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Chapter 4

A Revolution in the Middle Kingdom

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1. Introduction

The dawn of the Enlightenment late in the 17th Century can be marked by Isaac Newton's description of the gravity that binds two bodies, separated by enormous distances of the vacuum of space, in a tight and predictable synchrony. Newton's model was the key that opened the floodgates to scientific achievement that over the next two centuries would expand human knowledge in the realms of optics, electricity and magnetism, sound, and even chemistry. By the beginning of the Nineteenth Century, LaPlace had offered up an apotheosis of Newtonian mechanics by declaring that a super intelligence who could know the positions and momenta of all particles in the universe at any one instant could invoke Newton's laws to determine both the previous march of history and all subsequent events to come. The scope of science appeared universal and limitless.

Only a few years were to pass after LaPlace's rapture before Sadi Carnot made the disconcerting discovery that the processes of the transfer of heat and the creation of work could not be fully reversed. LaPlace's divining intelligence, relying as it did on Newton's reversible mechanics, could not predict Carnot's results. The ensuing half century was one of anxiety and uncertainty among physicists, as the burgeoning atomic theory lay hostage to the irrefutable phenomenology of thermodynamics. But a resolution of sorts eventually was achieved by Ludwig von Boltzmann and Josiah Gibbs, who proffered mechanical and statistical models wherein a large number of microscopic particles moving with virtual independence from one another could give rise to a preferred direction for time. At about the same time, the German monk, Gregor Mendel was discovering that biological phenomena sometimes do not happen in the gradual and continuous way that Darwin had supposed. Ronald Fischer discovered that this conflict between biological descriptions apparently could be reconciled using virtually the identical assumptions and mathematics that had been advanced earlier by Gibbs. As with statistical mechanics, Fischer's "Grand Synthesis" described how a large number of independent elementary genes at the microscale could give rise to an ensemble of genetic traits that grew progressively more "fit" with respect to their macroscopic environment. As a result of Gibbs and Fischer, the contemporary perspective on the universe has become bipartite. Significant events or causes may occur only among the many decoupled components of the stochastic microworld, or between a very few elements in the determinate macroworld. For the rest of the 20th Century all seemed well with the world, and the scope of science once again seemed all encompassing.

At the threshold of the 21st Century, however, some voices began to question this bipartite, almost schizophrenic depiction of the natural world. Could it really be that causes arise *only* at the peripheries of observation? Why is it that contemporary science looks exclusively into the unfamiliar realms of the micro world or the cosmological for the reasons behind the events that make up everyday existence? Is it possible that something is being overlooked; that modern science might be committing Aristotle's "error of the excluded middle"; that the explanations for much of what happens lies instead among the prosaic "Middle Kingdom", that is populated by systems made up of a modicum of entities that are loosely but definitely coupled?

The renowned developmental biologist Sidney Brenner was among those questioning voices. Brenner and his colleagues attempted to map exhaustively the correspondences between the microscopic genes and the macroscopic phenotypic traits in a very elementary multicellular nematode (Lewin 1984). Despite their Herculean efforts, they were forced to conclude that the full story "still remains elusive ... the molecular mechanisms look boringly simple, and they do not tell us what we want to know. We have to try to discover the principles of organization, how lots of things are put together in the same place." (Recent results from the Human Genome Project have only served to underscore Brenner's plea.) What Brenner was implying is that at least some of the answers to development lie not at the molecular levels, but at the meso-scale – among the patterns of metabolic processes themselves. Stuart Kauffman (1995) echoed the same theme when he suggested that not all biological order is encoded in the molecular genetics. Some of it appears "for free" out of the constraints imposed by (meso-scale) metabolic dynamics. Or, as Karl Popper (1990) exalted, "[W]e are, like all cells, processes of metabolism; nets of chemical processes, of highly active (energy coupled) chemical pathways", which transpire over scales commensurate with the organism itself.

It may be, however, that ontogeny and developmental biology are not the most propitious disciplines wherein to study meso-scale agencies, because an organism develops in an almost deterministic fashion. To grasp the essence of development, it is necessary to observe instead systems in which the unfolding of events follows a less scripted course. At the same time, it is probably wise to avoid human cognitive systems, where consciousness and intentionality play major roles. One seeks clues, then, in such mesoscopic disciplines as immunology, epidemiology and ecology – and probably nowhere is the relational, the crux of meso-scale dynamics, more pronounced than in ecology.

It should be noted that the bifurcation of natural phenomena into the stochastic and the determinate at the end of the 19^{th} Century forced a profound change in worldview and metaphysical assumptions. Following Newton, the world had been perceived as strictly deterministic. Suddenly, chance entered the scientific narrative, albeit only at atomic dimensions. The microscale uncertainty assumed in statistical mechanics paved the way for the even more radical microscopic behaviors that were to be encountered with the development of quantum theory a few decades later. Another assumption of the Newtonian metaphysic had to be changed as well. No longer could all natural processes be considered reversible, as Carnot had demonstrated, and outright historical processes had even been introduced by Darwin.

These qualifications notwithstanding, three other fundamental assumptions of Newtonianism (causal closure, universality and atomism) retained their sway over scientific thinking over the duration of the Twentieth Century. Now, as the possibility is recognized that mesoscale phenomena might follow their own set of rules and assumptions, one is led to ponder what the consequences could be for the remaining shell of the Newtonian household? In order to address this question more fully, it is helpful first to consider alternative ways by which chance might enter living dynamics.

2. Less radical contingencies

It was the opinion of Karl Popper (1990) that it will be impossible to achieve an "evolutionary theory of knowledge", without first amending fundamental attitudes toward causality to account for actions that are intermediate to pure stochasticity and strict determinism. It will not suffice simply to adjoin the incoherent events of a random netherworld onto the continuous and predictable action one sees in the "music of the spheres." He proposed, therefore, to generalize the newtonian notion of "force". Forces, he posited, are idealizations that can exist only in perfect isolation, like in the limitless vacuum of outer space. The goal of experimentation is to approximate isolation from interfering factors as best possible. In the meso-scale world, however, where numerous components are loosely, but definitely coupled, one should refer to causes rather as "propensities". A propensity is the tendency for a certain event to occur in a particular context. It is related to, but not equivalent to, conditional probabilities.

In Table 1, for example, are displayed the outcomes of 1 000 distinct events, which are arrayed as five possible outcomes, b_1, b_2, b_3, b_4, b_5, according to four possible eliciting causes, a_1, a_2, a_3, and a_4. Typically, the outcomes might be several types of cancer, such as those affecting the lung, stomach, pancreas or kidney, whereas the potential causes might represent various forms of behavior, such as running, smoking, eating fats, etc. In an ecological context, the b's could represent predation by predator j, while the a's would represent donations of material or energy by host i.

	b1	**b2**	**b3**	**b4**	**b5**	**Sum**
a1	40	193	16	11	9	269
a2	18	7	0	27	175	227
a3	104	0	38	118	3	263
a4	4	6	161	20	50	241
Sum	166	206	215	176	237	1000

Table 1. Frequency table of the hypothetical number of joint occurrences that four "causes" ($a_1 \ldots a_4$) were followed by five "effects" ($b_1 \ldots b_5$).

One notices from the table that whenever condition a_1 prevails, there is a *propensity* for b_2 to occur. Whenever a_2 prevails, b_5 is the most likely outcome. The situation is a bit more ambiguous when a_3 prevails, but b_1 and b_4 are more likely to occur in that situation, etc. Events that occur with smaller frequencies, e.g., $[a_1,b_3]$ or $[a_1,b_4]$ result from what Popper calls "interferences".

It is natural to ask how the table of events might appear, were it possible to completely isolate phenomena? Probably, it would look something like Table 2, where every time a_1 occurs, it is followed by b_2; every time a_2 appears, it is followed by b_5, etc. That is, under isolation, propensities degenerate into mechanical-like forces. It is interesting to note that b_4 never appears under any of the isolated circumstances. Presumably, it arose purely as a result of interferences among propensities. Thus, the propensity for b_4 to occur whenever a_3 happens is an illustration of Popper's assertion that propensities, unlike forces, never occur in isolation, nor are they inherent in any object. They always arise out of a context, which invariably includes other propensities.

	b1	**b2**	**b3**	**b4**	**b5**	**Sum**
a1	0	269	0	0	0	269
a2	0	0	0	0	227	227
a3	263	0	0	0	0	263
a4	0	0	241	0	0	241
Sum	263	269	241	0	227	1000

Table 2. Frequency table as in Table 1, except that care was taken to isolate causes from each other.

Popper's notion of propensity encompasses both chance and law-like behavior under a single rubric. It is noteworthy that the transition depicted from Table 1 to Table 2 involves proceeding from less-constrained to more constrained circumstances. It is the appearance of progressive constraints that actually gives rise to what is termed "development". One now asks the questions, "What natural agency might contribute to the transition from Table 1 to Table 2?"; or, in a larger sense, "What lies behind the phenomena called growth and development?", and "How can one quantify the effects of this agency?"

3. Dynamical agents at the focal level

Scientists are wont to search for the causes behind events either at the microscales below the phenomenon of interest or among the various constraints posed on the system by still larger entities. Efforts are almost never mounted to identify agencies within the mesoscales at which the system exists. This, however, is precisely what must be attempted, if interactions among Popper's propensities are to be understood more completely.

The search begins by changing Brenner's question slightly to read, "What happens when propensities are confined to act in close proximity with one another?" Any one process will either abet (+), diminish (-) or not affect (0) another. Similarly, the second process can have any of the same effects upon the first. Out of the nine possible combinations for reciprocal interaction, it turns out that one interaction, namely mutualism (+,+), has very different properties from all the rest. Investigators such as Manfred Eigen (1971), Hermann Haken (1988), Umberto Maturano (and Varela, 1980), Stuart Kauffman (1995) and Donald DeAngelis (1986) all have contributed to a growing consensus that some form of positive feedback at the level of the system itself is responsible for most of the order inherent in organic systems. Of particular interest here is a specific form of positive feedback, autocatalysis. Autocatalysis is a type of positive feedback wherein the effect of each and every link in the feedback loop remains always positive. In the framework of the newtonian assumptions, as autocatalysis is usually viewed in chemistry, such feedback appears merely as a particular type of mechanism. As soon as one admits some form of indeterminacy, however, several highly non-mechanical attributes suddenly make their appearance.

To be precise about what is meant here by autocatalysis, the reader's attention is directed to the three- component interaction depicted in Figure 1. Therein it is assumed that the action of process A has a propensity to augment a second process B. It should be emphasized that the use of the word "propensity" means that the response of B to A is not wholly obligatory. That is, A and B are not tightly and mechanically linked. Rather, when process A increases in magnitude, most (but not all) of the time, B also will increase. B tends to accelerate C in similar fashion, and C has the same effect upon A.

An illustrative example of autocatalysis from the field of ecology is the biotic community that centers around the aquatic macrophyte, *Utricularia* (Ulanowicz, 1995.) All members of the genus *Utricularia* are carnivorous plants. Scattered along its feather-like stems and leaves are small bladders, called utricles (Figure 2a). Each utricle has a few hair-like triggers at its terminal end, which, when touched by a feeding zooplankter opens the end of the bladder, and the animal is sucked into the utricle by a negative osmotic

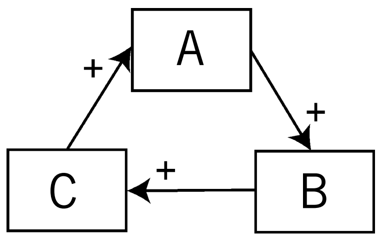

Figure 1. Schematic of a hypothetical 3-component autocatalytic cycle.

pressure that the plant had maintained inside the bladder. In the field *Utricularia* plants always support a film of algal growth known as periphyton (Figure 2b). This periphyton in turn serves as food for any number of species of small zooplankton. The catalytic cycle is completed when the *Utricularia* captures and absorbs many of the zooplankton.

Autocatalysis among propensities gives rise to at least eight system attributes, which, taken as a whole, comprise a distinctly non-mechanical dynamic that transpires, for the most part, at the mesoscales. Firstly, one notes that autocatalysis is explicitly *growth-enhancing* by definition. Furthermore, autocatalysis exists as a *formal* structure of kinetic elements. More interestingly, autocatalysis is capable of exerting *selection* pressure upon its ever-changing constituents. To see this, one imagines that some small change is occurring spontaneously in process B (Figure 1.) If that change either makes B more sensitive to A or a more effective catalyst of C, then the change will receive enhanced stimulus from A. Conversely, if the change in B either makes it less sensitive to the effects of A or a weaker catalyst of C, then that alteration will likely receive diminished support from A. Such selection works on the processes or mechanisms as well as on the elements themselves. Hence, any effort to simulate development in terms of a fixed set of mechanisms is doomed ultimately to fail.

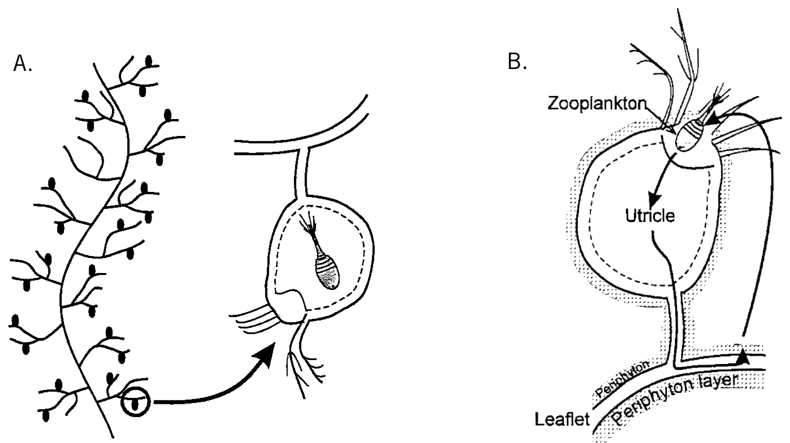

Figure 2. (a) Sketch of a typical "leaf" of *Utricularia floridana*, with detail of the interior of a utricle containing a captured invertebrate. (b) Schematic of the autocatalytic loop in the *Utricularia* system. Macrophyte provides necessary surface upon which periphyton (dotted area) can grow. Zooplankton consumes periphyton, and is itself trapped in bladder and absorbed in turn by the *Utricularia*.

It should be noted in particular that any change in B is likely to involve a change in the amounts of material and energy that flow to sustain B. Whence, as a corollary to selection pressure, one notes the tendency to reward and support changes that bring ever more resources into B. As this circumstance pertains to all the other members of the feedback loop as well, any autocatalytic cycle becomes the center of a *centripetal* vortex, pulling as much resources as possible into its own domain.

It follows, then, that whenever two or more autocatalyic loops draw from the same pool of resources, autocatalysis will *induce competition.* In particular, whenever two loops partially overlap, the outcome could be the exclusion of one of the loops. In Figure 3, for example, element D is assumed to appear spontaneously in conjunction with A and C. If D is more sensitive to A and/or a better catalyst of C, then there is a likelihood that the ensuing dynamics will so favor D over B, that B will either fade into the background or disappear altogether. That is, selection pressure and centripetality can guide the replacement of elements. Of course, if B can be replaced by D, there remains no reason why C cannot be replaced by E or A by F, so that the cycle A,B,C could eventually transform into F,D,E. One concludes that the characteristic lifetime of the autocatalytic form usually exceeds that of most of its constituents. This is not as strange as it may first seem. With the exception of neurons, virtually none of the cells that made up a given human body seven years ago will remain as part of it today. Furthermore, very few of the atoms that constitute the body at this instant were present eighteen months ago. Yet if the mother of that individual were to see her for the first time in ten years, she would recognize her immediately.

Autocatalytic selection pressure and the competition it engenders define a preferred mesoscale direction for the system – that of ever-more effective

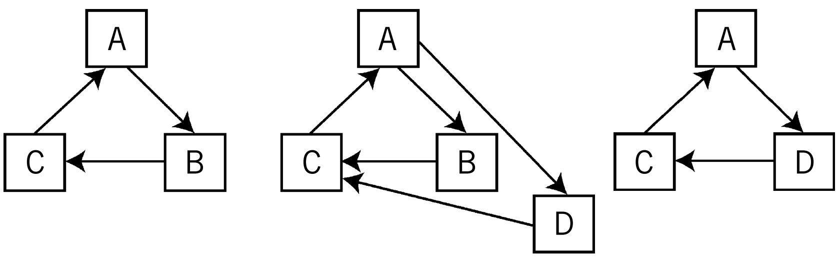

Figure 3. (a) Original configuration. (b) Competition between component B and a new component D, which is either more sensitive to catalysis by A or a better catalyst of C. (c) B is replaced by D, and the loop section A-B-C by that of A-D-C.

autocatalysis. In the terminology of physics, autocatalysis is *symmetry-breaking*. One should not confuse this rudimentary directionality with full-blown teleology. It is not necessary, for example, that there exist a pre-ordained endpoint towards which the system strives. The direction of the system at any one instant is defined by its state at that time, and the state changes as the system develops. Hence, the term "*telos*" will be used to denote this weaker form of directionality and to distinguish it from the far rarer and more complex behavior known as teleology.

Taken together, selection pressure, centripetality and a longer characteristic lifetime all speak to the existence of a degree of *autonomy* of the meso-scale structure from its microscopic constituents. Again, any attempt at reducing the workings of the system to the properties of its composite elements will fail in the long run.

In epistemological terms, the dynamics just described can be considered *emergent*. In Figure 4, if one should consider only those elements in the lower right-hand corner (as enclosed by the solid line), then one can identify an initial cause and a final effect. If, however, one expands the scope of observation to include a full autocatalyic cycle of processes (as enclosed by the dotted line), then the system properties just described appear to emerge spontaneously.

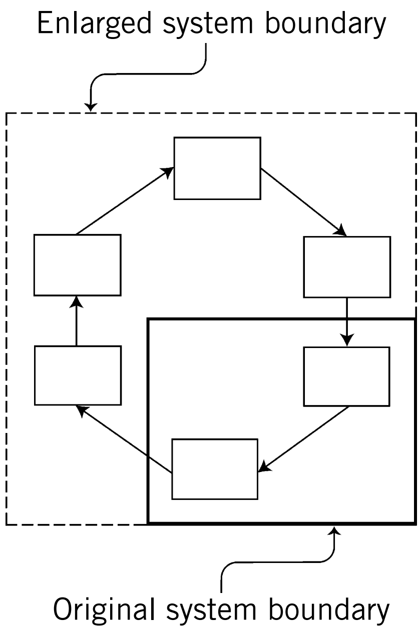

Figure 4. Two hierarchical views of an auto-catalytic loop. The original perspective (solid line) includes only part of the loop, which therefore appears to function quite mechanically. A broader vision encompasses the entire loop, and with it several non-mechanical attributes.

4. *Causis formalis* as mesoscale agency

It is important to note that selection pressure that arises from autocatalysis acts from higher scales downwards. Top-down influence is familiar to ecologists in the context of trophic interactions, but the classical newtonian metaphysic allows only influences originating at lower realms of time and space to exert their effects at larger and longer scales. Prior to Newton, however, the prevailing view on natural causalities had been formulated by Aristotle, who explicitly recognized the existence of downward causation. Following the leads of Popper (1990) and Rosen (1985), it may be helpful to reconsider Aristotle's ideas on causality:

Aristotle identified four categories of cause: (1) Material, (2) Efficient (or mechanical), (3) Formal and (4) Final. With all due apologies to the reader, an effective, albeit unsavory, example of an event wherein all four causes are at work is a military battle. The swords, guns, rockets and other weapons comprise the material causes of the battle. The soldiers, who act within localized subfields of action and who use those weapons to inflict unspeakable harm on each other become the efficient agents. Final cause extends beyond the battlefield and includes the social, economic and political factors that have accrued over time to bring the armies face-to-face. Factors existing at the *mesoscale* of the battle itself, such as the topography of the battlefield and the changing positions of the troops on the battlefield with respect to each other, constitute the *causis formalis*, or formal cause.

Newton's description of affairs between the planets made no use of formal or final causes; and, following the publication of his *Principia*, reference to these two categories of cause fell into disuse, and eventually into disrepute. The adoption of a bipartite view of nature at the turn of the 20th Century provided no reason for wanting to rehabilitate formal or final agencies. Now, however, because the mesoscale looms as a potential theatre for fundamental causes, one is forced to adopt a triadic, hierarchical view of events. Mesoscale pro-pensities at the focal, mesoscale level grade off at lower scales into stochastic incoherence, whilst at larger, more rarified dimensions they merge into deterministic forces. Accordingly, one may regard living systems as the combined outcomes of random efficient events at the molecular level, deterministic final forces impressed from the environment *and* formal configurations of processes at the focal mesoscale.

The Achilles heel of newtonian-like dynamics and the reason behind the anxiety of physicists during the latter 19th Century was that it could not in general accommodate true chance or indeterminacy. Should a truly chance event happen at any level of a strictly mechanical hierarchy, all order at higher levels would be doomed eventually to unravel. The metaphysical bandage that was applied to the ailing Newtonianism was to allow only non-interacting indeterminacies and to banish same to the microscales of the netherworld, where, because they acted so simplistically, all they could possibly offer up as players for the macroscale stage were benign averages. The schizoid nature of this contemporary worldview has already been mentioned.

The Aristotelian hierarchy, by way of contrast, is far more accommodating of chance and places fewer restrictions on the nature of any participating indeterminacies. Any spontaneous efficient agency at any hierarchical level would be subject to selection pressures from formal autocatalytic configurations above. These configurations in turn experience selection from still larger constellations in the guise of final cause, etc. One may conclude, thereby, that the influence of most irregularities remains circumscribed. Unless the larger structure is particularly vulnerable to a certain type of perturbation (and this happens relatively rarely), the effects of most perturbations are quickly damped.

This hierarchical scenario suggests that the very laws of nature possess a “finite radius of effect”. That is, laws should be considered to have finite, rather than universal, domain (Allen and Starr, 1982; Salthe, 1993). Each law is formulated within a particular domain of time and space. The farther removed an observed event is from that domain, the weaker becomes the explanatory power of that law, because chance occurrences and selection pressures arise among the intervening scales to interfere with the given effect. To the ecologist, at least, the world appears as granular, rather than universal, and this vision leads him/her to regard with skepticism attempts by physicists to marry phenomena belonging to widely disparate scales, such as, quantum phenomena and gravity (e.g., Hawking, 1988.)

5. The middle realm as the domain of the organic

It was these hierarchical inadequacies of the contemporary worldview that led Popper to exhort his readers that they should no longer be satisfied with the prevailing image of rigid mechanisms set opposite to complete disorder, with nothing in between. In a constructivist vein, Popper suggested the existence of a middle ground, wherein propensities interacting with each other give rise to non-rigid structures that nonetheless retain their coherence over time. That is, the middle realm is natural home to organic phenomena. But exactly which agencies potentially could give rise to organic- like, non- rigid structures? Once again, attention quickly sets upon autocatalysis.

From the foregoing considerations on autocatalysis one may abstract two primary aspects of its actions: Autocatalysis serves to increase the activities of all its constituents, and it prunes the network of interactions so that those links that most effectively participate in autocatalysis become dominant. This transition is depicted schematically in Figure 5. The upper figure represents a hypothetical, inchoate 4-component network before autocatalysis has developed, and the lower one, the same system after autocatalysis has matured. The magnitudes of the flows are represented by the thicknesses of the arrows. To the right appear the matrices that correspond to the pattern of flows. One recognizes immediately that the transition resembles the difference between Tables 1 and 2 that were presented earlier in connection with Popper's propensities.

There is not sufficient space to present in detail how these two facets of autocatalysis can be quantified. Suffice it here simply to present the results, and the reader who may be interested in the formal details is referred to Ulanowicz (1986) or Ulanowicz and Norden (1990.) One begins by defining the transfer of material or energy from prey (or donor) i to predator (or receptor) j as T_{ij}, where i and j range over all members of a system with n elements. The total activity of the system can be measured simply as the sum of all system processes, $T = \sum_{i,j} T_{ij}$, or what is called the "total system throughput". Growth thereby becomes an increase in the total system throughput, much as eco-

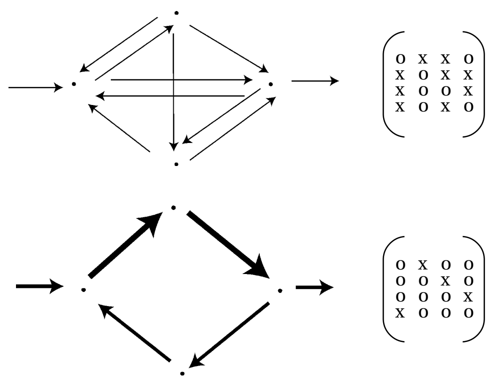

Figure 5. Schematic representation of the major effects that autocatalysis exerts upon a system. (a) Original system configuration with numerous equiponderant interactions. (b) Same system after autocatalysis has pruned some interactions, strengthened others, and increased the overall level of system activity (indicated by the thickening of the arrows.) Corresponding matrices of topological connections indicated to the right.

nomic growth is reckoned by any increase in Gross Domestic Product.

As for the "pruning", or development effected by autocatalysis, it will be related to changes in the probabilities of flow to different compartments. One notes, therefore, that the joint probability that a quantum of medium both leaves i and enters j can be estimated by the quotient $T_{ij}/\sum_k T_{ik}$, and that the conditional probability (which Popper associated with his propensities) that, having left i, it then enters j can be approximated by the quotient $T_{ij}/\sum_k T_{ik}$. One can then use these probability estimates to calculate how much information is inherent in the increased constraints. The appropriate measure in information theory is called the "average mutual information" or AMI.

$$AMI = \sum_{i,j} \left(\frac{T_{ij}}{T} \right) \log \left(\frac{T_{ij} T}{\sum_p T_{pj} \sum_q T_{iq}} \right).$$

To demonstrate how an increase in AMI actually tracks the "pruning" process, the reader is referred to the three hypothetical configurations in Figure 6. In configuration (a) where medium from any one compartment will next flow is maximally indeterminate. AMI is identically zero. The possibilities in network (b) are somewhat more constrained. Flow exiting any compartment can proceed to only two other compartments, and the AMI rises accordingly. Finally, flow in schema (c) is maximally constrained, and the AMI assumes its maximal value for a network of dimension 4.

Because autocatalysis is a unitary process, it is possible to incorporate both factors of growth and development into a single index by multiplying them together to define a measure called the system ascendency, A = T x AMI. In his seminal paper, "The strategy of ecosystem development", Eugene Odum (1969) identified 24 attributes that characterize more mature ecosystems. These can be grouped into categories labeled species richness, dietary specificity, recycling and containment. All other things being equal, a rise in any of these four attributes also serves to augment the ascendency. It follows as a phenomenological principle that "in the absence of major perturbations, ecosystems have a propensity to increase in ascendency." Increasing ascendency is a quantitative way of expressing the tendency for those system elements that are in catalytic communication to reinforce each other to the exclusion of non-participating members. The relevance of increasing ascendency to self-organizing systems other than those in ecology should be obvious.

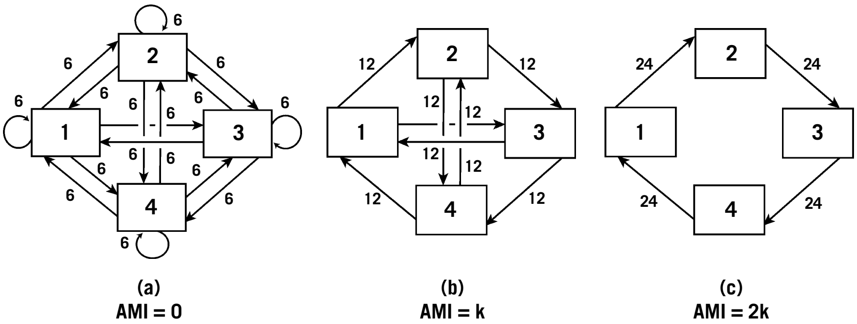

Figure 6. (a) The most equivocal distribution of 96 units of transfer among four system components. (b) A more constrained distribution of the same total flow. (c) The maximally constrained pattern of 96 units of transfer involving all four components.

It should be emphasized in the strongest terms possible that increasing ascendency is only half the story. Ascendency accounts for how efficiently and coherently the ecosystem processes medium. Using the same type of mathematics, one can compute as well an index called the system overhead that is complementary to the ascendency (Ulanowicz and Norden, 1990.) Overhead quantifies the degrees of freedom, inefficiencies and incoherencies present in the system. Although these latter properties may encumber overall system performance at processing medium, they become absolutely essential to system survival whenever the system incurs a novel perturbation. At such time, the overhead becomes the repertoire from which the system can draw to adapt to the new circumstances. Without sufficient overhead, a system is unable create an effective response to the exigencies of its environment. The configurations one observes in nature, therefore, appear to be the results of two antagonistic tendencies (ascendency vs. overhead) working off of each other in a relationship that resembles a dialectic.

6. The aftermath of revolution

As noted in the opening section of this article, the revolution(s) of the latter 19th and early 20th Century served to deconstruct two of the five pillars of Newtonian science: The world no longer can be considered a deterministic clockwork. The realization had dawned that there was a necessary and legitimate place for the contingent in nature. Originally, that place had been circumscribed as only the microscales of nature, but Popper has scoped out a home among the mesoscales for a less radical type of contingency when he noted that causes in that domain resemble propensities more than they do mechanical forces.

Quite independently, Carnot and Darwin had foreclosed the possibility that nature in its entirety was reversible. The latter, in fact, had demonstrated how it even could be *historical.* Irregularities, usually in the form of discontinuities, degrade predictability into the future and obscure hindcasting. The effects of past discontinuities are often retained (as memories) in the material and kinetic forms that result from adaptation. In recent decades, due largely to the discovery of how memory can be stored in molecular structures such as DNA, discussions on historical (evolutionary) memory have devolved to focus again almost exclusively upon the microscopic. This has been an unnecessary and unfortunate diversion, as memory can be created and sustained as well within mesoscale structures (e.g., neuronal and metabolic networks.) In any history, time takes a preferred direction. In thermodynamics it is that of increasing entropy. In evolutionary theory it appeared for a long while to be that of augmenting complexity (which some tie back to the entropic drive [Brooks and Wiley 1986.]) To these one can now add the *telos* of increasing ascendency, which is manifest primarily at mesoscopic scales.

Gradually, it has become clear (at least to this writer) that the bipartite image of nature as continuous at larger scales and chaotic at microscales is inadequate to the task of encompassing truly organic behavior. It is a conceit to maintain that legitimate causes can arise only at the exotic extremes of scale, such as molecules and galaxies. It is time to entertain the possibility that legitimate causes can arise as well among phenomena that occur at the more prosaic scales of human existence. With that shift in perspective, the three remaining pillars of Newtonianism tumble:

Peering into the mesoscales, for example, forces the observer to abandon the simplifying assumption of causal closure. Despite arguments by Dawkins (1976) and Dennett (1995) to the contrary, the living world no longer can be regarded as a collection of complex living machines. Mesoscale phenomena, such as those proper to ecology, immunology and epidemiology, appear to be *open* to the influence of non-mechanical agencies. Spontaneous events may occur at any level of the hierarchy at any time. Efficient (or mechanical) causes usually originate at scales inferior to that of observation, and their effects propagate upwards. Formal agencies appear at the focal level; and final causes exist at higher levels and propagate downwards (Salthe, 1985; Ulanowicz, 1997.)

The development of statistical mechanics and the subsequent "Grand

Synthesis" were attempts at perpetuating the universal applicability of scientific laws. Now, with the discovery of the myriad of behaviors that are proper to the mesoscopic realm, there seems to be little hope for or benefit from clinging to the notion that scientific laws must be universal. Rather, the world now appears *granular*. Models of events at any one scale can explain matters at another scale only in inverse proportion to the remoteness between them. On the other hand, the domain within which irregularities and perturbations can damage a system is usually circumscribed. Chance does not necessarily unravel a system.

Finally, the ideas of Democritus, although they have served well in the social theatre to disrupt draconian and oppressive regimes, can no longer be applied without qualification to the natural realm. Unlike purely physical systems, most biological systems are not easily decomposed. They are not atomistic, but rather *organic* in both composition and behavior. Propensities never exist in isolation from other propensities, and communication between them fosters clusters of mutually reinforcing propensities to grow progressively more interdependent. Hence, the observation of any component in isolation (if possible) reveals regressively less about how it behaves within the ensemble. On the other side of the equation, better insights into mesoscale phenomena have helped to refine significantly the meaning of the word "organic". No longer must the organic be viewed solely in the rigid context of ontogeny, wherein each component organ is forced to act in total sub-servience to the directions of the whole. Rather, in more loosely structured organic communities, such as ecosystems, there can exist considerable degrees of freedom within which the overall system may nevertheless cohere and persist (Ulanowicz 2001.)

The revolution in the "Middle Kingdom" does not leave science in shambles, because Popper's evolutionary suggestions have always maintained some connections with the orthodox and the classical. Unfortunately, it remains beyond the scope of this paper to demonstrate, for example, exactly how Popper's propensities are imbedded in the expression for the ascendency (Ulanowicz 1996.) Furthermore, because propensities are generalizations of newtonian forces, it comes as no surprize that the principle of increasing ascendency resembles the generalization of newtonian law upwards into the macroscopic realm, in a way similar to how Schroedinger's wave equation is an extension of Newton's second law downwards into the microscopic world of quantum phenomena. Although the metaphysical shell of Newtonianism has crumbled, the imprint of the core Newtonian laws remains discernible (Ulanowicz, 1999.)

In the end it may appear that what is happening resembles less a revolution than the natural process of maturation. With the dawn of the Enlightenment, science had burst on the scene with its vision of the world that was quite apart from everyday experience. The inevitable result was a sense of heightened conflict between science and almost every other field of human endeavor – the arts, religion, politics, etc. Science, by pioneering those realms peripheral to human existence and by extrapolating its findings back into the more proximate world, had posed enormous challenges to how humankind perceived itself. This sense of conflict was intentionally exacerbated by some, who with adolescent glee, wielded science as a weapon to tear down old social beliefs and structures. But the one-sided nature of the encounter could be sustained only so long as the sciences could afford to look only to the peripheral scales of nature as its sources of new ideas and laws. Inevitably, the time has come to regard events at more proximate dimensions in their own right. Whereupon the exchange has become more like a full dialogue, and the simplistic assumptions that had served science so well in its youth are brought under scrutiny, to be either discarded or amended in accounting for the ways things happen at middle scales. None of which is to suggest that conflict will soon disappear. Science should always enjoy a healthy degree of autonomy from other human endeavors, and it will continue to challenge and to be challenged in turn by what happens in the other arenas. But now science, by honestly confronting the complexities posed by living systems, has the opportunity to assume its proper place *alongside* other social endeavors in the march of human progress.

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