Creation, Crisis and Iconoclasm: Complex Societies at the Edge of Chaos

Michael Tuck
contact@michaeltuck.com

May 10, 2022
Toronto, ON

ABSTRACT: Crisis is inevitable; crisis is necessary. The flux of an out-of-equilibrium complex-systems universe implies the first conclusion; a new framework of cultural evolution through paradigm catharsis presented here implies the second. From art to economics to governance, human systems evolve through systems of ideas. Building from the human's experience of time, and synthesizing concepts in collapse and complex systems theories, the framework outlined here explores how ideas emerge and spread through understandable paradigms and the thresholded responses of individuals. Then, following the framework's outline, an illustrative model simulates a simple evolving society, organized by mutable paradigm rules, in which thresholded agent responses result in the creation, and cascading power-law spread, of paradigms through feedback with expected and real returns in oscillating periods of crisis and metastability. The framework implies that crisis is necessary both for societal evolution and to avoid societal collapse, but also that crisis may be further incorporated into social structures, like is already done through elections.

KEYWORDS: societal collapse, cultural evolution, self-organized criticality, bounded rationality, agent-based model, catharsis

This paper, with no regard for the boundaries of disciplines, stabs at the question of whether human societies are trapped in an endless evolutionary cycle of overextension and collapse. In doing so, the paper outlines a basic rhythm of human experience from which, though fractal repetition, the pseudo-cycles of history might emerge without contradicting those seemingly chaotic details that tend to break most grand historical theories.

Section “Antecedents” links collapse and complex systems theories together in the emergent cascading power-law change found in diverse events like earthquakes, stock-market crashes and wars.

Section “Framework” attempts to tease out the implications of the antecedents by synthesizing a new framework of cultural evolution (i.e. evolution at the level of ideas) in which cultural shifts happen in the cascading change of cathartic paradigms, hopefully threading the needle, with the help of complexity, between the order of Panglossian high modernism and the chaos of nihilistic post modernism.

Section “Model” explores how that framework might be used to model societal evolution at the level of ideas, illustrating the potential mechanics of cascading change through agent responses to expectations versus experience.

Section “Discussion” then suggests that were this framework to be accepted as a useful abstraction of reality, you would have to conclude that individual and societal crisis are necessary both for societal evolution and to avoid societal collapse. In other words, crisis in this synthesis becomes the cascading, creatively destructive core of societal evolution, at all levels from the individual to the whole--the nexus of choice and complacency where we might decide against continual overextension.

Antecedents

The **paradox of collapse,** says Tainter (1988: 151), is that “a drop in complexity brings with it a corresponding rise in the marginal return on social investment.” In Tainter’s framework, complex societies grow through a positive feedback loop of problem solving through energy investments in intensified agriculture and resource production, technical advances, increased information processing and complex socio-political organization, with returns on investment feeding more energy into the system for further problem solving. But the problems don’t stop coming, even as marginal returns from new investments decline. Thus, Tainter concludes that, long term, the **diminishing marginal returns of complexity**[1] tend to make investing in further complexity an increasingly unattractive problem-solving strategy, tipping societies into a negative feedback loop where problems that would have been minor during a society’s up-curve become the straws that break the back of that same society on the down-curve. Parts of system may then rationally choose to decompose, causing collapse. (Why pay heavy taxes to the Roman army to keep the barbarians out when not only can the army not keep the barbarians out, but those same barbarians offer protection at much reduced rates?) Yet collapse, as defined by Tainter as *rapid*

[1] Tainter’s complexity includes essentially all complications of a complex society (e.g. population, area, specialization, hierarchies), which is similar enough to the “order emerges from disorder” complexity of complex systems that sits, as Charbonneau (2017) describes, between simple and chaos, but (being complex) has itself no clear definition.

simplification,[2] by clearing out complexity through iconoclasm, destruction and death, increases the marginal returns of complexity for those who survive, encouraging societies to grow to the point of collapse yet again.

Examples of diminishing returns: Slash-and-burn farming is extremely productive, until it destroys the soil. Initial development of simple irrigation systems offers better returns than incrementally improving and maintaining those same systems. The printing press made it possible to know everything a medieval European could, but then fermented so much new knowledge that new specialization and administration was required (while also triggering Europe's descent into two centuries of religious wars). The steam engine helped spark the industrial revolution, but steam has physical limits, no matter how much you spend on R&D.

Following that complex societies, "like all living systems, are maintained by a continuous flow of energy" (Tainter 1988: 91), Bardi et al. (2019) model societal collapse using a trophic system to represent the flow and dissipation of energy through resource production and the economy. They find, unsurprisingly, that in a system with non-renewable resources, unless new resources are found, the system evolves towards irreversible collapse, but also that, even when modeled with renewable resources, the system still circles a phase-space attractor. In other words, societies like our own that rely on non-renewable resources face inevitable collapse unless they find new sources of energy and material, but even in societies using only renewable resources there is no stable state. Instead, such societies *oscillate*, evolving in an **out-of-equilibrium** state, like wolf populations that lag deer populations which themselves lag sapling growth. The lag in filling and emptying trophic stocks traps the system in the "Seneca" curve (Fig. 1).

Hence, **hysteresis**—the system's further evolution depends on its history: You can't, Bardi et al. conclude, simply cut the bureaucracy and expect the system to return to how it functioned while growing, but neither will further investments in organizational complexity stave off collapse. Examples given include the 19th century American whaling industry and the 20th century Japanese fishing industry, where operators continued to invest more in ships and equipment to mitigate for diminishing stocks even after gross returns were in decline. And likewise, Bardi et al. note that the Roman army continued to grow even as the Roman economy declined.

[2] Meaning, collapse under Tainter's definition allows some continuity, with the complete obliteration of societies being, he notes, extremely rare.

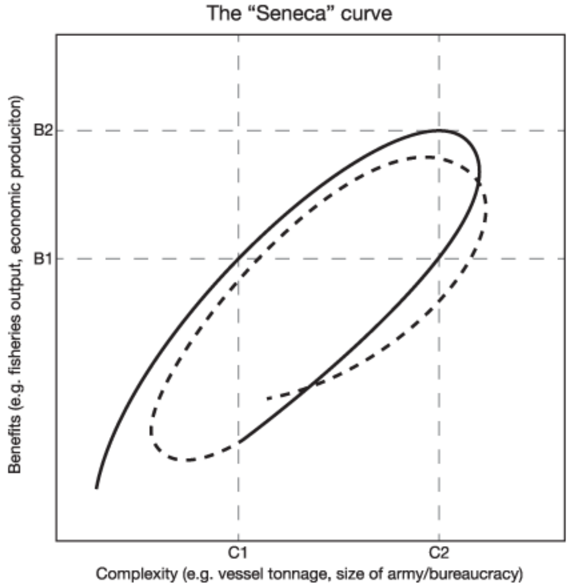

Figure 1: Adapted from Tainter (1988) and Bardi et al. (2019), the general curve of diminishing returns found in societal energy flow systems. The curve, following Bardi, differs from Tainter's in the rapidity of its fall and how in systems of renewable resources it circles an attractor. After B2, C2, Tainter considers collapse "a mathematically likelihood". Note the hysteresis: B1, C2 has the same benefits as B1, C1, but higher complexity. Called the "Seneca cliff" or "effect" by Bardi after a typically bite-sized Seneca the Younger adage: "Fortune is of sluggish growth, but ruin is rapid."

Faced with the problem of diminishing returns, Tainter (1995, 1996) adds that to assess the current risk of collapse we must understand our "historical position in a system of evolving complexity," and then, in order to face the fact of diminishing returns, we need to develop energy for further problem solving. Tainter (2000) develops this into three abstracted futures that all societies face. The European future: intense competition leads to ever increasing energy extraction to support ever increasing complexity. The Roman future: facing little competitive pressure, societies may find further investments in complexity an increasingly poor problem solving strategy, leading to collapse. The Byzantine future: in rare cases, some societies may choose a sort of conscious simplification—though again, this cannot mean simply a return to an earlier moment in the system's history. Byzantium's survival emerged alongside iconoclasm, the loss of most of its territory and the decimation of Anatolia, which freed land for a new semi-feudal army.

Are societies trapped in the paradox of collapse?

If that all feels a little too Malthusian or Club of Rome[3], here are two arguments against the almost fatalism of energy flows: the first might be called optimistic or Panglossian depending on your bent, whereas the second is a cultural argument.

The optimist-Panglossian argument: Innovation will forever save us from the diminishing returns of previous innovation. Tainter argues that investments in information processing (invention, science, R&D) also face diminishing returns, with increasing energy needed to innovate our way out of the diminishing returns of growth allowed by previous innovation as societies face "increasingly complex questions" (1988: 114). However, by looking mostly at data covering a relatively short time-scale, Tainter may underestimate the potential for *creative destruction* in innovative revolutions linked to long economic oscillations (Schumpeter 1942), where, like in the paradox of collapse, each economic crash brings with it simplification that makes further innovative complexity more appealing while simultaneously forcing creativity in order to survive. Hence, like in Bardi's trophic flow model, the economy seems to oscillate around an attractor, but as seen in a cost vs. return chart of the S+P 500 (Fig. 2), innovation moves that attractor, even if after major breakthrough eras, the following incremental inventions, though they might produce many minor patents, do little to change economic foundations until the next Kondratieff wave (Korotayev et al. 2011).

[3] Indeed, Bardi is a member of the Club of Rome and his research is in part an attempt to create "mind-sized" models that are easier to understand than the original *Limits of Growth* world3 model. Of note, according to certain proxies, the global system remains largely on course with two of world3's scenarios: one leading to collapse and the other only leading to decline, but with the latter scenario requiring much higher innovation than at present (Herrington, 2021).

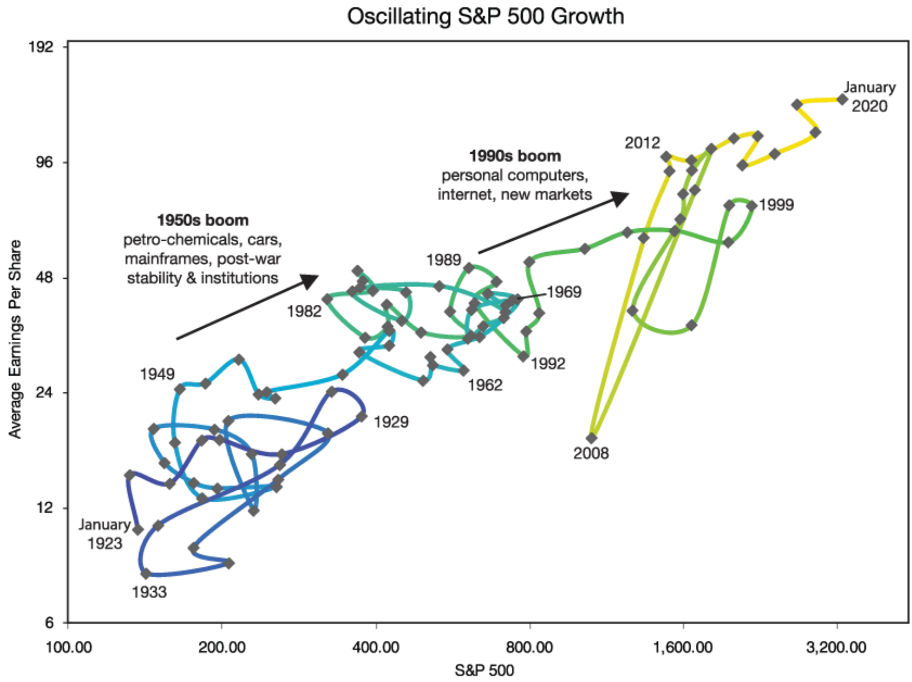

Figure 2: The S&P 500 as a proxy for the complexity of the corporate American economy, with earnings as the benefits of investing in that complexity. After each era of growth following breakthrough innovation and international reorganization, the economy appears to stall, as if oscillating around a new complexity-benefit attractor. Adjusted for inflation in source: https://www.multpl.com/s-p-500-pe-ratio/table/by-year

Growth through forever innovation might be theoretically possible, but the allometric (power law) scaling of innovation and population suggests that innovation must also accelerate to avoid stagnation and collapse (Bettencourt et al. 2007). Assuming we are not replaced by, merge with, or become parasitic pests of the technology we've created, the European model of forever competition and growth implies that at some point humans would simply not be able to keep up with information overload. Modular fission, fusion or advanced renewables might replace the diminishing EROI of fossil fuels, despite current challenges (Hall et al. 2014)—incidentally also preventing climatic destruction—and Moore's law might continue through successful quantum computers, but the energy created or freed could simply encourage growth to the limit yet again, whether that limit is the carrying capacity of technology + resources or human mental capacities. Hence, it might indeed be better to consciously choose controlled simplification—Tainter's Byzantine option—but even if we wanted to, how can we choose simplification if apparently rational (in the sense of utility-maximizing and future discounting) choices seem to inevitably lead to overextension and collapse?

Hence, the cultural argument: If some societies do consciously choose simplification, there must be some sort of individual or cultural influence beyond the determinism of economic reason. For example, Diamond (2004: 419-440) argues that while Tainter considers it improbable that societies—as defined as problem-solving organizations—will not try to respond to known challenges, many societies were in fact aware of incoming environmental problems and yet did little to respond. (Tainter might counter that it was rational for those societies to decompose rather than deal with increasingly burdensome problems.) More convincingly, Turchin (2006: 104) argues that Tainter shouldn't so easily dismiss cultural and "mystical" theories of collapse, and instead (across a wide body of work), by examining how economic and cultural factors intermesh, Turchin concludes that social trust and cooperation tend to decline in societies through feedback loops of rising inequality, intra-elite competition, state dysfunction and corruption preceding crisis and collapse—as in the late Roman empire, late medieval France and England, or pre-revolution France.

While Tainter (1988) dislikes cultural and "mystical" theories of collapse (e.g. Toynbee and Spengler) because they rely on subjective cultural and historical analyses, which he argues may be better explained through economic reasoning (high growth might cause a "vigorous" culture; high inequality might cause a "decadent" culture), Tainter (2000) appears to soften, adding that our rationality is *bounded*. Decisions are made through the experience and information provided by social relations and cultural values, where seemingly "nonrational behaviour may be quite sensible when situational constraints, especially those of embeddedness, are fully appreciated." (Granovetter 1985: 506)

For example, the more individualist assumptions of medieval European traders led rationally to creating complex institutions that allowed trust outside of family units—such as *colleganza* in Venice (Puga and Trefler 2014)—while competing Maghribi traders, also making rational decisions and initially holding the advantage, remained trapped in their family units (Grief 2006b)—the institutional hysteresis created by their systems of ideas. Later, the breakdown of medieval European systems pushed merchants and traders again to more expensive and complex organizational options like the English court system (Grief 2006a), building up the organizational hysteresis that helped more flexible and competitive systems in England and the Netherlands gain advantage in the Atlantic trade over more authoritarian systems in Spain and France (Acemoglu et al. 2005).

In systems terms, "A social system is at a higher level of complexity than a physical system. Each agent in or component of a social system is able to manipulate symbols representing ideas and concepts." (Teran 2001, s. 5) Our systems of ideas abstract the matter around us, including norms in relations with other agents, letting us create strategies and make choices at a meta level on top of already complex lower-level instincts that evaluate experiences based on perceived negative or positive feedback (Heylighen 1991). The aggregate-level patterns of complex societies—the macro forms in political economy and culture, from internet memes to wars—despite emerging from the micro matter of individuals and their interactions, also influence the further evolution of that matter.

In a complex-systems world—with causality more akin to Aristotle's relational *hylomorphism* (things as compounds of form and matter) than the familiar linear, materialist causality tacitly assumed in much modern thought (Walsh 2016)—individuals and society *coevolve* together out of the hysteresis of their interactions through nonlinear interactions. For example, instead of being something that's linearly imposed by an elite (the cause) onto a mass (the effect), national identity *emerges* in a complex system through the interactions of both (Kaufmann 2016). The forms of a society are both made by the matter of the people but also feedback on that people. So, bringing it back to Tainter: High growth (the matter) may indeed cause a "vigorous" culture (the form), but that vigorous culture may also feedback to cause further growth. High inequality may lead to a "decadent" culture, but that decadence might also encourage further competition, excess and inequality.

Self-organized critical complex adaptive societies

In the out-of-equilibrium flux of complex adaptive systems, the world might not be predictably deterministic, but neither is it just a world of random, maddening chaos. Instead, in a complex systems world, *order emerges from disorder,* with common macro patterns (regularities) found across systems with highly varied micro interactions, such as *power laws* found in systems as diverse as earthquakes, avalanches and wars (Fig. 3). For example, Pareto's power law describes the inversely proportional distribution of wealth (a few super rich and many poor), and other power laws found in economics include firm size, daily returns, number of trades per day and number of shares traded, implying that humans, as part of nature, create "optimized emergent structures" like that of branching fractal organisms with similar power-law patterns (Gabaix 2016). This emergent efficiency follows Zipf's (1949) *principle of least effort* suggested by his exploration of rank-frequency power-law distributions found in English word usage and the size of cities. And likewise on the internet, the number of pages, users, links, and unique views are all also Zipfian rank power laws (Adamic and Huberman 2002).

"Second only to the Gaussian distribution in terms of applicability" (Turcotte and Rundle 2002: 2463), a power law takes form as $f(x) = kx^{\alpha}$ (linear when $\alpha = 1$). Power laws are scale invariant, also referred to as being self-similar or statistically fractal. There's no typical size of something with a power-law distribution, and this difference from normal-distribution expectations, as Mandelbrot (1963) found while describing power-law tails in market fluctuations, suggests that *what are apparently outliers according to the assumptions of traditional statistics may in fact be more important to the evolution of a system than the general average state*.[4]

---

[4] A heterodox economist may tell you that a "leptokurtic crisis" created by Mandelbrot's 1960s work remains ongoing in economics as multiple counter paradigms, most recently econophysics, attempt to deal with "fat" tails in economic distributions (Walter, 2018).

Self-organized criticality (SOC) is one explanation for the abundance of power-law patterns in nature. Originally proposed as an explanation for outlier spikes found in electronic 1/f noise, Bak, Tang and Wiesenfeld's (1987, 1988) original SOC model is an open and dissipative system, described as a slowly-fed sand pile, creating avalanches of all sizes in power-law distribution. As single grains of sand are added to the pile, their effect might be anything from kickstarting major avalanches to simply settling where they land. Or in a forest, a single spark might cascade into a large fire if conditions created by the system's history are right—if large areas of burnable brush link together—but the same spark might also fizzle out if it hits previous areas of burning (or man-made fire-breaks).

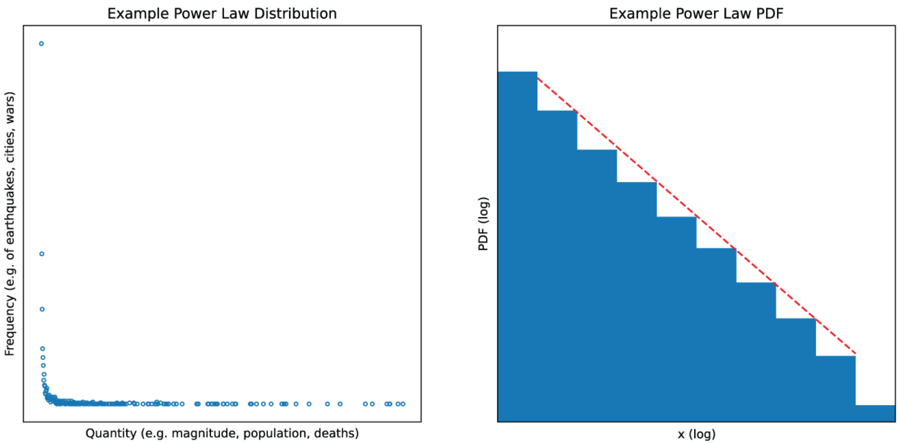

Figure 3: On the left, sample data showing the basic form of power-law distributions. On the right, the same data plotted as a log probability density function, where α becomes the slope as $\log f(x) = \alpha \log x + \log k$.

Akin to Bardi's trophic flows model with renewable resources, SOC systems oscillate around an attractor, but that attractor is also the critical point at which cascades of all sizes can occur, making it like a phase transition, except that SOC systems evolve towards this point without needing a tuned control parameter. Note though that this does not mean that "every local degree of freedom is close to some threshold." (Watkins et al. 2016: 19) Not every node in a forest system has to have a tree ready to burn; not every grain of sand will be just at the point of tipping. Instead, self-organized critical systems are sometimes said to be at the "edge of chaos", oscillating around the critical point through periods of cascades and relative (meta) stability. And while SOC systems are not deterministic, their power law correlations do allow for a certain degree of probabilistic interpretation (Watkins et al. 2016). While you can't say for certain when and where the tipping point for next earthquake might be, you can at least say what the frequency of an earthquake is, inversely proportional to its size.[5]

Beyond earthquakes, cities, language, the internet and economy, even the distribution of wars is power law, leading Roberts and Turcotte (1998: 357) to conclude that the "world order behaves as a self-organized critical system independent of the efforts made to control and stabilize interactions between people and countries." Hence, after already noting probable SOC processes in voting patterns (Brunk 2001), Brunk (2002: 225) makes the leap one step further, concluding that human societies might as a whole be described as SOC systems, with the unfortunate conclusion that, "if all societies are being drawn toward the edge of chaos, there is no absolute solution to the problem of collapse."

In other words, SOC offers a way to describe how optimized emergent structures evolve through cascades in power-law pattern, where, like in natural SOC systems, "socio-economic systems might *organise themselves* into a *critical state* with *avalanches* of change at all sizes via which dissipation mostly works itself out" (Teran 2001, s. 6), but if societies are SOC, then collapse is inevitable on a long enough time-scale, and worse, like putting out wildfires only to result in even larger fires later, "A socio-economic system might become catastrophically unstable if the system were manipulated and forced to attain a certain optimal state interfering with its natural dissipation process." The USSR is Teran's example, but think also the periodic stagnation and collapse of authoritarian Chinese dynasties whose efforts to enforce stability in the present often led to even worse crises in the future. Instead, Teran suggests, it might be better to try to reduce the frequency of large cascades with dissipation through more frequent smaller cascades—controlled social burns.

Self-organized criticality as a framework

Two SOC caveats: First, more sweeping claims that all fractals and power-laws in nature are created by SOC are controversial. There remain other competing power-law explanations and many complications in real data, such as stock market fluctuations that, while showing power-law features, are not unambiguously SOC (Bartolozzi et al. 2004). Instead, the strongest SOC claim is that "self-tuned transitions can (and do) exist in nature." (Watkins et al. 2016: 8) Second, the prevalence of some power laws also has doubters. Clauset et al. (2009), while confirming more power laws (e.g. calls received, severity of terrorist attacks, followers of religions, and even the number of citations received by academic papers), note that some popular power laws, such as forest fires, might better match the similar log-normal distribution—though this retains the key point that large events are not outliers as would be assumed with a traditional non-log normal distribution.

[5] While Bak (1996) argues against this sort of probabilistic predictability, noting that going longer without a large earthquake suggests it will be even longer till the next large earthquake, this is not actually misaligned with the probabilistic interpretation, as going longer without a large earthquake changes the data on the frequency of earthquakes.

Like other complex-systems models that allow "flight sim" style simulations with different parameters and the creative application of similar models to what might on the surface seem much different systems (e.g. Tero et al.'s (2010) already classic slime-mold model exploring efficiency and resiliency in transportation networks), SOC may not be the explanation of all complexity, but rather better thought of as a starting point for abstracting systems with certain similar properties into usable models (Moss 2002). For example, Chen and Zhou (2008) use SOC to describe the structure of cities, while in later work Chen (2010, 2016; et al. 2019) adds other analyses, notably allometric scaling.

Hence, synthesizing Bak, Moss and Heylighen, amongst others, Teran (2001 s. 4-6) suggests the possibility of an SOC socio-economic model in which dissipation occurs through the choices of individual agents who "interact with each other in accordance with the set of options they have, exploiting such options in order to increase their 'happiness'", leading to the survival of the agents with the best ideas for the moment, in which the least fit either die off or mutate, according to choices bounded by *internal models*, in which small changes may have large effects.

Framework

Towards a model of human evolution at the level of ideas

A world of self-organizing criticality would imply that collapse is essentially inevitable long term, but SOC might also help explain how the dissipation of ideas through the internal models of human agents in feedback with the flux of their environment could create the oscillating evolution and power-law patterns found in many human systems. And so, the following is an exploratory attempt to synthesize an abstracted framework that, starting from Jensen's (1998) SOC description, can be modeled as a system that is *slowly driven* and dissipates *local instability* through *thresholded interactions.*

Taking the antecedents as a starting point and examining each concept here in turn, an SOC pattern at the level of our ideas should be made up **individual interactions** with ideas, coevolving with the physical system (as agents in time). Second, individual actions are likely to be made according to the bounded, embedded, or otherwise limited rationality of individuals, depending on their social, cultural and institutional context within the system, which forms some sort of **internal model** (or paradigm) which, as with the difference of European and Muslim medieval traders, sets values and goals, defining the assumptions that lead to different responses to the same situation. Third, there should be some sort of **threshold** or instability in local interactions (becoming, as will be shown, the catharsis of paradigm expectations).

The approach here is exploratory, following threads and experimental associations of concepts from widely varied sources. Its strength, at this stage in the text, must be judged on its descriptive synthesis of antecedent requirements with quite a few zeitgeisty concepts—and a few more maybe not quite so in the ether.

But a bit of clarification before continuing: In a world of power laws, with no typical scale, where is the line between "crisis" and "collapse"? The line must be arbitrary and all arguments over it merely an academic game of categories. For example, large parts of the Western Roman system, in their decomposed state, continued into the early Middle Ages to varying degrees (churches, estates, clothing, bathing, etc.), yet the end of the hierarchical entity called the Western Roman Empire was also certainly an immense simplification, including the end of many systems of ideas forming that hierarchy. However, unlike cascades of rapid material simplification, cascading changes of ideas could also refer to the spread of new ideas—like "up-crashes" in the stock market—rather than just the destruction of old ideas. With this in mind, collapse, keeping Tainter's definition as "rapid simplification", becomes in this framework a particular subtype of crisis, where crisis in general will refer to cascades or distinct periods of cascades at either or both the level of physical matter and idea forms.

The agent in time: Change and response, mimesis and mutation

From their macro perspective in the flux of an out-of-equilibrium universe where possible futures branch from a past fixed by information (memory) in thermodynamic traces (Rovelli 2015, 2020), each human lives in the forward momentum of the arrow of time. The human being, to borrow Heidegger's (1927) term, is *thrown* through a world of constant change. But while (from our perspective) change might be the only constant, if that change has a rhythm, not only can we create meaningful categories describing the flux, the impossibility of comprehending the flux in its entirety within our bounded rationality means that *we must place categories over the flux to make any sense out of it*—responding to constant change by turning spatiotemporal patterns of matter into forms at the level of our ideas. For example, maybe historical periods are abstractions that hide the details and continuity of history—if you look deep enough into the details, any metanarrative might become untrue—but it's impossible to make any wider sense out of history without those abstractions, which can represent real, significant moments of cascading change in a somewhat recognizable rhythm of history. Maybe, as says Heraclitus, you can't step in the same river twice, in the exact sense of matter, but you can create a useful category for the distinct rhythmic event that's then represented by the word "river".

Hence, as we are thrown through time, we have to anxiously project (imagine) ourselves in many possible futures, says Heidegger, but, aligned with least effort, a threshold to individual change lets us take advantage of energy savings from routinization and cognitive scripts when "thorough elaboration would always come up with the same decision." (Jager, 2003: 2). Except, like the metastable moments of SOC systems or machine-learning algorithms that get stuck in local minima, habits may stop people from incorporating new information into their routines, and (Jager again), "whereas the habit may originate from a process in finding out the optimal behaviour given the prevailing circumstances, the circumstances may since then have changed such that alternative behaviour would yield better outcomes." Or in Kahneman's (2011) popular terms, patterns of thought and anchoring information let the mind's "system 1" act quickly, but sometimes poorly, without bothering the more logical and conscious but also lazy and energy intensive "system 2".

To abstract the thresholding of habits and habitual assumptions, consider a management technique called the *hangen* ("reduce-by-half") game, through which managers found that, instead of relying on incremental cuts, they could achieve more efficient results by cutting fully half the workers from production teams (Cooper 1995: 124-128). While small cuts result in **mitigation** as teams simply work harder to fill the gap, large changes, by making it impossible to output the same amount working the same old way, push **mutation** and the development of more efficient practices through creative destruction. Likewise, scarcity in materials also encourages creativity (e.g. Sellier and Dahl 2011; Mehta and Zhu 2016), as seen in how breakthrough technologies often emerge from outsider inventors and companies with few resources. Though outsiders may also have an advantage in not having to unlearn tacit habits, conventions and practices that can "lock in" large corporations and industrial agglomerations (Maskell and Malmberg 1999). Thus, upstarts Apple and Microsoft triumphed in the personal computer revolution instead of IBM and Xerox (even as Apple and Microsoft took their GUI from ignored iconoclasts within Xerox), while Google, Amazon and Facebook emerged out of internet opportunities that Apple and Microsoft missed. Not only are we trapped in the limited reasoning of our simplified internal models, before even recognizing those limitations we may need to be pushed out of our dreamworld of habits and rules.[6]

The point being, *there are multiple thresholds on the way to new decisions and habits*: The threshold to even question habits and ideas, the threshold to search for new ideas, and the threshold to change or mutate. Human decision-making heuristics exist across a wide spectrum of cognitive effort between unthinking repetition and the theoretical pure rationality of *homo economicus* (Jager and Janssen 2003).[7] And again following least effort, we largely learn through imitation—**mimesis**—rather than through our own creation. Mimesis lets us routinize and build complex structures based on shared assumptions in our internal models and previously built complex structures (a process Toynbee (1946) calls *etherialization*), but mimesis also further bounds our rationality and makes us reliant on specialists, the division of labour and the contingency of history. So, even in our immense complexity, via hysteresis we still

[6] Of course, mitigation and mutation are idealized categories that are highly dependent on the point of view. For example, mitigating climate change, as framed by climate research as reducing carbon emissions and implementing carbon capture, requires massive societal reorganization, looking far more like mutation (with its attendant high costs) to the average person. Whereas adapting to climate change, if framed as remaining reliant on fossil fuels while responding with piecemeal efforts to counter extreme weather, droughts, famines, etc., feels a lot more like mitigation (until overtaken by extreme events).

[7] Being focused more on possible thresholded responses rather than heuristics, the framework herein develops differently from Jager and Janssen's consumat approach, but there is basic alignment in the idea of a range of responses and social processing. Mimesis becomes in the model essentially a combination of consumat imitation, social comparison and satisficing.

use a system of time based on ancient Egyptian hours and Babylonian numbers because *unless pushed*, “Why fix what ain’t broke.” In other words, the decision to change beyond simple mitigation takes on two main forms: mimesis or mutation—adoption or creation—each with their own thresholds.

Additionally, because dissipation of ideas through mimesis creates shared structures and hierarchies (tribes, countries, companies), such systems may also be treated as aggregate meta-agents that must also respond to change as they hurtle through time, even if not all warriors, voters or employees within these systems agree with aggregate responses.

Social paradigm shifts

Next, to explore how ideas and agents might pass certain thresholds, switch the term “internal model” to “**paradigm**”. Through mimesis agents may adopt entire systems of ideas—paradigms—and these paradigms may emerge in a similar way to scientific paradigms (Khun, 1962), where anomalous information leads to crisis, pushing past the threshold to search for new ideas, sometimes leading to multiple new counter paradigms before the one with the best puzzle-solving power becomes the new dominant paradigm. The classic example: medieval astrologers had to add evermore circles to make the anomalous, wandering planets circle the Earth in an increasingly complex Ptolemaic model, but then: Copernicus.

If the paradigm with the most problem-solving power wins, a new economic paradigm should solve for the diminishing returns of complexity, but what about cultural paradigms? Heylighen (1991: 5) proposes that science, art, religion and philosophy all try to solve problems created by categorization—the splitting of the “continuous field of experience” that (because of our bounded rationality) is required to understand the world. But in Heylighen’s view, while science mostly splits the splits into even more splits, philosophy and art tend to create wider meta-systems of ideas to contain those splits, while religion tries to “transcend the fragmentation of the continuous field of experience by proposing an over-arching system of faith that binds the different domains of knowledge together.”

In general, successful movements or paradigms in science, art, philosophy and religion—or for that matter politics, business and culture in general—might not offer *transcendence*, but in order to be vaguely coherent, they must at least tacitly assume a sort of worldview or **metanarrative**, in the sense that a paradigm must link relevant categories in a causal pattern (action A causes result B), solving the problem of splitting the continuous field by uniting it again at a more abstracted level. Indeed, Khun (1962/2012: 111-134) suggests that adopting a new scientific paradigm, incommensurate with what was previously believed, requires a changed worldview. In order to accept the shift from the world of deterministic Newtonian physics to the world of relativity and quantum uncertainty, your metaphysical understanding must change as well. In order to accept that the sun is the center of the universe you must also accept that the Earth is not the center, and thus, is perhaps not all that special.

Taking the broadest view, any somewhat coherent system of ideas (including norms, practices, models and habits) becomes a sort of paradigm, with paradigm narratives creating **causal expectations** that allow some degree of future prediction and, if then combined with values or goals, creation of rules to guide agents through time. From accepted currencies to legal systems to an accountant's standard practices to your morning routine, all are paradigms from different spatiotemporal perspectives within a vast system of ideas. And like Khun (1974) adds, paradigms might contain other paradigms and paradigm shifts nested within. A researcher might cause a paradigm shift in a small paradigm within a larger paradigm, and that small paradigm shift may either reinforce or be anomalous with the larger paradigm. A family might go through a paradigm shift after a family member dies, but remain in the normal confines of the tribe or community's paradigm.

In sociological terms then, a paradigm is a structure existing *within* agents who form and are formed by that structure. The paradigm guides the agent, but the agent also has the ability to alter their paradigm or replace it entirely by mimesis or mutation, and the paradigm itself may guide agents in creating structures that allow lower-level paradigm shifts (e.g. elections), even while, akin to Bourdieu's (1984) *habitus*, agents may need different (even incommensurate) paradigms in different social fields.[8] Formed in this way, nations, political movements, religions, cultures, tribes, classes, castes, companies and families all exist as paradigms within individuals who are both the creators and followers of those paradigms, but that does not mean those paradigms are not useful abstractions of something real in the individual's experience and environment, even if, as in the paradigm of fiat money, the "realness" of that money depends on an environment of other individuals following a paradigm with the same causal expectations of fiat value.

Cathartic paradigms

By summarizing beliefs and expectations as a story describing cause and effect through the arrow of time, paradigms form a worldview that frames new problems. So in psychology, individuals have a *narrative identity* describing themselves—a paradigm of the self that includes expectations of the future and the surrounding world—that exists on top of inherited traits and learned skills and strategies (McAdams 1995). Hence, in an example from Haidt (2014, 10:06), whether you believe that capitalist creation raised us out of feudal poverty, or that capitalist destruction alienated us from our natures, these competing economic stories "shape the mental space in which we do our thinking." But which narrative abstraction of materialism's schisms you might believe depends on the hysteresis of interactions between the matter of your experience and the narrative form of known paradigms.

---

[8] Or for another continental comparison, Foucault's (1986) heteronormal spaces (e.g. ship, jail, brothel, DMV) become in this framework simply places with noticeably distinct paradigms (and power structures created by those paradigms), outliers in a sense, but following the same paradigm logic. Or, the other end, an episteme might be thought of as the overarching paradigm (often of unconscious assumptions) of a society as a whole (even if any description of which will be contradicted by innumerable individual caveats.)

At the nexus of matter and form, with catharsis understood from Aristotle as a sort of *felt understanding* (Shaper, 1968) rather than just "purgation" or "purification",[9] a paradigm's narrative is then cathartic if the form of its causal expectations creates understanding out of the felt (sensed) matter of an agent's experience. More than being just iconoclasm or creation, catharsis is and transcends both, with order emerging from disorder in *anagnorisis*, the discovery or realization that reveals true patterns of the world—the eureka moment that ties together and makes understandable disparate anomalous information and experience. (Anagnorisis is tragic if it cannot save protagonist from catastrophe, despite understanding—like a civilization that can see what's coming and yet does, or can do, nothing.) A story that provides catharsis gives confidence through some experienced understanding of the world and its complex causality, providing a little certainty about what might come next—becoming at its best like the *flow* state of positive psychology (Csikszentmihalyi, 1990), where the self moves in perfect sync with the flux of the present. Catharsis subsumes Kuhn's paradigm practices, rules, methods and models into a more general definition: *paradigms are systems of shared understanding,* created through mutive anagnorisis, assessed through catharsis, and spread through mimesis, and the breakdown of understanding through anomalous experience then creates a **crisis of catharsis**.

However, don't think of a crisis of catharsis as quite like the popularly termed "crisis of meaning" that assumes making (or permanently fixing) meaning is the goal. Instead, think of a crisis of catharsis as a misalignment of experience and understanding when a paradigm cannot meet its own causal expectations or solve new problems, where that understanding may be either fixed and conscious in language or assumed and tacit in decisions and habit (*unknown knowns* Donald Rumsfeld might say). Catharsis is the feeling of understanding, not some meaning attached. Unlike the implications of a crisis of meaning, an epicure who assumes pleasure and happiness are the goals in life might still emerge from a crisis of catharsis with those assumptions intact if they find or create a new paradigm that (temporarily) meets those expectations.

So, if art symbolizes "associative, experiential meanings" (Heylighen 1991: 5) an art style goes out of date—enters a crisis of catharsis—not only because "innovation within a style becomes increasingly difficult to achieve, leading to repetition and rearrangement of earlier work" (A. L. Kroeber via Tainter 1988: 200), but also because the catharsis of those meanings no longer matches the flux of a world that now has new associations and experiences—resulting in *diminishing returns of understanding*. Hence, while at one moment Van Gogh, through creation as a "passageway that destroys itself", might *unconceal* the world of a peasant's shoes in

[9] Another more traditional translation of catharsis, though much less used than "purgation" or "purification" is "clarification", and there is some history of catharsis being thought of as a sort of enhanced understanding that lets the reader see some universal law, as Greek tragedy is itself like a religious ritual where the worshiper experiences, through sacrifice and rebirth, a "transcendent sense of the coherence of things." (Hardison, 1968)

paint, the Being that a work of art brings forth, “never was before and never will come to be again” (Heidegger 1936/1977: 167-181). Or think of how movie, music, literature and fashion trends often emerge in clear shifts and fleeting cultural moments before becoming formulaic—repeated beyond their cathartic purpose.

In Khun’s terms, if *normal* science works to add detail and solve puzzles, in a generalized normal state, people use paradigms to understand the world and solve the problems wrought by constant change, which might mean solving for happiness, as often assumed, but could also mean solving for anything else that a paradigm can cathartically claim is the goal (e.g. meaning, virtue, power, peace, glorious death in battle). But when anomalous information breaks habitual expectations, the misalignment leads to *discomfort, stress and anxiety,* pushing past thresholds to create a crisis in which people may question long held beliefs and search for new catharsis in new abstracted understandings. And with least effort, most will look for something to copy, whether it be an alternate political party, religion, self-help regiment, breakfast cereal or conspiracy theory, so long as it helps organize the world into some sort of understandable causal pattern.

At macro scale, when facing crisis societies enter “scanning behavior” (Tainter 1988: 122, 210) in the search for new paradigms, and if no one dominant paradigm emerges, societies may descend into a *schism of the soul* (Toynbee 1946: 429-532), often found in declining civilizations, where, when faced with the seeming chaos of the world, and unable to successfully respond to new challenges, people retreat into competing, simplistic stories (i.e. bubbles and echo chambers). So in the declining Roman Empire, instead of Plato and Aristotle trying to unify the whole of nature, you get the supposedly opposed Epicureans and Stoics, except that both try to live with chaos instead of trying to understand it. Or, in Toynbee’s own terms, while one side retreats into *truancy* and *promiscuity* (corruption and hedonism), the other turns to *martyrdom* and *asceticism* (prophets and hermits), or, instead of dealing with the present as it actually is, while one side retreats into *futurism,* the other retreats into *archaism*.[10]

The framework of an evolutionary system of ideas in short (Fig. 4): Felt matter is understood by agents in forms, becoming one in catharsis when paradigms make sense of experience. But in the immense, evolving out-of-equilibrium complexity of our

[10] Toynbee (1946) adds that archaism may become futurism in its efforts to return to a past that (because hysteresis) cannot be returned to. Thus in trying to recreate a simplistic mythical past, the Nazis did not end up creating a bucolic rural feudalism, but instead industrialized horror in their attempts to destroy the present. Like seemingly most studying the rise and fall of civilizations, as Toynbee’s (1957) theory evolves, it becomes cyclical, where the fall of a universal state becomes necessary for spiritual enlightenment in the emergence of a new universal religion, which, when that religion declines in turn, leads to the emergence of another universal state. So, after exhausting the remains of Greek philosophy, the formerly persecuted proletarian religion from the fringes of the Roman Empire becomes the authorized religion, which must itself decline for there to be a new universal state that can then collapse and be replaced by a new proletarian religion.

world, any catharsis will be fleeting as necessarily abstracted categories, expectations and rules go out of sync with experience, leading to discomfort and stress, which may push a response of mitigation, mimesis or mutation (each with increasing thresholds), even as those options remain embedded in the uncathartic understanding of failing paradigms. And through mimesis paradigms could then, subject to the luck of hysteresis, cascade from agent to agent in power-law form, feeding back to create new structures.

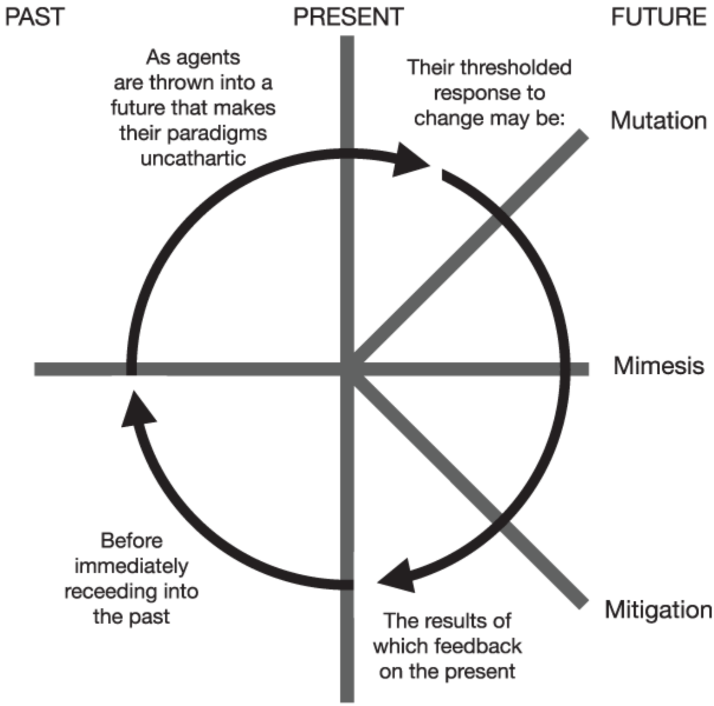

Figure 4: The proposed evolution of ideas experienced and created by responsive agents (e.g. individuals, corporations, countries) in the arrow of time. Termed the “iconorhythm” in the code.

Model

The model simulates a system of evolving farming settlements (the agents), which organize themselves according to land-use rules contained in shared paradigms that spread via mimesis from settlement to settlement (Figures 5 and 6), which results in mimesis cascades in power-law form, the main sign of an SOC system (see "SOC results" below).

Evolution at the paradigm level of ideas moves the attractor (carrying capacity) for local settlement yields and population (Fig. 7) through innovation in land usage and field rotation. Settlements have inhabitants who are born and die and who require food to live, which they produce by working settlement plots during each iteration (a "week"). The main risks for settlements are overpopulation and soil depletion caused by adopting paradigms with poor land-usage rules.

The paradigm model that follows in the next section is the core element under consideration, while the underlying "farming society" model is somewhat arbitrary—an initial testbed to see how the paradigm model reacts in a sufficiently dynamic system in tests with wide-ranging variations. The strength of the paradigm model, in the sense of being self-organized critical, is shown by how significantly the underlying economic model can be changed while the spread of paradigms retains a cascading, power-law form. (This may also make the paradigm model potentially useful as the evolutionary component it other models, such as say simulating the evolution of competing corporations with different and evolving rules and corporate values.)

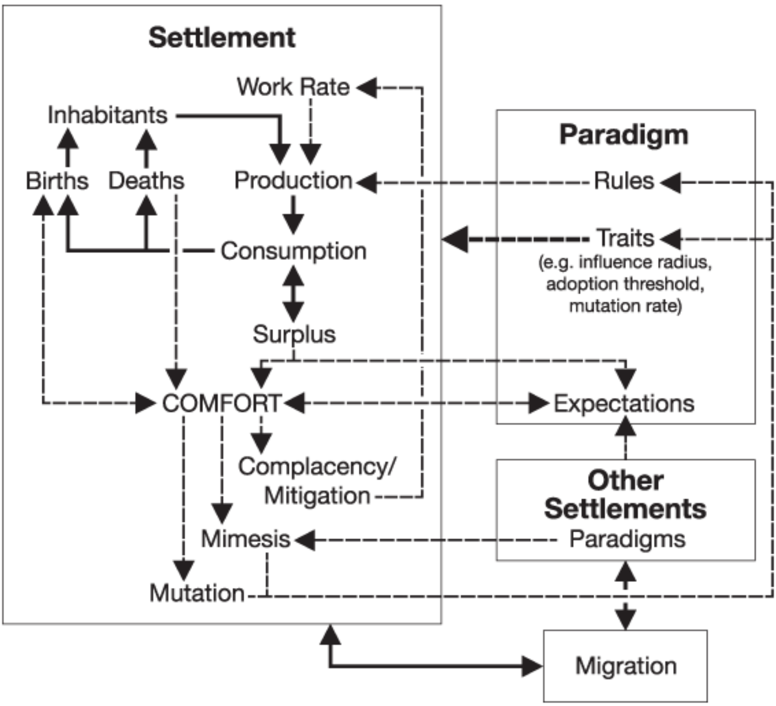

Figure 5: Model flow chart. Solid lines represent the flow of matter (the physical system), while dashed lines represent the feedback of forms (the system of ideas).

From framework to paradigm evolution model

Starting at the core of the model, settlements, following the proposed evolution of ideas, respond to discomfort, according to increasing thresholds, with mitigation, mimesis or mutation. For a bit of clarity, paradigms parameters and variables are lower case, settlement parameters and variables are upper case and system-wide parameters use Greek letters.

Settlement agents change their comfort C, bounded $0 \leq C \leq 100$, by increment C_i every four iterations (a "month"), creating the **catharsis update** comparing settlement experience to expectations:

$$C_i = (R + B) * s$$

where R compares the settlement's surpluses to paradigm expectations, B compares current and previous surpluses, and s is sensitivity to R and B. R and B respectively answer the questions, "Are things as expected?" and "Are things getting better or worse?" Note how s is essentially a cultural trait defined by the paradigm that the settlement follows.

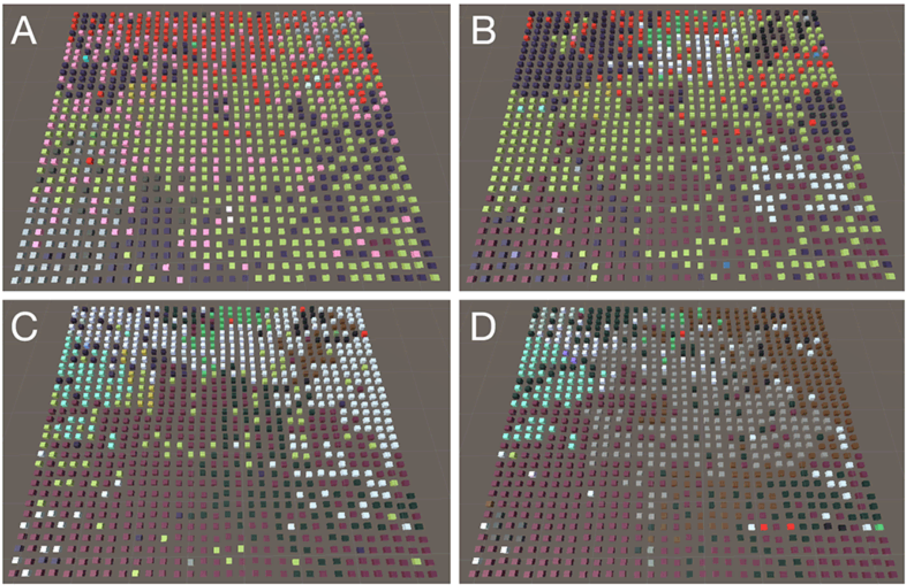

Figure 6: Screenshots of paradigm spread (mimesis cascades) in the running model. Each cube represents a settlement with its color representing the paradigm it follows. Note for example the maroon paradigm spreading across the South (A-C).

With S_c as the settlement's current monthly surplus (or deficit when negative), S_t as the settlement's cumulative surplus (i.e. stored yields), e as paradigm expectations, d as the desired amount of stored yields per inhabitant (i.e. a desire for long-term food security) and I as the number of settlement inhabitants,

$$R = \frac{S_c + e}{e} - 2 + \frac{S_t}{d * I}$$

And with S_p as the previous month's surplus and N as the number of plots in a settlement,

$$B = \frac{S_c - S_p}{N}$$

In addition, settlements increase their comfort by $C_b = z / I$ when a child is born, decrease comfort by $C_d = h / I$ when an inhabitant dies, and decrease comfort by $C_e = (I / G + 1) * u$ when people emigrate, where G is the number of people emigrating and z, h and u are paradigm traits (different paradigms may value births, deaths and emigration differently).

The monthly probability P_m that settlements will **mutate** a new paradigm is

$$P_m = D^3 * T * m$$

where m is the mutation rate, $D = 100 - C$ (i.e. discomfort or stress) and $T = (100 - t) * \omega$, where t, bounded $0 \leq t \leq 100$, is the base threshold and ω is the system-wide base probability. If then creating a new paradigm through mutation, the new paradigm is created by copying the old paradigm and, with a probability of 0.5, adding a new randomized land-use rule, and, with probability of 0.33, deleting a random existing rule, if any exist.

Settlements spread knowledge of their current paradigm to other settlements within the sphere created by the influence radius r, set by the current paradigm. The monthly probability that settlements will consider **mimesis** of a known counter paradigm is

$$P_k = D^3 * T$$

And if then considering counter paradigms, settlements will adopt the first counter paradigm, if any, in the list ("satisficing" rather than full deliberation of all options) that passes the condition,

$$e_c / e_p > t * a / D$$

where e_c is a counter paradigm's expectations, e_p is the current paradigm's expectations, and a is the current paradigm's adoption threshold. In the baseline model, $\omega = 10^{-7}$ so that when $t = D$, e_c must exceed $a * e_p$ for a counter paradigm to be adopted as a settlement's new paradigm.

Mutation and mimesis also add to settlement comfort, 20 and 10 respectively, assuming a sort of satisfaction in responding to change, but added largely to discourage extremely uncomfortable settlements from arbitrarily flitting between paradigms (the trade-off being that the system doesn't evolve as fast).

For **mitigation**, settlements increase their work rate W, bounded $0 \leq W \leq 1$, by 0.01 monthly when $D > t$, and because there must then be a way for work rates to fall, settlements become complacent, reducing their work rate by 0.002 monthly when $D < t / 3$.

All preceding formulas are contained in each settlement's "iconorhythm" object (riffing on iconoclasm). On the paradigm side, paradigms are linked to settlements through expectations, which abstract information spread. Each paradigm updates its expectations e, bounded $e \geq 1$, by increment e_i monthly for each follower settlement, denoted by subscript f, creating "word-of-mouth" feedback that lags reality (rather than being perfect information), based on follower comfort and returns in the form

$$e_i = \frac{(C_f - 50) * \lambda + (S_{fc} - e) * \theta}{n}$$

where λ is sensitivity to comfort, θ is sensitivity to surpluses, and n is the number of settlements currently following a paradigm. Baseline, λ = 0.001 and θ = 0.002. Comfort is included to augment the feedback of surpluses, making expectations more than just economic.

Baseline

Internal settlement logic creates a basic socioeconomic structure, with enough variation and competing pressures, both long and short term, to create an interesting environment for paradigms to evolve and spread in.

Summarized for skipability: Settlement inhabitants produce food by working plots with set soil types and changeable land uses. Some land uses produce high yields on different soil types and some deplete the soil while others regenerate it—giving a purpose to paradigm evolution. More inhabitants are born when comfort and surpluses are high, while more die when starving or old, and when starving some inhabitants may migrate to other settlements or repopulate abandoned ones. Arbitrary, but reasonable enough for an illustrative model.

The system starts with 1024 settlements in a square grid. Each settlement starts with a work rate $W = 0.7$, 10 plots, and 15 inhabitants with a randomized age from the range $0 \leq A \leq 2600$ in weeks, and all settlements start with the same shared paradigm containing no rules.

Settlements work their plots through a production module, in which each plot returns a basic yield weekly of

$$Y = \gamma * \mu * (1 - L)$$

where L, bounded $0 \leq L \leq 1$, is that plot's soil depletion, γ is the system-wide yield multiplier (γ = 10 baseline) and μ is the base yield on that plot's soil type for the land use currently assigned. Each plot's initial land use is randomized at the start, but can be changed by paradigm rules later, as either single land-use rules or two-year rotations. Plot soil depletion starts at $L = 0.25$ and updates weekly via $L = L + \beta$, where β is the weekly soil degradation (or regeneration if negative) on that plot's soil type for the land use currently assigned (see Table 1).

Base plot yields are adjusted via worker ages and the settlement's work rate to create the adjusted plot yield Y_f, where, with X as worker potential,

$$Y_f = Y * X * W$$

And with X_s as the sum of each inhabitant's potential X_i, where $X_i = A / 832$ for inhabitants with $A < 832$ (i.e. 16 years), $X_i = 1820 / A$ for inhabitants with $A > 1820$, and $X_i = 1$ for the remaining prime aged inhabitants,

$$X = \frac{X_s/(2 * N)}{1 + X_s/(2 * N)}$$

the assumption being that each worker added to a plot brings diminishing returns. Meaning, the amount of land, in plots per settlement, is the core limit on settlement carrying capacity.

Adjusted yields are then sent for consumption. Each inhabitant eats H yields produced weekly, where if $A < 1040$, $H = A / 104 + 2$, otherwise $H = 12$. Uneaten yields each week are added to stored yields S_t. Inhabitants eat from first to last added to the settlement, meaning younger inhabitants and recent migrants are the first to face insufficient food, which adds to that inhabitant's food deficit F. The probability of an inhabitant's death each week is $P_d = (F / 12 + A / 520) * \delta + \delta$, where δ is the base probability of death ($\delta = 0.0002$ baseline), designed simply to increase the probability of death with age and lack of food.

Additionally, before inhabitants eat, settlements must pay, from yields, costs carried over from the previous week: The influence cost $Q_i = r^3$ (the cost of spreading paradigms to neighbours) and more importantly, the cost Q_r for each rule implemented, where for each single land use $Q_r = N_a$, and for each two-year land-use rotation $Q_r = N_a * 1.5$ (i.e. more complex rules cost more than simple ones), where N_a is the number of plots that a land-use rule is applied to.

After passing the conditions $T > 1$ and $V_n < T$, where T is half the number of inhabitants over 16 and V_n is the number of births in the last nine months, and based on the assumption that people will have more children when more comfortable, the probability for a settlement to produce new children each week is $P_c = C * 0.01 * b * T$, and if passing these conditions, the number of births for a settlement is then $V = T * b + 1$ (truncated to an integer), where b is the paradigm birth rate.

And when the monthly surplus $S_m < 0$, with a probability $P_e = q * D / 2$, some inhabitants may migrate to another settlement, where q is the paradigm emigration rate. With those conditions passed, the number of inhabitants emigrating $G = D^2 * I * q$. Migrants first try to migrate to a depopulated settlement within radius $R = r * 4$, and if there are no depopulated settlements within that radius, at a probability $P_r = 0.2$ migrants may return to their original settlement, while otherwise migrating to a random settlement within radius R. Migration largely serves to repopulate depopulated settlements. At the population level, the system is closed, with no outward or inward migration to the system as a whole, like an isolated island. (Other migration effects are mixed, simultaneously relieving population pressure on some settlements while increasing pressure on others.)

For the baseline model, all paradigm cultural traits are constant. Sensitivity $s = 0.02$, desired storage $d = 2000$, paradigm threshold $t = 65$, mutation rate $m = 0.001$, adoption threshold $a = 3$, birth comfort $z = 4$, death discomfort $h = 10$, emigration discomfort $u = 0.002$, birth rate $b = 0.02$, emigration rate $q = 5\times10^{-5}$, and finally the influence radius $r = 3$, set so that settlements only spread paradigms to their eight immediate neighbours in the grid, like a cellular automata.

		Barley	Beans	Cattle	Clover	Forest/ fallow

	μ	0	0	1	0	0
Bare (rock)	β	0	-0.0008	-0.001	-0.001	-0.002
	μ	11	8	1.5	0.5	1
Clay	β	0.001	-0.0008	-0.001	-0.003	-0.002
	μ	7	4	1.5	0.5	1
Sand	β	0.0009	-0.0008	-0.001	-0.003	-0.002
	μ	5	4	1.5	0.5	2
Silt	β	0.0009	-0.0008	-0.001	-0.003	-0.002
	μ	5	4	4	0.5	1
Peat	β	0.0009	-0.0008	-0.001	-0.003	-0.002
	μ	6	4	1	0.5	2
Chalk	β	0.0009	-0.0008	-0.001	-0.003	-0.002
	μ	9	8	4	0.5	2
Loam	β	0.0009	-0.0008	-0.001	-0.003	-0.002

		Peas	Potatoes	Sheep	Tomatoes	Wheat
	μ	0	0	1	0	0
Bare (rock)	β	0	0.0008	-0.001	0.0003	0
	μ	6	2	2	8	10
Clay	β	-0.0008	0.001	-0.0007	0.0003	0.0011
	μ	2	8	2	9	6
Sand	β	-0.0008	0.001	-0.001	0.0003	0.0009
	μ	3	4	1	9	12
Silt	β	-0.0005	0.0008	-0.0007	0.0003	0.0011
	μ	2	2	1	6	6
Peat	β	-0.0009	0.0008	-0.001	0.0003	0.0009
	μ	8	4	3	3	5
Chalk	β	-0.0007	0.0008	-0.001	0.0004	0.0009
	μ	0	12	4	8	11
Loam	β	-0.0007	0.0008	-0.001	0.0003	0.0009

Table 1: Base weekly yields (μ) and soil degradation (β) for each soil type and land use.

Table 1 shows the different yield and depletion/regeneration rates for each land use and soil combination. Again, though named for real crops, these rates are simply designed to allow enough variation and difference in paradigm rules for evolution to have a purpose.

Of particular note are land uses with relatively slow depletion rates that lead to a long lag period between paradigm adoption and adverse effects. In tests, this sort of slow depletion is often a major cause of large yield and population collapses because paradigms may spread widely before poor word-of-mouth diminishes expectations. Growing tomatoes on clay ($\beta = 0.0003$) or wheat rotated with beans on sand ($0.0009 - 0.0008 = 0.0001$) will deplete the soil, but only after some 64 and 192 years respectively, which may be more dangerous to future generations of simulated humans than land uses that are more immediately destructive and thus more easily avoided.

Basic model behaviour

That's enough then for a model with a fair bit of dynamic development when paired with evolving paradigms, and indeed the system's evolution is highly variable (Fig. 7). A few population bubbles and paradigms that destroy the soil may result in extremely low yields and population for thousands of years, whereas a few well-matched land-use rotations might bring the system close to its potential carrying capacity within a few hundred years. Through paradigm mutation and mimesis settlements experiment, tending to gradually evolve towards more sustainable land-use combinations, but with the messy, cascading cultural shifts recognizable to history and its many failures and collapses.

Distinct features, like large paradigms or more frequent crises, often come in periods, though without any clear order. A crumbling paradigm might break into large factions, split in many competing directions (its very size may mean that there are few good alternatives to fall back on in a crisis), or be replaced by another paradigm over only a few months. And while the number of paradigm rules tends upwards as settlements and paradigms coevolve through trial and error towards better land-use assignments, the system also goes through periods of iconoclasm, as settlements drop complex paradigms in favour of simpler paradigms with fewer rules and lower costs, despite rule addition being favoured over rule deletion.

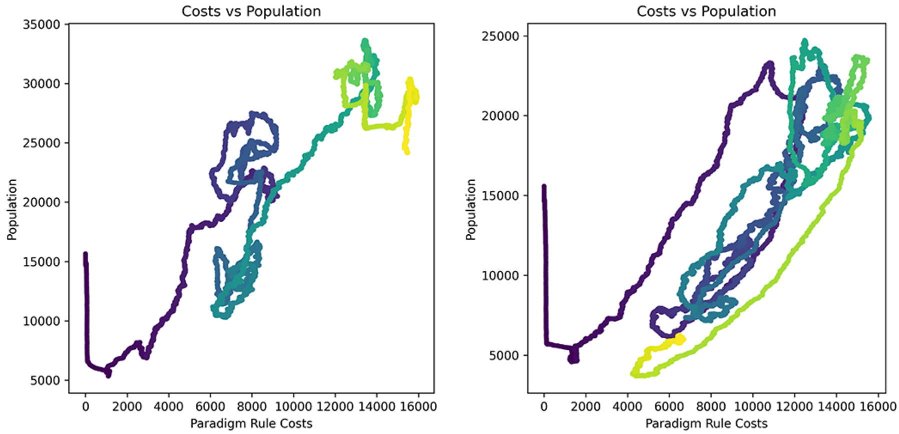

Figure 7: The cost of paradigm rules to settlements (i.e. organizational complexity) versus population, showing how the system moves its carrying capacity through innovation. Right: same test as in Fig. 8. Left : from another test with baseline settings. Note how on the right the system finds three relatively stable attractors with their own small cycles, while on the left the system cycles far more widely despite being run with the same settings.

However, even though each test's history is different in its specifics, evolution through thresholded responses, spread across many settlement agents, does create a general system-wide pattern, as seen in Figure 8, wherein discomfort and lowered expectations (i.e. distrust of dominant paradigms) lead to mutation and mimesis, which might lead to anything from growth to collapse, but will always eventually end in discomfort and lowered expectations yet again.

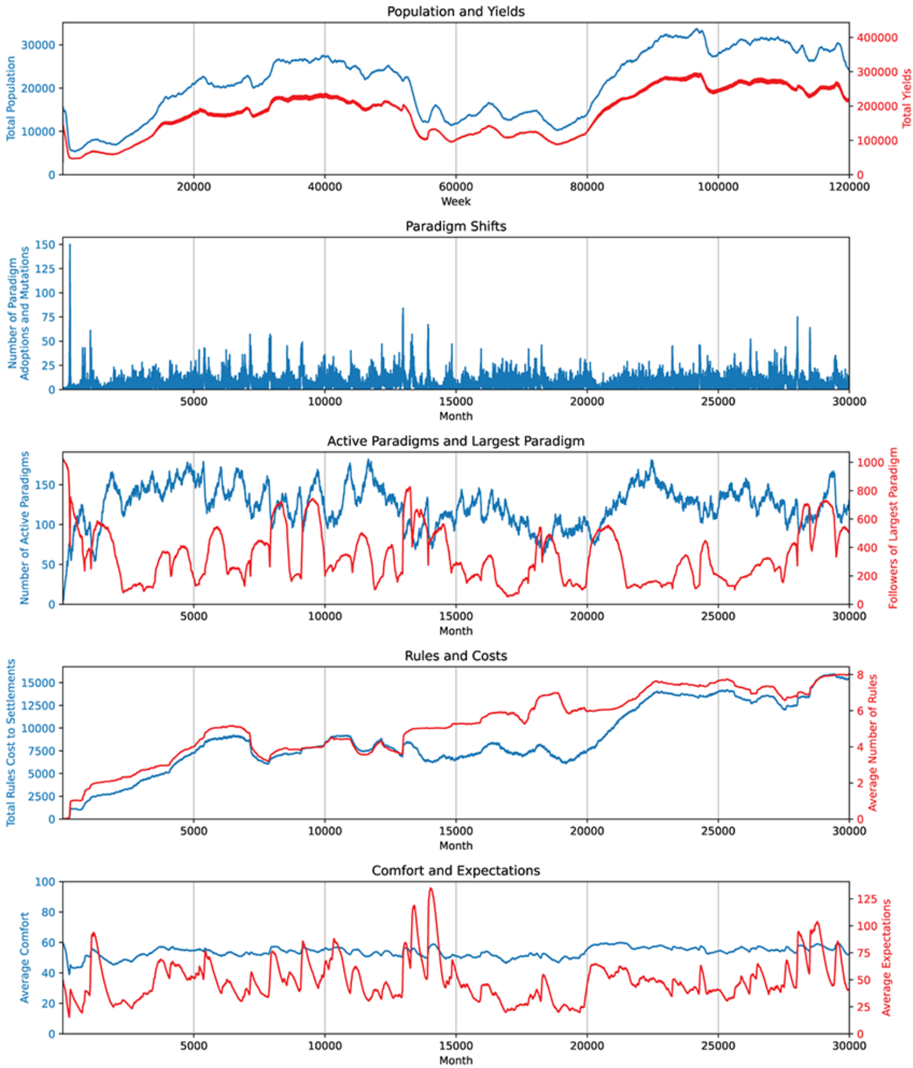

Figure 8: The results of one test with baseline settings. Note for example the periods of large paradigms in the second chart or expectation waves in the fifth.

SOC results

Following the basic SOC requirements that open the Framework section above, the model is open and *dissipative* at both the physical and paradigm level—crops grow and are eaten by people who are born, sometimes migrate, and eventually die;

paradigms are created, spread and eventually fall out of use. And at the paradigm level the system is *slowly driven* by the mutation rate of new paradigms, while the (often metastable) point of *instability* is the local comfort of settlements, causing local readjustments through interaction with neighbouring settlements when changing and spreading paradigms according to probabilistic *thresholds*.[11]

As expected then, at the level of ideas, the spread of paradigms across settlements, tracked both by the max number of settlement followers at any time and the total number of adoptions during the paradigm's life, shows power-law correlations—the main marker of SOC systems—across tests with highly varied parameters (Fig. 9). In all the modifications to the model described in the next section, and in the 910 tests done during development, the spread of paradigms remains consistently power-law, showing the strength of the paradigm model's self-organization despite significant modifications.

The model also matches Watkins et al.'s (2016) more detailed "phenotype" necessary conditions for SOC systems (non-trivial scaling, power-law correlations, self-tuned critical), and "genotype" sufficient conditions (non-linear interaction, avalanching and separation of timescales), avoiding continuous change so long as $m \ll 0$, keeping the probability of mutation significantly lower than mimesis.

Of note though, while the spread of paradigms self organizes into power-law form, the time paradigms are active (followed by at least one settlement) does appear related to various parameters, especially the adoption threshold. When this threshold is low (approx. $a < 0.5$ with other parameters baseline), time active is power law, but as is probably more realistic, when settlements generally aren't willing to expend energy trying a new paradigm unless it claims to be a certain degree better than what the settlement was already doing, the distribution starts to flatten, with more paradigms lasting long enough that you could say settlements are giving them a "fair shake" before giving up on them. In other words, while there is no typical size for paradigm mimesis cascades, suggesting SOC in the inversely proportional frequency of geographic spread, that doesn't negate the idea that there might be a vaguely typical length of time that paradigms (and thus perhaps trends, cultures, countries and civilizations) survive after their initial spread.

Overall, since the model meets the fundamental conditions of SOC, *it appears possible to model the evolution of societal paradigms, according to the framework described, as an SOC system*, which by creating power-law correlations like those found in many real human systems, shows that this framework's abstraction of paradigm evolution may indeed capture a significant aspect of humanity's evolution at the level of ideas and the oscillating instability of structures that emerge from and feedback on those systems of ideas.

[11] Tests using deterministic thresholds for mimesis and mutation also lead to power-law results, but since decision-making is a combination of emotion, habit and reasoning, purely deterministic thresholds seemed too simplistic to be worth using for most tests.

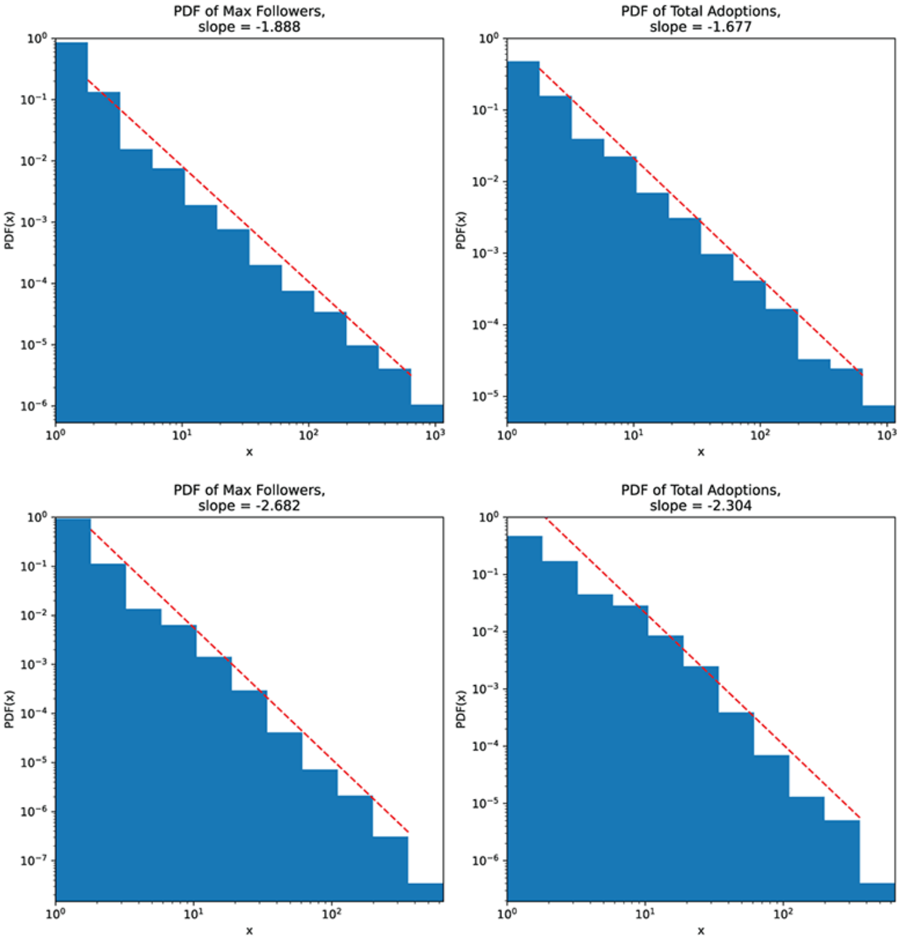

Figure 9: The spread of paradigms (mimesis cascades) in terms of the maximum number of settlement followers at any time and the total number of paradigm adoptions by settlements (settlements can switch between paradigms multiple times). Top row results from same test as Fig. 8, bottom row from same as Fig. 10. Note steeper slopes for Fig. 10 test: smaller cascades via evolution to high adoption thresholds and mutation rates.

Beyond the baseline

In baseline form, with the birth rate at $b = 0.02$, the model is essentially Malthusian, in the sense that population growth tends to outpace agricultural production, causing starvation and discomfort, leading to crisis and the creation and spread of new paradigms. However, removing this Malthusian assumption—by setting $P_c = b$ (stopping population waves created by high-comfort feedbacks) and by lowering birth rates to just above the level at which the system suffers total collapse ($b \sim 0.015$)—does not stop crises and power-law mimesis because of two other assumptions built into the model. First, the basic assumption of least effort that underlies the model's thresholds may lead to crises when overly comfortable settlements reduce work rates too far. However, even with this first assumption removed (by making work rates constant $W = 0.7$), while yields and population do become much more stable, power-law cascades continue because, second, the assumption that agents pick new paradigms based on satisficing word-of-mouth expectations means that *some settlements will always get worse results than the average*, leading to their discomfort. And similarly, because paradigms tend to spread based largely on expectations formed by early adopters (creating a sort of survivorship bias), later adopters may get worse results than expected, again leading to discomfort.

With paradigm expectations based only on comfort rather than returns (by setting $\theta = 0$), the system evolves through more continuous local crises to an almost stable level of oscillation (giving the resulting power-law spread a much steeper slope), but average expectations climb continuously out of line with reality. Whereas, increasing θ causes more frequent collapses by encouraging the spread of destructive paradigms with good early returns.

Increasing the influence radius of paradigms (essentially increasing the number of links at the level of ideas by increasing the number of counter paradigms that settlements are aware of) leads, as might be expected, to larger, faster mimesis cascades, making the system more volatile. (Think information technologies like the printing press and the internet letting all sorts of ideas run wild.) Likewise, decreasing the adoption threshold lets destructive paradigms spread more easily, while increasing the adoption threshold creates a sort of long-term thinking by giving time for word-of-mouth updates to decrease expectations for paradigms that offer high short-term yields at the long-term cost of destroying the soil. Similarly, arranging settlements so there are bottlenecks in the spread of paradigms (akin to mountain passes or land bridges), also slows the spread of paradigms, again making it less likely that the whole system will collapse as the result of one destructive paradigm with high expectations.

Increasing the probability of mimesis increases the speed at which paradigms spread (again making it easier for paradigms based on unsustainable land use rules to spread based on good early feedback), but a higher chance of mutation results not in more spread, but in more competing paradigms, leading to more failed paradigms, but also increasing the probability of finding land use combinations with sustainably higher yields. Especially when combined with a high adoption threshold, high mutation rates (approx. $m > 0.003$) lead to relatively stable system-wide population and yields over thousands of model years. Mimesis cascades continue at the level of ideas with many small paradigms and local crises, but the physical system settles into a decently slow-and-steady state, which while not reaching the extreme highs of some other tests or growing as fast, very rarely experiences large yield and population crashes across the system as a whole.

With trait mutation added, paradigms tend to evolve towards higher mutation rates and adoption thresholds through selection pressures, though mutation rates often fall again once good-enough land uses are found. This result holds with a weekly cost added for the adoption threshold, $Q_a = a * 7$, and a cost also added on mutation, $Q_m =$ 60 (about the highest the system, starting from baseline settings, can handle without consistently succumbing to total collapse.) These results might suggest a sort of stable society made of many small experimental polities that limit exposure to cascading instability in global systems (e.g. fragile just-in-time supply chains or viral financial crashes), but note that that land-use combinations limit innovative potential that might otherwise keep the system churning and that the model currently contains no possibility for emergent hierarchical structures or an uneven spread of resources to compete over.

With all cultural paradigm parameters (*s*, *d*, *t*, *m*, *a*, *z*, *h*, *u*, *b*, *q*, *r*) turned into mutable traits (each changing by a random increment during mutation), paradigms become a cultural force instead of mere farming rulebook, and paradigms start to emerge that could be described as more interested in their own viral survival than the survival of their settlement followers (Fig. 10). For example, high adoption thresholds do create a sort of long-term thinking, but also protect paradigms from the spread of other paradigms, and likewise, despite exponentially increasing costs to settlements, paradigms tend to increase their influence radius to spread farther faster. Paradigms also tend to lower birth rates, which can make the system more sustainable while also helping protect paradigms from Malthusian paradigm shifts, yet paradigms may lower birth rates so far that the system takes thousands of years to recover, if it recovers at all. Additionally, paradigms also tend to lower sensitivity *s* to its own expectations, while increasing sensitivity to births, deaths and emigration (*z*, *h* and *u*), passing the buck, you might say, from systemic paradigm problems to local conditions. On the other hand, selection pressures change desired storage little from baseline, while emigration rates tend to rise to around $q \sim 8\times10^{-5}$.

For those who might object to the assumption that human creativity is controlled by a stress threshold: The spread of paradigms does remain power law even when tested with a purely random mutation rate unaffected by settlement comfort. It is the mimesis threshold that is more important—just because someone has come up with a new idea doesn't mean others will adopt it. This does seem to align with patent applications, which while leptokurtic—implying dynamic processes—are not scale invariant, which Brunk (2003) suggests might be because patents represent some base level of research and curiosity outside of the pure cascades of an SOC system. Even if mutation and discovery were close to stochastic (like lightning strikes in a forest), the *spread* of paradigms may still be power law and SOC if there is a threshold to mimesis (and not even the original mutant might hold to their ideas without reason).

And for fun, one more addition: a very simple form of climate change can be added to this model by adjusting the yield multiplier with fractional Brownian motion[12] to represent oscillating yields caused by climate fluctuations. As might be expected, when the yield multiplier fluctuates minimally, it is at most the trigger for crises already growing within the system, but when the climate fluctuates greatly, its rhythms overwhelm the system, with most paradigm shifts following famines caused by sudden decreases in the yield multiplier.

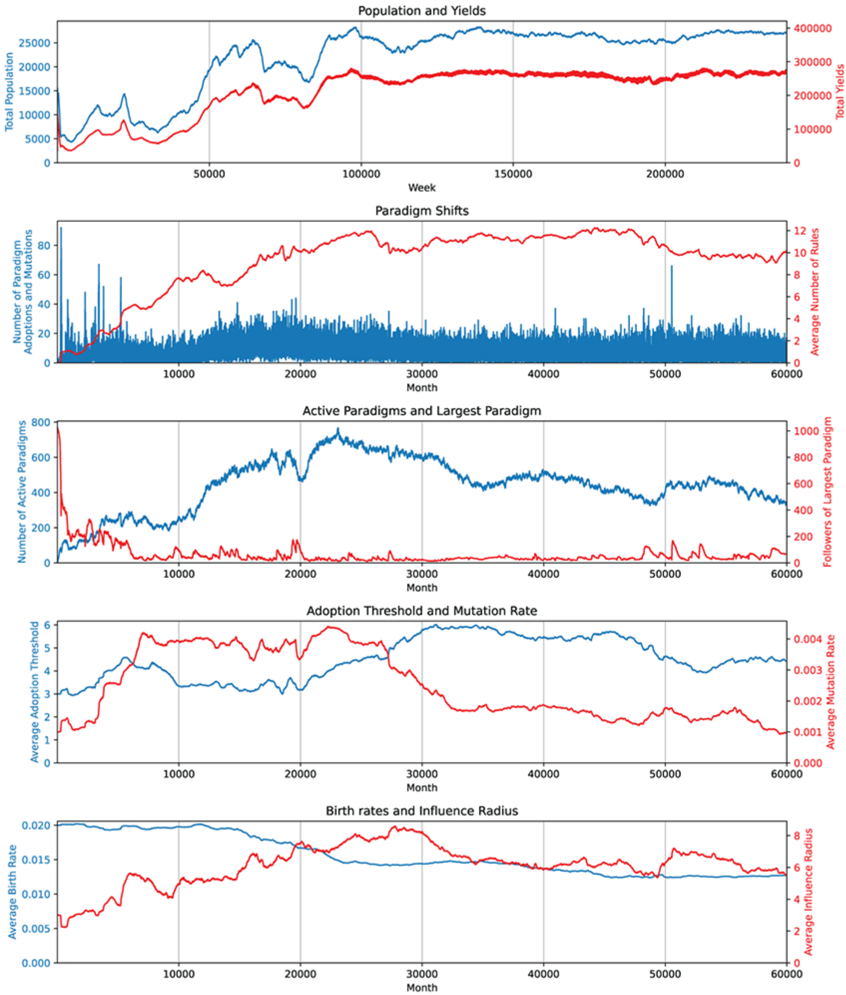

Figure 10: A test showing the evolution of the system with cultural paradigm parameters (not all shown) turned into mutable traits.

[12] Fractional Brownian motion (FBM) is a sort of layered noise. Mandelbrot's later stock market models use FBM (summary in Mandelbrot, 2001) and FBM is used for procedural generation and graphics shaders in computer games.

Discussion

A society's place in history

Supposing the humanity's power-law cascades, across the internet, stock markets and wars, do emerge through cascades at the level of ideas in a way comparable to the dissipation of thresholded paradigm shifts in the SOC model above, what would be the general implications?

Because mimesis cascades emerge from the thresholded responses of individuals, there must be some sort of stress that tips people into mimesis. There must be some sort of crisis in the system—even if completely atomized into individual crises of catharsis—to keep new ideas spreading, meaning, *crisis is not only inevitable, but necessary for the evolution of complex societies*. Thus, if defined as changing in a desired direction, *progress requires crisis*, and progress and stability cannot coexist. Moving the attractor of our oscillating political economies with new paradigms—whether your goal is European forever innovation or Byzantine conscious simplification—requires the creative destruction of crisis for those new paradigms to spread. Or, framed differently, despite the risk of collapse that it brings short term, *crisis is necessary for the evolution needed to avoid societal collapse* long term.

Hence, Tainter's paradox of collapse, in a power-law world of inevitable crisis at all possible scales, generalizes into the *paradox of crisis*, wherein oscillating material simplification and iconoclasm—the simplification of paradigms—frees energy to reorganize and abstract new cathartic understanding in new invention and organizational structures, generally leading to new growth in complexity. And as observed in the model, this tends to create an overall pattern of crisis, creativity and catharsis, but in a fractal, power-law form that subsumes the outliers that otherwise tend to break many grand historical theories.

In world in which complex societies are created through the dissipation of paradigms via discomfort thresholds, a few general signs that a society's history is leading it towards crisis:

1. *Widespread stress, anxiety and depression* point to a basic misalignment of dominant paradigm expectations (such as ever-increasing material wealth and happiness) with increasingly anomalous experiences and information, and cannot be simply mitigated at the individual level.

2. Likewise, *rising distrust in dominant paradigms* (and their enforcers) is not merely the result of ignorance, misinformation or subversion, and cannot simply be mitigated away with information, because that distrust suggests that dominant paradigms—through diminished returns of felt understanding—already lack catharsis in their core narratives.

3. Hence, *the accelerating emergence of counter paradigms*—created both through conscious rejection of dominant paradigms or through incremental offshoots—suggests that many uncomfortable people have already passed the threshold to attempt to create catharsis through new ways of splitting the flux. Of

course, most things like new political movements, economic structures, lifestyles and cults remain fringe at first, and most, in power-law form, will never be anything but, even as a few may become dominant in the future. (Think enlightenment thinkers discussing for a century the forms that only in 1776 and 1789 finally had a chance to become matter in revolution, or think Picasso, Kandinsky, Duchamp, Marinetti, Joyce, Gropius, Einstein, Bohr, Rutherford, Curie, F. W. Taylor and Ford sowing the seeds of modernism in the decade before 1914).[13]

4. From a broader view, you could say that comfort and peace are themselves dangerous signs of future crisis because they may lead to complacency and inert institutions, but then, in a framework where crisis is inevitable, with a wide enough view, every moment in history eventually becomes a sign of future crisis.

Note though that, because crisis can be atomized into individual crises of catharsis, while crisis might be necessary, this does not mean that it must take the form of famines, migrations, wars and genocides. For example, capitalism (when not monopolized) and democracy both dissipate crises in structured ways. Capitalism through atomized creative destruction (like high mutation rates in the model), and democracy through controlled social burns via voting as "a form of controlled revolutionary activity" within the meta structures of law (Hampton 1994: 34). And yet, the very success of democracy and capitalism may be a problem in that their flex has allowed us to grow—moving the attractor of our economic oscillations—to potentially unsustainable heights.

How to control crisis without blowback

You can't control crisis without blowback, not at least in the out-of-equilibrium flux of a complex-systems universe. The very action of trying to avoid crisis itself breeds crises through dissipation along other links and nested paradigms in the system. The best managed society will still run in directions its managers cannot predict because their paradigms cannot capture the whole complexity of the flux—which is the very thing that makes a paradigm useful in the first place. In hysteresis, there are no perfect or universal solutions, no end of history, and no way to turn back. From the human's perspective in the arrow of time, there is no ultimate catharsis, except death. Instead, *the inevitable necessity of crisis suggests the goal should be further incorporation of crisis into paradigms and social structures*.

Yet the reaction to crisis is often the opposite, as leaders, forgetting their creative role, try to mitigate, suppressing new ideas and necessary creative destruction—

[13] So, in science, even the biggest breaks build on old ideas—often reassessed with new information, or synthesized in a new way—yet to the general observer, these new paradigms may seem to come out of the blue during mimesis cascades. Stress and anxiety are like the buildup of brush on the ground, but that brush of misaligned expectations still requires a eureka-moment spark of cathartic mutation to start a mimesis cascade. You might be an extremely skilled artist, inventor, scientist, politician or revolutionary, but you still need to be in the right place at the right time where people are willing to consider new paradigms (you know, that form of hysteresis more commonly called *luck*.)

gradually going from, in Toynbee's (1946: 275-279, 579) terms, a creative minority that leads the response to change, to a merely *dominant* minority that, "infected with the mechanicalness of their followers" can do nothing but repeat the same failed responses to recurring challenges before often exchanging "the Pied Piper's pipe of persuasion for the whip of compulsion." But as seen with low mutation rates in the model, one of the most dangerous moments is when tested alternatives cannot emerge to replace the failed expectations of old paradigms.

Instead of suppression, Heylighen's (1991) solution to information overload created by accelerating innovation is an AI metabeing that will organize information at a higher meta-rational level, sounding somewhat like the social media algorithms that now fill our feeds. Yet, so far anyway (in an engagement-driven form), these algorithms only seem to be getting us more lost in the endless details of our complex world as they let us retreat into schismatic paradigms that make some sort of sense out of that world, even if it is simplistic identities, conspiracies, archaisms and futurisms. As in the model above (or with the printing press), vastly increasing the interconnectivity of our systems of ideas is seemingly helping fuel an increasingly volatile, chaotic world.

But in a framework where there is threshold to even considering new paradigms, the internet would not be spreading schismatic paradigms if people weren't already *stressed*, *distrustful* of uncathartic dominant paradigms, and *creating counter paradigms* to make some sense of anomalous experience. Embedded in a world where (to take a cynical survey) we're warned we might return to hunter gatherers lifestyles (Gowdy 2020) as the human climate niche collapses (Xu et al. 2020) while only a few "nodes of continuing complexity" survive (King and Jones, 2021), and demographic-structural pressures leading to increasing instability in the United States and Europe during the 2010s (Turchin 2010) remain unsolved (Turchin and Korotayev 2020), while people live in an "overfed, malnourished, sedentary, sunlight-deficient, sleep-deprived, competitive, inequitable, and socially-isolating environment" (Hidaka 2012: 10), with a repetitive culture that leaves them drowning in nostalgia and haunted by lost futures (Fisher 2013), it may be rational to seek the satisficing of temporary or escapist schismatic catharsis so long as dominant paradigms cannot cathartically solve those problems.

While the printing press might have enabled the Reformation's destructive dissipation of social pressures already built through centuries of plagues, heresies and alternate popes, the end result was Westphalian sovereignty. Information overload might not be a problem of too much data, but of the lack of a story that cathartically reveals new macro patterns in that data.

A new information age might demand new paradigms, but Heylighen's more basic request that we should at least be aware that all we believe is only one of many possible abstractions of reality might be a better start than an AI-controlled system of ever-shifting schisms. The system needs experimentation to offer alternative paradigms when dominant paradigms inevitably fail, but that might be further contained in a meta-paradigm aware of its own incompleteness and necessary crises.

Recognizing this, complex societies might consciously choose to override tendencies towards least effort in considering or creating other paradigms. (Think Meiji Japan's rapid modernization, achieved through conscious pursuit of mimesis and mutation within the meta restoration of old forms.) Societies might choose simplification—Tainter's rare Byzantine option—if people believe, via the felt understanding of cascading cathartic stories, that they have that choice and are not simply at the mercy of economic processes, even if after such simplification, that catharsis is forgotten and their complacent descendents are tempted into growing to the limit yet again.

Further Research

Scarcity created by complexity meeting paradigm limits implies that there will always be a place for people to seek power in controlling that scarcity. Power-seeking might be added to the model above with contracts, conquest, and the *expectation* of coercion creating emergent hierarchies according to evolving paradigm rules. With differentiated climate zones also added this might also lead to the emergence of border regions between hierarchies with consistently different evolved structures (i.e. dispersed versus centralized.)

Paradigm evolution might also be added to other models (in which some part can be controlled by mutable rules and traits) to simulate competitive evolution or to find parameters for the system that best balance stability with necessary crisis.

Model Download

https://github.com/acellular/Leviathan_original

The model runs in the Unity Engine (free for non-commercial use, link in readme) and includes ready-to-run sample tests. Note: settlements are called "leviathans" in the code, a reference to Hobbes.

References

Acemoglu, D., Johnson, S., and Robinson, J. 2005. "The Rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth." *American Economic Review* 95 (3): 546-579. https://doi.org/10.1257/0002828054201305

Adamic, L. A., and Huberman, B. A. 2002. Zipf's law and the Internet. *Glottometrics* 3: 143-150.

Bak, P. 1996. *How Nature Works: The Science of Self-Organized Criticality*. New York: Copernicus.

Bak, P., Tang, C., and Wiesenfeld, K. 1988. "Self-organized criticality." *Physical Review A* 38 (1): 364-375. https://doi.org/10.1103/PhysRevA.38.364

Bak, P., Tang, C., and Wiesenfeld, K. 1987. “Self-organized criticality: An explanation of the 1/f noise.” *Physical Review Letters* 59 (4): 381-384. https://doi.org/10.1103/PhysRevLett.59.381

Bardi, U., Falsini, S., and Perissi, I. 2019. “Toward a General Theory of Societal Collapse. A Biophysical Examination of Tainter’s Model of the Diminishing Returns of Complexity.” *BioPhysical Economics and Resource Quality* 4 (3). https://doi.org/10.1007/s41247-018-0049-0

Bartolozzi, M., Leinweber, D. B., and Thomas, A. W. 2004. “Self-organized criticality and stock market dynamics: an empirical study.” *Physica A* 350 (2-4): 451-465. https://doi.org/10.1016/j.physa.2004.11.061

Bettencourt, L. M., Lobo, J., Helbing, D., Kühnert, C., and West, G. B. 2007. “Growth, innovation, scaling, and the pace of life in cities.” *PNAS* 104 (17), 7301-7306. https://doi.org/10.1073/pnas.0610172104

Bourdieu, P. 1984. *Distinction.* London: Routledge.

Brunk, G. G. 2001. “Self-Organized Criticality: A New Theory of Political Behaviour and Some of Its Implications.” *British Journal of Political Science* 31 (2), 427-445. https://doi.org/10.1177/2158244020923354

Brunk, G. G. 2003. “Swarming of innovations, fractal patterns, and the historical time series of US patents.” *Scientometrics,* 56 (1), 61–80. https://doi.org/10.1023/A:1021998523825

Brunk, G. G. 2002. “Why Do Societies Collapse?: A Theory Based on Self-Organized Criticality.” *Journal of Theoretical Politics* 12 (2), 195-230. https://doi.org/10.1177/0951692802014002003

Charbonneau, P. (2017). *Natural Complexity: A Modeling Handbook.* Princeton: Princeton University Press.

Chen, Y. 2010. “Characterizing Growth and Form of Fractal Cities with Allometric Scaling Exponents.” *Discrete Dynamics and Society* 2010: 194715. https://doi.org/10.1155/2010/194715

Chen, Y. 2016. “The evolution of Zipf’s law indicative of city development.” *Physica A,* 448: 555-567. https://doi.org/10.1016/j.physa.2015.09.083

Chen, Y., and Zhou, Y. 2008. “Scaling laws and indications of self-organized criticality in urban systems.” *Chaos, Solitons and Fractals* 35 (1): 85-98. https://doi.org/10.1016/j.chaos.2006.05.018

Chen, Y., Wang, Y., and Li, X. 2019. “Fractal dimensions derived from spatial allometric scaling of urban form.” *Chaos, Solitons and Fractals* 126: 122-134. https://doi.org/10.1016/j.chaos.2019.05.029

Clauset, A., Shalizi, C. R., and Newman, M. E. 2007. “Power-Law Distributions in Empirical Data.” *SIAM Review,* 51 (4): 661-703. https://doi.org/10.1137/070710111

Cooper, R. (1995). *When Lean Enterprises Collide: Competing Through Confrontation.* Boston: Harvard Business Press.

Csikszentmihalyi, M. 1990. *Flow: The Psychology of Optimal Experience.* New York: Harper Perennial.

Diamond, J. 2004. *Collapse: How Societies Choose to Fail or Succeed.* New York: Penguin.
Fisher, M. 2013. "The Metaphysics of Crackle: Afrofuturism and Hauntology." *Dancecult* 5 (2): 42-55. https://doi.org/10.12801/1947-5403.2013.05.02.03
Foucault, M. 1986. "Of Other Spaces." *Diacritics: a review of contemporary criticism*, 16 (1), 22-27.
Gabaix, X. 2016. "Power Laws in Economics: An Introduction." *The Journal of Economic Perspectives* 30 (1): 185-205. https://doi.org/10.1257/jep.30.1.185
Gowdy, J. 2020. "Our hunter-gatherer future: Climate change, agriculture and uncivilization." *Futures* 115: 102488. https://doi.org/10.1016/j.futures.2019.102488
Granovetter, M. 1985. "Economic Action and the Problem of Embeddedness." *American Journal of Sociology* 91 (3), 481-510. https://doi.org/10.1086/228311
Greif, A. 2006a. "History Lessons: The Birth of Impersonal Exchange: The Community Responsibility System and Impartial Justice." *Journal of Economic Perspectives* 20 (2): 221-236. https://doi.org/10.1257/jep.20.2.221
Greif, A. 2006b. *Institutions and the Path to the Modern Economy.* Cambridge, UK: Cambridge University Press.
Haidt, J. 2014, December 3. *Jonathan Haidt: Three Stories About Capitalism (2014 WORLD.MINDS).* Retrieved from https://www.youtube.com/watch?v=iOu_8yoqZoQ
Hall, C. A., Lambert, J. G., and Balogh, S. B. 2014. "EROI of different fuels and the implications for society." *Energy Policy* 64: 141-152. https://doi.org/10.1016/j.enpol.2013.05.049
Hampton, J. 1994. Democracy and the Rule of Law. *Nomos* 36: 13-44.
Hardison, O. B. 1968. A commentary on Aristotle's Politics. In *Aristotle's Politics: A Translation and Commentary for Students of Literature*, 55-296. Englewood Cliffs, NJ: Prentice-Hall.
Heidegger, M. 1927/1996. *Being and Time.* Translated by J. Stambaugh. Albany: State University of New York Press.
Heidegger, M. 1936/1977. The Origin of the Work of Art. In *Basic Writings*, edited by D. F. Krell, 149-192. New York: Harper and Row.
Herrington, G. 2021. "Update to Limits to Growth: Comparing the World3 Model with Empirical Data." *Journal of Industrial Ecology* 25: 614-626. https://doi.org/10.1111/jiec.13084
Heylighen, F. 1991. "Cognitive Levels of Evolution: pre-rational to meta-rational." In *The Cybernetics of Complex Systems - Self Organization, Evolution and Social Change,* edited by F. Geyer, 75-91. Salinas, California: Intersystems. Quoted from http://pcp.vub.ac.be/Papers/CognLevels.pdf
Hidaka, B. H. 2012. "Depression as a disease of modernity: explanations for increasing prevalence." *Journal of Affective Disorders* 140 (3): 205-214. Quoted from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3330161/pdf/nihms346611.pdf

Jager, W. 2003. “Breaking ’bad habits’: a dynamical perspective on habit formation and change.” In *Human decision making and environmental perception: Understanding and assisting human decision making in real-life settings*, edited by L. Hendrickx, W. Jager, and L. Steg. Groningen: University of Groningen. Quoted from https://www.rug.nl/staff/w.jager/jager_habits_chapter_2003.pdf

Jager, W., and Janssen, M. 2003. “The Need for and Development of Behaviourally Realistic Agents.” In *MABS 2002*, edited by J. Sichman, F. Bousquet, and P. Davidsson, 36-49. Berlin Heidelberg: Springer-Verlag. https://doi.org/10.1007/3-540-36483-8_4

Jensen, H. J. 1998. *Self-Organized Criticality: Emergent Complex Behavior in Physical and Biological Systems.* Cambridge, UK: Cambridge University Press.

Kahneman, D. 2013. *Thinking, Fast and Slow*. Toronto: Doubleday Canada.

Kaufmann, E. P. 2016. “Complexity and nationalism.” *Nations and Nationalism*, 23 (1): https://doi.org/10.1111/nana.12270

King, N., and Jones, A. 2021. “An Analysis of the Potential for the Formation of ‘Nodes of Persisting Complexity.’” *Sustainability* 13 (15): 8161. https://doi.org/10.3390/su13158161

Korotayev, A., Zinkina, J., and Bogevolnov, J. 2011. Kondratieff waves in global invention activity (1900–2008). *Technological Forecasting and Social Change* 78 (7): 1280-1284. https://doi.org/10.1016/j.techfore.2011.02.011

Kuhn, T. S. 1974. “Second Thoughts on Paradigms.” In *The Structure of Scientific Theories*, edited by F. Suppe, 459-482. Urbana: University of Illinois Press.

Kuhn, T. S. 1962/2012. *The Structure of Scientific Revolutions.* Chicago: University of Chicago Press.

Mandelbrot, B. 2001. “Scaling in financial prices: I. Tails and dependence.” *Quantitative Finance* 1 (1): 113-123. https://doi.org/10.1088/1469-7688/1/1/308

Mandelbrot, B. 1963. “The Variation of Certain Speculative Prices.” *The Journal of Business* 36 (4): 394-419. https://doi.org/10.1086/294632

Maskell, P., and Malmberg, A. 1999. “Localised learning and industrial competitiveness.” *Cambridge Journal of Economics* 23: 167-185. https://doi.org/10.1093/cje/23.2.167

McAdams, D. P. 1995. “What Do We Know When We Know a Person?” *Journal of Personality* 63 (3): 365-396. https://doi.org/10.1111/j.1467-6494.1995.tb00500.x

Mehta, R., and Zhu, M. 2016. “Creating When You Have Less: The Impact of Resource Scarcity on Product Use Creativity.” *Journal of Consumer Research* 42 (5): 767-782. https://doi.org/10.1093/jcr/ucv051

Moss, S. 2002. “Policy analysis from first principles.” *PNAS* 99: 7267-7274. https://doi.org/10.1073/pnas.092080699

Puga, D., and Trefler, D. (2014). “International Trade and Institutional Change: Medieval Venice’s Response to Globalization.” *The Quarterly Journal of Economics* 129 (2): 753–821. https://doi.org/10.1093/qje/qju006

Roberts, D. C., and Turcotte, D. L. 1998. “Fractality and Self-Organized Criticality of Wars.” *Fractals* 6 (4): 351-357. https://doi.org/10.1142/S0218348X98000407

Rovelli, C. 2015. “Is Time's Arrow Perspectival?” *arXiv: History and Philosophy of Physics*. https://arxiv.org/abs/1505.01125

Rovelli, C. 2020. “Memory and Entropy.” *arXiv: History and Philosophy of Physics*. https://arxiv.org/abs/2003.06687

Schaper, E. 1968. “Aristotle's Catharsis and Aesthetic Pleasure.” *The Philosophical Quarterly* 18 (71): 131-143. https://doi.org/10.2307/2217511

Schumpeter, J. A. 1942/2008. *Capitalism, Socialism and Democracy.* New York: Harper Perennial Modern Thought.

Sellier, A.-L., and Dahl, D. W. 2011. “Focus! Creative Success is Enjoyed through Restricted Choice.” *Journal of Marketing Research* 48(6): 996-1007. https://doi.org/10.1509/jmr.10.0407

Tainter, J. 1988. *Collapse of Complex Societies.* Cambridge, UK: Cambridge University Press.

Tainter, J. 1996. “Complexity, Problem Solving, and Sustainable Societies.” In *Getting Down to Earth: Practical Applications of Ecological Economics*, edited by J. M. Alier, R. Costanza, O. Segura, S. Mageau, P. H. Jasinski, and J. M. Olson, 61-76. Washington: Island Press.

Tainter, J. 2000. “Problem Solving: Complexity, History, Sustainability.” *Population and Environment* 22: 3-41. https://doi.org/10.1023/A:1006632214612

Tainter, J. 1995. “Sustainability of complex societies.” *Futures*, 27 (4): 397-407. https://doi.org/10.1016/0016-3287(95)00016-P

Teran, O. 2001. “How Nature Works: The Science of Self-Organised Criticality.” (Essay review) *The Journal of Artificial Societies and Social Simulation* 4 (4). https://www.jasss.org/4/4/reviews/bak

Tero, A., Takagi, S., Saigusa, T., Ito, K., Bebber, D. P., Fricker, M. D., et al. 2010. “Rules for Biologically Inspired Adaptive Network Design.” *Science* 327 (5964): 439-442. https://doi.org/10.1126/science.1177894

Toynbee, A. J. 1946. *A Study of History: Abridgement of Volumes I-VI*, edited by D. C. Somervell. Oxford: Oxford University Press.

Toynbee, A. J. 1957. *A Study of History: Abridgement of Volumes VII-X*, edited by D. C. Somervell. Oxford: Oxford University Press.

Turchin, P. 2010. “Political instability may be a contributor in the coming decade.” *Nature* 463 (608): 26-32. https://doi.org/10.1038/463608a

Turchin, P. 2006. *War and Peace and War.* New York: Penguin.

Turchin, P., and Korotayev, A. 2020. “The 2010 structural-demographic forecast for the 2010–2020 decade: A retrospective assessment.” *PLoS ONE* 15 (8): e0237458. https://doi.org/10.1371/journal.pone.0237458

Turcotte, D. L., and Rundle, J. B. 2002. “Self-organized complexity in the physical, biological, and social sciences.” *PNAS* 99 (suppl 1): 2463-2465. https://doi.org/10.1073/pnas.012579399

Walsh, D. 2016, June 3. *Biological Identity Conference - Denis Walsh.* Retrieved from https://www.youtube.com/watch?v=UTYgH3Xri3w

Walter, C. 2018. “The Leptokurtic Crisis and the Discontinuous Turn in Financial Modelling.” In *The Making of Finance: Perspectives from the Social Sciences*, edited by I. Chambost, M. Lenglet, and Y. Tadjeddine, 77-89. London: Routledge.

Watkins, N. W., Pruessner, G., Chapman, S. C., Crosby, N. B., and Jensen, H. J. 2016. “25 Years of Self-organized Criticality: Concepts and Controversies.” *Space Science Reviews* 198: 3-44. https://doi.org/10.1007/s11214-015-0155-x

Xu, C., Kohler, T. A., Lenton, T. M., Svenning, J.-C., and Scheffer, M. (2020). “Future of the human climate niche.” *PNAS* 117 (21): 11350-11355. https://doi.org/10.1073/pnas.1910114117

Zipf, G. K. 1949. *Human Behavior and the Principle of Least Effort.* Cambridge, Mass: Addison-Wesley Press, Inc.