

Information generation in interactions: the link between evolutionary game theory and evolutionary economics

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Abstract

While criticizing the analytical settings of human interactions for their unrealistic nature many scholars have also suggested improvement measures. We incorporate those in the existing theories, whereupon the simple game theoretic settings change into those of countless decisions made by millions of individuals with diverse interests and abilities trying to interact in varieties of situations. By applying evolutionary game theory we are able to show that the evolutionary selection process steers the complexities away from chaos to orderly and resilient interaction systems. The information content of the emerging order is operationalized as norms, institutions, trust etc. It accompanies novel phenomena and co-evolves with physical, technical and cognitive systems. All these phenomena are evident in reality and are of considerable interest in economic and social studies.

JEL No. : B41, D80, C65, C73, A12

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1. Introduction

The importance of the topic discussed in this paper was brought to attention again and again in the pages of *Journal of Evolutionary Economics* (Friedman 1998; Witt 2008; Hodgson and Huang 2012). Friedman (1998) introduced evolutionary game theory as a novel technique that has considerable unrealized potential for modeling substantive economic issues. Ten years later Witt (2008) noted with surprise that researchers in evolutionary economics and evolutionary game theory take little notice of each other. Hodgson and Huang (2012) repeated the same sentiment. To explain why it is so Witt (2008) cited Nelson's (2001) arguments that evolutionary game theory differs from evolutionary economics in two ways. Evolutionary game theory is (i) less empirically oriented and (ii) more equilibrium oriented. Similar observations were made by scholars approaching evolutionary economics from game theory perspective. North abandoned game theory lamenting that "there is a vast gap between the relatively clean, precise, and simple world of game theory and complex, imprecise, and fumbling way by which human beings have gone about structuring human interaction" (North 1990: 15). In his study of a common property Sengupta (2006) used an evolutionary game model but rejected equilibrium search in favor of 'resilience', the ecological concept of stability.

One may hope that a duly modified game formulation, relieved of the twin deficiencies, would be able to meet the expectations of evolutionary economists. In this paper we make such an attempt and invite evolutionary economists to judge its worth. The paper is divided into seven Sections. In Section 2 we show how to eliminate the deficiencies of evolutionary game models. The improvements suggested are not merely methodological but also ontological, which demands that we start our discussions from the fundamental levels. Many of these ontological and methodological problems were noted by others authors. Some

of them could suggest possible remedies. On the basis of those suggestions and a few of ours, we develop a more realistic depiction of interactions in general, which turns out to be highly complex. In Section 3 we apply evolutionary game method which shows that only a few behavior types are "fit" to survive in this complex setting. Thus, instead of being always a chaos the complex setting may also, at times, self-organize into orderly systems. Section 4 explains the informational and economic meaning of the order so derived. In theory and practice alike, monitoring and enforcement is treated as essential for implementing cooperation. Using a deductive approach in Section 5 we show that there are several classes of facilitation measures, enforcement being just one of them. In Section 6 we draw attention to an important implication of the model that connects to creativity and long term evolution. This is followed by a conclusion Section.

2. Towards a better representation

We act, for producing goods and services, for being a fine mother in a family, to dance in joy, to find a vaccine, or to defend our possessions from a usurper. In all these acts we use our mental, physical, and material capabilities¹ (means of action) for an end. The

¹ Although proposed in a different context we prefer Sen's notion of capabilities over the materialistic means or resources. A particular set of means does not create the same set of actionable options for everyone. Following a lead due to Nussbaum (2000: 84-85) we suggest that there are three different ways of acquiring capabilities: inheritance, acquiring, and loss from embargo. (1) Inherited are the innate capabilities of human child like capacities of seeing, hearing, memory, etc. Some children may inherit not only biological but also some material endowments. (2) Acquired capabilities are like maturity of body, cognition abilities etc. along with acquired material and intellectual capabilities throughout one's life. (3) Embargoed capabilities: exercise of certain capabilities may not be allowed in specific ambience. One may be restrained to act in a certain way because of

techniques and the arts of combining and executing means of action for an act are studied under disciplines like science, engineering, fine arts. Under ‘economics’ we study *human behavior* as a relationship between ends and scarce means which have alternative uses (Robbins 1935: 15). Thus *behavior* in economics is not just psychological. It also depends on our knowledge of uses and alternative uses of our mental, physical, and material resources, as well as alternative techniques of a use.

The varieties of ways one can utilize parts of his limited means may be grouped into four types: (i) *repetitive*: repetitions of one’s earlier acts, (ii) *imitative*: imitation of someone else’s acts, (iii) *innovative*: acts without any precedence that includes whimsical acts as well as creative acts, and (iv) *cooperative*: joint acts with other individuals. An individual can choose to repeat, imitate, or invent but cannot cooperate on one’s own. Cooperation ‘happens’, depending on the actions chosen by all concerned. Noting this peculiarity von Neuman and Morgenstern (1944) invented the mathematical technique of game theory for analyzing such decision problems. Game theory has come a long way from the frustrating years of prisoner’s dilemma formulation to current models of cooperation using folk theorem and evolutionary game. But their ability to explain real world cooperation is limited owing to mismatches between the contextual reality and their mathematical representations as games, a point that was raised by North (1990: 15) and many others.

2.1 Real interactions vs. their game models

One major contribution of human behavioral studies, from philosophy to economics is that they are rational. The notion of rationality has been subjected to unrealistic assumptions that have come under severe criticisms (Simon 1955; Sen 2004). The best that can be said is

health risk. He may also refrain from an act fearing ghost attack. We discussed these in some details because the capabilities approach fits very well with many of the issues raised by us later, like bounded rationality or CBR.

that humans choose on the basis of reasoned scrutiny of options (Sen 2004). This may not be a feature unique to our species as studies of foraging behavior of animals show (Mobbs et. al. 2018). There are other problems. In game narratives like prisoner's dilemma the model maker, instead of the real player with his personal beliefs, decides which are to be considered rational responses by interacting agents (Grüne-Yanoff and Lehtinen 2012). Rationality raises problems of interpretation of the purpose of game theory. As a descriptive theory it is used to predict what would happen when rational players interact. It is also used as a normative theory prescribing rational actions to the players, who are supposedly rational themselves.

Little effort was made to connect mathematical entities like payoffs, rules of games, strategy sets etc. to real world phenomena. Game theory has not shown any interest in examining where the "rules of the game" come from or how they change (Ostrom 2005: 17). Games are narrated, as stories. It is presumed that real life events fit into the stories of Hawks and Doves, Prisoner's Dilemma etc. Behavioral game theorists find that such descriptions are not adequate for setting up experimental games. They design the rules of games, differently for different experiments. The players are then asked to learn and follow these rules before they start playing the games. The set of rules is the mandatory behavior, strategic play concerns behavioral options. Actual hawks are born to use the mandatory behavior. Experimental subjects have to learn those before they start playing. Already there are many such experiments and many sets of rules for these laboratory games. In real life, game-like situations are far more numerous. So are the rules of these games. Rarely are those taught at the spot by one. The players themselves have to identify the behavioral rules that must be followed. How do they do that? There are mathematical discussions about the intricacies in explanations of common knowledge in tricky situations. But there is nothing there explaining how an individual possesses the vast amount of common knowledge necessary to interact in numerous real life interactions.

Implicit in a situation modeled as a 2×2 game is that any individual playing the game knows both the strategies. Otherwise, the game does not exist. How reasonable is it to presume that everyone in a domain knows the strategy sets of the numerous game-like situations he faces and would be facing? Real people are not born with the knowledge of all possible scenarios, all possible actions, and their consequences. Even robots need to learn. Artificial intelligence (AI) studies developed a continuous problem solving and learning approach named Case based reasoning (CBR). Combining decision theory and CBR Gilboa and Schmeidle (2001) suggested in their Case based decision theory (CBDT) that individuals continually build up their memory collating information about past experiences and base their decisions on similarity of current choice situation to some of those experiences.

Game theory does not say much about the payoff except rightly, that this is not necessarily a share of the output. In reality, it is subjective valuation (as cardinal utility) of a bundle of receipts. A worker considers as payoff not only the wages but also the abusive nature of his coworkers or how dirty is the workplace. The payoffs of a prisoner's dilemma game depend on whether the prisoners are sworn enemies or a loving pair of mother and daughter.

In this article, we rework the existing game model of cooperation taking note of these criticisms so as to arrive at a more realistic representation. Thereafter we draw some of its implication.

2.2 An evolutionary game model

Some of these problems are overcome in evolutionary game theory. In this theory one studies a whole population consisting of many individuals, using many different strategies and with varying abilities, repeatedly interacting with one another in one task of cooperation. Human beings perform several group-based functions regularly. Each such function consists

of several interaction situations that are repeated and need cooperation². These are contexts suitable for applying the evolutionary game theory. The situations need not be identical. CBDT establishes that the concept of similarity plays a role in decision making (Hüllermeier 2007; Bhui 2018). Evolutionary games do not assume that players are perfectly rational (Samuelson 1997; Nowak and Sigmund 2005) nor does it face interpretation problems. The evolutionary approach studies how different strategies perform over time. The question of acquiring the necessary common knowledge remains unanswered even in this kind of game. There are a couple of other points where we make some modifications from the standard evolutionary game approach.

Several game theorists and economists have hypothesized how players learn and decide. But none of these mathematically convenient forms captures the totality. People use many different approaches, habitually and intelligently; shift from one to another for their private reasons; experiment, speculate, misjudge, and act erratically. In some circumstances they may be motivated, compelled, even threatened to make specific choices. Most often it is impossible to ascertain how exactly a decision was reached by an individual, or that a decision was irrational. We will treat human learning and decision process as black boxes, and for analytical purpose classify those by their manifestations as:

- *Adaptive behavior* – people appear to summarize the experiences of their own and of some others, and use those as positive and negative inducements in choosing their strategies.
- *Contrarian behavior* – all those behaviors that cannot be classified as adaptive.

² Through the notion of ‘routine’ Nelson and Winter (1982) suggest that organizations repeat functions for performing similar tasks.

In evolutionary games the performance of a promising strategy depends on the frequency of the strategy in the interacting population at the very beginning of the repetitions. It resembles the phenomenon known as *sensitive dependence on initial condition*, a characteristic of dynamical systems (chaos theory). We will make use of this feature to study the dynamic properties guiding the evolution of cooperation. Thereby we take care of such criticism that evolutionary game theory is directed to find equilibria neglecting to study how such equilibria are achieved (Nelson 2001).

We also list some terms that will be used in some specific sense. These are:

- i. *Domain*: Our analysis pertains to varieties of ‘population’, like that of the whole economy, small groups, even the close acquaintances of one. We refer to these as the domain of a particular activity or a group of activities.
- ii. *Behavior repository*: It follows from CBR that the behavioral strategy of individuals in a repeated game depends not only on the histories of play but also on the histories of players. We assume that each individual possesses a distinct behavior repository partly based on his memory. His choice of strategy in a situation is a behavior selected from within his private repository.
- iii. *Behavior structure*: All regularly occurring functions consist of one or more repeated interactions. Each participant of a typical such interaction selects a strategy from his behavior repository. Together, the behaviors of all the participants of that interaction constitute a behavioral strategy profile. Only some of these strategy profiles establish cooperation between participants and achieve cooperative outcomes. We name these profiles behavior structure. An interaction may succeed under different behavior structures, like which side to drive or which language to use for communication. But all participants of a successful interaction must follow a single structure.

The world consists of self-interested individuals. But their interests are not uniform, nor are their abilities, experiences, and knowledge base. Rational responses of people at similar nodes may differ. At times a decision is adaptive in appearance. At other times, a decision reached by using some intricate rationale, may appear as a contrarian. In such situations individual rationality does not lead to unique and predictable responses. The indeterminacy that we face, while trying to be realistic, is in the nature of social systems. Realizing this half a century earlier Hayek (1967) wrote in exasperation, “It is high time ... that we take our ignorance more seriously” and find ways to proceed in spite of that. He could not make much progress. But today it is possible by utilizing some tools of analysis developed since then.

3. Dynamics of interactions

We study a n -person interaction, where n varies from 2 to millions. This may be a network requiring specialized behavior at some nodes. Each individual occupying a node of the interaction network decides to behave in a certain way. But we have no way to predict his behavior. All that we know is that this is one from within his behavior repository. Formally, we assign unknown probabilities to all the behaviors included in one’s behavior repository. Together, the behaviors of all n -persons describe a set of behavioral strategy profiles (s) along with the joint probability of each such behavior that constitutes the profile. Thus, in an interaction between n people, each of them having many behavior options, their joint behaviors appear as a random experiment (S) resulting in behavior profiles with different probabilities e.g.

$$S = s_1, s_2, s_3, \dots, s_z \quad \text{with probabilities } p_1, p_2, p_3, \dots, p_z \quad (1)$$

Only some of these profiles establish cooperation between participants resulting in successful interaction. A behavior profile like this is a behavior structure (Δ). Sometimes the interaction succeeds even though one or a few more persons are missing at some nodes. Without such a possibility free riding cannot happen. We term these cases of successful partial cooperation sub-structures of the behavior structure. In a case of cooperation a participant uses only a node-specific behavior *consistent* with Δ . He may not know the whole of the behavior structure.

Proposition 1 - *Though promising, in a domain Ω a joint work opportunity requiring a new behavior structure ($\tilde{\Delta}$) for cooperative outcome*

- (i) *cannot sustain for long unless a sufficiently high proportion of people make use of the behavior structure (threshold level),*
- (ii) *self-organizes above the threshold level (emergent order),*
- (iii) *at this stage it is able to withstand small and temporary shocks (resilient system).*

Proof

To study whether an individual i would opt for the new opportunity we split the behavior profile of all n players given by (1) as $s = s_{i,-j} \times s_{-i,j}$, where:

$s_{i,-j}$: the behavior of i

$s_{-i,j}$; $j = 1, 2, \dots, y$: behavior profiles of $n - 1$ other participants excluding i .

We denote the probability of $s_{-i,j}$ profiles by p' . A p' term is the sum of all the p terms that differ between them only in the behavior of i . Using these symbols all possible behavior profiles of the $n - 1$ other participants may be written as:

$$S_{-i} = s_{-i,1}, s_{-i,2}, \dots, s_{-i,y} \quad \text{with probabilities } p'_1, p'_2, \dots, p'_y, \quad (2)$$

The decision maker i has no control on the occurrence of these profiles. At the most he may remember the actual payoffs (u_{it}) of some past interactions and use that for his decision. This kind of behavior is adaptive³. The direction of change in adaptive behavior phase can be foretold if we can predict u_{it} values.

Individual i needs to make a choice only when he does not have sufficient means to allocate adequately for participating in both the existing and the new opportunities. The choice occurs in the form of behavior, selected from within his behavior repository. Let i know that by choosing a particular behavior other than the \tilde{A} consistent one he can get utility β_i . We make no attempt to specify how he arrives at that assessment. This is another area of human thought process that should be treated as a black box. In economics β_i is called *reservation utility*. Alternatively, by choosing \tilde{A} consistent behavior i sacrifices β_i for getting gross utility b_i through complete and partial cooperation \tilde{A} . But he suffers net loss β_i if the interaction fails. The actual payoff in any round of play (u_{it}) depends on which $s_{-i,j}$ he was interacting with. Mathematically, this is $s_{-i,j} \rightarrow u_{it}$, or $S_{-i} \rightarrow U_i$. U_i is a random variable and there is no way to tell definitely what will be the payoff in a particular round played by an individual. However, the Central Limit Theorem permits us to say something about the average payoff i received in the past (\bar{u}_i).

In Appendix A we have explained how to get the mean (δ) and the variance (σ^2) of random variable U_i . Let m be the number of past experiences that i summarizes for decision making. This is comparable to a sample of size m drawn from U_i . Let \bar{u}_i be the average of these m observations. Then, by the Central Limit Theorem \bar{u}_i is distributed as Normal distribution: $\bar{u}_i \sim \mathcal{N}(\delta, \sigma/\sqrt{m})$. The following figure explains its implications.

³ Adaptation also includes imitation of someone else's behavior. But that is difficult to predict as are other contrarian behaviors like inventing something original.

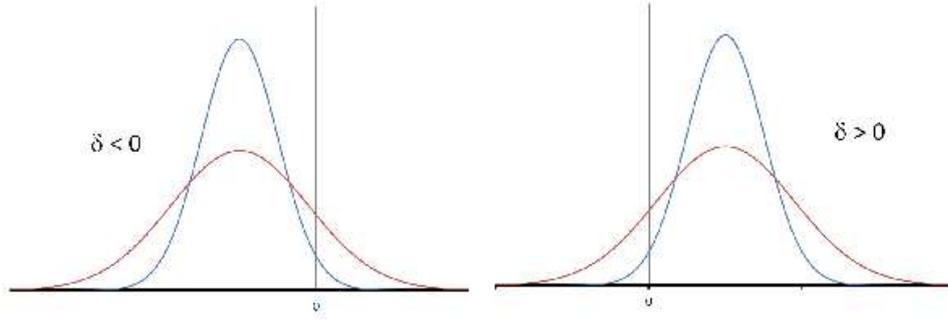


Fig. 1 Probability distribution of average payoffs. Note: Shows normal probability distribution $\mathcal{N}(\delta, \sigma/\sqrt{m})$ curves with two different means and two different m values. The blue line is of higher m than the red line. For Normal distribution the mean coincides with the mode. So we have not shown the δ value in the axis. The vertical axis crossing at 0 is shown.

The area enclosed by the normal curve shows the probability of getting a sample average below a particular value. $\text{Prob}(\bar{u}_i < 0)$ is the area left of the vertical line at 0 and $\text{Prob}(0 < \bar{u}_i)$ is the area right of the vertical line at 0. Figure 1 shows that

- for $\delta > 0$ the probability of having $\bar{u}_i > 0$ is higher. Also, it increases if δ is much greater than 0 and/or m is higher (3a)
- for $\delta < 0$ the probability of having $\bar{u}_i < 0$ is higher and the probability of $\bar{u}_i > 0$ is low. (3b)

A new strategy is either invented or imitated from others. Whether it is a better strategy than the rest is determined by actual experiences of the decision maker, summarized as \bar{u}_i . Its being positive or negative determines whether it will tend⁴ to be repeated or changed in the adaptive phases of the decision maker.

⁴ The tentative expression is because individuals have bounded rationality and in evolutionary game they show inertia (Samuelson 1997: 208).

Let us write p^* for the probability of the composite event of success along with i 's participation. Then the mean of the random variable U_i is given by (see Appendix A for deduction) is given by:

$$\delta = p^*b_i - \beta_i \quad (4)$$

Using this and conditions (3a) and (3b) we find that the behavior of i in his adaptive action phase will be as below –

- if $p^*b_i - \beta_i > 0$ he has a positive inducement to choose \tilde{A} (5a)

- if $p^*b_i - \beta_i < 0$ he has an inducement to switch away from \tilde{A} (5b)

This tentative statement is all that we can predict about the results of their adaptive behavior. Besides, people do not always act as adaptive individuals further augmenting the indeterminacy. Such a chaotic reality is the right context for a meaningful application of game theory. We show that the performances of different behavioral strategies are tested in evolutionary processes, out of which comprehensible patterns emerge in the domain.

What determines the direction of the inequality? Let $\rho(t)$ denote the proportion of people at time t in the domain Ω using the behavior structure consistent with \tilde{A} . Since the participants are selected from Ω the probability of the composite event that supports the new opportunity is a monotonically increasing function of ρ . We write this as:

$$p^* = F[\rho(t)] \quad (6)$$

Substituting this in condition (5a) we find that i may choose \tilde{A} consistent behavior now or later if -

$$F[\rho(t)] b_i > \beta_i \quad (7a)$$

A switch like this means a little increase in $\rho(t)$. Similarly, we obtain another inequality from condition (5b). It follows from these two inequalities -

- while acting as an adaptive person individual i will have incentive to switch to or continue using $\tilde{\Delta}$ consistent behavior if

$$\rho(t) > F^{-1} \left[\frac{\beta_i}{b_i} \right] \quad (8a)$$

- and will have some inducement to switch away from using $\tilde{\Delta}$ if

$$\rho(t) < F^{-1} \left[\frac{\beta_i}{b_i} \right] \quad (8b)$$

The R.H.S expression acts as a threshold point for a decision maker i . Each decision maker has such a threshold. Each switch to $\tilde{\Delta}$ consistent behavioral strategy means a little increase in $\rho(t)$ and vice versa. Thus, the inequalities actually describe a growth path of behavior structure $\tilde{\Delta}$ supporting the new opportunity. The threshold point varies from individual to individual. But one may define a fuzzy interval $(\tilde{\rho}_{min}, \tilde{\rho}_{max})$ containing *most* of the threshold points. This interval acts as a *bifurcation band*.

- (i) For any value of $\rho < \tilde{\rho}_{min}$, $\rho(t)$ reduces gradually implying that the behavior structure $\tilde{\Delta}$ is unable to repeat for long.
- (ii) For any value of $\rho > \tilde{\rho}_{max}$, $\rho(t)$ increases gradually evolving spontaneously towards the limiting equilibrium.
- (iii) The increase of ρ in the region above the bifurcation band, in the interval $[\tilde{\rho}_{max} \leq \rho(t) \leq 1]$ is not monotonous. Performance of an open system varies because of variations in the condition of the physical world, condition of the participants, or mere fatigue of them. People always experiment with contrarian strategies, including innovations and free riding. If irregularities in behaviors, or effects of adverse situations are *random* and *nominal* those work like small perturbations. The self-organizing feature of the system adjusts to it easily. Occasionally a large adverse perturbation may even result in a negative value of ρ . But a major disturbance may not be enough to push ρ below the bifurcation band jeopardizing the self-

organization process. If perturbations are random then there is a low probability of having a large adverse perturbation in the next period, and a much lower probability of having another large perturbation in the next period. Thus, after a temporary setback ρ is likely to increase again. Above the bifurcation band a self-organizing system regularly recovers after negative shocks.

To sum up, many interactive initiatives fail to perpetuate for long. Only a few efforts succeed and multiply. Over time these sustainable structures come to predominate. The following figure shows a simulated growth path of ρ .

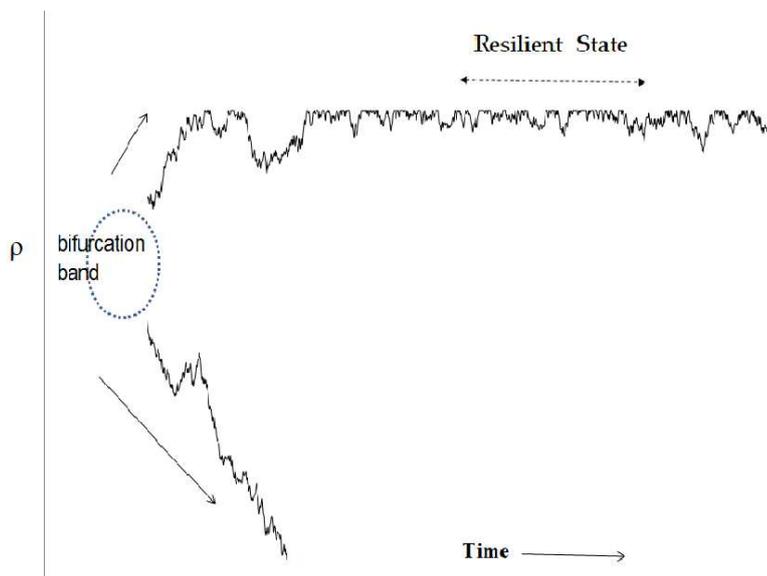


Fig. 2 Growth Path of Self-organization (Simulated)

The ratio $\frac{b_i}{\beta_i}$, which may be termed *perceived desirability index* (PDI) of an opportunity, is determined privately by each individual. It means that there is no need to peep into their private thoughts. They may have different interests, different ways of assigning utilities to benefits, and comparing utilities of different opportunities. Still they can repeatedly cooperate amongst themselves for the interactive better opportunity if a

sufficiently large number of individuals (a) feel that a joint work opportunity has a higher PDI compared to the existing alternatives and (b) behave as adaptive learners. Almost all decisions are subjectively rational in our framework. But only a few of those rational decisions become ubiquitous in evolutionary selection of interactions. In the following Sections we discuss their characteristics. In Appendix B we provide some idea of the numerical values of a bifurcation band.

4. Order and its uses

4.1 Information content of order

A summary measure of changing behavioral uncertainty along the growth path of an interaction is Shannon's information entropy. The entropy of S representing the distribution of different behavior profiles is –

$$H(S) = - \sum_{j=1}^z p_j \log p_j \quad (9)$$

Above the bifurcation band most participants of the interaction use behavior consistent with a single behavior structure that we named $\tilde{\Delta}$. In the extreme case, when all of them including i use $\tilde{\Delta}$ consistent behaviors, the composite behavior profiles has probability 1, i.e. $p^* = 1$. From equation (9) such a probability distribution has entropy 0, which implies perfect order. A low value of entropy indicates little uncertainty or high order. Therefore, the reduction of uncertainty on the way to the self-organizing phase is information generation.

4.2 The economy and the institutions

Till now we have discussed only one interactive opportunity. A human habitat includes many such activities and also many others that do not require joint work. Each

different activity does not have its captive domain. Individuals coming from a single domain participate in several different activities. But some of these works, if not all, require different behavior structures for success of the respective interactions. This is possible only if the members of the same domain use all these behavior structures. Each of the behavior structures may occur in the domain with a probability p_{Δ}^* ; $\Delta = 1, 2, \dots$. Since total probability has an upper limit all the p_{Δ}^* values corresponding to different interactions cannot be very high at the same time. It follows that the entropy of a domain that supports many different interactions requiring different behavior structures is quite high. How do the individuals belonging to a disorderly domain simultaneously exist as participants of several highly ordered self-organizing activities?

Such a domain containing many individuals and many activities, and with a definite boundary to contain all those, may be a whole economy or a society. Within the less orderly domain there are many highly ordered interactions and groups of interactions that are easily noticed, like residential clusters in a satellite image. These are identified by names. The group names of these clusters of regularities are norms, customs, codes of conduct, conventions, institutions, organizations etc. These behavior structures are perceived entities facilitating specific functions. Each such structure consists of one or more interactions along with resources, equipment, protocols etc. Analytically, these are structures for attaining additional order (i. e. less uncertainty) above that of the whole economy or society so that a particular function may sustain as a resilient system of cooperation. Douglass North has defined institutions from several perspectives. One of these, "Throughout history, institutions have been devised by human beings to create order and reduce uncertainty in exchange" (North 1991: 97) is close to our definition.

Among the various features evident in institutions, norms, customs etc. are numerous node-specific behaviors. These are mandatory behaviors that are required to be observed for

being a part of an existing behavior structures. Being evident out there those serve as role models to learn from. This is how individuals acquire the vast amount of common knowledge necessary to interact in numerous real life interactions. Guiding behavior is another function of norms, customs, and institutions along with increasing internal order by specific behavior structures.

4.3 Trust

In repeated game literature an important consideration in choice of strategy is the reputation of a player about a specific behavior. In our model behavioral information about the players are obtained as information entropy. For example, the uncertainty in behavior of $n - 1$ co-participants of i in expression (2) is:

$$H(S_{-i}) = - \sum_{j=1}^y p'_j \log p'_j$$

As per the definition of trust by Gambetta (1988: 217) this is the trustworthiness of those $n - 1$ participants (the trustees). Its subjective assessment by i (the trustor) is his trust in them. Trustworthiness of one or a group of co-participants of i may be obtained by using appropriate entropy terms. Although they do not calculate the mathematical entropy, when people *trust* they make use of the existing state of order in the behavior of their co-participants. In fact in mathematics, Shannon's is not the only possible measure of information entropy.

Earlier, we noted that behavior in economics depends also on one's knowledge of resources and techniques of use. Both Gambetta (1988) and Luhmann (1988) made it clear that trust includes not only the intentions of others not to cheat the trustor but also trust in their knowledge and skill to perform adequately. Sako (1992) referred to competence trust and Mayer et al. (1995) noted ability being a factor of trustworthiness. These aspects are not

getting enough attention in the experimental studies (Fehr 2009). For a candidate eager to be trustworthy it may be important to judge whether he should improve his skill or his commitment. But to a decision maker, who has to decide whether to trust or not, it does not matter whether her co-participants are lacking in competence or commitment.

4.4 Cultural milieu

Until the advent of intense globalization human population within a domain could evolve distinctly. Their knowledge about resources, techniques of use, competence of users, commitments to works, norms, customs, and mandatory behavior, their beliefs and trusts were acquired from other members of their communities. Anthropologists studying isolated communities termed these ensembles *cultures*. With the rise of interest in studies of cooperation it was noted that cultures carry information that guide individual behavior, including those that are essential for achieving cooperation (Richerson and Boyd 2005). Each cultural milieu supports distinctive behavior structures, which in turn, determines the nature of cooperation it may achieve (Sengupta 2001). Richerson and Boyd (2005) suggest that ‘dual inheritance’, from both gene and culture, separates us from other species. Our propensity to collaborate in large groups of unrelated individuals owes to our cultural inheritance.

5. Some facilitation methods

Order self-organizes only above a threshold. How does it reach the threshold? Also, occasional free riding that continues to occur even in a resilient state has a tendency to increase in a population of adapters. System resilience is not without limit. It may require

conscious effort to contain sliding below the threshold. Issues like these require facilitation measures some of which are listed in this Section.

5.1 Varying utility and values

Making use of cost-to-benefit ratio Nowak (2006) introduced five such facilitation mechanisms in biological world. We use PDI, utility-to-reservation utility ratio $\frac{b_i}{\beta_i}$ of the opportunity to individual decision makers to explain the working of this class of facilitation measures. The simplest of such measures is to introduce material *penalties* for not cooperating, or rewards for cooperating. Penalizing individuals selectively may require additional effort for monitoring and enforcement. Such measures are viable only when most people cooperate and only a few need punishing. An alternative is self-policing and psychological punishment (Enke 2019). According to Norenzayan (2013) the evolution of the concept of omniscient God who monitors human behavior all the time goes a long way to enforce cooperation. There are other ways of changing the perception of the outcome without making any substantive change in the output. Additional utility and disutility may result from pride and satisfaction for cooperating and guilty feeling for failure (Bowles and Gintis 2011). Some authors feel that punishing the defaulter itself is an act of altruism. Why would individuals punish if that is costly and there is no material gain for the punisher? Fehr and Gächter (2002) suggest that the acts of altruistic punishment have emotional value for the punisher. Betrayal aversion, not fear of losing control, let employers pay for the opportunity to punish untrustworthy employees (Bohnet et. al. 2008). Studies of the evolution of market (Greif 1993) and common property (Sengupta 2001: 83-84) institutions show that at the formative stages transient institutions push for very severe punishments that would send shivers through anyone willing to free ride or cheat. Sengupta (2001) described a case of step by step introduction of different types of facilitation measures ultimately creating an

extensive network of resilient irrigation management organizations that lasted for over two thousand years to the twenty first century.

5.2 Addition of allied activities

Numerous institutionalized behavior and their positive results accumulate in peoples' behavior repositories. Some individuals may add experiences of not cooperating in some situations. When a new opportunity arises people search these behavior repositories for a suitable one. Thus, existing behavior structures are regularly tried for extension into new activities. Some of these may succeed. We term these activities 'allied' to an existing behavior structure. All the allied activities need not be repetitive. The existing set of behavior structures may also assist in establishing cooperation for occasional works. Thus, numerous and diverse interactive functions, both repetitive and occasional, are supported in a domain by only a handful of behavior structures. In turn, they lend strength to the supporting structures by increasing their desirability (PDI).

5.3 Inclusion and exclusion

The entropy of a random experiment S conditional on the knowledge of another random experiment S_θ is called *conditional entropy*. It can be shown that conditional entropy cannot be greater than the original i. e.:

$$H(S | S_\theta) \leq H(S) \quad (10)$$

This principle is used ingeniously to effect reduction of entropy for attaining self-organization. For example, using their background information candidates are differentiated into categories with specific characteristic properties (θ). People with specific

characteristics may be more trustworthy than others in terms of their competence and commitments. Screening for either induction or exclusion of participants is in use. One may take into account more and more additional characteristics provided one is certain which are to be used for inducting and which others are for exclusion. The following are some common applications of this principle:

- After one successful interaction the same individuals, agencies, or groups of people are engaged again and again. Towards this end organizations like factories, offices, or performer groups are formed, brand loyalties arise in markets.
- Works at specific nodes may need specific skills. To meet this requirement candidate participants are screened for their competence by their training, past experiences etc. In turn, this set of designs creates signals like degrees, certificates, recommendations, apprenticeship of European Guilds, or hereditary occupational divisions like Indian castes.
- Associations as above are irrefutable. But not so are other signals that are in use. Designers may believe that some specific social or ethnic groups are more committed and/or competent than others. This is the basis of what is known as statistical discrimination. Even though spurious, the association may exist and may not be a bad indicator of trustworthy candidates. But it also means exclusion of some trustworthy candidates for not possessing certain spurious characteristics. When spurious features matter people care less for improving competence and commitments, as some well-designed recent studies show (Bertrand and Mullainathan 2004; Glover et. al. 2017; Bordalo et. al. 2019). Single minded pursuit of opportunities using facilitation measures that also discriminate may help establish order but may not be desirable because of their adverse social impacts.

5.4 Coding and transmission

A behavior repository is like a bag of tools for use of the appropriate one in a given situation. If a situation needing joint work arises the willing participants should find the applicable and mutually compatible behaviors as quickly as possible. This is easily achieved if the domain from which the participants arrive contains facilitating arrangements for individuals to develop suitable behavior repositories a priori. Human societies have developed many systems for teaching knowledge and skills, desired moral and cultural attitudes, as well as close group affinity and discrimination. Sociologists and social psychologists name the transmission process *socialization*. Role theory of sociology suggests that role learning occurs in many different steps starting from one's childhood, ultimately making a person aware of the appropriate behavior and behaviors expected of other participants of interactions in different situations (Turner 2001). In his model based study Tabellini (2008) shows that individual decisions to cooperate are influenced by values transmitted from earlier generations. Indeed, 'culture' refers to the process of transmission from one generation to the next, via teaching and imitation, of knowledge values and other factors that influence behavior (Boyd and Richerson 1985).

Nature transmits biological traits from generation to generation by writing them as genetic codes. Human societies also developed cultural codes and social processes for transmissions of behavioral characteristics. Richerson and Boyd (2005) described this as dual transmission. Culture evolves more rapidly than genes, which explains why humans are quick to adapt. Culture also creates distinct environments that expose genes to new selective pressures. Many human genes that have been shown to be under recent or current selection are changing as a result of new environments created by cultural innovations. Some recent studies (e.g. Adolphs 2002; Delgado et. al. 2005; Kosfeld et. al. 2005; Cesarini et. al. 2008) suggest that some human genes are changing because of such pressure.

6. Coevolution and revolution

Guiding behavior is a function of institutions. Numerous node-specific behaviors of existing institutions act as role models to learn from. Behavioral norms identify acts that people must do and must not do, leaving only a few that people are allowed to do. These are internalized through socialization processes and programs, secured by selection, exclusion, moral ordering, and enforced by various means when needed. In a resilient system contrarian behavior is resented, unorthodox action is looked with suspicion. Long-standing stable societies tend to be conservative, custom bound, uninquisitive, all for the purpose of maintaining the state of order. It has its cost.

Creative works and innovations are contrarian behaviors to the existing system of cooperative activities. But they are essential. Even at the mature stage of a societal domain perturbations occur regularly disturbing the order and trust. They motivate people to design viable technology, activity, and facilitation methods by improvement of the existing ones. These are what North termed incremental change (North 1990). These are easily accommodated within the existing institutions as allied activities. But there are more profound changes. External factors like environmental change and population growth are not temporary. Cultural domination may be prolonged. Perturbations caused by the Subprime crisis or COVID-19 virus are not nominal. They may endanger existing institutions supporting social and economic opportunities in place. While promoting moral codes, ethical behavior, and altruism facilitating institutions also whip up sectarian affinity, varieties of prejudice, manipulation and parochialism. Contrarianism may be expressed as criticisms of exclusion, as environmental concern, as demand for parity at the workplace, or as opting to work from home. Our analysis suggests that certain old ways start disappearing when a

sufficiently large number of people, with their subjective concerns, perceive an upcoming alternative as more desirable. Thus, far from being a story of modest dynamism, of just perturbations and recuperations, institutions mutate, evolve, prosper and wane after reaching self-organizing states.

The process of change is better understood as coevolution of productive activities and institutions. It accompanies coevolution of many other associated phenomena like facilitation mechanism, individual behavior, technology, repertoire for learning and communications, and environmental system through their impacts. Contrarianism endangers existing society but is also essential for long term survival and development of it. Societies that remain indifferent to increasing disorder as well as those others who ruthlessly suppress all kinds of unorthodox behavior are doomed in the long run. They need to strike the right balance in supporting both conservative and contrarian activities.

7. Conclusion

Information is discussed in economics mainly under two sets of topics. One is asymmetric information. The other topic is game theory; players choose their strategies depending on information they have. In this article we introduce a third sphere – generation of information from human interactions, as norms, customs, institutions and other behavior structures. We show that in the process of evolutionary selection information-rich populations are the ones fit to survive. Our cultures include large stocks of behavior structures coevolved with successful cooperation. Being embedded in such a cultural milieu games of human interactions are often played between trusted players. That makes it simple for humans to establish cooperation in varieties of situations. This is how we far outshine our non-human neighbors in the natural world.

We show this using a model built up from elementary levels, and after discarding many unrealistic assumptions of economics. Indeed, this methodological improvement was the pre-requisite for our study. The purpose of these assumptions was to make complex reality amenable to simple mathematics by eliminating uncertainties and indeterminacy. But then, there was little left in these orderly constructs for studying information generation. We show that the process of evolutionary selection establishes order in real situations, no scholarly assistance is needed. Refraining from equilibria search also pays rich dividend. In disequilibrium models violations of order occur, almost always. This too is a correct description of reality. Property rights for example, are violated needing dispute settlement mechanism. But mediation and enforcement of penal provisions are viable only as long as there are just a few disputes; most other aspirants of the property cooperate with the existing right holders. The disequilibrium model makes atypical behaviors endogenous indicating that those must remain within some tolerance limits. It has an important implication. Innovations and creative works are included among the atypical behaviors. The model not only internalizes those in stable economic systems but also favors systematic support for creative and innovative activities. Innovative and creative behaviors are welcome to the extent that those do not erode system resilience.

Appendix A : Complete and partial cooperation

Let s_1 in expression (1) be a behavior profile supporting the interaction. To account for supportive partial cooperation we also consider four behavior profiles s_a, s_c, s_g, s_h with one or more persons missing at particular nodes. These five behavior profiles therefore, describe a behavior structure \tilde{A} and its sub-structures supporting the interaction and generating payoffs from the new opportunity. Each partial cooperation profile includes one or more free riders, who receive payoffs but allocate their scarce possession in some other acts, not for the new opportunity. Let individual i be one such free rider in profiles s_g and s_h . In the other two cases of partial cooperation s_a and s_c someone else free rides; i allocates his scarce possession for participating in the new opportunity.

Individual i gets reservation utility β_i for which he uses E_i of his scarce possessions. This includes payoffs from profiles s_g and s_h . By allocating E_i for participating in the new opportunity he sacrifices β_i but would actually get gross utility $B_{i,1}, B_{i,a}, B_{i,c}$ when the interaction succeeds, i.e. when s_1, s_a , or s_c happens. But he would suffer net loss β_i if the interaction fails. Hence the transformation $S_{-i} \rightarrow U_{it}$ results into a random variable of net utility: $(B_{i,1} - \beta_i), (-\beta_i), \dots (B_{i,a} - \beta_i), \dots (B_{i,c} - \beta_i), \dots (-\beta_i)$ with probabilities $p'_1, p'_2, \dots p'_a, \dots p'_c, \dots p'_y$. Its mean is given by:

$$\begin{aligned}
 & p'_1(B_{i,1} - \beta_i), p'_2(-\beta_i), \dots p'_a(B_{i,a} - \beta_i), \dots p'_c(B_{i,c} - \beta_i), \dots p'_a(-\beta_i) \\
 & = p'_1 B_{i,1} + p'_a B_{i,a} + p'_c B_{i,c} - \beta_i, \quad \text{since } \sum_1^y p'_j = 1 \quad (\text{A.1}) \\
 & = \delta \text{ (say).}
 \end{aligned}$$

Similarly we may find the variance of U_{it} . Let this be σ .

Let us write p^* for the probability of the composite event:

$$p^* = (p'_{1} + p'_{a} + p'_{c}) \quad (\text{A.2})$$

Let b_i be the gross utility i receives by participating with $\tilde{\Delta}$ consistent behavior. This is a weighted sum of receipts from complete and partial cooperation:

$$b_i = \frac{p'_{1}}{p^*} \cdot B_{i,1} + \frac{p'_{a}}{p^*} \cdot B_{i,a} + \frac{p'_{c}}{p^*} \cdot B_{i,c}$$

Then the mean, given by (A.1), reduces to $p^* b_i - \beta_i$, that is

$$\delta = p^* b_i - \beta_i \quad (\text{A.3})$$

Appendix B : Threshold points and bifurcation band

We can get some idea about the numerical values of threshold levels of interactions in general. In Sections 3 we defined thresholds in terms of the proportion of people (ρ) in domain Ω using consistent behavior. But ρ needs redefining when the selection process is more complex. Here we consider one with a facilitation mechanism like inclusion and exclusion (Section 5.3). We use an example where the n number of people required for the new opportunity are selected from m categories of people with characteristics: $\theta_1, \theta_2, \dots, \theta_m$. We will use $(\rho|\theta_x)_j$ to denote the probability of people belonging to the category with characteristic θ_x using behavior $j = 1, 2, 3, \dots$. The behavior set of a category of people has to include all the behavior repositories of the group members. Being a probability distribution

$$\sum_j (\rho|\theta_x)_j = 1 \quad (\text{B.2})$$

Let the participants be selected randomly by picking up n_1, n_2, \dots, n_m persons respectively from m categories of people with characteristics: $\theta_1, \theta_2, \dots, \theta_m$. We assume that there is no unmanned node. Hence $n = n_1 + n_2 + \dots + n_m$. Inclusion and exclusion facilitates but does not guarantee obtaining $\tilde{\Delta}$ consistent behavior from a person so selected. One may still use any of the $j = 1, 2, 3, \dots$ behavior. All that we can say is that he will use a particular one, say j^* with probability $(\rho|\theta_1)_{j^*}$. When such people are selected for as many as n_1 nodes of the interaction the joint probability that all of them will be showing behavior j^* is given by $[(\rho|\theta_1)_{j^*}]^{n_1}$. Similar arguments apply for the other nodes of the interaction. Let us denote the $\tilde{\Delta}$ compatible behaviors as $j(s_1)$, giving rise to behavior profile s_1 in equation (1). Under category based selection probability of occurring s_1 is given by

$$[(\rho|\theta_1)_{j(s_1)}]^{n_1} \times [(\rho|\theta_2)_{j(s_1)}]^{n_2} \times \dots \times [(\rho|\theta_m)_{j(s_1)}]^{n_m} = \hat{\rho}^n \quad (\text{B.3})$$

where $\hat{\rho}$ is the geometric mean.

Interaction succeeds also in some cases of partial cooperation, where one or a few more persons do not use $\tilde{\Delta}$ compatible behavior, $j(s_1)$. As an example, let a person from the category corresponding to θ_k be engaged at a particular node where he may behave also in some other ways $j(s_o)$ without affecting the success of the interaction. Hence the probability that his behavior helps in the success of the interaction is $(\rho|\theta_k)_{j(s_1)} + (\rho|\theta_k)_{j(s_o)}$ about which we only know that by equation (B.2)

$$(\rho|\theta_k)_{j(s_1)} \leq [(\rho|\theta_k)_{j(s_1)} + (\rho|\theta_k)_{j(s_o)}] \leq 1 \quad (\text{B.4})$$

By substituting (B.4) for the corresponding term in equation (B.3) we get the joint probability of success of the interaction from both complete and partial cooperation included in the range $[\hat{\rho}^n, \hat{\rho}^{n-1}]$. In this way we can show the joint probability of success of the interaction is included in the closed interval $[\hat{\rho}^n, \hat{\rho}^{n-\alpha}]$ if partial cooperation attaining success permits as many as α persons abstaining from the use of $\tilde{\Delta}$ consistent behavior.

Let our decision maker $i \in \theta_1$. The best that we can say about $F(\rho)$ of equation (6) is:

$$\hat{\rho}^{n-1} \leq F(\rho) \leq \hat{\rho}^{n-\alpha} \quad (\text{B.5})$$

By inputting this range in inequality (7a), which leads to equations (8a) and (8b) we can get some idea of the threshold point. As a ready reckoner we include here Table I showing the values of the three parameters for the solution of the equation:

$$\rho^\lambda = \frac{\beta}{b} \quad (\text{B.6})$$

Knowing the interaction size n and the PDI $= \frac{b_i}{\beta_i}$, the desirability of the new opportunity to a decision maker i we get an idea of the range that includes the threshold point for him. Proceeding in this way we get certain ranges for the individual thresholds, which may be used to obtain the bifurcation band for the interaction.

As an example: let us consider a new opportunity that requires interaction of 8 persons but succeeds even if 3 of them free rides. Now let us consider a decision maker i who feels that the PDI of the new opportunity is 1.5. Then the threshold point for him in terms of $\hat{\rho}$ is somewhere between 0.922 and 0.944. If all participants of the interaction assess the PDI of the opportunity as between 1.2 and 2 then all the threshold points lie somewhere between 0.871 and 0.974. There is no exact margin above which cooperation grows. This leads us to define the bifurcation band as the interval that includes most of the threshold points. We use a

fuzzy set approach to formalize the term ‘most’. Accordingly, the band membership values of each of these points lie between 0 and 1, instead of being either 0 or 1.

Table 1 Values of ρ for solution of $\rho^\lambda = \frac{\beta}{b} = \frac{1}{PDI}$

<i>PDI</i>	λ				
	<i>1</i>	<i>2</i>	<i>5</i>	<i>20</i>	<i>100</i>
<i>1.05</i>	0.952	0.976	0.990	0.998	1.000
<i>1.2</i>	0.833	0.913	0.964	0.991	0.998
<i>1.5</i>	0.667	0.816	0.922	0.980	0.996
<i>2</i>	0.500	0.707	0.871	0.966	0.993
<i>5</i>	0.200	0.447	0.725	0.923	0.984
<i>10</i>	0.100	0.316	0.631	0.891	0.977
<i>50</i>	0.020	0.141	0.457	0.822	0.962

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