Context Changes Everything

How Constraints Create Coherence

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Persistence—Delaying the Second Law

Persistence can be described as stability over time (Pascal and Pross 2015). As realized in biological lineages and cultures, character traits, family resemblances, and social practices, constraint regimes endure longer than their moment to moment realizations. What persists are interlocking and covarying mutual dependencies held together by constitutive and governing constraints across spatial and temporal scales. This persistence holds even if the possibility landscapes that contain those interdependencies turn increasingly rugged over the entity's existence or lifespan. This rumpling of possibility space occurs in response to other more local and timely constraints. Earlier in this work, coherent interdependencies were referred to as realizing unity of type. What persists in individual realizations is not the material substrate of concrete particulars but the stored information embodied in constraint regimes.

In the case of living things, that metastable information enacts inherited genomic, epistatic, and epigenomic constraints. It is carried by the enabling and constitutive constraints that hold together as a configuration in dynamic metastability. Earth's metastability was generated and is preserved by a constraint regime that persists despite significant changes in its constituent details, such as the introduction of photosynthesis. Dissipative structures are also metastable, and for the same reason: enabling constraints in open systems under conditions far from equilibrium first precipitate a phase transition; the interlocking constraints of the resulting constitutive regime then preserve its coherence despite perturbations and fluctuations. Previous chapters emphasized that such contextually constrained interactional types are not universal, eternal, and unchanging; they are local and temporary. But given the contextual constraints that generated them, and while their constitutive and governing constraints hold, they are real and effective. And they persist.

Which sorts of constraints generate persistence? Previous chapters described processes and constraints that, upon reaching closure, interweave mereological relations. We saw that the overarching hyperloop formed in constraint closure takes longer to complete than the individual reactions that constitute it. By folding reactions back on themselves, recursion, autocatalysis, and feedback loops reinforce, replicate, and reproduce those conditions, components, and reactions that preserve mereological relations and prevent decoherence. They also incorporate real features of their world into their very constraint regimes.

This chapter focuses on persistence as a product of temporal constraints. Chapter 10 surveys diverse forms of entrenchment, a temporal constraint that reinforces persistence.

Persistence and Thermodynamics

How do coherence and persistence fit in with thermodynamics?

As articulated by Clausius, the second law of thermodynamics states that it is impossible for a process only to transfer heat from a colder to a warmer body. The end point of any thermic process is a state of equilibrium with its environment, a permanent and unchanging condition.

The received interpretation of the second law as formulated by Austrian physicist and philosopher Ludwig Boltzmann rests on a distinction between macro- and microstates. *Macrostates* are descriptions of large numbers of identical and independent particles, like molecules of gas. The temperature and pressure of a thermodynamic system, for example, can be realized by more than one microstate, the position and velocity of each molecule of gas.

The second law's arrow of time describes probabilistic tendencies of macrostates. Consider gas molecules in an enclosed container divided into two reservoirs, one hot, the other cold. Such a highly improbable initial condition (most molecules confined to one end and few molecules in the rest) is the system's initial macrostate. It lasts only while the partition between the two sides remains secure, or energy continues to be pumped in to keep the two sections separate. Once the partition is removed, the existing gradient inexorably dissipates.

Macrostates like this one that are realized by fewer configurations (two reservoirs) are less likely to occur than those with more configurations. The textbook heuristic is the following: throwing a pair of six-sided dice will come up a total of 7 more often in the long run because more combinations realize macrostate 7 than other macrostates. Despite each throw of the dice being an independent event, long runs of double sixes or snake eyes are possible. Unlikely, but possible.

Macrostates with a more uniform distribution of microstates are more likely than inhomogeneous ones such as the initial condition where molecules are bunched over at one end of the container and a near vacuum at the other. Over time a tendency appears, from less likely (more inhomogeneous) macrostates to more likely (more uniform) ones.[1] To illustrate: as more throws of the dice occur, 7 appears more often than double 6s or double 1s. In thermodynamic processes the distribution of molecules becomes increasingly uniform until it reaches the inevitable (most likely because most uniform, and therefore most stable) state of thermal equilibrium. As required by the second law, the tendency's overall direction, from least likely to most likely, is irreversible until the process reaches thermal equilibrium, the equivalent of white noise.

A tendency is a probabilistic measure. The statistical interpretation of the second law therefore equates *more likely* (macrostate probability) with *more stable*. And most stable with unchanging and therefore most lasting. Decades before Richard Dawkins repeated the quip, Herbert Simon (1969) riffed that this interpretation of the second law amounts to "the survival of the stable."

What, exactly, does this lasting condition amount to? Once reached, thermal equilibrium lasts, but there is *no-thing* that persists at thermal equilibrium (Ladyman and Ross 2010). White noise is no-thing; equiprobability is no-macrostate. Macrostates that appear to pop up along the way to thermal equilibrium (like a long run of snake eyes) are statistical improbabilities. Since on this interpretation microstates are independent of each other, those macrostates do not represent covarying relations formed and preserved by interlocking context-dependent constraints. Thermal equilibrium at the end lasts because the total absence of constraints ensures permanent no-thingness. The path to thermal equilibrium is the process of progressive relaxation of arbitrarily and extraneously set context-independent constraints (Barbour 2020).

Riffing on Simon, the second law could therefore also be characterized as "the survival of no-thing" since at thermal equilibrium there are no constraints and consequently no stored information that is qualitatively other than the aggregate or sum of the equally likely *microstates*. There is no stored information because there are no covarying interdependencies. There are no covarying interdependencies because there are no constraints. Thermal equilibrium carries no information and can do no work. Unconstrained equilibrium (white noise) is a statistical description, but it is a macrostate in name only. There is no "it" that persists as itself over time (Ladyman and Ross 2010). Thermal equilibrium is not identical to persistence.

On the probabilistic interpretation of classical thermodynamics, equilibrium is *nonorder*. To repeat: because there are no constrained interdependencies, there is no organization, no structures, and no configurations. What is usually described as a process that goes from order to disorder is in fact only the progressive relaxation of an existing gradient whose source is unexplained (Barbour 2020)—whether of the Big Bang or a closed box partitioned into two reservoirs. Left to itself, cosmic expansion diffuses until it reaches uniformity, the total absence of constraints. Left to itself—that is, without energetic input that keeps the two reservoirs separate—the gradient dissipates until the molecules of gas are uniformly distributed throughout the space. This form of dissipation is significantly unlike the constrained, order-generating process of nonequilibrium dissipative structures. The two processes are different because according to standard physics micro-events are independent of one another and there are no relations—and therefore no relations of continuity, covariance, or dependence, much less constraint—between them.

Other than the stasis of thermal equilibrium, then, do the concepts of persistence and endurance have any meaning in classical thermodynamics? To return to the dice example, since each throw is independent of the others, a long run of snake eyes is not an ontic entity that persists as itself. "A run of snake eyes" refers only to an observable statistical fluke. If persistence is defined as continuity of the same sort of thing despite changes in composition, is there any provision in classical thermodynamics that accounts for the persistence of coherent entities—entities that in some sense endure despite changes?

The second law of classical thermodynamics is blind to "configurations," that is, to real patterned energy flows (Bejan 2020). Energy does not organize into persistent configurations because there are no contextually constrained relations between states. Because no context-dependent constraints make flows dependent on one another and weave them into internally coherent (because interdependent) dynamics, any such patterns that seem to arise and last are coincidental sequences of microevents. A run of snake eyes. They are not ontologically informed. It is not just that there are no persistent macrostates as such in classical thermodynamics; there cannot be because each momentary microstate is independent of and uncorrelated from the rest.

The second law is therefore silent about the generation of stable but nonequilibrium configurations of interdependent streams of energy flow, their persistence, or their evolution. The constructal law (Bejan and Lorente 2008; Bejan 2020) is meant to extend the second law by addressing precisely this issue, the formation, persistence, and evolution of designs or patterns of energy that flow, in a discernible direction, versus time. The new configurations satisfy the second law because patterns—constrained order—facilitate energy flow.

This book has proposed that operating against a backdrop of context-independent constraints like thermal gradients, context-*dependent* constraints are responsible for the generation of such patterns. Constraints naturally and irreversibly intertwine and organize independent and separate particles and events into coarse-grained types or patterns of energy, matter, and information flow with emergent properties. Contextually constrained relations and interactions set against the background established by context-independent constraints generate metastable and persistent configurations—real macrostates because of the interdependencies they weave among their components. In irreversible phase changes paid for by an overall increase in entropy, constraints interleave streams of matter, energy, and information flow such that overarching constraint regimes with qualitatively distinct properties arise. The coherence of those interlocking interdependencies embodies and enacts newly created information. That information manifests as the emergent properties of the constraint regimes.

In open systems far from equilibrium, that is, ordered configurations emerge out of nonorder and retard thermalization in virtue of the interplay of constraints. From the perspective presented in this book, configurational patterns—their emergence, persistence, and evolution—are the products of context-dependent constraints, operating against the backdrop of context-independent constraints. As a result, identifiable, constrained, multiply realizable interdependencies can endure despite changes. They last as constitutive constraint regimes with emergent properties.

Persistence under nonequilibrium conditions is implemented (top down) by the governing powers of constitutive constraints that confine token realizations to within the basin of attraction of an overarching coordination dynamic—the attractor generated by constraints. As we saw in the illustration of epigenetic landscapes, since attractors are multiply realizable and generated in response to context-dependent constraints, they are not rigid monoliths; over time, their realized tokens explore the adaptive space of the attractor's constraint regime. Coordination dynamics generated by constraints are true examples of the formation of macroscopic order out of nonorder.

This interpretive framework is therefore also about macro–micro relations. The difference with the classical view, however, is that the latter's statistical interpretation does not address constraints; it formulates no principle whereby microevents become interdependent with each other and real macrostates can form and persist as coherent entities, then adapt, and ultimately evolve. In contrast, the perspective presented here considers multiply realizable interdependencies to be real and irreversibly generated in open far from equilibrium conditions by intertwined context-independent and context-dependent constraints. The explanation of constraint closure presented in chapter 7 accounts for these mereological dynamics.

Interdependencies persist because, as contextually constrained coordination dynamics, their constraint regimes coarse-grain nature into types of entities whose governing constraints are degenerate: they can be realized by more than one microstate. Functions such as homeostasis and metabolism are examples of coarse-grained or smoothed-over constraint regimes. So are organisms and lineages; they can be realized by more than one microstate or configuration even as their unity of type persists. Mereological constraints therefore account for why and how organisms last longer than their cells, and lineages last longer than their specimens. Nature generates such multiply realizable types because they have more paths to persistence—to metastability over time—than do the individual tokens or components that realize those types. Multiple realizability therefore also supports evolvability, the capacity to evolve.

The cosmos, we can conjecture, tends to coherence-making by constraints for the same reason that trajectories in the probabilistic interpretation of classical thermodynamics go from hotter to colder: energy flows more easily when constraints align individual energy streams into more coarse-grained dynamics through which to flow. Multiply realizable constrained ontic patterns also underpin the freedom to explore newly formed relational states (Bejan 2020). In short: interactional types are real, not mere observables. Their systemwide properties persist in reality because they are metastable; they are metastable because they embody contextually constrained interdependencies. Such mereological interdependencies, formed by contextual constraints, are degenerate.

From the perspective presented in this book, the capacity for persistence is therefore the outcome of naturally occurring constraints—not, as Boltzmann-inspired thermodynamics would have it, the absence of arbitrarily and exogenously initialized constraints. Local pockets of constrained and enduring inhomogeneities in nonequilibrium are neither improbable and unexplained initial conditions nor observed coincidences. Interactional types or kinds of entities are real products of the organizing capacity of constrained energy flow. Types form and last longer—as real, patterned configurations of energy flow—than either their token realizations or the components and stages that make up those patterns (Nicolis and Prigogine 1977).

Interactional types as conceived here are not universal or eternal. They are induced by context-dependent constraints and realize self-reinforcing, persistent forms that are multiply realized as distinct path-dependent histories and trajectories. By originating from a combination of context-independent and context-dependent constraints, coordination dynamics precede the origin of Life. Form is not synonymous with shape. Forms are context-dependent constraint regimes with emergent properties and powers. They expand dramatically with chemistry and explode with the emergence of dissipative structures, living things, and biological lineages. On this view, conscious beings and the Anthropocene they have created are just the most recent iteration of this dynamic process.

The Principle of Persistence

Analogous to Bejan's proposals, the principle of persistence also aims to extend the second law, from "survival of the thermally stable" to "Nature seeks persistent forms" (Pross 2012; Pross and Pascal 2013; Pascal and Pross 2015). Its authors claim that since persistence (stability in time, rather than the stasis of heat death) is the more general concept, it can embrace the unchangingness of thermal equilibrium as well as temporary and local pockets of form, those improbable macrostates in dynamic nonequilibrium that are realized in physicochemical and biological dissipative structures. The principle of persistence's own arrow of time goes from less persistent and less probable macrostates to more persistent and therefore more probable ones, with thermal equilibrium winning out in the end.

Pascal and Pross recognize that the concept of stability is utilized in two quite different senses, one that refers to heat death, the other to stability in time. As noted, in classical thermodynamics, persistence, strictly speaking, refers only to the absence of constraints—heat death. There is no form or principle of identity at thermal equilibrium. There is no-thing that persists as itself.

In contrast, persistence in open and nonequilibrium dynamical systems consists of self-reinforcing and self-maintaining dynamics that, thanks to constraints, hold fast despite changes at the microscale. Persistence in nonequilibrium open systems is realized as *dynamic kinetic stability* (DKS), not thermal equilibrium (Pascal and Pross 2015; Pross and Pascal 2013). According to the two authors, the source of DKS's persistence is exponential growth such as the growth driven by autocatalysis.

What, exactly, grows exponentially? The principle of persistence considers stability in time to be the ability of certain replicating entities, "to make copies of themselves at a rate that results in a non-equilibrium steady state population of replicating entities being maintained over time" (Pascal and Pross 2015, 16162). In living things, this translates to the ability to reproduce at a rate that outruns entropy or outcompetes other species (Pascal and Pross 2015), if only locally and temporarily. Pascal and Pross, correctly, include nonliving things such as physicochemical dissipative structures in the category of entities that can outrun entropy. They highlight the exponential growth of autocatalysis as the driver of DKS.

The authors also recognize that it is the "*population* of replicators that is stable/persistent rather than the individual replicators that make up the population at any given moment" (Pascal and Pross 2015, 16162; emphasis added). As has been noted above, lineages and populations persist relative to individual organisms, and organisms persist vis à vis individual cells. Mutatis mutandis, this is true of all open nonequilibrium dynamical systems that self-organize in response to constraints. They are multiply realizable, and their token realizations can differ at the microscale despite the continued persistence of the self-organized and coherent whole.

More precisely, then, it is the metastability of multiply realizable and coherent constraint regimes that outruns entropy and persists, at various scales. This is what Pascal and Pross aim to capture with the term *dynamic kinetic stability* (DKS). From the perspective of this book, DKS represents the persistence of coherence, that is, of multiply realizable interdependencies brought about by intertwined enabling constraints and preserved by governing constraints under nonequilibrium conditions. Such continued coherence over time subtends DKS, which is fundamentally the product of enabling and governing capabilities of constraints.

The hypothesis proposed in this book, then, has been that individual physicochemical dissipative structures and biological systems alike temporarily delay entropy by holding fast unity of type—that is, by preserving multiply realizable interlocking interdependencies over time—despite turnover of individual reactants and products, individual catalysts and elements, or individual organisms and cells. Bénard cells persist despite turnover in the individual water molecules; BZ reactions persist despite replacement of individual reactants. This is also so in the case of organisms, of course: the removal and replacement of individual organs, the births and deaths of individual cells, and so on are an integral part of their multiply realizable dynamic. Cells, too, replicate cell type despite mitotic division, replacement of organelles, and so forth. And metabolism preserves homeostatic stability despite changes in glucose utilization, and so on. Throughout, the coherence—the constraint regime—persists.

If the point made in the previous section is correct, however, basing persistence on exponential replication and reproduction and thereby outrunning entropy production begs the question by presupposing the capacity to replicate and reproduce unity of type tout court or, in Pascal and Pross's terminology, form. As noted, form is not identical with shape. As described at the beginning of the book, Platonic forms were historically postulated to account for type identity—for the capacity to persist as the same sort of thing throughout differences and modifications. Forms and Aristotelian and Cartesian substances were postulated as explanations of why spatiotemporally distinct tokens are alike despite differences. Absent Platonic forms, Aristotelian and Cartesian substances, or natural kinds, the principle of persistence must explain the generation and persistence of multiply realizable coherent dynamics, be they realized by autocatalytic replicators or living things.[2]

That is, the principle of persistence must account for DKS's emergence and metastability despite inevitable perturbations and fluctuations. Otherwise, the principle presupposes the persistence it is trying to establish. All positive feedback including autocatalysis can spin out of control. So how do autocatalytic reactions or loops of feedback processes become stabilized into DKS that persists in nonequilibrium? Coherent, self-reinforcing, and self-stabilizing dynamics that preserve unity of type despite remaining in nonequilibrium cannot be presupposed in the explanation by stating that the puzzle of life lies in the types and nature of persistent systems such as some chemical systems present. On pain of petitio principii, it is precisely those types and nature that call for an explanation.

There are no types as such at thermal equilibrium, where, as noted earlier, stability and persistence refer to the absence of constraints. Interactional types as described in this book can hold together and persist in open conditions far from equilibrium only as products of constraint, not their absence. Stating that "even replicative change that appears prebiotically . . . manifests a logical and irreversible drive towards greater persistence" (Pross and Pascal 2015, 16163) begs the question of whence the original capacity for replicative change to make more of the same type of entity, whether of ~~a~~ physicochemical dissipative structures, predator–prey cycles, or species of organisms, all without spinning out of control. As discussed earlier, replication and reproduction are more-makers precisely because they are not cosmic runs of 6s: each replicate's traits are not independent of those of the parent or the previous step. Subsequent steps and generations are conditioned upon earlier ones. It is only because iterations of complex systems are context-dependent and path-dependent that each turn of the exponential spiral makes more of an already coherent structure. This is so for dissipative structures generally, both abiotic and biological.

Exponential replication, in short, presupposes context-dependent constraints.

Whether each microevent is independent of or interdependent with a previous step, both in time and place, marks a significant difference between classical thermodynamics and the coherence-making by constraint inspired by complexity theory. Context-dependent constraints are absent in the first and very much present in the second. The source of endurance of complex systems is the generation and maintenance of form—that is, of coherent interdependencies held together by regimes of constraint. If persistence presupposes the capacity to preserve a coherent structure or dynamic that endures despite changes, proposing to expand the second law by postulating that the evolution of forms displays a direction from less to more persistent begs the question with respect to the generation and coherence of such persistent patterns of dynamic equilibrium—especially since actual realizations of macrostates are not independent of each other.

Pascal and Pross (2015) note "the stability of such systems depends not just on the system but on factors outside the system" (16163). This book has proposed that the role of contextual constraints in generating DKS in the first place is that factor. BZ reactions and tornadoes persist in nonequilibrium conditions as coherent constraint regimes. Without the role of context-dependent constraints in producing dynamic equilibrium, DKS cannot be presupposed in explanations of persistence and form (interactional type, as it is labeled here). Doing so begs the question.

To summarize: exactly what persists at thermal equilibrium and as dynamic kinetic metastability are quite different: contextual constraints underpin dynamic kinetic stability under nonequilibrium conditions; and there are no constraints at all at thermal equilibrium. We can conclude that the principle of persistence begs the question and commits the fallacy of ambiguity along the way; *persistence* (as the authors use the term) spans both thermal stasis and dynamic stability far from equilibrium only if the term is used ambiguously.

Selection by Persistence

Advocates of the principle of selection by persistence present a different understanding of the relation between stability and persistence. This hypothesis interprets persistence as the outcome of a continuous process of selection based on stability. Whence the criteria of selection on this view?

The *modern synthesis*, which merges Darwinian evolution with Mendelian genetics, maintains that random DNA mutations are the sole source of variation from which selection then culls the reproductively advantaged. Over time, the fittest specimens come to predominate. On this view, phenotypes are the product only of accidental genetic mutations.

Since there are "no competing reproducing planets for natural selection to choose between" (Holmes 2019, 34), the modern synthesis breaks down at the level of Earth as a whole. What, then, accounts for the planet's remarkable capacity for long-term self-regulation, a form of self-stabilization[3]—despite, as mentioned earlier, the appearance of photosynthesis, which dramatically changed the atmosphere? Earth's relatively constant temperature range and overall levels of oxygen, carbon, nitrogen, and phosphorus have remained relatively steady over millions of years. Recent discoveries that Earth's geologic activity appears to follow a 27.5-million-year cycle could be considered additional evidence that lasting geological patterns might not be statistical flukes; they hint at the possibility of constrained and evolvable dynamics (Rampino et al. 2021).

Evidence that Earth has managed to persist far longer than living things capable of adapting to their environment have been in existence suggests, in other words, that evolution by selection of the reproductively fit might be only one of several selection mechanisms at work in the cosmos. In contrast to the usual emphasis on random mutations, proponents of selection by persistence maintain that rethinking selection more generally in terms of persistence over time can include abiotic processes as well as living things under one principle.

Once again, the idea of selection implies a macrostate–microstate distinction; it implies a variety of specimens from which the embedding context, a real and constrained macrostate, culls. Previous chapters argued that interactional types span multiply realizable coordination dynamics. In consequence, culling is not a random lopping off. Reminiscent of the craft of tailoring, natural selection is a process of fitting together or rendering compatible an entity and its embedding context. This fitting together is carried out in back and forth cascades of feedforward and feedback loops, from the dynamic's governing constraints (in virtue of which its constitutive constraints remain coherent) to those of the actual token.

Earth's rocky shell, its abiotic atmosphere, hydrosphere and cryosphere, are fitted together with living things to constitute the biosphere, a constrained and integrative, multiscale and multidimensional set of interdependencies. Interfaces between the various levels of organization and dimensions of this complex ecosphere are the active sites where the fitting together process takes place; in the case of the planet, the biosphere serves as the interface between Earth's geological strata and outer space. It actively selects and realizes actual tokens through cascades of top-down negative feedback loops, which change the probability distribution of individual events. Phrased differently, order parameters of the biosphere (be they the dynamic equilibrium of Earth's temperature range, the relative reproductive fitness of living things, or even the distintegrating impact of human actions on the biosphere itself) describe the multiple constraints that the biosphere as interface must simultaneously satisfy. Only those potential tokens that satisfy that constraint regime are selected for persistence.

It is in this manner that constitutive and governing constraints of complex dynamic systems simultaneously stabilize and enhance metastability. They allow autocatalysis's exponential growth to outrun entropy without spinning out of control. As noted, however, the stability of complex systems is not formless, unconstrained, and static thermal equilibrium. Quite the contrary, it is a constantly varying metastability that thanks to a constitutive constraint regime persists as a coherent dynamic in nonequilibrium.

As just discussed, in classical thermodynamics, stability commonly refers to a system's lowest energy state. In contrast, Earth's overall dynamics have persisted for eons as a pocket of constrained metastability away from equilibrium with surrounding deep space. The validity of the hypothesis of selection by persistence therefore turns on a particular understanding of stability.

Its advocates (Lenton and Latour 2018) recognize that the planet's atmospheric conditions are metastable despite being in nonequilibrium with space. Lenton proposes the following. Suppose Earth accidentally arrived at[4] a configuration of elementary constituents that is particularly stable. Such a pattern would not only tend to persist and become self-reinforcing; it would also supersede destabilizing perturbations because stabilized states generate more stability. They do so because, whether physical, chemical, or biological, stable systems as such "not only persist; they get better at persisting over time" (Lenton, quoted in Holmes 2019, 35) by sequentially selecting among degrees of stability. Insofar as stable states "sequentially select" states that are even more stable (see also Henrich 2016), the idea of selection by persistence therefore proposes a form of "sequential selection."

The hypothesis thus postulates that the cosmos must have accidentally reached a state that does not easily and reversibly wash out despite diversely realized configurations or undergoing regular perturbations or fluctuations. The hypothesis also proposes that particularly stable macrostates beget and select even more stable states.[5] Considering that the second law is "blind to configurations" (Bejan 2020) and does not countenance relations among microprocesses, however, how can primordial and improbable but real states not naturally wash out—absent constraints? A primordial and improbable state that holds together either in a principled way, or due to an internal logic, is not contemplated in classical thermodynamics.

In response to critics who question the relative selective advantage of stability over regular and entropic destabilizing forces, proponents of the Stability as Persistence thesis maintain that any stability that persists must be *robust*,[6] that is, able to withstand fluctuations and insults without decohering. What property might delay thermalization and thereby turn the state robust? Without using the terminology of degeneracy or multiple realizability, much less constraint, Lenton notes that certain features are required for robustness.

> Robust systems have some degree of *redundancy* so the loss of any particular component (the extinction of a species, say) doesn't critically compromise the whole. Second, they have *diversity*, which increases the odds that at least some species will be able to cope with unexpected changes. Third they have *modularity* so that a failure of part of the system doesn't bring down the whole thing. (Lenton, quoted in Holmes 2019, 36; emphasis added)

By emphasizing redundancy, diversity, and modularity, the stability as persistence hypothesis implicitly appeals to the notion of macrostates. In light of the previous discussion, this requirement immediately prompts the question, "What mechanism generates real macrostates that are redundant, diverse, and modular?" Without an origin story for these three features, this hypothesis, too, begs the question.

In contrast, the central thesis of this book, that constraints are the agents of coherence-making, offers just such an origin story.

It is evident, then, that just as the advocates of the principle of persistence used the term stability to mean DKS, advocates of selection by persistence use the term stability to mean *metastability*. The robustness required for persistence is a naturally emergent metric of diversely realizable constrained interdependencies. Such variety is not measured in numbers of identical tokens of the same type; it requires interdependencies among interwoven but distinct constraint regimes (Brillouin 1962; Collier 2003b; Collier and Hooker 1999). Integration into a general type of entity in response to constraints lowers internal entropy production and realizes metastability. The more types and subtypes, the more paths to realization. The more deeply multiply realizable and degenerate, that is, the more metastable and robust.

Modularity, the third prerequisite of robustness identified by advocates of the selection by persistence hypothesis, is a common feature of coherence-making by constraints, especially in hierarchy formation. It contributes to a hierarchy's capacity to evolve. Chapter 12 will return to modularity's contribution to coherence-making and hierarchy formation.

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