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The common developmental road: tensions among centripetal and centrifugal dynamics

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ABSTRACT

Western thought since the Enlightenment has been predominantly linear in scope, while Eastern philosophy has focused mostly on the cyclical. Recent advances in complex systems, however, have highlighted the importance of cycles in nature, thereby opening an avenue for new common endeavors. This analysis centers on the role of autocatalytic loops and addresses the evolutionary relationship between competition and cooperation. It posits an evolutionary chain running from individual competition, to individual cooperation, to collective competition, to deep cooperation. We identify the centripetality that is consequent to autocatalysis and define three types of centrifugalities. Development is defined in the context of the tension between these opposing directions. Finally, we propose an evolutionary process consisting of four stages: (i) autognosis, (ii) autocatalytic loop formation, (iii) self-control and (iv) self-realization (*sensu* Taoism). The developmental narrative promises to become a useful tool for facilitating communication between Eastern and Western cultures.

Keywords: development, evolution, autocatalytic loop, centripetality, centrifugality

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The worldwide search for sustainable development has yet to achieve much success [1]. Various indexes have been proposed (e.g. Costanza *et al.* [2]) and ecocentrism, although widely praised, is rarely practiced. It seems that only by articulating the actual process of social change can we formulate measures that might move us towards a more desirable future.

The goal here is to demonstrate how sustainable dynamics depend upon the tensions between competition and cooperation within various autocatalytic loops as these actions are related to cycles of processes. The focus will be upon autocatalytic configurations, their consequent centripetalities and residual centrifugal social/economic forms that are too often overlooked.

THE EVOLUTIONARY RELATIONSHIP BETWEEN COMPETITION AND COOPERATION

It is an ancient idea that the patterns in the world result from a struggle between countervailing forces, e.g. competition vs. cooperation, order vs. disorder [3]. The Tao recognized this tension as Ying vs. Yang, while the Greek philosopher Heraclitus saw nature as the outcome of two opposing tendencies—one that builds up order and an opposing one that tears it down [4]. Such duality exists, however, imbedded in a world of manifold network connections. It is important to realize that 'Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves' [5]. Thus do many things remain beyond the control of the individual or even the collective.

One way of understanding what is going on in these complicated networks is to concentrate on the autocatalytic cycles (indirect mutualisms) imbedded in them [6–8]. Autocatalysis arises as the ability of a system element to enhance its own operation via cooperation with other elements at the same scale. The action of autocatalysis is widespread—like compound interest in accounting or the multiplier effect in economic analysis.

Autocatalysis possesses five important attributes: foremost among them is natural selection, in that any factor or component that enters an autocatalytic configuration must do so at the expense of some non-participant [4]. The second property is that the form of the autocatalytic cycle derives from mutual cooperation (e.g. John Locke's 'identity of interest' [9]; see also Nowak's fundamental rules for cooperation [10]). The third is 'centripetality', or the tendency for participants in autocatalysis to draw progressively more resources into their own orbit, which is a property of the loop as a whole that acts in a top-down fashion [11]. The fourth attribute is the flexibility for new elements to enter an autocatalytic configuration by accident and, whenever their action happens to improve overall autocatalysis, the new actor will replace some less effective one [11]. Fifth, as autocatalysis comes to dominate a system, its performance increases at the expense of opposing flexibilities, freedoms and redundancies.

Because ascendency quantifies inherent network organization, it was natural to assume that ascendency would progressively increase over the course of system development [11]. But the Chinese proverb, 'The more a knife is finely sharpened, the more easily it is broken', vividly makes the point that, in order for a system to persist, its ascendency (performance) must remain within bounds. That is, the system must retain sufficient redundancy to prevent brittleness [12] (see Supplementary Material I). While the action of autocatalysis is distributed across a network, we choose to simplify matters by concentrating upon autocatalysis as if it were embodied in a single cycle. In order to demonstrate the evolutionary relationship between competition and cooperation, we consider two countries that have different autocatalytic efficiency (Fig. 1).

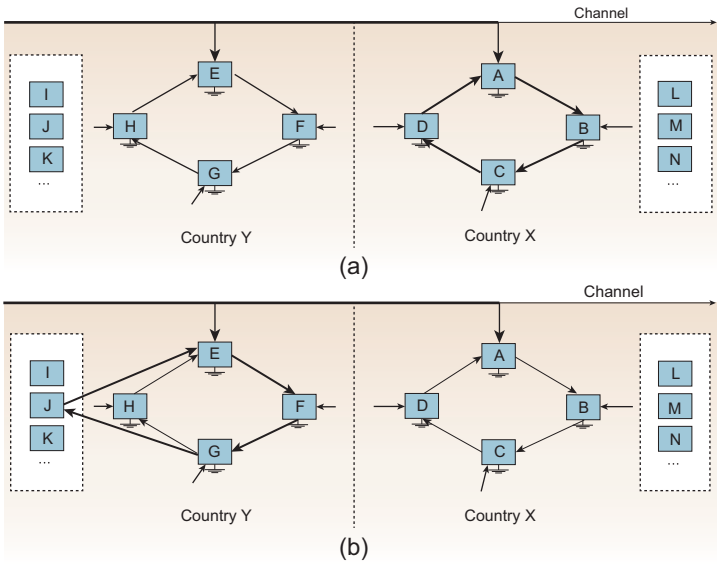

Figure 1. Schematic representations of the major effects that autocatalysis might exert upon the evolution of two different countries. (The thickness of an arrow indicates flow magnitude.) (a) Hypothetical original system configurations of two different countries. (b) The same system after country Y has formed new autocatalytic loop.

Figure 1a depicts hypothetical autocatalytic economic activities in two countries. Country X (loop A-B-C-D) initially has higher autocatalytic efficiency than country Y (loop E-F-G-H). In the original system, country X absorbs more resources than country Y from the common channel and from the surrounding environment. To better compete, country Y enters into cooperation with node J to form a new and more efficient autocatalytic cycle (loop E-F-G-J in Fig. 2). This process of forming a new autocatalytic cycle involves chance natural selection from among various candidate nodes (such as I and K in Fig. 1) that comprise what Kauffman calls the 'adjacent possible' [13].

Higher autocatalytic efficiency in loop E-F-G-J will improve country Y's place in resource allocation, and eventually the system might resemble the one depicted in Fig. 1b. Initially, the cooperation among nodes E, F, G and J arises by chance and exhibits the directionality that is characteristic of an autocatalytic cycle. That is, node J competes with nodes I and K for the chance to cooperate with nodes E, F and G to form an autocatalytic loop. Once the new autocatalytic loop is formed, node J will contribute to the competition between whole loops (E-F-G-J) and (A-B-C-D). At the same time, it will also enter into competition with node H and replace it.

Because autocatalysis engenders a centripetal effect, it induces a competition among groups of nodes at the collective level (the next level up). Using Figs 1 and 2, one may trace an evolutionary chain between competition and cooperation that consists mainly of four stages: (i) individual competition, in the form of Darwinian natural selection among the primary nodes H, J, K or L, M, N in Fig. 1; (ii) individual cooperation, which is the process of forming new autocatalytic loops, such as A-B-C-D, E-F-G-H or E-F-G-J; (iii) collective competition results from centripetalities that compete for common resources and takes place between whole loops A-B-C-D and E-F-G-J, or between A-B-C-D and E-F-G-H; (iv) 'deep cooperation', which is the process of maintaining the two opposing agencies (like ascendency and overhead) within the window of vitality. It takes place between loop A-B-C-D and loop E-F-G-H, or between loop A-B-C-D and loop E-F-G-J, or simply between node J and node H.

By studying the transition scenarios depicted in Figs 1 and 2, it is easy to discern that a particular

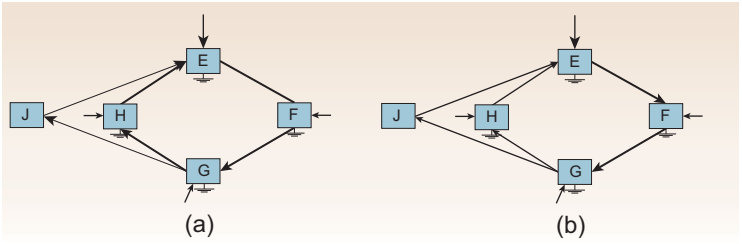

Figure 2. The competition by node H in the feedback loop with a more efficient external element J. (a) The new node J enters the network. (b) The same system after the autocatalytic loop has strengthened the connections with J as well as those from E → F and F → G.

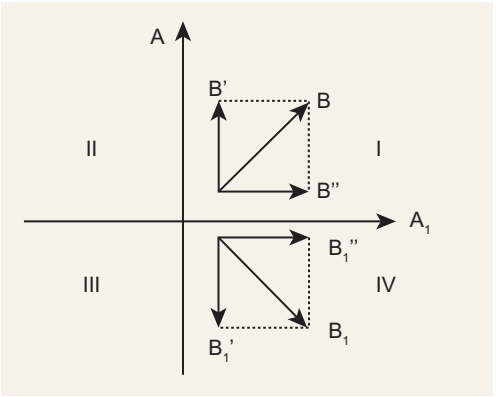

Figure 3. Cooperation and deep cooperation.

node's behavior will differ depending on how the network of processes evolves. For example, node J will always demonstrate competitive behavior with nodes I and K, but it will either engage in cooperative behavior with nodes E, F and G should the loop E-F-G-J be formed, or with nodes B, C and D should J replace node A. That is to say, a node's behavior is partly determined by the state of the system at a particular time. Such conditionality had been ignored by those who formulated the theory that a history of farming rice makes a culture more interdependent, whereas the farming of wheat leaves the members of a culture more independent [14]. Unfortunately, the determinate rice theory cannot explain how team and organizational learning [15], so typical of collective thinking, originated in places that emphasize individualism, nor can it explain how the circular economy of China was borrowed mostly from Germany, the European Union and the USA, rather than having arisen out of the ancient Chinese philosophy that focused on the cyclical [16].

It should be emphasized that individual cooperation among different nodes involves common interests. By contrast, deep cooperation is a tacit tolerance between two opposing agencies that develops over time (Fig. 3). Familiarity with Hegelian dialectics helps one to understand deep cooperation. Accommodating two opposing tendencies requires a spirit of generosity that is born of both forbearance and a long-term view.

Each arrow on Fig. 3 represents an individual's objective, or what Popper [17] called a propensity. The propensity of individual A is orthogonal to that of individual A_1, meaning that no mutual influence exists between individuals A and A_1. The propensity of another individual B can be decomposed into component B' which indicates a common propensity with A and B", which is orthogonal to A. Because individuals A and B share a common propensity, they can cooperate relatively easily, and vice versa, except for the orthogonal sub-propensity B_1" with individual A. The other sub-propensity B_1', however, is fully opposed to the propensity of individual A. So, for individuals A and B_1 to engage in deep cooperation, there must be some unifying relationship at a higher level.

Self-centeredness, being a common facet of human nature, makes it difficult to establish the consensus that human society is a sub-system of the ecological system—the crux of ecocentrism. It is not difficult, however, to envision the constitution of human nature as resolved into orthogonal components, like the A and A_1 of Fig. 3. In order to realize the full potentialities of the living world [18], system development (B) should fall into quadrants I and II. Conversely, when the ecosystem is over-exploited, ecosystem development will lie either in quadrant III or quadrant IV and thereby diminish the full subsidy that the ecological realm can render to humanity. Ulanowicz [11] described how a drop in ecosystem diversity can indicate a diminished capacity for system growth and development, thereby providing a theoretical rationale for the conservation of ecological diversity. Some believe that, if we can unify the opposition between humanity and the ecosystem, problems will cease. However, if we drive the ecosystem to collapse, making its restoration very difficult, then we will never be able to establish a unifying relationship at some higher scale. Thus, we should maintain a conservative 'reverence for life' [19] that will preclude driving ecosystem development into quadrant III or IV.

CENTRIPETALITY AND THREE CENTRIFUGALITIES

In considering which direction human development should take, it is easy to overlook the roles of autocatalysis and its consequent centripetality and centrifugalities in competition and cooperation.

Autocatalytic loop

Contemporary discussions on evolution tend to exaggerate the role of elimination in nature (i.e. natural selection) at the expense of growth, which was prominent in Darwin's original narrative. Considering the cooperation inherent in autocatalytic loops should help restore the prominent role that growth plays in evolution. While chance, self-reference and history all play roles in the process of forming autocatalytic loops [20], there also exist common interests among nodes in complex systems that increase the likelihood of cooperation. In addition, the centripetality of autocatalytic action imparts directionality to the movement of resources, thereby enhancing the possibilities for cooperation.

In management practice, we often make mistakes in three areas: very often we look too narrowly and short-term and so cannot perceive the larger autocatalytic loops in which our process of interest is embedded. Failing to include all the members of an autocatalytic loop will make the system appear linear in nature and mis-identify an initial cause and a final result. Towards the goal of achieving a sustainable scale, there exist ways of forming an autocatalytic loop that include the ecosystem so as to render conservation profitable [21].

This pathway was taken recently in the Zhangye municipality on the Hei River in northwestern China. The Zhangye municipality lies in a water-scarce region of the nation. The municipality adopted a bookkeeping system based on virtual water and moved to transfer water resources from agriculture to a third industry (eco-tourism) so as to relieve the overall water shortage, while at the same time reckoning the feedback this transfer would produce in the overall virtual water budget [22]. The resulting strategy subtly resolved a dilemma posed in the virtual water accounting: Zhangye municipality was actually exporting virtual water, when the goal of the strategy was to *import* virtual water. In addition, the plan allowed the municipality to safeguard reservoirs in the plain, thereby correcting earlier erroneous allocations that did not account for autocatalytic dynamics (see Supplementary Material II).

The second mistake is to ignore the possibility that the system might create a new autocatalytic loop. Current research is too inflexible in that it aims to allocate resources within a fixed network of configurations. The optimal mechanical outcome pertains only to the given fixed constraints. This leads to what Alfred North Whitehead called 'the fallacy of misplaced concreteness'. For example, a researcher might think a farmer does not have sufficient knowledge to allocate local resources, even though Schultz [23] had demonstrated that the immediate efficiency of traditional agriculture is usually higher than its modern counterparts. So, if we want to transform traditional agriculture, we need to be open to creative ways of forming new autocatalytic loops. Kauffman [13] suggests much the same perspective and urges us to focus on how to derive new goods and services—an option that is ignored by traditional economists, who focus on competitive general equilibrium.

The third problem is that we often cannot envision the correct end-effect, even though we may be aware of the autocatalytic configuration. Current Chinese circular economics recognizes that autocatalytic loops are growth-enhancing and Chinese economists have developed numerous efficiency indicators to measure the effect [16], but little attention has been paid to the centripetality that inevitably accompanies autocatalysis. Unfortunately, the slogan 'reduce, reuse, recycle' just focuses on how to improve the efficiency of autocatalytic loop through technological progress. Technological progress should rather be pursued on two fronts: extractive and end-use [24]. Extractive technological progress obviously does not contribute to the conservation of biodiversity through its depletion of ever more natural capital. Theoretically, end-use technological progress could reconcile economic growth with biodiversity conservation, but autocatalytic loops usually arise among the components of end-use processes (especially in a circular economy), thereby accelerating the depletion of resources [25] through the accompanying centripetality. These 'demand-side' considerations have been ignored by previous emergency 'supply-side' treatments [16]. A similar conundrum arises in the fields of water-resources utilization and energy use. The conservation of water for irrigation often actually increases overall water use [26], and increasing energy efficiency sometimes does not improve environmental quality or sustainability [27,28]. A more appropriate approach might be to combine commerce with the ecosystem, so as to mimic and strengthen the production and allocation dynamics of the whole ensemble [29]. By including the ecosystem as a part of the autocatalytic loop, conservation can become profitable. By way of counter-example, the upturn in the water-distribution curve in Hei River was a misuse of autocatalytic centripetality (again, see Supplementary Material II).

The first centrifugality

According to Ulanowicz [3], the state of a system is the outcome of a tension between contrasting attributes—constraint and indeterminacy (or the

lack of constraint). Constraint (ascendency) and lack of constraint (overhead or flexibility) can be quantified using information theory. When a system is already highly developed (ascendency ≈1), the dominant effect of overhead is to disrupt established feedback loops, resulting in an abrupt loss of organized performance. That is, overly efficient systems can be too brittle to withstand a major perturbation. This action of overhead can be seen as a type of centrifugality. The magnitude of overhead gauges a system's reliability under random perturbation. This first centrifugality can appear catastrophically whenever single goals (especially efficiency) are pushed too far. For a system to persist, it must retain sufficient overhead to avoid such a trap. That is, one should seek a balance between the opposing attributes, efficiency and flexibility. Too little or too much of either could prove fatal [30]. Ulanowicz [12] observed that a balance between efficiency and flexibility in naturally persistent, sustainable ecosystems exists near the values $A = 40\%$ and $\Phi = 60\%$. This balance resembles that between Yin and Yang in traditional Chinese culture, which calls for moderation in seeking anything. Even steady-state economics recommends that one should maintain only those constant stocks of wealth and people that are sufficient for a long and good life [31].

Keeping two opposing tendencies near balance requires sufficient self-control to avoid pushing any single goal too far. It was noted earlier that self-control requires generosity, which in turn demands some knowledge of the transfer dynamics and the unifying relationship between the countervailing tendencies. George [32], for example, recognized that the obstacles that finally bring progress to a halt arise during the course of that progress—that what have destroyed all previous civilizations have been the conditions brought about by the growth of civilization itself. Currently, many research institutes are focusing on resilience as a keystone concept and devote most of their energies toward how to build the capacity to adapt to change [33].

The second centrifugality

The asymmetry in autocatalysis gives rise to the centripetal amassing of material and available energy. The presence of more than a single autocatalytic pathway in a system presents the potential for competition. New components replace old components like node J replaces node H in Fig. 2. The propensity of the new configuration fully opposes the centripetality of the old autocatalytic structure, giving rise to what we call the second centrifugality. In practice, such centrifugality is manifested by the exclusion of old components by new ones. In this way, autocatalytic cycles behave like distributional coalitions or special-interest groups [34]—on the one hand, they self-enhance, on the other, they function to exclude new components.

The second centrifugality is like the subtle serpent that Malthus introduced into the harmonious paradise of Locke, when the former reiterated the Hobbesian problem [9]. But why are extant societies not in this dire state of a constant, unlimited struggle for subsistence? The reasons are attributed mainly to self-control countermeasures that mitigate conflicts, such as the institution of fiscal transfer payments, the introduction of imperial examinations in Chinese history and the antitrust laws in Western countries. Additionally, an integrative management can subsume and redirect individual or collective competition by treating it as 'inner competition'.

Within any country, domestic countermeasures to the second centrifugality abound, because mitigation need involve only a subset of components with a limited range of influence. Furthermore, the prerequisite for any competition (e.g. the competition between node H and J in Fig. 1) is mutual cooperation, or symbiosis (e.g. the cooperation among nodes E, F, G and H, and among E, F, G and J). Thus, the deep cooperation required of nodes H and J is not as prominent here as it is between the third centrifugality and centripedality.

The third centrifugality

As mentioned in the last section, multiple centripetalities arising within a limited pool of resources induces competition among the various configurations [4]. An autocatalytic loop with high efficiency can absorb resources that otherwise would be available to a loop of lower efficiency. This dynamic is clearly centrifugal and is called the 'Matthew effect', whereby the rich get richer at the expense of the poor, who grow poorer still [35]. This third centrifugality affects a wider range, involving more components than the second centrifugality. Moreover, competition is also occurring among different autocatalytic loops, so that control cannot be exerted by the lower-efficiency autocatalytic loop.

Interactions between efficiency and resilience often obscure the operation of the third centrifugality from an observer. Rothman [36], for example, speculates that what may appear to be improvements in environmental quality in wealthy nations may in reality reflect the ability of wealthy consumers to ignore environmental degradation caused elsewhere by their consumption. The inequity only grows when

the country with higher efficiency thereby achieves greater ability to absorb surrounding resources. Research on forest-resource trade between Japan and Southeast Asia provides an example of the mistake often made in this regard. Seo and Taylor [37] provided evidence that the exporter overharvests its forestry resources, allowing the importer to underutilize its own resources—a situation they described as 'dual decay'. It is useful to examine this trade dynamic from the ascendent perspective [11]. The overharvesting at the exporters' end comes at the expense of its resilience, which in turn diminishes its development capacity. Under-utilization at the importers' end, however, actually increases its own resilience, because the imports allow the importer's forest land to stand and diversify, which *increases* the country's development capacity. Such storage can later be harvested, so that it is incorrect to say such trade results in dual decay. Rather, the importer is the clear beneficiary. This is not to conclude, however, that Japan should be held responsible for Southeast Asia's deforestation crisis because, if the statuses of Japan and Southeast Asia were reversed, the global economy would see forestry resources flowing from Japan to Southeast Asia.

Given that competition exists between autocatalytic loops, it becomes clear that national attitudes, such as 'smaller is beautiful' [38], the Chinese ideal of living in 'Peach Blossom Spring' and Bhutan's goal of increasing gross national happiness, are adaptations that can apply only in those countries that have small populations and are largely closed to trade. Autocatalytic loops are driven to absorb surrounding resources, so that those countries striving for 'smaller is beautiful' will be overtaken and absorbed by those countries with advantages in size and organization, and/or will serve as a pollution sink for economically stronger nations. Larger countries thus seem fated to engage in the international economic 'arms-race'. The image of sustainable progress proposed by Costanza *et al.* [2] clearly does not account for competition between autocatalytic loops. They depict the issue as a dichotomous choice between economic growth (increasing ascendency) that is not sustainable (because it overtaxes the system's overhead) and sustainable development that is based on a healthy ecosystem. But the dynamics are hardly that simple and bear similarity to the aforementioned exchange of forestry resources between Japan and Southeast Asia, where increasing the order in the local system can be achieved only at the expense of greater disorder in the larger system in which it is embedded [39]. Such progress hardly merits being called sustainable. The process perspective reveals similar problems with the work of Costanza *et al.* [2]. GDP indeed has many drawbacks and is in need of improvement, but the most important problem is that we push the goal of *maximizing* GDP well beyond mere improvement of welfare. Shedding this exaggerated emphasis is perhaps the most important way to improve our approach to sustainable development.

The hope is that conflict between the third centrifugality and centripetality can largely be resolved through trade regulations. Otherwise, war looms as an alternative route. Absent intervention, free trade will drive down forestry resources ever smaller and sparser. Perhaps a more appropriate countermeasure would be to regulate trade so as to keep autocatalytic loops within the vital window, but this option becomes ever more difficult in a world of open international trade [37]. Perhaps only deep cooperation can resolve the problem, but achieving that state requires forbearance and a long-term view on the parts of all parties.

THE COMMON DEVELOPMENTAL ROAD—A BRIDGE BETWEEN EASTERN AND WESTERN CULTURAL COMMUNICATION

Development

The evolutionary dynamic of human civilization follows the rise and fall of competition and cooperation. That is to say, except for natural selection, virtually all real problems relate to the conflict between centripetality and the aforementioned three centrifugalities. Usually, the interplay of the first centrifugality with centripetality eludes us, because most prefer to blind themselves to anything but monist behavior. In nature, this interplay is the starting point for resolving conflicts that result from the interactions of the other centrifugalities and centripetality. The key objective in the life of a country or an individual, however, is to order one's own life—to put the surrounding environment under one's own control. At this level, the conflicts that arise between the third centrifugality and centripetality become most important, and those struggles involve the greatest number of system components and influence the broadest range of outcomes.

One way to acquire or retain an advantageous position in the competition between different autocatalytic loops is to improve the efficiency of original autocatalytic loops by technological progress. For example, the autocatalytic loop of country X (loop A-B-C-D in Fig. 1a) has a higher efficiency than that of country Y. Whence, country X is at an advantage. A second way to acquire/retain advantage is to form a new autocatalytic loop. The

advantage in technological progress by country X is bound to diminish, because technology inevitably will diffuse to country Y. This diminution of country X's control over Y drives X to form a new autocatalytic loop with which to regain its control over country Y. Conversely, country Y has an even stronger incentive to form new and more highly efficient autocatalytic loops, so that it can escape from control by X.

The most salient example in this regard is the replacement of agricultural civilization during the industrial revolution. From 1500 to 1800, China was the largest and most productive agricultural economy in the world. The specialization of agricultural production, increased market exchanges and improved transportation (technological progress) pushed it toward an increasingly labor-intensive agriculture that achieved an advantageous position over the Euro-American world system. China was more developed as a solar-based economy [40] and could retain its advantage via its long-established autocatalytic loops. With the industrial revolution in England, the old pattern was shattered. It enabled society to escape from the constraints posed by reliance on solar energy and to build whole new economies and ways of organizing human life based on stored sources of mineral energy, in particular coal and oil [40]. As a result, humanity embarked upon a path of ever-increasing productivity, social wealth and standards of living. Industrial civilization became the dominant way of life and achieved an advantageous competitive position in the world [36]. Over the last half-century or so, however, the Western industrial world, with its need for constant economic growth and rising standards, has encountered growing scarcities in a wide range of resources and has experienced diseconomies resulting from growing pollution levels and other environmental degradations. This environmental catastrophe can be attributed largely to not recognizing the ecosystem as a component of the economic autocatalytic loop, and to not considering the competition between various autocatalytic loops.

Rather than making utopian plans for sustainable development, we need to adopt the process perspective [41], which is more conducive toward finding practical and viable countermeasures that will help us to avoid the traps that accompany the dynamics between competition and cooperation. Sen [42] defined development as change that removes various constraints to choice or opportunities to exercise reasoned agency. To a developing country, the challenge is to form new autocatalytic loops so as to escape the constraints that have been imposed by other systems with higher efficiency. To a developed country, the task is to form new autocatalytic loops that will increase its control on the surrounding environment. Development as viewed from the process perspective is not solely concerned with efficiency, however. The persistence of the system must also be taken into account [43].

To summarize, development should be approached in two stages: the first is to form new autocatalytic loops that can help a developing country to escape its constraints and enable a developed country to increase its ability to control its environment. The second is to insure persistence—that is to say, to recognize that development is the outcome of dual and opposing tendencies, and deal with the balance between centripetality and the forms of centrifugality just discussed.

The common developmental road

A developmental road common to East and West can be pursued in four stages: (i) autognosis, (ii) forming new autocatalytic loops, (iii) self-control and (iv) self-realization (Table 1). The first stage, 'autognosis', is the precondition for the second stage, 'forming new autocatalytic loops', while the fourth stage, 'self-realization', is enabled by the persistence of the third stage.

Autognosis

We need to achieve a thorough knowledge about ourselves—about our advantages and disadvantages, merits and drawbacks, and our position in the surrounding field of competition. Recognizing our merits and advantages will help us to avoid self-deprecation, while knowing our drawbacks and disadvantages will enable us to avoid over-confidence. This is good self-positioning, and is appropriate at any level—be it person, district or country. In traditional Chinese culture, autognosis is to perceive the Yin-Yang. To immerse ourselves too much in either side would be to fall victim to a closed perspective. Only by appreciating both sides can we achieve a truly open psychology, and an open psychology leads to the vision of an open window that no cause covers [17]. Such freedom can widen the range of causal analysis and allow us to discover other (top-down) causes beyond the material and mechanical [11]. Only when we pay attention to residual categories can we embark upon a new era of theoretical systems science in which we can carve out new positive concepts and reconstruct theoretical systems analysis [9,30].

Clearly, autognosis is requisite for the second stage, 'forming new autocatalytic loops' (discussed above). At the same time, as a preliminary to the third stage, 'self-control', it is important to envision

Table 1. The common developmental road.

Stage	Autognosis	Forming new autocatalytic loops	Self-control	Self-realization
Main characteristics	Knowing own merits/advantages vs. drawbacks/disadvantages Knowing their mutual dynamic	From individual competition transitioning to individual cooperation, and knowing the non-mechanical attributes of autocatalytic loop	Keeping the two opposing tendencies inside the vital window	Naess's self-realization and Chinese Taoism

the transformative relationship, Yin-Yang, under differing contexts.

Of course, Western civilization already has points in common with its Eastern counterpart. For example, utilitarianism assumes that human behavior is driven by coexisting selfish and compassionate tendencies. Catholics, for example, are exhorted to do good works and are promised support in the form of grace from God, but they are also commanded to inventory their shortcomings at regular intervals, confess them, but not be discouraged by them, lest they interfere in their efforts to help others.

Forming new autocatalytic loops

In order to form new autocatalytic loops and recognize their non-mechanical attributes, one must adopt a long-range view and think beyond the mechanical in terms of configurations of processes. Mechanical and algorithmic systems are deterministic in principle. Networks of processes, by contrast, often exhibit indeterminacy, owing to the massive combinatorial possibilities inherent in the significant heterogeneity among the nodes they connect [44,45]. Working as we do from the mechanical mindset, we too often approach a problem from one side only and pursue a single goal to its extreme. Such a narrow vision makes us incapable of seeing all the possible components of an autocatalytic loop and thus do we often make mistakes (see aforementioned examples and Supplementary Material II). In essence, studying the formation of new autocatalytic loops is to truly appreciate how things change.

Self-control

Generosity is the common theme of human engagement. The Chinese pictograph for ecology signifies that one should enlarge one's heart a bit more than ever. In the West, Francis of Assisi, the patron saint of ecology, preached a generous respect for the natural world. Generosity is also prerequisite to attain the self-control needed to implement the countermeasures that can alleviate the conflicts between the three centrifugalities and centripetality. Keeping any living system within its vital window necessitates balancing two opposing tendencies, and tolerating such conflict is a very difficult challenge. It demands magnanimity—the fundamental virtue in traditional Chinese culture. While it may seem difficult to tolerate two opposing tendencies, an ability to do so was actually born in us. Our daily routine of working by day and resting at night is a manifestation of our capability to cope with opposites. It is necessary only to develop further these proto-virtues.

Self-control becomes the key to enabling persistence.

Self-realization and Taoism

The final stage in healthy development is what Arne Naess calls self-realization, which has a counterpart in 'Taoism' [18]. In stage 2, we are encouraged to enlarge our vision, and stage 3 exhorts us to be generous to everything around us. If we nurture these two key characteristics within ourselves, we can achieve the Taoist state of self-realization through process philosophy. Process philosophy requires some inversion of contemporary thought.

The conventional wisdom regards Holism as desirable, but impractical to achieve—like sustainable development or ecocentrism. Combining stages 2 and 3, however, provides a practical avenue to approach the self-realization of Taoism. Furthermore, these approaches, when viewed through the lens of process philosophy, make it easier to recognize the importance of the ecosystem and how its proper functioning can improve the potential for *all* life. The process view accords the ecosystem the same status as humans, thereby making ecocentrism more plausible.

Regarding human development, knowing what we are able to do shows us how we are likely to grow. That much is straightforward. However, knowing what we cannot do or should not continue to do shows us how we have to mature—a far more difficult task. Simply put, self-realization in Taosim bids us to balance what we can do (Yang) with what we cannot do (Yin). The essence of Taoism is very simply Yin and Yang. From this perspective, we discover

that the final stage in a deep way returns us to the first stage. The common developmental road is itself an autocatalytic loop!

CONCLUSION

The process approach to reality bids us abandon utopian, deterministic attempts at sustainability in deference to the realization that sustainability results from a balance between efforts at efficient design and a certain tolerance for inefficient, incoherent and redundant functions that can impart reliability to a system during times of novel disturbance and change. Often, patience is a necessity. Antagonisms that first appear as outright competition, for example, could mask an underlying deep cooperation.

Thus, the common developmental road consists of a myriad of aspects that deserve serious study. It should be emphasized, however, that the most important feature of the road is the mandate to help other people to fulfill themselves, while simultaneously developing ourselves. That combination implies that we should strive for sustainable development from within, not via external fiat [46]. It is more important to do the right things than to do things right [47]. If the majority of our notions are right, then our will to act will be strong. If, however, we are filled with spurious notions, we are likely to remain passive [48]. Let us, therefore, begin our journey on the road to sustainable development with the conversion of our hearts.

SUPPLEMENTARY DATA

Supplementary Data are available at *NSRSCP* online.

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REFERENCES

1. Matthews JA and Herbert DT. *Unifying Geography: Common Heritage, Shared Future*. London: Routledge, Taylor & Francis Group, 2004.
2. Costanza R, Kubiszewski I and Giovannini E *et al*. Time to leave GDP behind. *Nature* 2014; **505**: 283–5.
3. Ulanowicz RE. *Growth and Development: Ecosystems Phenomenology*. New York: ToExcel Press, 1986.
4. Ulanowicz RE. Widening the third window. *Axiomathes* 2012; **22**: 269–89.
5. Coleman DA. *Ecopolitics: Building a Green Society*. New Brunswick, NJ: Rutgers University Press, 1994.
6. Haken H. *Erfolgsgeheimnis der Natur*. Berlin: Ullstein-Verlag, 1984.
7. Matutinovic I. Organizational patterns of economies: an ecological perspective. *Ecol Econ* 2002; **40**: 421–40.
8. Ulanowicz RE. Autocatalysis. In: Jørgensen SE and Fath BD (eds). *Systems Ecology*. Vol. 1 of *Encyclopedia of Ecology*. Oxford: Elsevier, 2008, 288–90.
9. Parsons T. *The Structure of Social Action*. New York: Free Press, 1937.
10. Nowak MA. Five rules for the evolution of cooperation. *Science* 2006; **314**: 1560–3.
11. Ulanowicz RE. *Ecology, the Ascendent Perspective*. New York: Columbia University Press, 1997.
12. Ulanowicz RE. The dual nature of ecosystem dynamics. *Ecol Modelling* 2009; **220**: 1886–92.
13. Kauffman SA. *Reinventing the Sacred*. New York: Basic Books, 2008.
14. Talhelm T, Zhang X and Oishi A *et al*. Large-scale psychological differences within China explained by rice versus wheat agriculture. *Science* 2014; **344**: 603–8.
15. Senge P. *The Fifth Discipline Field Book: Strategies and Tools for Building a Learning Organization*. New York: Doubleday, 1994.
16. Geng T. Measuring China's circular economy. *Science* 2014; **339**: 1526–7.
17. Popper KR. *A World of Propensities*. Bristol: Thommes, 1990.
18. Naess A. *Ecology, Community and Lifestyle*. Cambridge: Cambridge University Press, 1989.
19. Meyer M and Bergel K. *Reverence for Life*. Syracuse, NY: Syracuse University Press, 2002.
20. Ulanowicz RE. *A Third Window: Natural Life beyond Newton and Darwin*. West Conshohocken, PA: Templeton Foundation Press, 2009.
21. Daily GC and Ellison K. *The New Economy of Nature: The Quest to Make Conservation Profitable*. Washington, DC: Island Press, 2002.
22. Marris E. More crop per drop. *Nature* 2008; **452**: 273–7.
23. Schultz TW. *Transforming Traditional Agriculture*. Chicago: University of Chicago Press, 1969.
24. Wils A. End-use or extraction efficiency in natural resource utilization: which is better? *System Dynamics Review* 1998; **14**: 163–88.
25. Czech B. Technological progress and biodiversity conservation: a dollar spent, a dollar burned. *Conservation Biology* 2003; **17**: 1455–7.
26. Ward FA and Pulido-Velazquez M. Water conservation in irrigation can increase water use. *Proc Natl Acad Sci* 2008; **105**: 18215–20.
27 Jevons WS. *The Coal Question*. London: Macmillan and Co., 1866.
28. Hanley N, McGregor PG and Swales JK *et al*. Do increases in energy efficiency improve environmental quality and sustainability? *Ecol Econ* 2009; **68**: 692–709.
29. Hawken P. *The Ecology of Commerce: A Declaration of Sustainability*. New York: Harper Collins Publishers, 1993.

30. Ulanowicz RE. Towards quantifying a wider reality: Shannon exonerata. *Information* 2001; **2**: 624–34.
31. Daly HE and Farly J. *Ecological Economics: Principles and Applications*. Washington, DC: Island Press, 2004.
32. George H. *Progress and Poverty*. New York: Cosimo, Inc., 2005.
33. Berkes F, Colding J and Folke C. *Navigating Social-Ecological Systems: Building Resilience for Complexity and Change*. Cambridge: Cambridge University Press, 2003.
34. Olson M. *The Rise and Decline of Nations: Economic Growth, Stagflation and Social Rigidities*. New Haven: Yale University Press, 1982.
35. Merton RK. The Matthew effect in science. *Science* 1968; **159**: 56–63.
36. Rothman DS. Environmental Kuznets curves-real progress or passing the buck? A case for consumption-based approaches. *Ecol Econ* 1998; **25**: 177–94.
37. Seo K and Taylor J. Forest resource trade between Japan and southeast Asia: the structure of dual decay. *Ecol Econ* 2003; **45**: 91–104.
38. Schumacher EE. *Small is Beautiful*. London: Harper & Row Publishers, 1989.
39. Hornburg A. Machine fetishism, value and the image of unlimited good: towards a thermodynamics of imperialism. *Man* 1992; **27**: 1–18.
40. Marks RB. *The Origins of the Modern World: A Global and Ecological Narrative from the Fifteenth to the Twenty-First Century*. New York: Rowman & Littlefield Publishers, 2007.
41. Whitehead AN. *Modes of Thoughts*. New York: The Free Press, 1968.
42. Sen A. *Development as Freedom*. New York: Anchor Books, 1999.
43. Ulanowicz RE, Goerner SJ and Lietaer B *et al*. Quantifying sustainability: resilience, efficiency and the return of information theory. *Ecol Compl* 2009; **6**: 27–36.
44. Longo G, Montevil M and Kauffman SA. No entailing laws, but enablement in the evolution of the biosphere, 2012, ArXiv, 1201.2069 [q-bio,OT].
45. Ulanowicz R. Process ecology: making room for creation. *Sophia* 2016; **55**: 359–80.
46. Wang Y. *Wang Yangmin's Lectures and Letter Book*. Zhengzhou: Zhongzhou Ancient Books Publishing House, 2012.
47. Drucker PF. *The Effective Executive*. New York: Harper-Collins, 1967.
48. Spinoza BD. *Ethics*. Oxford: Oxford University Press, 1927.