Co-evolution of norms and cooperation

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Abstrac

Cooperation is profitable from an evolutionary point of view as long as individuals have the right combination of cognitive and emotional faculties that enable them to extract the beliefs and values that are hidden on the behavior of other individuals.

The ability of imitating intentions and not only actions has informational and regulatory reasons in social life that can generate cooperative equilibriums.

Using simulation models it is possible to study how the process of institutional evolution affects the evolution of cooperation in a group of agents involved in a social dilemma situation.

ADICO grammar proposed by Elinor Ostrom (2005) allows us to accurately classify and study the process of institutional evolution between different types of institutional statements.

In this paper we use a cellular automata as an idealized version of a complex adaptive system and discuss how a shared strategy (AIC) can evolve to become a norm (ADIC) and what is the impact of this process on the evolution of cooperation in the system.

It can be shown that this process of institutional evolution can promote a great diversity of norms from a single shared strategy.

It is observed that the process of co-evolution of norms and cooperation produces better outcomes for populations of individuals who develop internal and external delta values compared to cases where no institutional evolution is achieved.

Keywords: Institutional Evolution, Co-evolution, Shared Strategies, Norms, Cooperation, Cellular Automata, Agent-Based Model.

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Introduction

As a part of her interest in problems that require cooperative solutions, Elinor Ostrom[3] studied extensively the most important contributions of Agent Based Models to collective choice theory and Common Pool Resources management (CPR). The most relevant contributions according to Ostrom cover the following five topics:

The development of cooperative strategies in repeated Prisoner's Dilemma games.

One of the classic studies that led to the use of Agent Based Models is attributed to Robert Axelrod (1984). The agents were strategies represented by computer algorithms engaged in a virtual tournament of Prisoner's Dilemma game between pairs of players. In the original tournament and another subsequently organized the winning strategy was also the simplest Tit For Tat. After it was shown that Tit For Tat was not the best possible strategy in repeated and finite Prisoner's Dilemma games.

At a later stage, Axelrod used Genetic Algorithms to simulate the evolution of strategies in repeated Prisoner's Dilemma games (Axelrod, 1997; Mitchel, 1998). The strategies adopted by Axelrod have some of the characteristics of Tit For Tat as never defect first, correspond to cooperation, punish desertion and be forgiving.

Over more than three decades Ostrom has found evidence that the Prisoner's Dilemma game has been used in a variety of social situations that include exploitation of a Common Pool Resource (Dasgupta and Heal, 1979; Ridley, 1998; D. Richards, 2001), it is for this reason that the search for strategies in repeated Prisoner's Dilemma game remains as a relevant problem to solve.

The influence of spatial patterns in interactions of collective action.

A simple model developed by Martin Nowak and Robert May (1992) shows the importance of spatial distribution[4] of agents playing an iterated Prisoner's Dilemma game with their neighbors (Nowak and Highfield, 2012, Alexander, 2007). It has been shown that in this type of spatial games the way agents update their states is also crucial in the evolution of the system (Nowak, Bonhoeffer and May 1994; Huberman and Glance, 1993).

Other studies show that the network structures different from the regular structures such as Cellular Automata, can promote cooperation under certain conditions (Ohtsuki et al, 2006; Santos and Pacheco, 2005).

[3] Elinor Ostrom was awarded whit the Nobel Prize in Economics in 2009.
[4] Nowak and May used a two-dimensional Cellular Automata, where each agent interacts with its neighbors in a Moore neighborhood.

In public goods games that take into account the spatial structure has been observed that when agents can voluntarily leave the game can coexist cooperators, defectors and non-participants (Brandt, Hauert and Sigmund, 2003; Hauert et al, 2002) and that the geometry of the interactions has consequences in the observed level of cooperation (Hauert and Szabo, 2003).

Another set of studies is based on the possibility of group selection (Janssen and Goldstone, 2006; Boyd et al, 2003; D. Wilson, 1983; M. Wade, 1977 and 1978; Wright, 1945) and in demographic mobility (Killingback, Bieri and Flatt, 2006; Wright, 1945) as determinants of altruistic behavior.

The effect of indirect reciprocity in the evolution of cooperative strategies.

Tipping models derived from the work of Schelling (1960 and 1978) predict levels of cooperative behavior between agents that have no prior interaction history. The explanation of indirect reciprocity studies coincide with these models (Poteete, Janssen and Ostrom, 2012).

In other models is demonstrated that the use of tags or labels (Holland, 2004) and the ability to detect and use that information produces high levels of cooperation (Janssen, 2008, Hales, 2001; Riolo, Cohen and Axelrod, 2001, Nowak and Sigmund, 1998; Lindgren and Nordahl, 1994; Frank, 1987).

There are also studies on the use of reputation to decide to cooperate or select someone to interact with (Schluessler, 1989; Ashlock et al, 1996; Stanley, Ashlock and Tesfatsion, 1994 and Congelton Vanberg, 1992).

Another series of studies show that when agents have preferences that take into account others, cooperation can be promoted in the population (Janssen, 2008; Bester and Güth, 1998; Ahn, Janssen and Ostrom, 2004).

The conditions that favor the evolution of costly punishment.

Many experimental studies have suggested that costly punishment is an important factor for the evolution of cooperation (Fehr and Gächter, 2002; Ostrom, Walker and Gardner, 1992).

The Game Theory provides an explanation for some cases of possible equilibriums and the required conditions when there is some sort of punishment (Ostrom, 2005; Boyd and Richerson, 1992; Hirshleifer and Rasmusen, 1989; Fundenberg and Maskin, 1986).

The extension of these explanations using Agent Based Models can include cultural processes for group selection (Boyd et al, 2003) and show that high levels of cooperation in small groups can be achieved if punishment is allowed (Hauert et al, 2007; Boyd et al, 2003).

The evolution of social norms and metanorms.

Axelrod (1986) studied under what conditions could persist the norms that support the cooperation strategies in a population. The game proposed by Axelrod assumed the existence of punishment norms and metanorms that supported cooperative norms[5]. Axelrod's theory has proved to be consistent with field evidence.

Based on the ideas of Axelrod evolutionary models have been developed to explore the feasibility of a shared common strategy that cooperates in the process of acquiring resources and imposes sanctions on non-participants (Kameda, Takezawa and Hastle, 2003).

Many problems of collective action and CPR management have been dealt using formal methods such as Game Theory and Agent Based Models. Most of the work describes the effect of a specific institutional structure in the evolution of cooperation, however in most cases there is no explanation of how such institutional structure emerges. For this reason there is a great interest in understanding the processes of evolution of formal rules for the solution of complex dilemmas (Poteete, Janssen and Ostrom, 2012).

Janssen (2005b) proposed a framework to model the evolution of institutional rules from libraries of each of the components of the Ostrom's ADICO grammar (Poteete, Janssen and Ostrom, 2012). The construction of rules is done by selecting a component of each library and combining them to create an institutional rule that includes the five components. The rules thus constructed can be used to tackle some problems of collective action.

Subsequently Janssen and Ostrom (2006a) reported some attempts of modeling in which a group of agents equipped with a set of rules could agree to accept a rule that decreased their individual short-term returns but increased their long-term returns, however they claim that the next step is the study of the evolution of the institutional rules (Poteete, Janssen and Ostrom, 2012).

Traditionally the institutional analysis has focused on rules for two reasons:

[5] In the game proposed by Axelrod there isn't an explanation of how norms and metanorms evolve, but its effect on the strategies of cooperation.

1. It is often necessary to analyze the impact of a change in the rules, whether the change is being proposed or has actually occurred.
2. Institutional analysts recognize that “changes in the rules may be easier or more stable than attempts to change the situation through changes in the biophysical world or attributes of the community." (Ostrom, 2005:138)

While it is true that the use of rules can be justified to discourage certain behaviors in individuals which may be harmful to others, we must bear in mind that the use of rules can present a major drawback to the level of overall system performance, due to the fact that resources are consumed in the monitoring and sanctioning determined by the rule. For this reason, although it is more complex it is always more desirable than the individuals who are immersed in a social dilemma develop and internalize norms and that the rules would have a secondary role within the institutional structure to modify the behavior of individuals.

The problem of the institutional evolution not only refers to the creation and classification of shared strategies, norms and rules and the study of their evolutionary processes as separate sets, but it must also address the processes by which an institutional type of statement can be transformed into another type, and the consequences resulting from this process.

In this paper we will focus on this latter aspect of the institutional evolution that in our view is essential to explain the evolution of cooperation in a population engaged in a social dilemma situation.

We will use a Cellular Automata as an idealized version of a Complex System and using the Ostrom’s ADICO grammar (2005) we will study the way in which a shared strategy (AIC) in a population can evolve into a norm (ADIC) and what is the impact of this process of institutional evolution in the evolution of cooperation.

Cellular Automata

An important feature in most of decision problems that occur in social contexts is that they occur repeatedly (Alexander, 2007). A useful approach for studying this feature of recurrence is the evolutionary game theory to analyze models of repeated games with agents of limited rationality. Evolutionary models specify the laws that cause dynamic changes in the population and provide at all times a representation of the states of the population.

To represent the population we can use a model of continuous type or one of discrete type. In a continuous type model, such as the replicator dynamics for example, all the peculiarities and differences between individuals are lost when using aggregate data or aggregate statistics that represent some state of the population. Therefore, the aggregative models "cannot represent the structure of society and social interactions" (Alexander, 2007: 26).

Discrete models also called Agent Based Models maintain the identity of each individual in the population. The identity of each individual can include information about its location and role in the population and other relevant additional properties.

The inclusion of spatial structure in the models of the evolutionary game theory makes a real difference in the long-term behavior of the models (Alexander, 2007; Nowak and Highfield, 2012). "Incorporating structure into agent-based models enable us to model situations whose long-term convergence behavior more closely approximates the behavior found in real human populations" (Alexander, 2007:27).

A Cellular Automata is a rectangular array of interrelated agents with the neighbors around them as shown in **Table 1**.

$A_{1,1}$	$A_{1,2}$		...	...	...	...	...	...		$A_{1,N}$
$A_{2,1}$	$A_{2,2}$		...	...	...	...	...	...		$A_{2,N}$
					V_1					
				V_4	A	V_2				
					V_3					
$A_{N,1}$	$A_{N,2}$		...	...	...	...	...	...		$A_{N,N}$

Table 1: Agent "*A*" in a Von Neumann neighborhood

A Cellular Automata is a particular type of Agent Based Model. The importance of the Cellular Automata is that it can be used as an idealized version of a complex system in which the spatial structure plays an important role[6].

[6] Irrigation systems, forestry, agricultural, etc. are heavily dependent on one fixed spatial structure where agents can eventually move from one place to another (Ostrom, 1990). The spatial position within the

For each agent in this two dimensional array has its corresponding 4 neighbors a simple solution is used. The top line is pasted with the bottom line forming a cylinder, and then the two ends of the cylinder are pasted forming a Toroid as shown in **Figure 1**.

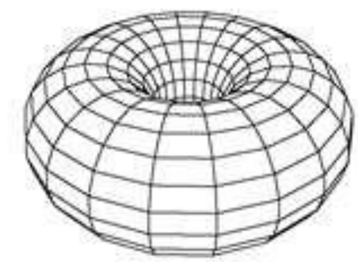

Figure 1: Toroid.

In this way an agent such as $A_{1,1}$ has as neighbors to $A_{N,1}$ (above), $A_{2,1}$ (below) , $A_{1,N}$ (left) and $A_{1,2}$ (right).

To generate the evolution of the system, the Cellular Automata will update its states through a deterministic decision rule followed by each of the agents that are part of the Cellular Automata (Miller and Page, 2007). Each agent choose its state for the next period on the basis of their current state and the current state of its neighbors, in this way the evolution of the Cellular Automata is based on the decisions in each time period of each of the agents that are part of the Cellular Automata.

Depending on the specific context, agents can use any of the possible updating rules that can be defined. Alexander (2007) mentions 4 types of rules: three based on imitation and one based on a version of better adapted response to rational individuals. These rules can be described as follows:

1. Imitate the best neighbor. In each generation each agent reviews the payoff obtained by all their neighbors and adopts the strategy of the neighbor who gets the highest payoff. The agent will not change its strategy if there is no incentive to do so, that is to say, if its payoff is equal to or greater than that of its neighbors. In case of a tie if two or more neighbors get the higher payoff is necessary to define a tiebreaker rule, in such a way that the agent copy the strategy of only one of its neighbors.
2. Imitate with probability proportional to success. Each agent compares its payoff with the payoff of its neighbors and copy the strategy of that obtaining

system can take on greater importance if the resource flows in a certain direction, as in the channels of an irrigation system.

the highest payoff. If other neighbors were obtained a payoff better than the agent but not the maximum, the agent copies this strategy with a probability proportional to its relative success.

3. Imitate the best average payoff. Each agent calculates the average payoff of each strategy in their neighborhood and copy the one whit the highest payoff. The agents evaluate the situation based on the group's performance using a particular strategy.
4. Best response. The agents take the strategy that will give them the highest possible payoff in the next generation, under the assumption that none of its neighbors will change their strategy for the next generation.

In the model of Nowak and May (Alexander, 2007) is assumed that in each time period, each agent interacts with each of its 4 neighbors in a Prisoner's Dilemma game.

The total payoff T_{ij} for an agent is the sum of the payoffs obtained when interacting whit each of its neighbors through a Prisoner's Dilemma game. The dynamics of the model comes from a simple imitation rule, the rule of imitating the best neighbor. At the start of the game, at $t=0$, each agent chooses an action (C or D) and for the next period, $t=1$, the agent updates its state through this Imitation Rule (IR). This process is performed again and again generating the temporal evolution of the Cellular Automata.

To measure the overall performance of the system, we can think of the total gain of the system in each time period as the sum of the total payoffs of the agents that are part of the system, i.e.

$$GT = \sum_{i,j} T_{ij} \qquad (1)$$

ADICO Institutional Grammar

The syntax of the institutional grammar proposed by Ostrom (2005) includes five components from which it can be built any institutional statement.

The ATTRIBUTE [A] is a variable that establishes the set of participants affected by a particular statement.

The DEONTIC [D] indicates a prescription to actions and results through operational phrases "may" (Allowed), "most" (Obliged) or "most not" (Forbidden). The introduction of a deontic component into an institutional statement is made formally through the inclusion of delta parameters in the payoff matrix of the game being analyzed. "The existence of a deontic component implies the presence of additional information that individuals uses in developing their expectations about others' behavior and thus their own best responses" (Ostrom, 2005:147).

Delta parameters are defined as follows:

$$\delta^o = \delta^{oi} + \delta^{oe}$$
$$\delta^b = \delta^{bi} + \delta^{be}$$
$$\Delta = \delta^o + \delta^b$$

and represent the reward and the perceived cost of obeying (δ^o) and breaking (δ^b) a prescription; the superscript *i* denotes a change in the expected payoffs originating from internal sources[7] and *e* denotes a change in the expected payoffs originating from external sources[8].

The AIM [I] is a description of a working part in an action situation to which the institutional statement refers. "The description can include information about a process or a formula" (Ostrom, 2005:148).

CONDITIONS [C] "indicate the set of variables that define when and where an institutional statement applies" (Ostrom, 2005:149).

The OR ELSE [O] "is the consequence that an institutional statement assigns to detect noncompliance whit the others components of that statement. In some cases the OR ELSE specifies a range of possible punishments if a rule is not followed" (Ostrom, 2005:149).

The concept of "institutional statement" (Ostrom, 2005) comprises three types of statements that can be described on the basis of the components of the Ostrom's ADICO grammar as follows:

1. Shared Strategies. A shared strategy is a type of institutional statement that contain three components : [A][I][C]
   For example:

   [A_1 *and* A_2][Cooperate][Always]

2. Norms. A norm is an institutional statement that contain four components: [A][D][I][C]

---

[7] Internal sources include, for example, guilt or shame by breaking a prescription or the feeling of self-satisfaction by obeying a prescription.
[8] External sources are primarily associated with social approval or disapproval and reputation.

For example:
[A_1 *and* A_2][Most][Cooperate][Always]

"One might think of norms as heuristics that individuals adopt from a moral perspective in that these are the kinds of actions they wish to follow in living their lives. Once some members of the population acquire norms of behavior, the presence of these norms affect the expectations of other players. Moreover, once norms are generally shared in a population, expectations can converge to focal points" (Ostrom and Walker, 2003: 41).

3. Rules. A rule is an institutional statement that contain the five components: [A][D][I][C][O]
   For example:
   [A_1 *and* A_2][Most][Cooperate][Always][OR ELSE they will be punished with a fine F]

The deontic component [D] is introduced in the form of δ^o and δ^b parameters in the payoff matrix perceived by the agent, while the component [O] is introduced in the form of a fine F on objective payoff [9].

In terms of Ostrom's ADICO grammar the imitation rule[10] (IR) has the structure of a shared strategy [A][I][C] that can be described as follows:

Shared Strategy (IR)

[Each Agent][Cooperate][The Agent or any of its neighbors cooperates and gets the maximum payoff in the previous round]

[Each Agent][Defect][The Agent or any of its neighbors defect and gets the maximum payoff in the previous round]

It is easy to see that the structure [A][I][C] of a shared strategy can be written in the form [A][D = 0][I][C]. The shared strategy will become a norm when there is some mechanism that allows the evolution of the (internal or external) delta parameters and therefore agents adopt the structure [A][D ≠ 0][I][C], i.e. :

[9] In Ostrom's institutional grammar delta parameters and sanctions are added to objective payoffs in additive form, i.e., $T-\delta^b-F$. This creates a major problem to define the units being compared with payoffs in the resulting payoff matrix because the delta parameters are subjective assessments that should be added to objective payoffs. However, if the information is weighted using the delta parameters it is possible to avoid ambiguity in the definition of the units in the form $T\delta^b-F$. In this way the parameter δ^b serves as a dimensionless unit of scale for objective payoff T.

[10] In general, update rules on a Cellular Automata are not rules in terms of Ostrom's ADICO grammar, but are Shared Strategies.

$$[A][D_{(t=0)} = 0][I][C] \xrightarrow{t} [A][D_{(t>0)} \neq 0][I][C]$$

We can think that the evolution of institutional statements can be given in the form shown in **Figure 2**.

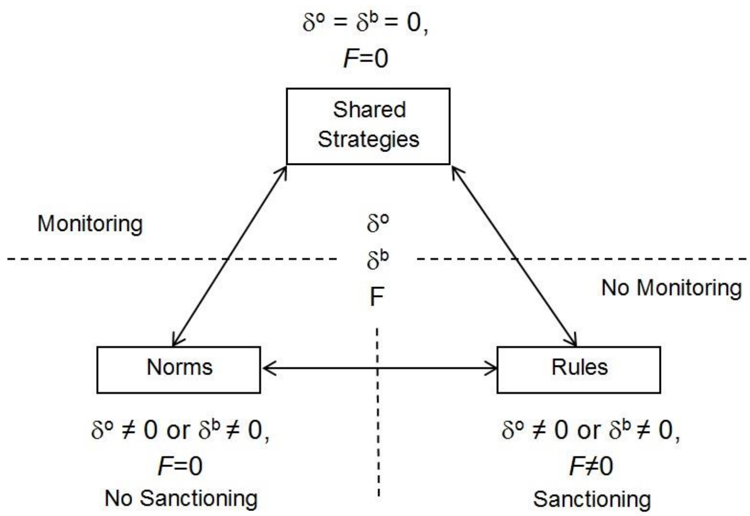

Figure 2: Evolution of Institutional Statements.

How can we explain this process of institutional evolution?

Moralization and amoralization processes can help us to do.

A major problem occurs when individuals have to decide between a mindset that judges behavior from the perspective of preferences and a mindset that judges behavior from the perspective of value (Pinker, 2012).

Both preferences and values are linked to affective systems. However, the values (or their violations) are of particular interest because they tend to invoke strong moral emotions such as anger, contempt, disgust, guilt and shame (Rozin, Markwith and Stoess, 1997).

Moralization is a rather common process through which objects or activities that were previously morally neutral, acquire a moral component (Rozin, Markwith and Stoess, 1997). Moralization process is reversible and is called amoralization; in this case, something in the moral domain can gradually cease to be so, and become a simple preference (Rozin, 1999).

Moralization usually transforms the preference of an object or morally neutral activity (N) into something with negative moral status (negative moralization: M-). On the other hand, the positive moralization (M +) transforms the preference for an object or morally neutral activity into something considered morally virtuous (Rozin, 1999).

Similarly we can consider the existence of two types of amoralization, converting an object or activity with positive moral status to neutral or from negative moral status to neutral (Rozin, 1999). These processes are shown in **Figure 3**.

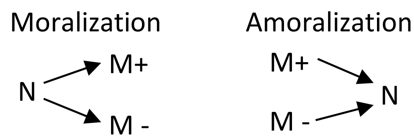

Figure 3. Moralization and Amoralization Processes.

The process of moralization that transforms preferences into values is important because when an entity acquires moral status (usually negative), the process occurs and has effects on two levels: the individual level (psychological) and the historico-cultural level (collective) (Rozin, 1999)[11].

At individual level, moralization occurs by two mechanisms operating one or both at once: the moral expansion and the moral piggybaking (Rozin, 1999).

In the moral expansion a new experience (affective route) or knowledge (cognitive route) can cause a person to adopt a new moral principle. In the moral piggybacking new experiences or knowledge can cause a previously neutral activity falls under an already functioning moral principle.

The moralization creates significant differences in the behavior of individuals because values are more durable than preferences; are more strongly internalized and therefore are more specific to the individual; are often subject to legal and institutional support; transmission of values is more likely and robust in the family environment via socialization-internalization. Besides, the moral justifications are stronger than those based only on preferences (Rozin, Markwith and Stoess, 1997; Rozin, 1999).

At historico-cultural level, moralization happens quite frequently at the level of groups or societies. Many religious groups, for example, have promoted moralization processes throughout history. In addition, virtually within any moral system, cause unjustified harm to others is considered a moral violation.

[11] Individual level is related to the internal deltas while the historico-cultural level is related to external deltas in Ostrom´s ADICO grammar.

One factor that seems to favor the success of moralization is the formation or association of groups related to the activity in question. In addition, factors of socio-historical context can lead to vulnerable or chaos periods, which encourage self-control and thus moralization. Finally, moralization can be facilitated if the activity in question has the potential to increase the reasons to support the prohibition (Rozin, 1999).

Moralization may be a gradual process driven by a minority of the population. However, the extension of moralization to the entire population may depend on other factors such as the extent of the popularity and prevalence of activity or if the activity is carried out by a dominant group of the population. (Rozin, Markwith and Stoess, 1997).

A typical example of moralization is the conversion of the personal preference of cigarette smoking into a socially immoral activity (Rozin, 1999). As a result of this process of moralization, the prohibition on smoking in public places has become a norm (morally sanctioned) in some cases or a rule (financially sanctioned) in other cases, according to Ostrom´s ADICO grammar.

Based on this example we can see that as a result of a process of moralization, institutional evolution can be promoted to generate norms and rules that did not exist before the process. Furthermore Rozin (1999) mentions other effects of moralization processes including participation of institutions (foundations, schools, etc.) which can provide the assistance necessary to produce the required change in society; at the scientific level, discovery of relationships and processes that confirm the new legal entity is promoted.

Moralization is often related to health issues (such as smoking or eating habits) (Rozin, 1999; Rozin, Markwith and Stoess, 1997). However, in recent times the situations related to logging, mineral extraction, oil extraction, research on AIDS, research on breast cancer, among others, have acquired a moral perspective (Pinker, 2012)[12].

For problems related to a CPR, besides the above-mentioned socio-historical factors we must consider the nature of the CPR as a determinant factor to promote the process of moralization.

The moralization process can be inserted into the study of social dilemmas to explain the processes of institutional evolution as outlined below.

On the one hand the moralization explains the evolution in the cases:

[12] These issues are related to the Common Pool Resources and New Commons management.

$$[A][I][C] \xrightarrow{t} [A][D][I][C]$$

$$[A][I][C] \xrightarrow{t} [A][D][I][C][O]$$

In these cases the mechanism of moralization is the moral expansion. An individual can expand his own institutional repertoire S based on his personal experience of interaction with other individuals (affective route) or by evaluating internal models (lookahead) (cognitive route). The moralization process expands the original set of S = {[A][I][C]} to S '= {[A][I][C], [A][D][I][C]} or to S'' = {[A][I][C], [A][D][I][C][O]}

The amoralization process by other hand can help us explain institutional evolution in the cases:

$$[A][D][I][C] \xrightarrow{t} [A][I][C]$$

$$[A][D][I][C][O] \xrightarrow{t} [A][I][C]$$

In the case of institutional evolution between norms and rules

$$[A][D][I][C] \xleftrightarrow{t} [A][D][I][C][O]$$

the evolution of graduated sanctions observed in many situations of social dilemmas seems to provide the appropriate mechanism of institutional evolution and expansion of the institutional repertoire. The reverse process can be explained when incentives for breaking the rule does not outweigh the potential benefit and individuals come to internalize strong norms to prevent the application of the penalty [O] of the rule. In this case the individual has the rule as part of his own institutional repertoire, but in practice the behavior is based on the norm (moral piggybacking).

This completes the scheme proposed for institutional evolution between different types of institutional statements.

The Model

To observe the impact of the evolution of norms in the evolution of cooperation we depart from specific initial conditions and look at the different paths of evolution of the system.

By initial conditions we refer to the following:

1. We will use the same payoff matrix (objective payoffs) of the Prisoner's Dilemma base game.

		A_2	
		C	D
A_1	C	(16 ; 16)	(4 ; 20)
	D	(20; 4)	(8; 8)

When adding delta parameters agents also evaluate subjective payoffs therefore the payoff matrix is modified as follows

		A_2	
		C	D
A_1	C	$(16 + \delta^{oi} + \delta^{oe}\ ; 16 + \delta^{oi} + \delta^{oe})$	$(4 + \delta^{oi} + \delta^{oe}\ ; 20 + \delta^{bi} + \delta^{be})$
	D	$(20 + \delta^{bi} + \delta^{be}\ ; 4 + \delta^{oi} + \delta^{oe})$	$(8 + \delta^{bi} + \delta^{be}\ ; 8 + \delta^{bi} + \delta^{be})$

2. The same imitation rule (RI) will be used (with or without the corresponding delta parameters).
3. For each series of simulations the same initial configuration of Cellular Automata will be used.

External delta parameters

Because each agent has direct interaction with its neighbors, we assume that there is monitoring and each agent has the social pressure of the 4 neighbors that surround him, generating values for the external delta parameters (δ^{oe} and δ^{be}). The external delta parameters that represent the social pressure may have relatively stable values in a small population at some time interval (Ostrom, 2005) and change more slowly than the internal delta values.

What is the effect of external delta parameters?

External delta parameters modify the structure of the payoffs matrix perceived by agents and can change the structure of the Prisoner's Dilemma base game producing another different game whit a different equilibrium. The external deltas are limited in scope to change the dynamics of the system, because they produce a single game for all the agents in the system that remains unchanged until external deltas change again. The experimental and field evidences show that even under the action of monitoring and social pressure the internal motivations may be stronger for changing the behavior of individuals (Ostrom, 2005).

We start with the simplest model of evolution of cooperation using the rule to imitate the neighbor who gets the best performance (IR)[13]. In this case, the agents evaluate only their objective payoffs and do not consider the weight of social pressure.

We use the initial configuration, at *t=0*, of the Cellular Automata shown in **Table 2**.

D	*D*	*C*	*C*	*D*	*D*	*C*	*C*	*C*	*C*
D	*C*	*D*	*C*	*C*	*D*	*D*	*D*	*D*	*D*
C	*D*	*D*	*D*	*C*	*D*	*C*	*C*	*D*	*C*
C	*D*	*D*	*D*	*D*	*C*	*D*	*D*	*D*	*C*
C	*D*	*D*	*D*	*C*	*D*	*C*	*D*	*C*	*D*
D	*D*	*C*	*C*	*C*	*D*	*C*	*C*	*C*	*C*
D	*C*	*C*	*C*	*C*	*C*	*D*	*C*	*D*	*C*
D	*D*	*C*	*C*	*C*	*C*	*C*	*C*	*D*	*D*
C	*D*	*D*	*D*	*C*	*C*	*C*	*C*	*C*	*D*
D	*C*	*C*	*D*	*C*	*D*	*C*	*D*	*D*	*C*

Table 2: Initial configuration at *t=0*.

To introduce the effect of social pressure due to monitoring we assume that together the four neighbors of an agent have influence in its valuation through the δ^{oe} and δ^{be} parameters (IR + ed = Imitation Rule + external deltas).

Figure 4 shows the results corresponding to the following conditions:

IR + ($\delta^{oe} = 0.0$, $\delta^{be} = -0.0$)

IR + ($\delta^{oe} = 0.5$, $\delta^{be} = -0.5$)

IR + ($\delta^{oe} = 1.0$, $\delta^{be} = -1.0$)

IR + ($\delta^{oe} = 2.0$, $\delta^{be} = -2.0$)

IR + ($\delta^{oe} = 2.5$, $\delta^{be} = -2.5$)

[13] This correspond to the case $\delta^{oe} = 0$ and $\delta^{be} = 0$.

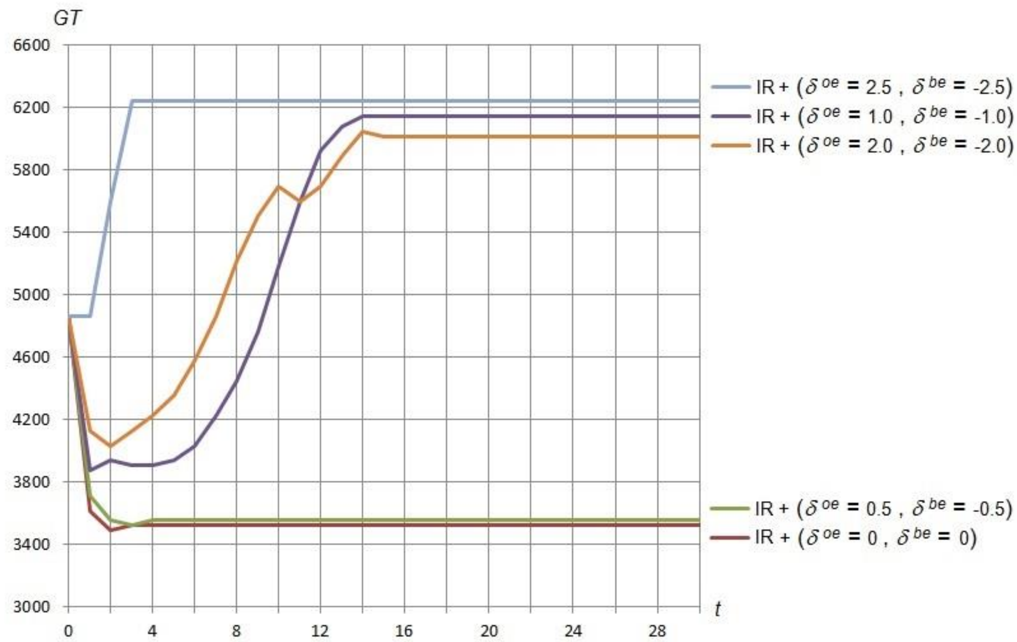

Figure 4: Effect of external delta parameters on evolution of cooperation measured in terms of system performance GT.

The classical Game Theory predicts that in the Prisoner's Dilemma game the dominant strategy and Nash equilibrium is (D, D), however it is noted that with the base game the system does not reaches widespread desertion $ALL\ D$ state. So even if we know the equilibrium of the game, classical Game Theory is not adequate to describe a dynamic model.

In cases ($\delta^{oe} = 0.5$, $\delta^{be} = -0.5$) and ($\delta^{oe} = 1.0$, $\delta^{be} = -1.0$) the structure of the Prisoner's Dilemma game is maintained with a dominant strategy and Nash equilibrium (D, D). However, we see that in the evolution of the system the level of cooperation is increased due to the introduction of these external deltas.

The cases ($\delta^{oe} = 2.0$, $\delta^{be} = -2.0$) and ($\delta^{oe} = 2.5$, $\delta^{be} = -2.5$) do not maintain the structure of the Prisoner's Dilemma game. In the first case the game has no dominant strategy or Nash equilibrium[14]. In the second case the dominant strategy and Nash equilibrium is (C, C), however the system din not reach the widespread cooperation $ALL\ C$ state, so again knowing the Nash equilibrium of the game is not enough to describe the evolution of the system.

[14] The game has no Nash equilibrium in pure strategies, but according to the Game Theory there is a Nash equilibrium in mixed strategies.

Social norms generated by monitoring are not always enough to change the results in a Prisoner's Dilemma game (Ostrom, 2005) and even it may not be socially beneficial due to the cost of generating external delta parameters through monitoring . The alternative to improve the level of cooperation is to generate internal norms that do not generate monitoring costs.

Internal delta parameters

We use δ_t^{oi} and δ_t^{bi} to denote the values of the internal delta parameters at time *t*. We assume that at time *t=0*, each agent starts with internal delta values equal to zero ($\delta_0^{oi} = 0$ y $\delta_0^{bi} = 0$) and in each period modify these values according to the personal history of interaction with their neighbors.

We use the schemes for the evolution of internal delta parameters of the agents listed below:

- Scheme 0

If an agent copies a *C* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi}$ and $\delta_{t+1}^{bi} = \delta_t^{bi}$

If an agent copies a *D* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi}$ and $\delta_{t+1}^{bi} = \delta_t^{bi}$

- Scheme 1

If an agent copies a *C* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} + 1$ and $\delta_{t+1}^{bi} = \delta_t^{bi}$

If an agent copies a *D* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi}$ and $\delta_{t+1}^{bi} = \delta_t^{bi} + 1$

- Scheme 2

If an agent copies a *C* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} + 1$ and $\delta_{t+1}^{bi} = \delta_t^{bi} - 0.5$

If an agent copies a *D* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} - 0.5$ and $\delta_{t+1}^{bi} = \delta_t^{bi} + 1$

- Scheme 3

If an agent a copy a *C* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} + 1$ and $\delta_{t+1}^{bi} = \delta_t^{bi} - 1$

If an agent a copy a *D* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} - 1$ and $\delta_{t+1}^{bi} = \delta_t^{bi} + 1$

- Scheme 4

If an agent a copy a *C* strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} + 1$ and $\delta_{t+1}^{bi} = \delta_t^{bi} - 0.5$

If an agent a copy a D strategy then: $\delta_{t+1}^{oi} = \delta_t^{oi} - 0.25$ and $\delta_{t+1}^{bi} = \delta_t^{bi} + 0.5$

These Schemes show how it is valued and reinforced the behavior of the agents through the corresponding internal delta parameters.

The Scheme 0 corresponds to a rational selfish agent that does not develop internal delta values, its calculations are based strictly on the objective benefit.

In the Scheme 1, for example, when copying a C strategy an agent reinforces the value δ^{oi} increasing its value for the next period and does not change the value δ^{bi}. But if the agent copies a D strategy then reinforces this behavior and increases the value δ^{bi} for the next period and the value δ^{oi} is maintained without change.

Schemes 1-3 represent situations in which the valuations of the choice of a strategy C or D have symmetry with respect to the parameters delta.

Scheme 4 shows a situation in which the delta parameters corresponding to the choice of C or D, are asymmetric. In this scheme, as in the previous cases the strategy reporting the greatest benefit is reinforced, but such reinforcement is greater in the case of the cooperative strategy.

The agents evaluate its performance and that of its neighbors based on both objective payoffs as subjective factors reflected in the delta parameters. As every agent knows the history of actions of their neighbors, we suppose that can infer the type of norms (delta parameters) than their neighbors are developing and can then use this information to construct the corresponding payoff matrix. In this way the values of the internal delta parameters can be used as a measure of the reputation of the agents.

From now on we will consider the effect of social pressure with the fixed parameters $\delta^{oe} = 2.0$ and $\delta^{be} = -2.0$. To introduce the effect of the internal delta parameters to the model the Schemes 1 to 4 will be used (IR + ed + Sch x = Imitation Rule + external delta + Scheme x).

Below are the results of 4 cases of analysis corresponding to four initial configurations of a Cellular Automata of size 10 × 10.

Based on the payoff matrix and the size of Cellular Automata employees, it is expected that the GT value which measures overall system performance varies between 3200 ($ALL\ D$) and 6400 ($ALL\ C$). Any intermediate value corresponds to a configuration in which C and D strategies coexist in the system.

- <u>CASE 1</u>

We will use the initial configuration at $t = 0$ of the Cellular Automata shown in **Table 3**.

D	*D*	*C*	*C*	*D*	*D*	*C*	*C*	*C*	*C*
D	*C*	*D*	*C*	*C*	*D*	*D*	*D*	*D*	*D*
C	*D*	*D*	*D*	*C*	*D*	*C*	*C*	*D*	*C*
C	*D*	*D*	*D*	*D*	*C*	*D*	*D*	*D*	*C*
C	*D*	*D*	*D*	*C*	*D*	*C*	*D*	*C*	*D*
D	*D*	*C*	*C*	*C*	*D*	*C*	*C*	*C*	*C*
D	*C*	*C*	*C*	*C*	*C*	*D*	*C*	*D*	*C*
D	*D*	*C*	*C*	*C*	*C*	*C*	*C*	*D*	*D*
C	*D*	*D*	*D*	*C*	*C*	*C*	*C*	*C*	*D*
D	*C*	*C*	*D*	*C*	*D*	*C*	*D*	*D*	*C*

Table 3: Initial Configuration at $t=0$.

Figure 5 shows the results of the simulations with the different conditions of delta parameters.

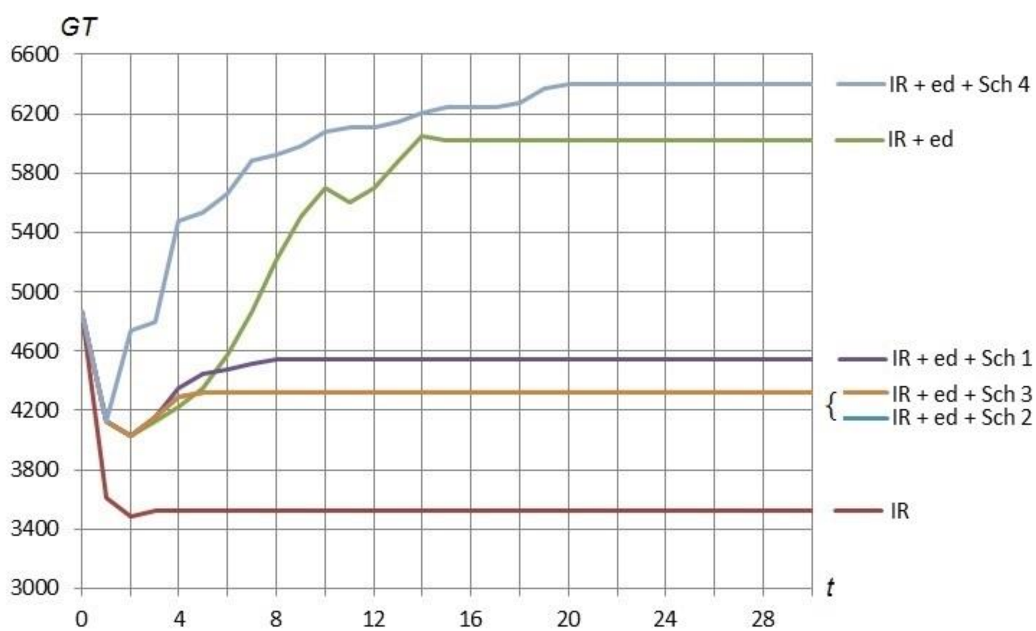

Figure 5: CASE 1. Co-evolution of norms and cooperation, measured in terms of system performance *GT*.

In this case we can see that:

1. By using only the imitation rule (IR), the level of cooperation in the system decays quickly although does not reach the *ALL D* state.
2. By adding external delta parameters (IR + ed), the level of cooperation declines slightly and then begins to increase sharply to a stable and close to *ALL C* state.
3. When adding schemes for evolution of internal delta parameters (IR + ed + Sch x) we note two well defined types of behavior. First, the Schemes 1-3 produce levels of cooperation and *GT* performance similar but lower than the initial state of the system at $t = 0$. Indeed, Schemes 2 and 3 produce identical results at all times. Second, Scheme 4 shows a small decrease, followed by a rapid growth in the level of cooperation reaching the *ALL C* state.
4. In the 6 paths of evolution the system reaches static configurations of Cellular Automata, in terms of *C* or *D* states, although internal delta parameters are modified at all times in accordance with the corresponding Scheme.

- <u>CASE 2</u>

Table 4 shows the initial configuration at $t = 0$, of the Cellular Automata used.

C	*D*	*D*	*C*	*D*	*D*	*C*	*C*	*C*	*C*
D	*C*	*C*	*D*	*D*	*C*	*C*	*D*	*D*	*D*
C	*C*	*D*	*D*	*D*	*C*	*D*	*D*	*D*	*C*
C	*C*	*D*	*D*	*C*	*C*	*C*	*C*	*D*	*C*
C	*C*	*C*	*C*	*D*	*D*	*C*	*D*	*C*	*C*
D	*C*	*D*	*D*	*C*	*C*	*C*	*C*	*C*	*C*
D	*D*	*D*	*C*	*C*	*C*	*C*	*C*	*D*	*C*
C	*D*	*D*	*C*	*D*	*D*	*D*	*D*	*C*	*C*
D	*D*	*C*	*C*	*C*	*C*	*C*	*C*	*D*	*C*
C	*D*	*C*	*D*	*C*	*C*	*D*	*C*	*D*	*D*

Table 4: CASE 2. Initial Configuration at $t=0$.

Figure 6 shows the results of the simulations with the different conditions of delta parameters.

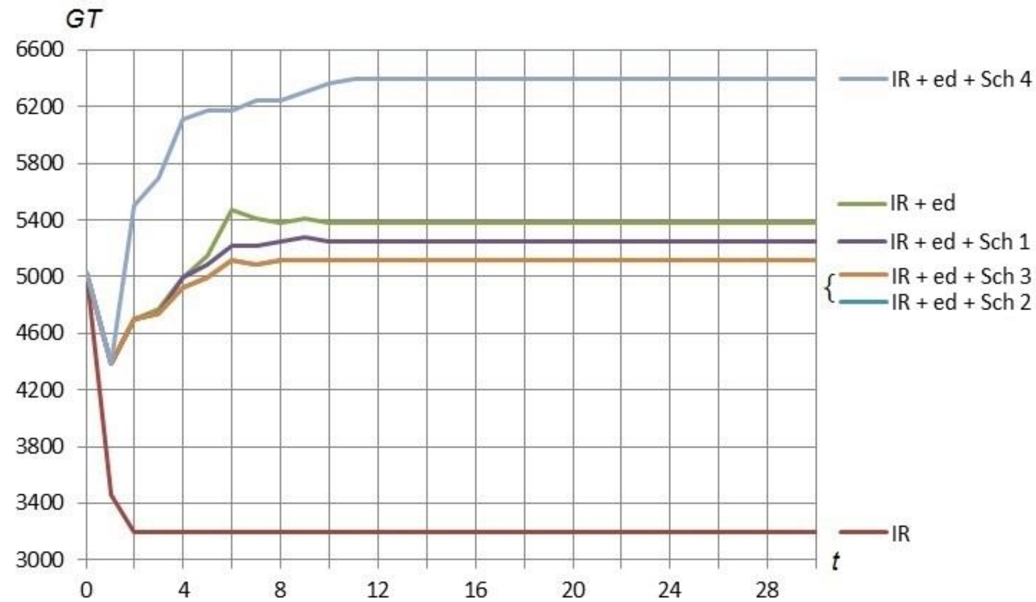

Figure 6: CASE 2. Co-evolution of norms and cooperation, measured in terms of system performance *GT*.

In this case we can see that:

1. The exclusive use of the imitation rule (IR), causes the level of cooperation in the system decays quickly to *ALL D* state from *t=2*.
2. By adding external delta parameters (IR + ed), the level of cooperation declines slightly and then begins to increase to a value slightly higher that *GT* at initial system state.
3. Adding Schemes for evolution of internal delta parameters (IR + ed + Sch x) we note two types of behavior. First, the Schemes 1-3 produce levels of cooperation and *GT* performance similar but slightly higher than the initial state of the system at $t = 0$. Indeed, Schemes 2 and 3 produce identical results at all times. Secondly, Scheme 4 shows a small decrease followed by a rapid increase in the level of cooperation to achieve the *ALL C* state.
4. The trajectory IR + ed + Sch 2 (= IR + ed + Sch 3) which reaches a constant value of *GT* from $t = 8$ does not maintain a static configuration, but oscillates between two alternating configurations of Cellular Automata.
5. In the rest of evolution paths the system reaches static configurations of Cellular Automata in terms of *C* or *D* states for each agent, although internal delta parameters are modified at all times in accordance with the corresponding Scheme.

- <u>CASE 3</u>

Table 5 shows the initial configuration at *t = 0*, of the Cellular Automata used.

D	*C*	*D*	*C*	*C*	*C*	*C*	*C*	*C*	*D*
C	*D*	*C*	*C*	*C*	*D*	*C*	*D*	*D*	*D*
C	*C*	*D*	*C*	*D*	*D*	*C*	*D*	*D*	*C*
C	*D*	*D*	*C*	*C*	*D*	*C*	*D*	*C*	*D*
D	*D*	*D*	*D*	*C*	*C*	*C*	*C*	*C*	*C*
C	*D*	*D*	*C*	*C*	*C*	*D*	*C*	*D*	*C*
C	*C*	*C*	*C*	*C*	*D*	*D*	*C*	*D*	*D*
D	*D*	*D*	*D*	*C*	*C*	*D*	*C*	*C*	*D*
C	*C*	*D*	*D*	*C*	*C*	*C*	*D*	*D*	*D*
D	*C*	*D*	*D*	*D*	*D*	*D*	*C*	*D*	*D*

Table 5: CASE 3. Initial Configuration at *t=0*.

Figure 7 shows the results of the simulations with the different conditions of delta parameters.

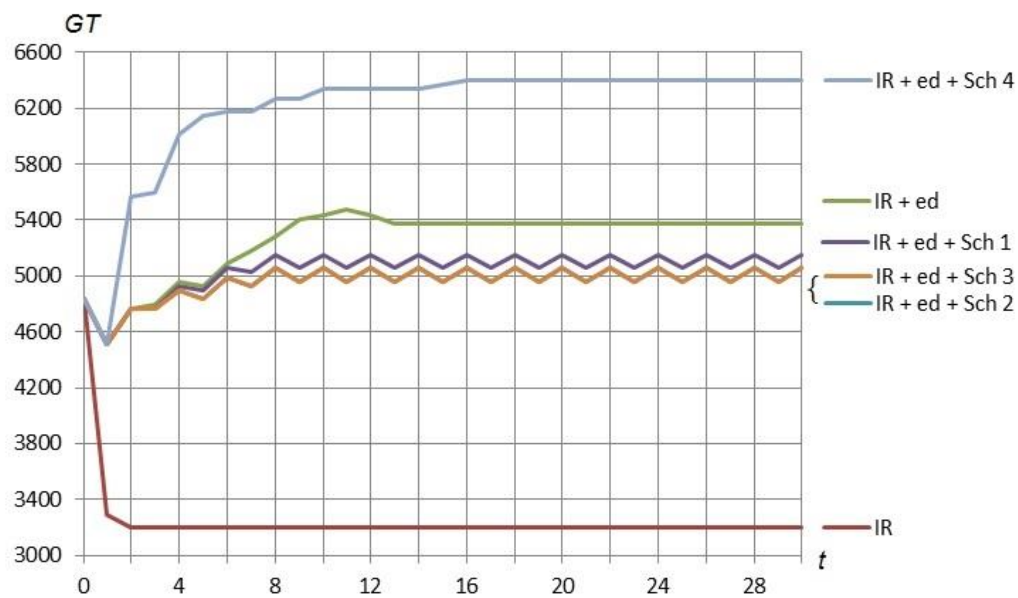

Figure 7: CASE 3. Co-evolution of norms and cooperation, measured in terms of system performance *GT*.

In this case we can see that:

1. In the case of using only the imitation rule (IR), the level of cooperation in the system decays rapidly until it reaches the *ALL D* state from *t = 2*.
2. By adding external delta parameters (IR + ed), the level of cooperation declines slightly and then begins to increase to a value slightly higher that *GT* at initial system state. In this case a static configuration of Cellular Automata is reached from *t = 13*.
3. Adding schemes for evolution of internal delta parameters (IR + ed + Sch x) we note that the Schemes 1-3 produce levels of cooperation and *GT* performance similar but slightly higher than the initial state of the system at *t = 0*. Indeed, Schemes 2 and 3 produce identical results at all times.
4. The case IR + ed + Sch 1 oscillates between two configurations of Cellular Automata.
5. The trajectory IR + ed + Sch 2 (= IR + ed + Sch 3) also oscillates between two alternating configurations of Cellular Automata.
6. The combination IR + ed + Sch 4 shows a small decrease, followed by a rapid growth in the level of cooperation to reach the *ALL C* state from *t = 16*. In the interval from *t = 10* to *t = 14* the value *GT* is maintained at a constant level and likewise remains a static configuration of Cellular Automata, though at all times the internal delta parameters are changing according to Scheme 4 and this causes changes in *t = 15* and *t = 16* leading to the final configuration at *ALL C* state.

- CASE 4

Table 6 shows the initial configuration at *t = 0*, of the Cellular Automata used.

C	C	C	D	D	D	C	C	D	C
C	C	C	D	C	C	C	D	C	C
C	C	C	C	C	C	D	D	D	C
C	C	D	D	D	D	D	C	D	D
C	D	C	D	C	D	C	C	D	D
D	C	D	C	C	C	C	D	D	C
C	C	D	C	D	D	C	D	D	D
C	C	C	D	C	D	C	C	C	C
C	D	C	D	C	C	D	C	C	D
C	D	C	C	C	D	D	D	C	D

Table 6: CASE 4. Initial Configuration at *t=0*.

Figure 8 shows the results of the simulations with the different conditions of delta parameters.

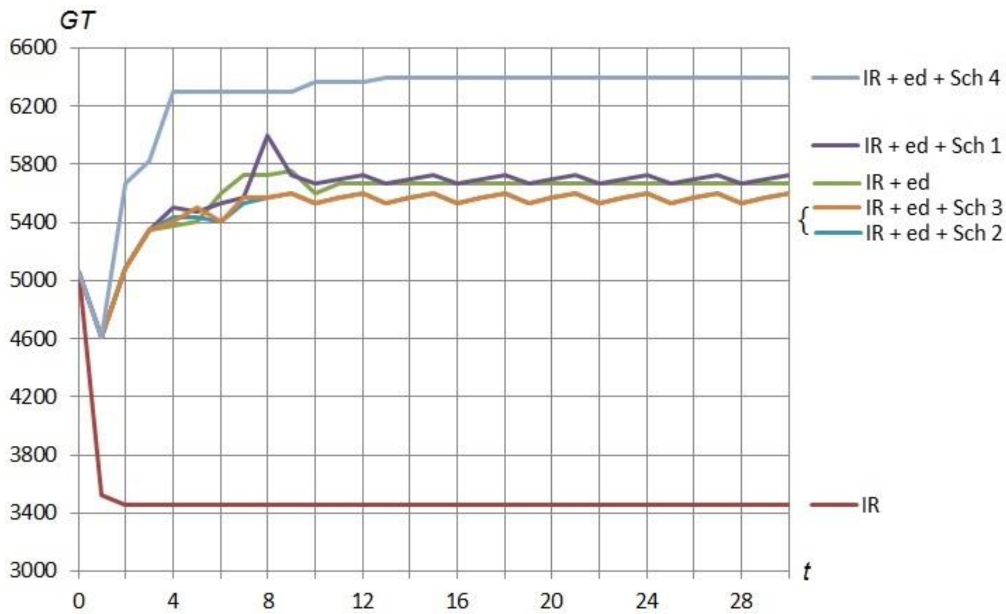

Figure 8: CASE 4. Co-evolution of norms and cooperation, measured in terms of system performance *GT*.

In this case we can see that:

1. By using only the imitation rule (IR), the level of cooperation in the system decays rapidly but the *ALL D* state is not reached.
2. By adding external delta parameters (IR + ed), the level of cooperation declines slightly and then begins to increase to a value slightly higher that *GT* at initial system state. In this case a static configuration of Cellular Automata is reached from *t = 11*.
3. By adding Schemes for evolution of internal delta parameters (IR + ed + Sch x) we note that the Schemes 1-3 produce levels of cooperation and *GT* performance similar to the configuration of RI +ed. Indeed, Schemes 2 and 3 produce identical results except in the interval from *t = 3* to *t = 8*.
4. The trajectories IR + ed + Sch x (x=1, 2, 3) oscillate alternating between three configurations of Cellular Automata.
5. The combination of IR + ed + Sch 4 shows a small decrease, followed by a rapid growth in the level of cooperation to reach the *ALL C* state from *t = 13*. In the interval from *t = 4* to *t = 9* a static configuration of Cellular Automata is maintained and the *GT* value is also maintained at a constant level, however at all times delta internal parameters are changing according to Scheme 4 and this causes a change in Cellular Automata configuration at *t = 10*. In the interval from *t = 10* to *t = 12* also remains a static configuration of Cellular Automata

and is the evolution of the internal delta parameters which causes the change in *t = 13* where eventually the *ALL C* state is reached.

Conclusions

The CASES 1 to 4 presented above are a sample of the possible range of results that can be obtained from the co-evolution of norms (from shared strategies) and cooperation.

In the four CASES consistently is shown that the imitation rule (IR) produces sub-optimal results, although not necessarily the *ALL D* state is reached.

The introduction of external delta parameters (IR + ed) makes a big difference compared to the use of the imitation rule (IR), but it is difficult to predict with certainty the *GT* performance level to be achieved. In CASE 1, for example, *GT* reaches a level quite close to the optimal while in the remaining cases slightly higher levels are achieved than those who are at the beginning. In general we can see that there is a downward trend at the beginning followed by intervals in which behavior is observed increasing and decreasing until reaching a stable level.

Adding schemes for evolution of internal delta parameters (IR + ed + Sch x) is also a difference with respect to the combination of IR + ed. Consistently we observe that the combination IR + ed + Sch 4 reaches the *ALL* C state, and therefore the optimum value of *GT*.

Combinations IR+ ed + Sch x (x = 1, 2, 3) produce more diverse results. In CASES 1 to 3 these combinations produce results inferior to those obtained with IR + ed (in the CASE 1 the difference is quite large), however in CASE 4 it is shown that IR + ed + Sch 1 is above IR + ed in different time instants.

In the four CASES we use the same Schemes for evolution of internal delta parameters but there are differences in terms of equilibrium states that are reached.

In CASE 1 a static equilibrium occurs in the configuration of Cellular Automata as in the level of overall system performance *GT*.

In CASE 2, using the combination of IR + ed + Sch 2 (= IR + ed + Sch 3) produces an oscillation in two states of Cellular Automata, but remains constant system performance *GT*.

In CASE 3, the combinations IR + ed + Sch x (x = 1, 2, 3) oscillate in two states and also cause an oscillation on two values of *GT* .

In CASE 4, the combinations IR + ed + Sch x (x = 1, 2, 3) cause oscillations in three states of Cellular Automata with corresponding oscillations of GT.

In CASES 3 and 4 the combination IR + ed + Sch 4 allows us to observe that the configuration of Cellular Automata can remain static in an interval of time and the evolution of the internal delta parameters can change again the state of the Cellular Automata.

The evolution of the internal delta parameters turns out to be crucial in promoting and maintaining cooperation in the system because they change based on personal experience without incurring in additional costs and may result in major changes in the system because are changed more often than external delta parameters. The internal deltas are the main source of institutional diversity and internal models in the individuals that are part of the system. This diversity is necessary to avoid stagnation in the search for solutions and has a direct impact on the evolution of cooperation.

The introduction of institutional factors in the models has proven to be a way in which agents with limited resources and capacity can partly overcome their shortcomings when building optimal strategies and achieve thus sufficiently acceptable solutions to problems that require joint cooperation.

We need a better understanding of the process of evolution of norms (internal and external deltas), in particular we need to answer how can we get this information about delta parameters from a real population? , what schemes for evolution of internal delta parameters are suitable in a specific context? , how can these schemes effectively be implemented in a population?

It is clear that although all the agents in a population know and use the same scheme of evolution of norms (external and internal deltas), the evolutionary process can generate a wide variety of norms and therefore behaviors within the population, according to the personal history of each individual. Then a process for selection of norms is required so that the most suitable norms are generally adopted in the population.

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