-colony\(^2\) of Japanese red wood ants. It is estimated to be thousands of years old and currently houses close to 300 million workers, with the queens living up to 10 years and workers up to 3 years. Typically, a monogynous (i.e., a single-queen-based) colony lasts for the duration of the queen’s life (i.e., 10–30 years). In contrast, the Hokkaido super-colony (i.e., a polygynous-polydomy or a multi-queen, multi-mound colony) that hosts close to a million queens can last thousands of years and is therefore far more long lived and sustained than the stand-alone monogynous ant colonies. Of the 12,000 known ant species, only 20 form super-colonies. The common red wood ants are not endangered, but the Hokkaido super-colony of red wood ants that stretches across 12.4 miles along the Japan Sea is economically unsustainable at all the constituent intermediate, B levels. B-level sustainability is, therefore, a holistic, emergent property of the system that pertains to its ability to maintain its state despite perturbing forces from within (endogenic) as well as from without (exogenic). As an emergent property, the sustainability of a system is not reducible to its constituent levels. The concept of emergence will be discussed further in the context of CASs.

When studying sustainability, it is crucial to understand that it pertains to the lifespan of an emergent property of a CAS such as the ant colony. As described in Holland,\(^3\) CAS’s “are systems that have a large number of components, often called agents that interact and adapt or learn.” Let us denote the CAS agents as \( \alpha \) agents. Also, let us denote the properties that emerge as the \( \beta \) properties. In the case of the ant colony, the collective property of the colony to persist and sustain as a colony across long durations is an example of such a \( \beta \) property. Typically, the ant colonies rebuffer ants of the same species that belong to a different colony. However, in the case of the ant super-colony, they learn to co-exist and freely exchange members between them. An organized constellation of CAS units constitutes a CAS of systems (or CASOS). As a CASOS, the super-colony sustains itself at a higher level than that of an ant colony. The lifespan of a CASOS is usually orders of magnitude larger than the lifespan of the various contained CASs. Sustainability threats, as well as stabilizers to a CASOS-\( \beta \) exist at a different scale compared with threats/stabilizers to a CAS-\( \beta \). Studying the designs in naturally occurring CASOS systems is of significant value as it may inform us in stabilizing our various precarious systems of increasing complexity and inter-dependence.

**DFS**

The concept of sustainability has a self-renewing etymological origin. The term originated in 1713 as Nachhaltigkeit, which is the German forestry practice of limiting the harvest not to exceed new growth yield.\(^4\) New growth endogenously replenishes and sustains the forest. As suggested by Suh,\(^5\) “Nature sustains life by renewing itself periodically.” Thus, periodic renewal and replenishment (to maintain the status quo) is one way we could deliver on the seven-generations ideal.

Self-renewing motifs face both endogenous and exogenous limits and afforances; for example, a lightning strike that triggers forest fires that either limit the age of boreal forest or triggers new growth; alternatively, forest disease caused by native pathogens such as fungi or viroids. Notice that these agents operate at vastly different scales and governing scientific laws (i.e., multi-model). For example, the endogenic pathogens are microscopic, while exogenous factors (such as lightning) are macroscopic and operating as per different natural laws. Therefore, the problem of sustainability is a multi-scale/multi-model problem that, at its core, is adaptive, and needs adaptive agents evolving alongside its respective cohort system.

Authors McDonough and Braungart highlight a holistic life-cycle approach to waste and sustainability. Thus in “Cradle to Cradle,”\(^6\) they indicate that, “The Cradle to Cradle approach is to see waste as food, as a nutrient for what is to come … When someone buys a floor covering from Shaw or Desso, it means that while he lives with that floor, he imagines its afterlife.” Wallace and Suh\(^7\) formulate how “information content can be applied to environmental design problems.” Herein, they provide a fundamental critique against the use of weighting schemes: “Most systems devised to assess the overall suitability of designs use weighting schemes to rank the importance of design criteria. [Our] approach does not employ a weighting scheme for two important reasons. First, the use of weights would reduce the meaning of the information metric … The second reason stems from concern as a designer that weighting factors can be highly arbitrary and very difficult to establish.” Instead, by relying on the information axiom, design items of greater significance would “naturally tend to make large contributions to the overall rating due to their narrow acceptable design range.”

In his doctoral thesis on sustainable design in the furniture industry, Seyajah\(^8\) proposes a sustainability design index (SDI) based on the triple bottom line (TBL) (environmental, economic, and social aspects). Design selection involves using SDI alongside AD. Unfortunately, as mentioned earlier, SDI is based on an ad hoc weighting scheme that runs counter to the information-theoretic approach. Stressing the strategic advantage of the bottom-up local versus the top-down global approaches, Seyajah writes,\(^9\) “A simple example is using local resources; that is one of the major sustainability guidelines and it will result in less transportation, less energy consumption, less air pollution and finally saving production expenses and making more profit for manufacturing companies.” Recommendations also include a modular, open-plan architecture for facilitating adaptation to changing requirements.

The general criticism against TBL is that it is primarily an economically driven framing that shortchanges both the social
and the environmental. As highlighted by James, the Triple Bottom Line approach reduces environmental questions to externalities and social questions to background issues. Instead, James proposes the circles of sustainability (COS) framework presented as a spider chart along four equally weighted axes (economics, ecology, politics, and culture), each then further sub-divided into seven finer subdivisions. Each of the 28 sectors is then scored along a nine-point scale ranging from critical (red) to vibrant (green). As seen with Seyjah’s doctoral work, the COS approach also runs counter to the information-theoretic approach.

The criticism against TBL was that it allowed economics to dominate and integrate the selection process. However, a framework such as COS that presents 28 dimensions is perhaps too complex to aid decision making. In practice, COS is an ad hoc reification (in the form of a spider chart) of a higher-level set of concepts that may still be missing. From an AD framework, the COS design problem has not been hierarchically abstracted sufficiently high. As suggested in Suh, "When such a hierarchical nature of decision making is not utilized, the process becomes very complex." Similarly, as Brown and Rauch indicate, "Sustainability problems require multi-scale solutions, seamlessly integrated into design processes."

Embedded within the COS framework is the struggle to capture the appropriate creative tension between the global and the local. As James indicates, "the phenomenon of globalization has been occurring across the world for centuries, but in changing ways, and massively intensifying across the mid-twentieth century to the present ... [it] does not imply that everything has or will become global. In these terms, globalization is not a totalizing condition, nor is it an endpoint that will be achieved when everything that is local becomes global. Rather, a series of relations continue to be uneven and contingent, even as we can see dominant patterns emerging ... Ironically, intensifying globalization has brought about a significant self-consciousness about local places." The authors are critical about "disembodied globalization," i.e., the movement of international capital. “... at the most materially abstract end of the spectrum, disembodied globalization, although always localizing in some way or other, and with profound consequences for how people live locally, is the least embedded in local places.” The recent experience of numerous national and regional dislocations caused by the 2007–2008 global financial crisis agrees with the disembodied globalization critique. As suggested by James, “We need an alternative paradigm that can respond to the challenge of connecting globally debated principles and new ideas about sustainability with locally engaged practices.”

In order to reconcile the local-global conflict, we need to study the original pioneering work of Patrick Geddes, who is considered the father of modern town planning. Geddes was the originator of the TBL approach, which he had coined as “place, work, folk” (i.e., environment, economy, society). His seminal work from 1915 “Cities in Evolution” is the origination of the “think globally, act locally” (TGAL) ideal. Geddes helped organize town-planning exhibitions and projects across Europe, the US, and India. Such global cross-fertilization of town-planning practices captures the think-globally aspect. As to the act-locally ideal, Geddes suggests that, “On pain of economic waste, of practical failure no less than of artistic futility, and even worse, each true design, each valid scheme should and must embody the full utilization of its local and regional conditions, and be the expression of local and of regional personality ... Each place has a true personality; and with this shows some unique elements—a personality too much asleep it may be, but which it is the task of the planner, as master-artist, to awaken.” Unfortunately, modern planners have replaced TGAL with think globally, act globally (TGAG). As summarized in Kumar and Whitefield, “Geddes has been hijacked by the planning fraternity, who dominated and integrate the selection process. However, a framework such as COS that presents 28 dimensions is perhaps too complex to aid decision making. In practice, COS is an ad hoc reification (in the form of a spider chart) of a higher-level set of concepts that may still be missing. From an AD framework, the COS design problem has not been hierarchically abstracted sufficiently high. As suggested in Suh, “When such a hierarchical nature of decision making is not utilized, the process becomes very complex.” Similarly, as Brown and Rauch indicate, “Sustainability problems require multi-scale solutions, seamlessly integrated into design processes.”

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As mentioned in section AD framework, a fundamental solution to DFS requires that we address DITA alongside DFA. While the issue of DFA was addressed in section AD framework, DITA needs detailing in the form of a highly abstract and generic design pattern.

As Suh suggests: “the student must be taught to see the big picture and the ability to conceptualize a solution, as well as how to optimize an existing product or process.” Design patterns are sufficiently “solution neutral” while aiding in structuring the abstract/big-picture conceptual design.

In its broadest terms, the DITA-style abstract design pattern for sustainability may be sketched as shown in Figure 5. The composition is lower triangular, capturing the inside-out (i.e., design the security, conservation, and development of the internals before opportunistically attempting the same for the externals) design. Prior to designing the inside-out structure (i.e., the second and third rows), we need to establish the boundary element design (i.e., the first row). If the boundary elements are absent or ill-designed, the system (designed for sustainability) will likely succumb to dissipative forces that may be endogenous or exogenous in origin. Here, we do face the classic chicken-and-egg problem of how the boundary elements arise if there is no existing system that needs to be secured in the first place. This is where the iterative nature of design plays a role. Initially, the boundary elements are indeed ill-defined. However, across multiple crises that threaten the sustainability of the nascent system, a clear articulation of the boundary element requirements and its design percolates. Furthermore, once the boundary elements have been established, they are conserved across the future evolutions. The migratory dynamic of the boundary elements to get established at the first row is as captured in the bottom panel of Figure 4D. The tertiary status of the exogenous design follows from the fact that it is only in the context of a well-defined endogenous composition that the very issue of what might be exogenically beneficial (versus neutral or harmful) to the entity might be clearly articulated and therefore apportioned. The lower-triangle design matrix in Figure 5A captures the inside-out logic of the DFS design. We will use the inside-out design pattern when considering design for financial sustainability. The inside-out design logic equally applies across all the levels of a multi-scale/multi-model CASOS design problem.

Inverting this logic (e.g., the outside-in approach of engaging and developing the external elements before developing the internals) tends to create coupled designs that are unsustainable. In fact, in this hypothetical scenario, every exogenic agent and the exogenic environment at large now has dominance. The entity (at the embedded system level that it exists within) would need to expend its meager resources to fix the totality of the exogenic order before it could attempt to address its systemic concerns at the level that it exists in. Every exogenic agent/agency has a direct, dominant stake in articulating the internal architecture, which then spills over into the requirements and design of the boundary. In other words, the outside-in design would inevitably result in the migration of the exogenous system design to the dominant first-row status. The entity now exists at the behest of external agents, thus compromising the DFS mandate. Such, for example, is probably the case of the cell-powerhouse mitochondrion that got entrapped within the eukaryotic cell via endosymbiosis and progressively lost its independence across billions of years. Its contribution to the evolving β is therefore minimal. As a subervent, it, for example, could never establish a mitochondrion super-colony (such as the Hokkaido super-colony). Embedded, therefore, in the ideal of sustainability is the requisite freedom among its agents to flourish, evolve and emerge into higher β order.

**Geological time**

James Hutton first put forth the concept of geological time in 1788. It captures the long period as captured in the Earth’s 4.5-billion-year geological history. It is demarcated across four eons (i.e., Hadean, Archean, Proterozoic, and the current Phanerozoic). Except during the Hadean (when surface temperatures were in the range of 1,982°C [3,600°F]), every other eon has had one or more ice ages. We are currently in the quaternary ice age that began 2.5 Ma (million years) ago. It is composed of alternative glacial and interglacial segments. During the glacial, the temperatures are markedly lower, and the glaciers advance, while, during the interglacial, the temperatures are warmer, and the glaciers recede. It is challenging to grasp geological time when relating it to the anthropocentric time of our limited 79-year average life span. Thus, we naturally experience and interpret daily and seasonal weather changes within the scope of our living memories. In contrast, as recorded in the (radioactive potassium-to-argon dated) rocks of the Earth, climate change happens at a glacial pace across geological time scales. A possible anthropocentric cognitive bias is in conflating these two very different scales. The problem of disambiguating the climate-change signal (that resides in the geological time frame) from the weather-change noise (that resides in the anthropocentric time frame) is not easy. As Nobel Laureate Prof. Robert B. Laughlin explains: “Six million years ago, the Mediterranean Sea dried up. Ninety million years ago alligators and turtles cavorted in the Arctic. One hundred fifty million years ago, northern Europe burned to a desert and coal formed in Antarctica … Nobody knows why these dramatic climate changes occurred in the ancient past.” In contrast, the “weather patterns are dominated by large multi-year events in the oceans, such as the El Niño Southern Oscillation and the North Pacific Gyre Oscillation, which have nothing to do with climate change.” Highlighting the subtlety of the problem, Prof. Laughlin writes that “you’d have to separate these big effects from subtle, inexorable changes on scales of centuries, and nobody knows how to do that yet.”

**Climate change**

Figure 6 shows the temperature range over the last 500 Ma (million annum). The zero of the y axes corresponds to the average surface temperature of 14°C or 57°F. The temperature divide at which the polar ice caps melt or form is approximately 62°F. This divide is as captured in the tan and green horizontal panels respectively, in Figure 6. The last ice age was during the Pleistocene, which occurred 100 ka (kilo annum) ago.

We are currently in the Holocene interglacial and just beyond the post-Holocene optimum. Climate-wise, the interglacial midpoint is considered the optimum; for the Holocene, it occurred 5–9 ka ago.
Now that the broad parameters of the climate-change problem have been framed, it is essential to ask why we ought to maintain the average global temperatures at the just-right “Goldilocks,” pre-industrial level? On the top left of Figure 6 (in blue) are the five extinction event markers. They were triggered predominantly by volcanic activities, lava flows, and asteroid strikes. In other words, these were geological shock events. Note that each of these occurred during periods when the global temperatures were markedly high. Life en masse is likely not sustainable when the atmosphere is unbearable and fires are raging in habitats where plants and animals shelter. However, note that life does know to thrive even in hot climates. This was the case during the Cambrian Explosion 485–540 Ma (as shown in top left of Figure 6) when global temperatures averaged was the case during the Cambrian Explosion 485–540 Ma (as shown in top left of Figure 6) when global temperatures averaged over 100 °C (212 °F).'' In other words, “During the Cambrian, the average global surface temperature was approximately 22°C (72°F). This is as compared to the current average of approximately 12.5°C (54.5°F).” In other words, the Cambrian Explosion occurred under greenhouse conditions. As to the biodiversity of life during the Cambrian, National Geographic reports that: “The Cambrian period, part of the Palaeozoic era, produced the most intense burst of evolution ever known. The Cambrian Explosion saw an incredible diversity of life emerge, including many major animal groups alive today. Among them were the chordates, to which vertebrates (animals with backbones) such as humans belong.” The problem is that such life may not be in the forms that currently exist. Thus, left unstated in the Goldilocks ideal is the wish to sustain the current lifeforms as-is in a narrow temperature band.

Consider now the immense range in global temperatures (as shown in Figure 6). First, the unknown processes that govern such an immense system range preceded human advent by millions of years. Second, these processes are slow moving but visible across geological times. Third, the temperature bias is decidedly in favor of the upper half with zero ice caps. Fourth, the unknown natural processes are operating at a vastly superior scale to anything human. Fifth, if the underlying unknown process is mean reverting (as seems to be the case), we are currently at an unsustainable lower extreme. It is, therefore, rather quaint to think that we will be able to hold global temperatures within our present Goldilocks range across geological times. This is especially so when we consider the aging sun. As reported by Gronstal, “as the Sun ages, it is steadily becoming somewhat hotter.”

It is not to suggest that we should not hold on to our Goldilocks zone for as long as possible, especially given that it is humanity’s known cradle. Nevertheless, we do need to eventually venture forth to embrace and adapt to the inevitable climate change that Figure 6 foretells. Thus, while it is worthwhile holding on to the Goldilocks zone, the sustainability focus should be on the fragile system range of the diverse biological agents that currently coexist with us and how best to help this biota (including ourselves) adapt to the inevitable. In other words, we will need all our design-erly ingenuity to help us as well as our biological companions, survive, adapt, and flourish as our Cambrian ancestors once did. Furthermore, there is a fundamental difference between nature’s designs as compared with designs as conceived by humans. Nature’s designs lack foresight and are therefore reactive and constrained to evolve at a glacial pace across long inter-generational spans. In contrast, the human faculty of foresight, if used wisely, would allow us to proactively anticipate and design for future eventualities, both in the abstract as well as in the concrete. However, to use our faculties wisely requires us to learn from designs in nature that have been perfected over millions of years.

The extreme climate in the Cambrian forced our ancestors to toughen up and innovate. 67% of the 35 animal phyla first
Laughlin,25 “Humans can unquestionably do damage persisting and those that nurture and support us). As summarized by that is not true of the biological systems (including ourselves The physical systems range of planet Earth is broad. However, Biodiversity for a better approach. 

Grand scale. We may wish to consider the tardigrade example have failed and gone extinct. 

Imagine if, instead, the tardigrade had followed the outside-in anti-pattern and gone about expending its scarce re-

Abstracted as shown in Figure 7. Imagine if, instead, the tardigrade had followed the outside-in anti-pattern and gone about expending its scarce resources on fixing the harsh external environment (to match its preferred internal Goldilocks regime); it would undoubtedly have failed and gone extinct. Embedded in the climate-change ask is the wish to anchor the totality of earthly nature fixed at the Holocene optimum. It would mean that the outside-in anti-pattern is being attempted at a grand scale. We may wish to consider the tardigrade example for a better approach. 

Biodiversity

The physical systems range of planet Earth is broad. However, that is not true of the biological systems (including ourselves and those that nurture and support us). As summarized by Laughlin,25 “Humans can unquestionably do damage persisting for geologic time if you count their contribution to biodiversity loss. A considerable amount of evidence shows that humans are causing what biologists call the ‘sixth mass extinction,’ an allusion to the five previous cases in the fossil record where huge numbers of species died out mysteriously in a flash of geologic time … Extinctions, unlike carbon dioxide excesses, are permanent. The earth didn’t replace the dinosaurs after they died, notwithstanding the improved weather conditions … It just moved on and became something different than it had been before. Carbon dioxide, per se, is not responsible for most of this extinction stress. The real problem is human population pressure generally-overharvesting, habitat destruction, pesticide abuse, species invasion, and so forth.”

In other words, the anthropocentric value system conflicts with the implicit biocentric value system. It does not necessarily have to be conflicted, but it currently is. The biological systems surrounding us and are part of us (as our internal microbiome) are far too fragile, and their extinction is irreversible. Therefore, the onus is on us to align the two value systems before it is too late. Align does not mean one dictates the other, or vice versa. However, it does mean that they are not needlessly in conflict. Nevertheless, currently, they are. In order to align the two value systems, we must learn the language of biology. 

Consider the rainforest ecosystem from a sustainability perspective. The Daintree Rainforest in Australia is estimated to be 180 million years old. The Malaysian Borneo and Taman Negara are estimated to be 140 and 130 million, respectively. In contrast, the Amazon is relatively young at 55 million. To put this in context, the earliest known tree, the 8 meter tall fern-like Wattieza, appeared during the mid-Devonian around 385 million years ago. The dense biodiversity embedded in the rainforest ecosystem is captured in the fact that, with just 6% of the Earth’s surface, it harbors over 50% of its flora and fauna. In other words, these are some of the most complex, ancient, and enduring habitats for life, with some that have survived three of the five mass-extinction events since the Cambrian Explosion. To help frame this in the human context, consider that, while Homo sapiens arrived about 300,000 years ago, the longest continuously inhabited city is Damascus, only about 11,000 years old. In other words, the oldest city as a human ecosystem has been around for just 4% of the duration that humans have been around; in contrast, the oldest forest has been
Biodiversity Index (LPI) based Regional Threats to Populations

| Regions                  | Development Driven Habitat Loss | Species Overexploitation | Invasive Species and Disease | Pollution | Climate Change |
|--------------------------|---------------------------------|--------------------------|------------------------------|-----------|----------------|
| North America            | 52.5%                           | 17.9%                    | 14.4%                        | 10.2%     | 5.0%           |
| Europe & Central Asia    | 57.9%                           | 19.7%                    | 10.9%                        | 7.5%      | 4.0%           |
| Latin America & Caribbean| 51.2%                           | 21.6%                    | 12.2%                        | 2.3%      | 12.5%          |
| Africa                   | 45.9%                           | 35.5%                    | 11.6%                        | 2.8%      | 4.1%           |
| Asia Pacific             | 43.0%                           | 26.8%                    | 14.0%                        | 11.0%     | 5.0%           |

Figure 8. Regional threats to biodiversity

around for 47% of the time since the advent of the first tree. There is much we could learn about how to attain human sustainability by studying it in the world’s rainforests. Also, a reflective question that confronts us today is whether these amazingly resilient mass-extinction survivors will survive the human advent?

Over the last 250 years, we have lost 1.9 billion hectares of overall forests (a 32% loss, from 5.9 billion to 4 billion) and 0.9 billion hectares of rainforests (a 60% loss, from 1.5 billion to 0.6 billion). Given the rapid pace of deforestation across the globe, the window of opportunity to learn about nature’s sustainability and reverse these trends is short. According to the UN, the dominant cause for deforestation is agriculture (subsistence farming, commercial agriculture, logging, and fuel-wood removal).

By focusing primarily on holding the global temperature within the Goldilocks band, we may have missed the far more significant and causally direct human destruction of the biosphere that is happening in the anthropocentric timescale. Moreover, the conflation of these time scales can lead to subtle decision errors by the governing world bodies. For example, the World Economic Forum (WEF) has been tracking global risks for the last 16 years. However, it is only since 2020 that biodiversity loss has risen to the top five risks (both in likelihood and impact). Better late than never, the investment community has noticed the change. As the Bloomberg press reports, “The ‘E’ in ESG has typically been shorthand for carbon emissions and climate change. Now though, a growing number of investors at firms including Fidelity International and Axa Investment Managers are focusing on the separate but interrelated threat of biodiversity loss: an impending natural catastrophe that could have enormous economic consequences, with more than half of the world’s total gross domestic product dependent on natural resources from food to ingredients for medicine.”

Likewise, the World Wildlife Fund (WWF) applauded the WEF’s inclusion of biodiversity in its Living Planet Report 2020. The WWF has been tracking the Living Planet Index (LPI; is a measure of biodiversity) since 1970. As per its website, “The Living Planet Index (LPI) is a measure of the state of the world’s biological diversity based on population trends of vertebrate species from terrestrial, freshwater and marine habitats.” Accordingly, the WWF reports that “The global Living Planet Index continues to decline. It shows an average 68% decrease in population sizes of mammals, birds, amphibians, reptiles and fish between 1970 and 2016. A 94% decline in the LPI for the tropical subregions of the Americas is the largest fall observed in any part of the world.” Figure 8 captures the five-factor regional threat decomposition regarding LPI. Notice the relative size of the climate-change component versus the rest.

What to do about habitat loss, which is the driving factor in Figure 8? The fundamental problem of habitat loss results from the need to feed burgeoning human populations in cities or elsewhere. The problem is best understood by considering the biological design of the lungs. The adult male can hold approximately 6 L (i.e., 0.6 ft³) of air. However, because of the large number of alveoli (300 million), the surface area of the lung expands to about 800 ft². Something that is merely 2 ft² in its non-fractalated area is now presenting a fractalated internal surface area of 800 ft². Add to that the fact that there are 1,500 miles of airways within the compact space of 6 L to efficiently transport the gases to and from the rest of the body. The lungs are a masterpiece in three-dimensional design that, at its core, has the essence of the solution to the fundamental problem of habitat constraint as the population grows.

To understand the relationship, consider the architecture of the Amazon rainforest canopy. The Amazon rainforest is considered to be the lungs of planet Earth. Its rich canopy exploits the third dimension via the power of fractalizing the Amazonian forest volume across its lush green leaves, which function like alveoli. With the birth of the skyscraper, humans discovered the third dimension in their cities. Our tallest skyscraper is twice as tall as the tallest redwood tree. Heretofore, agriculture has predominantly been practiced on a two-dimensional surface. We could bring agriculture indoors into a controlled environment. We could fractalize and exploit the vertical dimension. Also, we could toughen the boundary element (as per the inside-out design logic). Moreover, we could engineer the controlled internal space to the finest fractalated nano-level. Despommier explores similar themes in his visionary work on vertical farming. Agriculture could fundamentally be transformed, thus helping humans overcome the problem of habitat loss.

Stigmergy

What might be the universal language of biological systems? In other words, how exactly does nature signal, coordinate, evolve, and fashion elaborate webs of mutual dependence among non-conceptual entities and then sustain the patterns that emerge across immense time-spans? Stigmergy may be a possible mechanism by which nature coordinates her activities across time scales large and small. Etymologically it is of Greek origin (stigm-oí meaning pricking, signing, marking; and erg-on meaning work), while entomologically it is from a study in 1959 by Grassé on termites. The stimulation of the workers by the very performances they have achieved is a...
significant one inducing accurate and adaptable response, and has been named stigmergy.” Stigmergy may be illustrated (see Figure 9) by the ant trail that emerges (denoted as the \( \beta \) pattern) from pheromone droppings by the ant agents (denoted as the \( \alpha \) agents). The trail then helps organize the community of ants to forage for food. These (and other similar trail markings) aggregate to provide organizational directives available at various levels, both within the environment and within and between agents. Thus, even though no one controls the set of agents in a top-down sense, there is nevertheless system-wide control being established in a bottom-up sense. Across multiple iterations, the stigmergic trail smoothens and tightens (see Figure 9), thus indicating minimization of the embedded information content.

When conditions change, transitions also need to be stigmergically managed. The negative feedback mechanism that controls the stigmergic tightening in the exploitative phase would need to switch to the converse, exploratory wide-angle search via stigmergic-loosening (i.e., positive feedback) when the target food source is exhausted.

In a multi-scale sense, exploratory, lower-order positive-feedback mechanisms are operating within the context of higher-order negative feedback mechanisms. When we cast this from an inside-out design pattern perspective (see Figure 5), exogenically focused FR3 is exploratory and operates within the context of higher-order endogenically focused, exploitative FR2. Reversing this logic is seldom wise. Or, as the proverb goes, a bird in the hand is worth two in the bush.

Stigmergic organizational motifs also operate in human societies. Parunak\(^{46} \) reports on a few such, including Google page ranks, peer-to-peer computing, forest trail formation, highway traffic flows, democratic elections, group document editing, social-media groupings, viral marketing, and Amazon-style recommender systems. Problem solving via stigmergy occurs wherever the problem context is beyond the ken of any one agent. In other words, one may expect stigmergic solutions to operate in regimes that would be deemed too complex for individual agents.\(^{47} \) When conducted within a CAS context (to which we turn next), the stigmergic logic could help resolve the aforementioned (section DFS) TGAL versus TGAG conflict.

**CAS**

Now consider the evolution of the ant colony as a colony, which brings us to the concept of the CAS (see section sustainability). Holland (1929–2015) is rightly considered the father of genetic algorithms. He also laid the foundational work in the study of CAS. As Holland\(^{13} \) describes it: CASs “are systems that have a large number of components, often called agents that interact and adapt or learn.” Holland proposed a two-tiered system, as shown in Figure 10A. The lower \( \alpha \) tier follows a fast dynamic and is engaged in the flow of resources between diverse \( \alpha \) agents that also leave behind stigmergic markings. In contrast, the upper \( \beta \) tier follows a slower dynamic that captures and aggregates the stigmergic markings into emergent \( \beta \) patterns, which is then emitted system-wide as stigmergic signals that help the governed agents to self-organize and scale. The operative logic is self-organize versus command and control. Self-organization (SO) is the preferred motif in biological systems coordinating via non-conceptual stigmergy. In contrast, command and control (\( \mathcal{C}_2 \)) is the historically preferred motif in human societies coordinating via conceptual means.

From an evolutionary perspective, \( \mathcal{C}_2 \) systems may begin as uncoupled/decoupled designs yet deteriorate into coupled designs. This happens because it becomes increasingly difficult to conceptually scale the complexities of the design as the original set of FRs scale in complexity, size, and change dynamic. Humans are increasingly siloed into anthropological groupings and disciplines,\(^{46,47} \) and are therefore unable to achieve the holistic completeness that biological systems naturally obtain. In contrast to \( \mathcal{C}_2 \), SO systems begin as coupled designs, but, over the course of multiple iterations, they settle into lower-triangular decoupled designs. The drawback to SO, however, is that it operates at a glacial pace. Ideally, these two approaches ought to be combined. Ant algorithm techniques\(^{46} \) may be a way to bridge this gap in silico, whereby efficiency, conceptual order, as well as holistic completeness may be obtained.

As indicated in the section on sustainability, the problem of sustainability is intimately linked with the ability of the CAS system to propagate its \( \beta \) logic across time. For example, life itself is an emergent \( \beta \) property. At the individual-agent level (in a given society), when its life ceases, this property then dismerges. It is this emergence-dismergence logic that frames the issue of sustainability across all the various levels. The higher up the tiered \( \beta \) structure, the longer is the life span. Thus, the ant super-colony outlasts the ant colony, which outlasts the agent ant. Threats to the continued viability of the \( \beta \) logic may be internal or external to the CAS. Thus, when an ant eater comes to feast at an anthill, it is an exogenous attack on the ongoing viability of the stigmergically obtained anthill logic. In contrast, the dismergence of a monogynous ant colony with the death of the queen would be endogenously driven. The evolution of a monogynous ant colony into a polygynous-polydomous super-colony addresses the endogenously driven sustainability threat.

For the sake of simplicity, all the agents in Figure 10A have been placed homogeneously in the lower tier. Such a simplification does not quite capture the iterative evolution and development of the CAS layering. Instead, at each iterative emergence of the \( \beta \) layer, there is a follow-up bifurcation of the target population into higher levels of organizational complexity (i.e., \( \alpha \) grouped in level i, and \( \beta \) grouped in level j). In each subsequent
iteration, the population is now composed of bifurcated ensembles of agent nodes and artifacts (as indicated by the dotted ovals in Figure 10 B). Bifurcation creates hierarchies (as shown in Figure 10 C). Iterative CAS, therefore, creates SO and structure in both of these interacting entity spaces. In each follow-on iteration, the respective number of nodes in each of these dotted ovals is asymptotically decreasing (with allowance for population dynamics) while the dotted ovals proliferate. Agents could task switch and migrate across these boundaries (as shown in Figure 10 C). This agrees well with Gordon’s findings:

“An ant’s behavior changes if conditions change. Removal of the ants of one size causes the others to switch task. For example, Wilson found that in many Pheidole species, the removal of minors, the smaller ants who tend to perform brood care, caused majors, the larger ants, to switch to brood care.” Note that the organizing power of the CAS hierarchy remains in the agent-free β layer. Based on this logic, every agent (including the queen) that resides in the various α layers then self-organizes. In other words, the queen in the ant nest or the beehive does not truly rule.

This again agrees well with Gordon’s findings as reported in the essay titled “The queen does not rule”:

“In an ant colony, no one is in charge or tells another what to do. So, what determines which ant does which task, and when ants switch roles? The colony is not a monarchy. The queen merely lays the eggs. Like many natural systems without central control, ant societies are in fact organised not by division of labor but by a distributed process, in which an ant’s social role is a response to interactions with other ants.” Except for the DOL issue, the above remark does agree with the iterative-CAS logic as shown in Figures 10 B and 10 C. Gordon is focused only on the α layer where what is visible are the agents, the distributed processes, and the agent interactions.

However, that begs the question: what process created these organizing motifs in the first place? In the iterative-CAS framework (as depicted in Figure 10 B), the organizational logic for the ant colony is in the stigmergically obtained β layer (which includes evolutionarily obtained biological artifacts). In the human context, the organizational β logic is our ever-growing stigmergic/conceptual knowledge. The regularities that emerge from the α into the β layer (via aggregate stigmergic/conceptual patterns) provide the fundamental integration-of-labor (IOL) logic, which, when fed back into the α layers then provides the DOL logic. Within an organism, the β → α feedback may submerge into its genetic constitution; within a eusocial context, it may submerge into the cultural norms. IOL has to precede any of the DOL orchestrations. The logical fallacy in stand-alone DOL is that there cannot be a division unless something integrated preceded it. IOL has the fundamental half that is missing in economics ever since Adam Smith highlighted the role of DOL. The IOL lacunae

![Figure 10. Complex adaptive system](image-url)
in economics (which ought to have been the governing \( \beta \)-level logic) has left the world of finance without a unifying anchor in its quest for sustainability. Without the upward-flowing IOL loop providing constant new integrative insights, the downward-flowing DOL loop is fragile, frozen, and unsustainable across the changing landscape. Thus, when dealing with CAS systems, the fundamental problem of sustainability/unsustainability reduces to the problem of securing the ongoing \( \alpha \rightarrow \beta \) emergence/submergence duet.

When considering the ant super-colony, each of the constituent colonies has its governing hierarchy, which, in aggregate, forms the hierarchal-hierarchy as depicted in Figure 10D. Likewise, in human societies, various populations aggregate into distinct hierarchies, interacting and growing hierarchically. Hierarchies are denoted as \( |H| \); hierarchies as \( |H| \). Given the variety of contexts such a burgeoning \( |H| \) (i.e., hierarchic hierarchy) creates, it is prudent to anchor the value system (and the rights that follow within that society) by the essential defining nature of individual agents at \( \alpha_1 \). In human societies, that essential defining nature would be rationality. Here, the ethical issue that needs to be resolved is, why should we locate values and rights at the level of individual agents at \( \alpha_1 \), and not at the higher levels? Given the immense combinatorial complexities of an \( |H| \), anchoring the values and rights at any other level will inevitably violate the values and rights of individual agents at the \( \alpha_1 \) level. This is because the emergent information flow in a CAS system is \( \alpha \rightarrow \beta \) and not vice versa. Violation of this flow would fundamentally cease the \( \alpha \rightarrow \beta \) emergence/submergence duet, and therefore the very sustainability of the underlying CAS system under consideration. No centralizing agency could intuit the diverse set of values of the subsumed membership without the explicit handover in a free exchange between the \( \alpha_1 \) agents. This is the fundamental reason why values and rights need to be anchored solely with the individual agents at the \( \alpha_1 \) level. Anchoring values and rights at any other level is an invitation to a Hobbesian “war of all against all.”

Thus, rights remain at \( \alpha_1 \); only its limited representation flows to the higher levels. In contrast, the organizing power in a CAS is vested in the \( \beta \) layer and not in any of the \( \alpha \) agents executing as per the \( \beta \) patterns. This is the fundamental reason why Gordon is right when she asserts that the queen does not rule. It is also why the Periclean dictum is apt and applicable; i.e., that everyone is equal before the \( \beta \) law; i.e., that it is \( \beta \) knowledge that rules. Human \( \alpha \) agents who execute as per the higher-level \( \beta \) roles may mistakenly think that the \( \beta \) power is henceforth vested in them. However, that would be a mistake, because what it does is that it stops the emergent upward flow going forward. This is the CAS logic underlying Lord Acton’s statement that “power tends to corrupt, and absolute power corrupts absolutely.” Here, corruption pertains to the corruption of the overall system as it implies the cessation of the aforementioned \( \alpha \rightarrow \beta \) CAS process. Thus, in a CAS system, the right attitude (especially when executing at the higher stratum of the \( \beta \) hierarchy) is to grasp that all values exist at the \( \alpha_1 \) level, and that every other level is subordinate and merely adds valuable services to the \( \beta_1 \) layer. It is, therefore, neither false pride nor false humility to acknowledge that it is knowledge (i.e., the \( \beta \) layer) that rules. This agrees well with traditional systems thinking as explicated by Meadows:

“Hierarchical systems evolve from the bottom up. The purpose of the upper layers of the hierarchy is to serve the purposes of the lower layers.” It also establishes the bicameral logic embedded in the TGAL dictum. Here, think globally (TG) pertains to the \( \beta \) layer, while act locally (AL) pertains to the \( \alpha \) layer. Between the two, \( \alpha \) has dominance and is rooted at the \( \alpha_1 \) layer. The aforementioned inside-out design pattern is based on the evolutionarily sensitive CAS framework, which is simultaneously both top down and bottom up. \( \alpha \rightarrow \beta \) is bottom up, while \( \beta \rightarrow \alpha \) is top down. Between the two, in each iteration of the CAS evolution, \( \alpha \rightarrow \beta \) (i.e., inside-out) precedes. In this fundamental sense, the inside-out design pattern may be considered as bottom up, given its evolutionary sustainability potential. However, when considered as an overall system, it is both top down and bottom up in its bipartite dynamic. Furthermore, when considering a multi-scale system of systems (i.e., a CASOS), threats to system integrity may arise at different levels of the multi-scale. Therefore, it is prudent to study the system as a whole while recognizing the bottom-up/inside-out dominance.

The moral framework

In his work “Treatise of Human Nature,”\textsuperscript{54} Scottish philosopher David Hume raised the fundamental problem of grounding the moral equation, which is known as the “is-ought” gap or “Hume’s guillotine.” Since the issue is fundamental to all designs, not just to DFS, it is essential to clarify the issue. The is-ought problem is about bridging the gap between positive statements (i.e., what is) and normative statements (i.e., what ought to be). The designer only has access to factual statements of things that exist (i.e., what is). Based on such statements, how could one infer the logical status of projective moral statements concerning what ought to be? Restating Hume’s guillotine in the AD framework, the issue is about the mapping between the FRs and the DPs, with the FRs being all about what ought to be, and the DPs being the set of all things available in the designer’s design palette. If Hume is correct, then no design is possible, including each zigzag hierarchical mappings between the FR and DP domains. The clue to resolving the 280-year-old Humean puzzle is in the Christmas-tree-like structure of the two design hierarchies that form (i.e., the FR and the DP trees). Once the apices of the two respective trees are properly mapped, then the rest of the lower branches may also be logically mapped across under the deductive shadow of the apical map. Historically, there have been two approaches proposed, one that is teleological (or Aristotelian,\textsuperscript{55} Figure 11A), the other deontological (or Kantian,\textsuperscript{56} Figure 11B). In the teleological approach, the principle of life (DP\(_L\)) sits at the apex; in the deontological approach, duty as a felt or intuitively arrived-at cause (DP\(_D\)) sits at the apex. The teleological life principle is positioned at each individual living entity level (i.e., at the \( \alpha_1 \) level). Kant positioned the categorical felt imperative (that is being intuited from the otherwise inaccessible noumenal realm) at the total societal level represented at \( \alpha_2 \) (Figure 10C). In other words, Aristotel’s approach is bottom up and SO while Kant’s is top down and C\(^2\). Later philosophers replaced Kant’s totality constraint and allowed it to be located at intermediate sub-group levels instead of the total. Referring back to Figure 10C, this would mean that DP\(_D\) is anchored at the \( \alpha_1 \) level within each individual \( \beta_1 \) agent (by the essential defining nature of all such agents \( \alpha_1 \)); in contrast, DP\(_L\) could be anchored at any of the \( \alpha_2 \) group levels (by the essential
defining nature of the group $\alpha$. In the latter case, it is therefore possible for the same entity to be in harmony with the ethical norms established and accepted at one level while being in conflict when the entity’s membership is considered at a different level. As mentioned earlier, the deontological approach devolves into a subjectivist Hobbesian war of all against all. In contrast, the teleological approach anchors the moral within the individual grain at the $\alpha$ level and nowhere else. Agent-level conflicts would then need to be resolved by appealing to the agent-defining principle at the $\alpha$ level (i.e., rationality). The teleological approach agrees with the aforementioned discussion of values and rights in the context of a human CAS system. The fundamental problem with the teleological approach is the rationality or, more precisely, the lack of it within the individual grain at the $\alpha$ level. This is because it presupposes a rationality-based educational system. However, the educational system itself is a CAS system that ideally is keeping abreast of the moving knowledge corpus, which, again, is yet another CAS system. Absent rationality, there is no fundamental difference between the two systems. Much depends on a healthy, vigorous educational system as the foundation for a sustainable future. Unfortunately, that is not the case. Our educational systems are failing on account of poor designs. When the queen dies, the ant colony dismerges; likewise, when our educational systems die, the human civilization itself dismerges.

Values and value systems only apply to living entities because they are the only ones capable of bridging the Humean gap. In the teleological framework, it is the life principle (denoted as $DPL$) that sits at the apex of all designs (whether conceptual or stigmergic in origin). Life is an “is” that provides the governing direction, which dictates the rest of the is-ought design. For example, the sunflower solved the Humean puzzle by stigmergically mapping its life principle, which is an “is” (i.e., $DPL$ to the very first FR$_1$: “To live, it needs to obtain as much sunlight, etc.”). Furthermore, the $DPL$ for this FR$_1$ would then be heliotropism. Indeed, every teleological act of purposeful living by any of the living entities would similarly be operating under the shadow of the life-affirming principle, $DPL$. Everything that a living entity does is orchestrated around this fundamental “is”. In other words, every act of design (regardless of whether it is art, architecture, engineering, culinary, legal, medical, sociological, etc.) is subsumed under the life principle, $DPL$. It is life itself that is the fundamental justification for the mapping of all subordinate values. Absent life, no entity can map across the Humean divide. Thus, the Earth, which itself revolves around the sun, does not have a moral standing as it lacks a similar $DPL$. It simply is; there is no ought that dictates its actions. In other words, value and value systems do not apply to abiotic entities. Having established life as the primary logic for all of morality, let us now consider the issue of environmental ethics.

Figure 11. Bridging the Humean is-ought gap
(A) Teleological Humean gap closure.
(B) Deontological Humean gap closure.
All living entities along with abiotic elements are approximated as in Figure 12. Anthropocentrism-strong (AS) is a variant of AS, except it rejects the deontological arbitrariness of felt preferences. Instead, it will only allow considered or rational preferences. It is not to suggest that rationality is infallible, but it is the sanest of all our options. The AW framework adopted herein is a CAS variation on Norton’s considered-preferences approach in the sense that it appeals to considered or rational preferences at the higher level. The problem with Norton’s approach is that only humans at the individual level have the requisite faculty for rational thought and action. Also, as Baba Dioum indicated, it is bottom-up, grain that brings about the rational order. The act of design is about making reasonable comparisons and choices. Unfortunately, reasoning about the comparative behavior of large socio-eco-technical CAS systems is not straightforward. Questions are 2-fold: (1) how best to make reasonable comparisons? (2) How to conduct experiments in a field setting that affords few controls? The following two sections briefly describe the comparative method and natural experimentation.

### Comparative method
Comparing and contrasting is at the foundation of all learning. As psychologist/philosopher Watzlawick wrote, “all perception and thought is relative, operating by comparison and contrast.” The comparative method emerged in the eighteenth century in social sciences to analyze “two or more systems … for finding commonalities across an extraordinary range of aesthetic, social, and scientific fields of research, from philology to anatomy, from geology to sociology.” At the base of the comparative method is the collection and collation of data. There are four basic data-collection approaches:

| Ethical System                  | Valuation Principle                        | Valuing Agent                                      |
|--------------------------------|--------------------------------------------|---------------------------------------------------|
| Anthropocentrism-Strong (AS)   | All entities (living, non-living) valued as means to human ends via “felt” preferences. | Individuals who aggregate to Institutions, Markets, Government, Society, etc. |
| Ecocentrism (E)                | All living entities along with abiotic elements have intrinsic value | Empaths who aggregate to Institutions, Markets, Government, Society, etc. |
| Biocentrism (B)                | All living entities have intrinsic value    | Empaths who aggregate to Institutions, Markets, Government, Society, etc. |
| Anthropocentrism-Weak (AW)     | All entities (living, non-living) valued as means to human ends via “considered” preferences. | Individuals who aggregate to Institutions, Markets, Government, Society, etc. |

Figure 12. Environmental ethics
1. Primary sourcing: historically original records and official documents from archives and museums.
2. Secondary sourcing: historical accounts by historians, archeologists, paleontologists, and other researchers.
3. Ongoing statistics: base-level time-series data such as census, infections, control-measures, and death rates.
4. Personal recollections: memoirs, diaries, letters, biographies, etc.

Each of these approaches will find use in the upcoming financial sustainability case study. Data problems may result from a narrow inductive base (see section AD framework), cognitive bias among researchers, incomplete records, data loss, etc.

One of the early pioneers of comparative analytics, John Stuart Mill, proposed five methods for analyzing observations, one of which is the method of difference: “If an instance in which the phenomenon under investigation occurs, and an instance in which it does not occur, have every circumstance save one in common, that one occurring only in the former; the circumstance in which alone the two instances differ, is the effect, or cause, or an indispensable part of the cause, of the phenomenon.” Thus, if greater numbers of financial crises are observed with a particular set of policy structures and less so with a non-overlapping set, these differences may be causally related.

Comparative analytics is currently bifurcated across the rational choice approach versus the cultural/historical approach. Bednar and Page try to bridge this gap from a CAS perspective. Their approach agrees with the bottom-up CAS architecture in which outcomes in complex systems emerge from the bottom up. Cast in the logic, the cultural/historical approach is more , while the rational choice approach is more . The resolution of the bifurcated structure is in establishing the dominance (as was the case in TGAL) and tracing the evolutionary buildup toward the .

Natural experiments
Socio-eco-technical systems are CAS within CAS; i.e., they are CASOS in nature. With a bottom-up CAS system lacking central control, the experimenter cannot conduct randomized controlled experiments. To elicit the causal structures of such an unwieldy system, the researcher could use the help of natural experiments. Dunning summarizes all experiments across three defining characteristics:

1. The ability to compare the response to a given treatment between the intervention group versus the control group.
2. The ability to randomly assign subjects between the treatment versus the control group.
3. The ability to design the treatment to be administered to the intervention group.

Randomized controlled experiments share all three attributes. In contrast, observational studies engage in only the first of the above attributes as it can observe and compare across cohort groups and case studies, but without the ability to intervene. This characteristic is also shared in the case of natural experiments. Furthermore, as Dunning states, it is also able to “at least partially share (2), since assignment is random or as good as random.”

The paradigm example of a natural experiment is the analysis by Dr. John Snow on the mode of transmission of the London cholera outbreak in 1853–1854. A random natural ordering of water contamination occurred across the township and social strata. As recounted by Snow, “In many cases a single house has a supply different from that on either side.” It is such naturally occurring randomness that aids in studying CASOS-style complex phenomena from a scientific perspective. Unfortunately, there is currently little research done to study CASOS from a natural experiments perspective. However, the methodological infrastructure does exist.

Having articulated the AD/CAS DFS framework (along with supportive literature on geological time, climate change, biodiversity, the moral framework, comparative analytics, and natural experimentation), we now consider the problem of financial sustainability from an inside-out design pattern perspective.

Case study: Recurring financial crises
Global financial systems are composed of local, national, and international institutions that form interlocking CASOS structures capable of transmitting contagious shock waves across the system and precipitating financial contagion. Economists Laven and Valencia (from the IMF) have compiled the flagship database of all major global financial crises that spans the period 1970–2017. This case study is based on the data from Laven and Valencia.

The database is split across high- versus middle/low-income economies. Income group breakdowns are as defined by the World Bank. Furthermore, each of the included crises is classified as banking versus currency or sovereign-debt related, with the underlying rationale as discussed below. There are 141 middle/low-income economies (MLIEs) versus 57 high-income economies (HIEs). There were 83 crises (average of 1.46 crises/country) in the HIE group during the period 1970–2017 versus 383 crises (average of 2.72 crises/country) in the MLIE group. In other words, the MLIE group suffers approximately double the number of crises compared with the HIE group. The year-by-year tally of the crises across both groups is as captured in Figure 13. Here, the blue trace is the HIE, while the tan trace is the MLIE. There has been an uptick in the severity and the number of crises since the 1980s, and ever since the dissolution of the Bretton-Woods agreement in 1971. For the most part, the tan MLIE trace envelops the blue HIE trace, except during the global financial crisis (GFC) that began in 2007. The GFC began in the US and UK and spiked across 21 of the remaining 55 HIE countries. The fundamental question that needs to be considered is whether any of the world nations have systematically been able to avoid the crisis phenomenon across the years? If so, what aspect of their inherent design captures their remarkably resilient and sustainable behavior?

All of the 198 countries that comprise the IMF database are as shown in Figure 14. The 57 HIEs are in orange (with index tag 4), while the breakdown of the 141 MLIEs (with index tags 1–3) is captured in a spectrum of colors ranging from blue to dark green. HIEs are predominantly geo-located in North America/Europe. Every country in Africa is part of an MLIE.

As mentioned, three separate classes of financial crises are being tracked: banking, currency, and sovereign debt. Each has well-defined thresholds that help track whether the crisis
has reached system-level distress. Thus, a banking crisis is declared when system thresholds on bank runs, bank failures, losses, or liquidations are breached. Also, these breaches need to trigger distinct system-level, interventional banking policy responses to qualify. Similarly, to qualify as a system-level currency crisis, a country’s national currency needs to depreciate at least 30% in value against the US dollar within the following year. Also, the rate of depreciation needs to be at least 10% more than in the previous year. Finally, a sovereign-debt crisis is declared when a national government defaults on its debt obligations or postpones payments on them.

Figure 15 captures the rarest of the rare: the geographic distribution of the exceptional zero net financial crisis across HIE nations. Note that Canada and Australia stand out as exemplary cases of financial stability among fully developed nations.

Given the above country-specific context across the 47-year duration, it is now possible to attach fine-grained event timelines and the countries involved to these three crisis categories. Figures 16, 17, and 18 explore the crises-event timelines broken across HIE versus MLIE categories. As per the IMF database, the US suffered two systemic banking crises (Figure 16) during the 47 years of the study: the US savings-and-loan (S&L) crisis in 1988 and the GFC in 2007.

S&Ls were the primary source for the financing of US housing across half a century (1925–1975). There were very few failures during this period as they were locally grounded (in agreement with the CAS/TGAL logic) in their communities and serviced the mortgage end to end. In other words, they were intimately familiar with the risk profile and the carrying capacity of their customer base.

The crisis occurred in the shadow of the 1987 stock-market crash. However, the crisis had its origins in the heightened inflationary 1970s that triggered the need for FED-driven yield-curve inversion in the early 1980s, portending back-to-back recessions (Figure 19). Yield-curve inversion caused the S&Ls to be highly uncompetitive in the capital markets. S&Ls borrowed at short-term CDs to make long-term loans. With an inverted yield curve, the S&Ls became a losing proposition. In Figure 19, notice the pattern that whenever the yield curve inverts, then, within a year or so, a recession (shown as the gray vertical band) inevitably follows. If the Federal Reserve were a driver, the yield-curve inversion phenomenon is akin to stepping off the gas and hitting hard on the brakes. Furthermore, the amount of time it takes for the economy to enter the recession phase is indicative of the momentum that was earlier built up by an expansive FED monetary policy.

Restricted by regulations from paying higher interest rates to its depositors, the S&Ls saw their capital assets migrating to better-yielding money market funds. Even when the S&Ls obtained partial regulatory relief in 1978 that allowed them to offer competitive rates, these flexibilities were restricted to new accounts, leading to the problem of portfolio-level duration mismatch and continued hemorrhaging of their asset base. In 1980, the US Congress passed the Depository Institutions Deregulation and Monetary Control Act (DIDMCA), which began the process of dismantling the regulatory restrictions that were in effect since the Great Depression.
Reserve History,”68 the purpose of the act was “to provide for the gradual elimination of all limitations on the rates of interest which are payable on deposits and accounts, and to authorize interest-bearing transaction accounts.” However, despite the removal of the earlier restrictions, the crisis had already picked up momentum. Thirty-four S&Ls failed in 1981; 73 in 1982. Alarmed at the rate of failures, Congress doubled down on the deregulation by passing the Garn-St. Germain Depository Institutions Act in 1982. This act further allowed the S&Ls to engage the capital markets by speculating in high-yielding junk bonds as well as commercial real estate. It further loosened the regulatory oversight by adopting a systematic policy of “regulatory forbearance,”69 which meant the non-enforcement of existing accounting rules. Thus, GAAP accounting was dropped in favor of regulatory accounting principles (RAPs). RAP allowed the S&Ls to overstate income while understating expenses. Similar to Greensham’s law, bad regulations were driving out good regulations aimed at detecting fraud. The stage was set for a perfect storm; all that was needed to demolish the S&L industry was the accidental 1980s oil glut shock that cut oil prices to a third. S&Ls that had speculated on commercial real-estate development centered on the earlier Texas oil boom faced major losses and therefore failed. Between 1986 and 1995, approximately one-third of the 3,234 S&Ls had failed, costing $160 billion in losses and bailouts, with 80% charged to the taxpayers. 

However, it is critical to note that those S&Ls that had not yielded to the newly available speculative revenue-generating schemes indeed did survive. Abacus Federal Savings Bank in New York’s Chinatown community is one such S&L that had opened for business in 1984 during the crisis. As recounted by Abello,70 “Abacus survived these crises by avoiding speculation, staying focused on making home mortgages to Chinese and other Asian immigrant borrowers.” In other words, it stuck to its knitting instead of venturing into speculative capital markets where it lacked expertise; i.e., it remained true to its community-focused roots of providing amortizing mortgages for marginalized immigrants.

Along with the yield-curve inversion as well as regulatory roadblocks, the S&Ls also faced stiff competition from government-sponsored Fannie-Mae and Freddie-Mac. Fannie and Freddie had a significant competitive advantage in that they had the benefit of government guarantees backing their debt. This allowed them to obtain much lower cost of capital in the financial markets (some with leverage of 1,000:1). This differential created a substantial barrier for any other market players from entering the mortgage space. By and large, at the end of the crisis, the S&L industry that had served the nation for close to half a century had ceased to exist as a community-centered enterprise with local roots and risk awareness. Its community-based portfolio was systematically transferred and consolidated under the governance of Freddie-Mac and Fannie-Mae that had the taxpayer backing and, therefore, the imprimatur of TBTF. Effectively, TGAL had yielded to TGAG.

TBTF was first articulated in 1984 by congressman Stewart McKinney in the context of a $5.5 billion bailout of the Continental Bank that, like some of the S&Ls had speculated in the Texas oil boom-and-bust. The concept of TBTF is that a given failing institution designated as TBTF is of such vital national significance that its failure would bring down a significant number of CASOS-linked/co-dependent institutions along with it. From a design-matrix perspective, such an institution is so poorly designed that it tries to couple itself to every other institution via
its TBTF claim. It effectively attempts to dissolve every boundary across all the $a_i/b_i$ layers to therefore flatten the heterarchic hierarchies that power the underlying CAS structures.

The TBTF argument is that every TBTF institution should be bailed out (by the hapless taxpayer) if it fails and goes bankrupt. TBTF is also known as systemically important financial institution (SIFI). Once established as a governing principle, TBTF is an economy-wide moral hazard. Moral hazards occur when one or more parties in a given transaction are blase about taking risks as they know they will never be held accountable for any adverse consequences of their actions, as there is some other third party (often, the future taxpayer) who will be held accountable. TBTF played a significant role in the $3.6 billion bailout of Long Term Capital Management (LTCM) in 1998. Since Canada has been mentioned previously as an ideal for sustainable banking, it needs to be mentioned that all six of the largest Canadian banks have been officially designated as TBTF since 2013. All other things notwithstanding, just this one aspect of the Canadian system may not, therefore, be a good design from a coupled-design perspective. The erstwhile S&L industry did indeed have the proper micro-economic tradition for bottom-up, community-based risk aversion and decision making; however, it lacked the necessary wherewithal to navigate the harsh macroeconomics (especially when the yield curve inverts) without getting distracted. In general, bottom-up heterarchically distributed micro-economic systems are preyed on by highly disciplined, top-down, and hierarchically orchestrated macroeconomic forces. At scale, $C^2$ systems are fundamentally aligned and are able to take down SO-based CAS systems. However, AD could aid in the proper design of heterarchically hierarchic systems that could anticipate and phase-shift between the two modes based upon leading market indicators such as the yield-curve inversion logic. Sustainability requires the entity under consideration to successfully navigate both favorable as well as adverse economic environments.

The next US banking crisis flagged in the IMF database is the 2007 GFC. Once again, it centered on the US housing market. Multiple causes triggered it: the 2006 yield-curve inversion (see Figures 19 and 20); the sub-prime lending debacle; immense regulatory forbearance via the Community Reinvestment Act, which incentivizes lenders to make unsustainable loans such as the no-income-no-job-no-assets (NINJA) loan in poor communities; predatory lending; poorly designed derivatives instruments (i.e., ill-tested, highly leveraged/financialized, and massively coupled MBSs, CDOs and CDSs); rating-agency failures; as well as (by now) the well-established and symptomatic bailout cure for multiple TBTF firms, including AIG, Bank of America, JP Morgan Chase, Morgan Stanley, Citigroup, Goldman Sachs, and Wells Fargo. The immediate bailout cost has been estimated to be $1.488 trillion (Bear Stearns, $30 billion; TARP, $440 billion; Fannie & Freddie, $187 billion; ARRA, $831 billion). However, from a broader perspective, the US Treasury estimated the total loss to household wealth to be close to $19.2 trillion.

The collapse of Lehman Brothers sent the sub-prime contagion across the global financial CASOS system. The financial systems between the US and UK are tightly coupled; the UK, therefore, faced the GFC contagion during the onset year (2007) alongside the US. Nineteen other countries from the HIE

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**Figure 15. Zero financial crises across select HIEs (IMF database)**
group faced financial crises (and predominantly in the banking sector) the following year (2008), including Germany, France, Portugal, Ireland, Iceland, Switzerland, and Spain. Eight failures occurred during the same period in the MLIE group. Both groups are plotted in Figure 21, with HIE in green and MLIE in pink. The map shows that these failure groups are geographically coupled and tend to act in unison during the crisis. It is not that the other countries unflagged in the IMF database are somehow unaffected by the GFC. For example, sub-Saharan Africa was strongly affected by the GFC spillover. In the global value chain, Africa is primarily a commodities exporter. Africa likewise slowed down when the economies downstream on the value chain slowed down because of the GFC. For example, as reported in Arieff,72 “total exports to the United States from all 41 countries eligible for trade benefits under the African Growth and Opportunity Act (AGOA) declined by 63% in the first half of 2009, compared to the same period of 2008.” Nevertheless, African nations did not cross the IMF financial crisis database threshold.

As is evident in Figures 16, 17, and 18, rarely do crises occur individually; instead, they flock together. In other words, there is serial correlation between CAS systems that form part of a larger CASOS. How might we quantify system coupling from a coupled-design perspective (Figure 4D)? Between contagion, connectedness, and correlation,73 contagion is the uncontrolled spread of a risk factor (whether a viral infection such as corona-virus disease 2019 [COVID-19], a forest wildfire, or a financial crisis). When everything is connected to everything else, and there are no systemic boundaries/de-couplers that partition and disengage the various parts of the overall system on an as-needed basis, then the whole system is caught up in an uncontrollable conflagration that can cripple the productivity of otherwise viable elements downstream along the contagion chain. The exponential scale-up of available pathways to contagion within a coupled design is as shown in Figure 22. An uncoupled design at every level is akin to the FR or DP tree structure where there is exactly one single pathway between any two nodes. This is as shown in Figures 22C–22E. For a $16 \times 16$ design matrix, there are, at worst, $2^{16}$ such single pathways (i.e., $n(n - 1)$, where $n = 16$ is the size of the design matrix). In contrast, in the case of a highly coupled, full-design matrix, there are $2^{n(n - 1)}/2^{n(n - 2)}$ pathways. With $n = 16$, that is an exponential number of over 2 billion pathways for the contagion to spread. In the early days of a viral pandemic, it may be possible to contact trace and quarantine the exposed members; but such is not the case once a large percentage of the population is exposed. Indeed, the early stages of a viral contagion are similar to a sparse-design matrix where the causal linkages between FRs and DPs are few and far between and therefore easily traced. When cast in the design-matrix framework, the problem of contact tracing during a runaway contagious pandemic is similar to
the problem of contact tracing during an out-of-control financial contagion. Once the pandemic has spread widely across the population base, the problem of contact tracing is akin to disambugating the causal linkages between FRs and DPs across a full-design matrix.

From a principled design perspective, left unchecked, every financial crisis attempts to create ever-larger design-matrix couplings for the next iteration. It happens because, absent the principled approach, it becomes increasingly impossible to perform the diagnostics as to what transpired in the last iteration, let alone project the right way to tackle a similar crisis going forward.

For parties at the receiving end of losses incurred during a financial crisis, erstwhile relationships of trust break down during ages to various TBTF sources that may be embedded both endogenously as well as exogenously. Earlier, it was mentioned that the overall average of all crises was 1.46 crises/country in the HIE group, while it was 2.72 crises/country in the MLIE group. In other words, the MLIE countries suffer, on average, approximately twice as many crises per country in comparison with the HIE-member countries. Nevertheless, how does this overall average distribute across banking, currency, and sovereign-debt categories? Figure 23 captures the average statistics at the finer grain. Between HIE and MLIE, banking suffers about the same order of crises per country, whereas currency and sovereign debt suffer three times as many. Coupling could exist across all three sectors. Thus, banks could have sovereign exposure or could be bailed out. Likewise, sharp currency depreciation could lead to fund transfers to safe-havens, etc. Currency and sovereign-debt crises...
are rare among HIEs on account of the reserve currency status that many in this group (directly or indirectly) enjoy. As regards the dominance of banking crisis compared with currency and sovereign-debt crisis, Laeven and Valencia highlight the micro-to macroeconomic flow (i.e., from firm-level banking to the nation-state as well as the global scale): “It is common for banking crises to happen at the same time or precede currency crises.”

Overall, the financial sustainability issue is equally severe for both HIEs and MLIEs. MLIEs face the gambler’s ruin in the sense that their capital reserves are low, their range of maneuverability under crisis conditions is limited, they are at the low end of the global value-chain add, etc.; they could therefore be severely impacted under crisis conditions. Likewise, given the highly unsustainable, profligate, TBTF-style response among many of the leading HIEs, they also face the risk of unsustainability, especially given their declining demographics profile.

In the above summary, the concept of pro- versus anti-cyclical economic control needs to be re-stated from an AD/CAS perspective. It is generally acknowledged that, given their seasoned economic life-cycle maturity, the HIEs have a complete set of anti-cyclical controls; in contrast, MLIEs are far more pro-cyclical. The anti-cyclical design can marshal negative feedback loops to help smoothen a wayward business cycle; in contrast, a pro-cyclical design is at the mercy of positive feedback loops that deepen the business cycle/crisis. Such asymmetries become all the more pronounced when pro-cyclical MLIE moves are chained to anti-cyclical HIE moves across a global CASOS. The anti-cyclical design may be best illustrated (see Figure 24) using the example of the accelerator/brake combination in controlling the motion of a vehicle. The accelerator (or gas pedal) helps increase the speed of a vehicle. If one wants to slow the vehicle down, then taking the foot off the accelerator does allow external friction of the road to slow down the vehicle. However, if going downhill, merely taking the foot off the gas pedal does not help reduce the speed. We need two DPs (i.e., the accelerator and the brake) working independently to help...
control the two FRs (increase the speed and decrease the speed). Such a decoupled design may be considered to be operating anti-cyclically. Thus, brakes may be the lifesaver if the motorist is going downhill or needs to come to a stop quickly. However, absent the brakes, the system would be considered operating pro-cyclically, as it is missing a DP to help it from becoming a runaway vehicle. Absent the necessary number of DPs, the design is therefore coupled. Sustainable systems (including economic systems) are a careful balancing act between similar but opposing controls. Unsustainable systems are coupled systems that lack such counter-balancing forces (that help in the controlled scaling of the system) and therefore lead to the unsustainable runaway vehicle problem. Criticizing the economic business cycle, Suh15 remarks that “The Economic Cycle is a well-known phenomenon. Often new economic opportunities created by a new technology may initiate a boom in economic activity. When a new technology is created, initially a real wealth is created when new jobs and new products spur economic activities and promote productivity and growth. However, when these things turn into a speculative spiral, it cannot be sustained, since it is not a real wealth creating activity.”

In the economic context, that runaway vehicle is the unsustainable boom-and-bust phenomenon. Counter-balancing controls may either be obtained via a top-down command C² economy or via a bottom-up CAS SO economy.

HIEs are predominantly decoupled counter-cyclical designs. Also, most of these are top-down C² economies (under their respective central banks) with sufficient DPs to either accelerate or tamp down the economic growth as the need arises. However, a few of the newer entrants are less of a command structure and more of a CAS structure (for example, South Korea after weathering the 1997 chaebols-driven TBTF financial crisis16). During the life-cycle maturity of an economy (and under scaling pressures), bottom-up CAS economies mistakenly yield to top-down command economies operating in the global arena. In general, bottom-up CAS economies are more robust, resilient, and sustainable in the long run. In contrast, the more mature top-down C² economies are subject to repeat booms and busts. Even though the central banks seem to have the requisite controls, they cannot time the deployment of the control actions. As is evident in Figure 19 in the context of yield-curve inversion, they miss their cue, often by as much as a year or more. It is because the fundamental problem that the HIE central bankers face is that of scale. In the context of a crisis, they are effectively trying to command a massive container ship during a perfect storm as if it were a speed boat. In the end, instead of uncoupling the design, it becomes even more of an unwieldy, massively coupled TBTF design. Compared with the HIEs, MLIEs are predominantly pro-cyclical in the sense that they do not have counter-balancing economic forces to help stabilize their economies when subject to predominantly exogenous shocks. Lacking the requisite number of DPs, these economies are, therefore, coupled. Even so, it is more likely that a few of these MLIEs will eventually evolve a better CAS-based economic model than the predominantly top-down HIEs.

Consider now the architecture of the overall financial system using the paradigm inside-out design pattern operating in a $x_2$-dominant (micro to macro) SO mode (see Figure 25A). As before, the design leads off with establishing the boundary elements. In the financial context, these would be the standard regulatory requirements around know your customer, money laundering, data privacy and security, etc. However, beyond these traditional boundary management functions is the added mandate to surveil the macro/microeconomics to activate

Figure 19. Yield-curve inversions and recessions; self-citing graph from Federal Reserve67
the biphasic shift between growth and wealth conservation correctly. Leading market indicators (such as yield-curve inversion) ought to be used to help decide when to shift between the two. It would thus be a fatal conceit (as happened to the Continental Bank in the early 1980s) to engage in speculative real-estate investments when the yield curve had suffered back-to-back inversions.

It is also essential to recognize the various CASOS boundaries within the matryoshka doll that is modern finance. Given the hopelessly siloed nature of finance, very few firms recognize the various CASOS structures within their firms, let alone across the multitude of exogenic agencies they interface and engage. Each of these boundaries has its unique legal structures and risk profiles. These relationships ought to be mapped, disambiguated, and teased out in a bottom-up sense to reveal the underlying “loosely coupled” flexibilities (if any) towards managing a crisis.

Having established the governing boundary regime, the second leg of the design focuses on the endogenic requirement to conserve and develop financial resources toward long-term sustainability and growth. Between endogenic versus exogenic factors, endogenic dominance is critical for the sustainability of the financial institution. This dominance is captured in the lead

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**Figure 20.** Yield-curve inversion, December 2006

**Figure 21.** Financial failures in HIE/MLIE economies during the global financial crisis (2007-2008)
position of FR2/DP2 versus FR3/DP3. DP2 is very much akin to the current role of the commercial bank. One of the critical measures involved in securing the sustainability of the financial unit is the maintenance of adequate capital reserves. The biphasic stance at the boundary layer may influence this. Being embedded in the community it serves, the endogenic unit is intimately aware of the strengths and vulnerabilities of its clientele. With a clear mandate toward maintaining existing functions rather than growth, the commercial bank cannot afford to engage in speculative booms and busts. In sharp contrast, the third leg of the design (i.e., the exogenic unit) is predominantly invested in growth beyond its current endogenic state. Traditionally, this function was served by the investment banks.

A good way to grasp the design distinction between FR2/DP2 versus FR3/DP3 is to compare the design with that of a plant. In the plant context, the exogenic boundary element (i.e., FR1/DP1) could be the dead bark that protects the tree against the externals. Alternatively, it could be the waxy cuticle covering the leaves and stems to help the plant retain water. Or it could be the cell wall composed of cellulose and protecting the cell against mechanical/osmotic stress. In general, plants have two types of tissue: permanent versus meristematic (Figure 25B). Permanent cells are the non-dividing cells. These cells may be living or dead. Their main functions include structural support, protection, photosynthesis, and the transportation of minerals, nutrients, and water. The burden of sustainability of the plant as a plant falls primarily on the permanent tissue. Absent the life support that the permanent tissue provides, the plant would succumb to the lack of food and water. In contrast, the meristematic tissue is in charge of plant growth via cell division (with
meristos being Greek for division). Apical meristem found at the tip of the roots and stems adds to the linear length of the growing plant. Intercalary meristem helps in the linear elongation of the middle regions of the already-established stem. Lateral meristem helps the stem scale laterally in cross-wise girth.

If we cross over to the banking aisle, we ought to see a very similar design with commercial banking providing the permanent tissue like sustainability features, including structural support for the commercial activities in a given region (such as mortgages and loans), advice, and protection against fraudulent schemes, insurance protection against untoward events, business networking for ongoing/current ventures, etc. In other words, the commercial bank is invested in securing the AL aspect of the banks TGAL responsibility; i.e., the commercial interests of a given community as it currently exists. Given its mandate on securing the sustainability of the community it serves, the commercial bank is traditionally supposed to be risk averse. In contrast, the investment bank is akin to the meristematic tissue that is sensing the dynamics in the economy to position the community it serves for strategic growth. Similar to the apical meristem, it scouts out and establishes the initial stakes for entirely new areas for growth. Like the intercalary meristem, it helps scale the existing ventures into new markets. In other words, it is exhibiting the TG role in TGAL paradigm. Furthermore, similar to the transverse meristem, it helps scale the existing ventures within the current context.

**Pro-Cyclical vs Anti-Cyclical**

![Pro-Cyclical vs Anti-Cyclical Design](image)

**Figure 24. Pro- versus anti-cyclical design**
In the banking parlance, FR$_2$ would be akin to “run the bank,” while FR$_3$ would be akin to “change and grow the bank.” As is evident from the lower-triangle design, these two FRs are best satisfied jointly between DP$_2$ and DP$_3$. Currently, because of the history of Western banking over the last 120 years, these two functions are coupled with each other, with the two DPs competing for both the FRs and the result being a fully coupled design. Note that CO$_2$-driven, top-down regulatory de-couplers are ill-equipped to address bottom-up SO decoupling needs. With the arrival of FinTech, it is perhaps possible to rearchitect the banking system to be less of a coupled design by first rearchitecting DP$_1$, then DP$_2$, and finally DP$_3$. However, FinTech that tries to replicate the current coupled design (with perhaps better technology) would only make the situation worse on account of technology-driven scaled-up couplings.

With this framework in mind, consider now the issue of recurring bank failures. Banks fail because of their risk-taking behavior. When these failures are compared across developed nations, one country stands out as a paragon of banking stability (i.e., Canada). Copelovitch and Singer recycle that, “Residents of countries around the world who have experienced the anguish of banking crises have looked at Canada’s remarkably stable banking system with awe and envy. Beginning in 2008, a global financial crisis swept North America and Europe … Canada was different. No Canadian bank failed or required emergency funding from the government … Canada’s banking stability is not a new phenomenon. During the Great Depression of the 1930s, not a single Canadian bank failed.” This pattern continues across much of the last 100 years. As recounted by Copelovitch and Singer, the Canadians have the FR$_2$–DP$_2$ perfectly aligned with clear dominance for commercial banking versus investment banking. This, however, is not by design. Instead, it is a fortuitous historical accident that the underdeveloped securities market is not allowed to dominate and be the “tail that wags the dog.” As recounted in Copelovitch and Singer, “We argue that Canadian banks’ famous conservative bias and history of stability are attributable primarily to weak competitive pressures from underdeveloped securities markets rather than from the concentrated nature of the Canadian banking system or the structure of Canadian banking regulation.” FR$_2$, the growth factor, is therefore underdeveloped. In other words, even Canada could also do better on the FR$_3$ front without compromising its FR$_2$ dominance.

The fundamental notion of financial security implies sufficient cash flows and reserves to meet routine, emergency, and long-term/retirement needs. Among the three, ambiguity around long-term/retirement needs parallels the problem of sustainability: e.g., how far into the future should one make provisions, what known and unknown health-related and similar needs may inevitably arise, and how best to provide for the necessities of life as we age.

Recent research on goal-based investing and wealth management aligns well with the form-follows-function approach embedded within the axiomatic approach. Here, FRs map to goals, DPs map to the various financial instruments that currently exist (or those that need to be designed de novo), and PVs map to the market microstructure of taxation and trading processes across various levels. The well-developed axiomatic framework could help systematically develop the goal-based investment framework across various levels and domains.

Before the advent of goal-based investing, financial products were being offered without regard to the custom goals and design constraints of financial carrying capacity and maturity of a given client. In other words, it was a mass market. With the help of FinTech automation, the financial industry is transitioning from a mass market to a mass-customized market. It is now possible to customize the offering to fit client (institutional/retail) needs. While...
much of the downward sloping deductive arch (see Figure 3A) may safely be handled by FinTech automation, the upward sloping inductive arch is where the financial adviser can differentiate and provide the creative human touch. Induction versus deduction is the fundamental DOL between humans and machines.49

The goal-based investment framework9–36 also aligns well with the inside-out design pattern (Figure 25A). The liability hedging portfolio (LHP) concept aligns well with the endogenic FR2-DP2. The performance-seeking portfolio (PSP) concept aligns with the exogenic FR3-DP3. However, notice the missing FR1-DP1 that helps establish the requisite boundaries across the various levels, absent which we again face the risk of TBTF coupling.

Our current global financial system is a poorly architected CASOS with weak boundary elements and highly coupled/centrally located TBTF elements that have proven failure pathways. As a result, the architecture is highly unsustainable and ripe for catastrophic contagion. FinTech is currently attempting to automate and integrate many of the banking functions end to end. However, that does not address the problem of an unsustainable design that it is trying to replicate and automate. Replicating a poor design with better technology does not solve the fundamental problem of an unsustainable banking architecture. In contrast, the plant-biology architecture that has evolved over 500 Ma is similar in function and far more sustainable.

Results and discussion

CAS systems create a fundamental conundrum for traditional, top-down $\beta \rightarrow \alpha$ designers. In traditional systems design, we generally consider the whole system before decomposing it into its constituent parts. Thus, we design the house as a whole before we consider the interior design, and the actual furnishings in each room. In the case of the CAS-system design, the traditional top-down order would need to be reversed. It is as if the lowest-grain $\alpha$-level, LEGO blocks need to be envisioned first, then how these may function either independently or in combination with other units to deliver on a variety of emergent $\beta$-level functionalities. As in nature, such bottom-up designs are usually coupled to begin with, but, over multiple iterations, they settle into a lower triangle that is both adaptive as well as functionally reasonable. However, whatever may be the grain of design, there is a common, consistent, AD-assisted, inside-out design pattern that could help the designer attain the goal of sustainability at every level of a multi-scale/multi-model CASOS system. We illustrated the simplicity and elegance of the inside-out design pattern in biological systems that span and sustain across millions of years. It is sufficiently abstract (DITA) as well as adaptable (DFA) to novel circumstances. When applied in the financial context, it could help restructure our otherwise highly coupled (TBTF) and unsustainable financial systems from a bottom-up SO perspective.

The findings, limitations and future work are summarized as follows:

1. Philosophy of DFS:
   a. Findings. Philosophically, we located the problem context of DFS in the B level of the $A \rightarrow B \rightarrow \Omega$ continuum. A and $\Omega$ are the unchanging Parmenidean eternals, while the B’s are the unsustainable Heraclitean fluxions.
   b. Limitations. A conceptual body of knowledge is missing that could help bridge such a vast set of existents that span multi-scale/multi-model B’s.
   c. Future work. What general principles may be gleaned by studying highly sustained systems (whether physical or biological)?

2. CAS versus CASOS in the context of sustainability life span:
   a. Findings. Using the case study of the ant super-colony, we highlight the significance of the emergent $\beta$ in order to show how CASOS systems have a longer sustainability life span compared with the constituent CAS’s.
   b. Limitations. While CAS systems have been well researched, there is a paucity of research on CASOS systems.
   c. Future work. Empirically and theoretically explore the CAS-CASOS linkages.

3. TGAL versus TGAG:
   a. Findings. We have compared and contrasted TGAL with TGAG in the context of CAS.
   b. Limitations. TGAL has not been studied rigorously in the context of CAS.
   c. Future work. Explore all the combinations (TGAG, TLAL, TLAG, TGAL) in the context of CAS.

4. Inside-out design pattern for DFS:
   a. Findings. Using straightforward logic, we have framed the inside-out design pattern for DFS.
   b. Limitations. While the inside-out design pattern makes logical sense, are there cases for variations on this theme?
   c. Future work. While the biological cell is following an inside-out design pattern, the mitochondrion is following an outside-in design pattern. Theoretically explore and contrast all the other combinations (inside-in, outside-out, outside-in, and inside-out).

5. IOL versus DOL:
   a. Findings. Indicate how IOL is the missing body of knowledge in economics, the neglect of which creates misalignment in human societies by creating top-down $\beta$-dominance when, in reality, it ought to be bottom-up $\alpha$-dominance.
   b. Limitations. Logically, it makes sense that DOL cannot occur without IOL preceding it. However, this is a hypothesis that needs to be empirically grounded.
   c. Future work. Explore what evidence there is for IOL. Who does it? Moreover, how are they compensated? Is it, therefore, any different from DOL? If so, how?

6. Hume’s guillotine from an AD perspective:
   a. Findings. Bridging Hume’s is-ought gap by using the power of hierarchical decomposition and the FR-DP mappings.
   b. Limitations. Historically, Hume’s guillotine fractured human knowledge into disconnected silos. Where are the most significant impacts of this breach? What will it take to bring back unity into the design and structuring of human knowledge?
   c. Future work. What are the philosophical and practical scientific/engineering implications of overcoming the Humean obstacle?
7. Moral framework based on AD-based teleology:
   a. Findings. We have framed the moral framework from an AD-based teleology. We have then used it to capture the four main environmental ethics viewpoints, including AW.
   b. Limitations. The role of principled design in the realm of ethics has not been widely explored, yet it is critically needed.
   c. Future work. Study and critique various ethical systems from a design perspective.

8. Comparative methodology from an iterative $\mathcal{A} \rightarrow \mathcal{B}$ logic:
   a. Findings. The comparative method was put to good use in the comparisons involved in the case study. Currently, the comparative method is bifurcated between the rational choice versus the cultural/historical approach. Researchers have recently framed the methodology in basic CAS terms. By casting the above two antipodal approaches in an iterative $\mathcal{A} \rightarrow \mathcal{B}$ CAS framing, it may be possible to bring richer alignment between the two. Such a resolution could aid in developing design methodologies when dealing with socio-eco-technical systems, since comparative methods are central to exploring the choice structures in this complex.
   b. Limitations. Currently, the CAS approach to comparative analysis (both basic as well as iterative) is at the proposal phase. However, the benefit to socio-eco-technical systems research could be substantial since many of the sustainability problems exist within this complex.
   c. Future work. Augment with the iterative $\mathcal{A} \rightarrow \mathcal{B}$ logic.

9. Natural experiments to study CAS/CASOS:
   a. Findings. We introduce the promise of natural experiments for the study of CAS-based socio-eco-technical systems.
   b. Limitations. While the potential for utilizing natural experiments in the context of vast CAS-based socio-eco-technical systems is promising, there is a dearth of research in this field.
   c. Future work. Examine the methodological underpinnings of natural experiments from an iterative $\mathcal{A} \rightarrow \mathcal{B}$ CAS framework that can extricate the unfolding fractal structures.

10. Case study: inside-out design to tackle financial crisis:
    a. Findings. We explored the abstract inside-out design pattern to solve the problem of repeat financial crisis by establishing bi-phasic boundary controls to limit financial contagion and give dominance to endogenic versus exogenic artifacts.
    b. Limitations. Across history, the varieties of ways that financial systems may enter the zone of crisis is immense. It is perhaps naive to think that a single design pattern could cover all the varieties of ways that financial systems could end up in ruins.
    c. Future work. Perform comparative analytics on a variety of financial crises (especially those that did not meet the IMF database threshold) to understand the genesis of these in the small scale, before it crosses the IMF threshold criteria. Evaluate these instances to see if they confirm as an anti-pattern to the inside-out design pattern.

11. Contagion from TBTF as a case of highly coupled design:
    a. Findings. We showed how a highly coupled design matrix exponentially grows in the number of ways the design can fail. Moreover, that TBTF is an example of a highly coupled design matrix.
    b. Limitations. While it is assumed that each of the TBTF contagion pathways is equally likely, that may not be true.
    c. Future work. Perform meta-analysis on financial contagion research findings from a design-matrix perspective to explore preferred TBTF contagion pathways.

12. Design for goal-based investment and wealth management:
    a. Findings. We highlighted the alignment between AD and goal-based investment and wealth management. There is also alignment between the inside-out design pattern vis-à-vis goal-based investment.
    b. Limitations. There are significant areas of misalignment when considering the absence of an explicit design matrix when mapping the FRs to the DPs and PVs. Thus, the problem of coupling would remain implicit and obscure. Also, from an inside-out design-pattern perspective, the problem of missing boundary elements could lead to similar TBTF issues as is currently the case.
    c. Future work. Develop goal-based investment and wealth management from an axiomatic/inside-out design pattern perspective.

It is critical to acknowledge and grasp that CAS systems are not operating under top-down, hierarchical $C^2$ control; instead, they are fundamentally distributed and operating under bottom-up SO control. As Gordon summarizes it, “Understanding how ant colonies actually function means that we have to abandon explanations based on central control. This takes us into difficult and unfamiliar terrain. We are deeply attached to the idea that any system of interacting agents must be organized through a top-down hierarchy. Our metaphors for describing the behavior of such systems are permeated with notions of a chain of command.” The design of a CAS system (which is fundamentally bottom up) requires the designer to pay close attention to the nature of the individual $\mathcal{A}$-agents and the degrees of freedom they need in order to sustain, flourish and emit their $\mathcal{B}$-pattern-making signals across the various levels of the CAS/CASOS. When these degrees of freedom are curtailed under a hierarchical $C^2$-control regime, so likewise is the ongoing adaptive emergence of the upward arching $\mathcal{B}$-patterns, which in essence dictates the life span and therefore the sustainability metric of the CAS/CASOS.

**EXPERIMENTAL PROCEDURES**

**Resource availability**
This was an inter-disciplinary comparative analytics study based on publicly available data, including the IMF database on financial crises.
Lead contact
Further information and requests for resources should be directed to and will be fulfilled by the lead contact, John Thomas (johntom@cogtools.com).

Materials availability
This study did not generate new unique biological or chemical materials.

Data and code availability
Data reported in this paper may be shared as per open access. This paper does not report original code.

DECLARATION OF INTERESTS
John Thomas is employed at AeroFarms (a vertical farming company) post the submission of this article. He is also a founder of Cognitive Tools Inc. LLC, which has provided consulting services in the financial sector. Pam Mantri is a founder of Cognitive Tools Inc. LLC.

AUTHOR CONTRIBUTIONS
J.T. and P.M. contributed equally in the conceptualization, methodology, literature-search, investigation, formal analysis, writing, illustrating, reviewing, and editing. P.M. provided lead insights in the biological framing of the issues. J.T. provided the philosophical, design, and financial framing.

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