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THE EVOLUTION OF RULES IN SHEDDING-TYPE OF CARD GAMES

MARCO A. JANSSEN

School of Human Evolution and Social Change,
Center for the Study of Institutional Diversity,
Arizona State University, PO Box 872402,
Tempe, AZ 85287–2402, USA
Marco.Janssen@asu.edu

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Shedding-type of card games are used as a fruit fly to study the evolution of institutional arrangements. Eleven types of rules are identified which leads to a spectrum of 2048 possible shedding games. Each game can be evaluated by the length and difficulty of the game and as such a fitness landscape of possible shedding games can be constructed. Building on cultural group selection simulations are performed with 100 groups which start with randomly throwing cards and evolving to games similar to UNO. Finally, experiments have been performed where characteristics of agents co-evolve with the rules of the game.

Keywords: Institutions; card games; evolution of rules.

1. Introduction

Institutional rules are the prescriptions that humans use to organize all forms of repetitive and structured interactions or situations that humans get involved in at different levels of scale [8]. Rules are defined as shared understandings that refer to enforced — by a third party — prescriptions about what actions are *required*, *prohibited*, or *permitted* [4]. Those rules (e.g. law, regulations, contracts) can be defined explicitly on paper or not. In contrast, norms are shared understandings but are not *enforced* prescriptions, meaning that it is not explicitly defined to a third party what to do when a prescription is not met.

Institutional rules facilitate people making decisions in complex situations. Given that people often pursue multiple objectives, which may be conflicting, limits of people's mental capacity compared with the complexity of the decision environment prevents him/her from exploring all the alternatives. Bounded rationality is assumed to explain that people adopt a "satisficing" rather than an optimizing strategy, searching for solutions that are satisfactory, given some aspiration levels [12]. Institutional rules and social norms may facilitate the coordination among actors and reduce transaction costs [8].

Institutions, rules and norms which govern the interactions between people, evolve over time [8, 9]. Institutions affect the functioning of markets, traffic flows, appropriation of common resources, use of the internet, social order in a classroom, etc. The interest in studying institutions relates especially in understanding when and why institutions do not function: overharvesting of common resources, ineffective educational system, illegal downloading, etc. However, we cannot easily fix an institutional arrangement. The history of the institutional arrangements plays an important role in how they can change. This so-called path-dependency affects the options and effectiveness of institutional change. One way to derive a better understanding of the evolution of institutional arrangements is to develop computational models which can be used to do controlled simulation experiments.

It is important to understand the difference between norms and rules [4]. Norms are statements which define what activities by whom are allowed or not. Rules are statements like norms, but explicitly include the consequences if the rule is broken. For example, a norm can be "You must not park your car at this location". But this does specify what happens if you park on that spot. A rule in this situation will be "You must not park your car at this location or else you have to pay a fine of $60 to the parking office". It much be noted that the distinction between norms and rules include some gray zone. Even if one breaks a norm, this does not mean that there are no consequences. Norm breakers can be excluded or experience violent confrontations. With a rule, a third party, say police, can step in and enforce the rule.

Institutional rules are imbedded in a nested system of rules [8]. At the lowest level, operational rules exists which define the day-to-day activities of human interaction. At the collective choice level, a subset of the actors of the operational level come together and adjust the operational rules within the context of the constitutional rules. The constitutional rules are the highest level of rules that define the basic principles in which social order needs to be governed. In fact, the constitutional choice level defines the rules and how to change the rules at the collective choice level. Changes in constitutional rules are a slow process with additional checks and balances. The model discussed in this paper only includes the rules of the operational and collective choice level, assuming a fixed set of constitutional rules.

There has been considerable history on using models to understand the conditions in which certain norms evolve [1]. Typically these models study the evolution of cooperation and whether norms evolve to cooperate or not with which type of agents. There have also been game theoretical studies on the evolution of rules [11] which assume perfect rational agents selecting equilibria with constraints.

We are interested to develop a formal model of the evolution of institutional rules using rationally bounded agents in order to improve our understanding of societal dynamics of the past, present and future. Such a formal analysis of rules is lacking (but see Janssen [6] and Smajgl *et al.* [13]).

We have limited information available how institutions evolve over time. Only in unique circumstances, highly accurate data over time is available [7]. Besides the empirical difficulties, institutional arrangements of real societies become too complex for an initial study of evolving rule systems. To start developing a model of rule evolution we would like to use a problem that is defined by a limited set of rules, but is relatively simple in order to explore the whole spectrum of possible rule configurations. Card games are chosen here as such a problem. The rules of the game define how players play the game and there are official descriptions of the rules. Each change of the rules can lead to distinctly different outcomes of how the game is played and how players evaluate the game. It must be mentioned that the use of games has a distinguished history in the study of collective action since the pioneering work of Jean Piaget with marble games [10].

Children are tinkering with rules of marble games, as well as card games, which make them interesting candidates for the study of rule evolution. The goal of this exercise is to provide a proof of concept on the evolution of actual rule sets, instead of abstractions of rules, using rationally bounded agents. Can we evolve in a simulated environment a population of agents who play card games which mimic the principles of actual card games? We focus here on a simple class of card game, a shedding-type of games like UNO and crazy eights.

In the next section, we analyze the rules of the shedding-type of card games. Then we present a model to simulate a group of agents playing such card games and show how crazy eights and UNO are within a fitness landscape of variations of the card game. This brings us to the core of the paper, the evolution of rules for which we describe the model and present model analysis. The paper concludes with a discussion how this work can be extended to the study of institutional change in social-ecological systems.

2. Rules of the Shedding-Type of Card Games

The shedding-type of card games is a family of games played by two or more players who receive a specific initial number of cards with the objective of being the first to "shed" all of their cards.[a] An example is crazy eights, and there are many variations including the popular UNO game.[b] The large diversity of rules of shedding games show that this kind of games allow for tinkering of the rules and make interesting variations of the same base game.

The basic idea is to have a pack of N cards and randomly distribute an initial amount to each player. The undealt stock is placed face down on the table, and the top card of the stock is turned face up and placed beside the stock to start the discard pile. In order, the player must either play a legal card face up on top of the discard pile, or draw a card from the undealt stock. A card is legal when it matches the rank or suit. There are various special cards. Some cards

[a] http://en.wikipedia.org/wiki/Category:Shedding-type_card_games accessed June 21, 2008.
[b] http://www.pagat.com/eights/ accessed June 21, 2008.

Table 1. A description of the cards and their roles in crazy eights and UNO.

Card	Crazy eights	UNO
Number of cards	52	108
Number of suits/colors	4	4
Initial amount of cards	5	7
Normal cards	2, 3, 4, 5, 6, 7, 8, 9, 10, Jack, Queen, King, Ace	0, 1, 2 , 3, 4, 5, 6, 7, 8, 9
Skip card	—	Skip the next player's turn
Reverse card	—	The direction of play switches
Wild card	—	Might be played on any card and player calls color to be played by next player
Draw two	—	The next player draws two cards and skip his/her turn
Wild draw four	—	Might be played on any card, and the next player draws four cards and skips his/her turn. Wild Draw Fours may only be played if you do not have a card of the current color. The player might bluff and play a Wild Draw Four illegally, though the player drawing the cards may "challenge" the card. If the card was played illegally, that player is penalized with drawing two cards, if not, the challenger is penalized
Eight card	Can always be put and player can define suit (like Wild card of UNO)	—
End game	—	Must say "uno" when one card is left
Drawing cards	May draw card if one can play. Must draw card until one can play	May draw card if one can play. Must draw one card if one cannot play

lead other players to have to pick up more cards from the stock, or skip a turn (see Table 1).

There are many variations of the shedding-type of card games.[c] We define now a more general shedding game which covers some of this diversity in a systematic way. By defining a systematic way to create shedding games, we can develop computational models of rule evolution.

The basic rule is that a player must play a legal card when it is his/her turn. We assume that players use one or two decks of cards with four suits of thirteen cards per deck. These thirteen cards included numbers 1–10, Jack, Queen and King. Some cards may have special meanings:

— 10 can become a Wild card (we use 10 instead of 8 to make it more fluid)
— Jack can become a Reverse card

[c]http://www.pagat.com/invented/uno_vars.html accessed June 21, 2008 and http://www.pagat.com/invented/eights_vars.html accessed June 21, 2008.

— Queen can become a Skip card
— King can become a draw two card

If there is a second deck, 10 s of the second deck become a Wild 4 card.

Besides the special cards, the following rules may vary:

— One or two decks of cards
— Random order or fixed order or turns. With random order we mean that a N-sided dice is thrown each round to determine which of the N agents is allowed to play
— The color of the card must match color or not of the card on top of the discard pile
— Wild Draw Four can be drawn legally any time, or only when there is no card of the same color
— One must draw until one can play or only draw one

We now can define a spectrum of the shedding-type of card games as variations of a set of rules. Eleven rules are varied which leads to $2^{11}(= 2048)$ variations of shedding games in which Crazy Eights and UNO are special cases.

Since we are interested in rule evolution, it is important to recognize that there is only one point in the game where we explicitly include the breaking of a rule. Namely the use of the Wild Draw Four which can only be used when one has no card of the same color as that on top of the discard pile. We may consider that people do not draw cards if they have to, or that they peek at the cards of other players. However, this kind of behavior is difficult to properly include into a formal model, and we assume that the agents play the game in an orderly way. A drawback of using the card games as an analogy for institutional change is the constant monitoring of the players, which is not happening in most other action arenas.

Table 2. The rule space is build up from 11 types of rules. The well-known shedding games are 2 of the 2048 possible games within the rule space.

Rules	Options	“Crazy eights”	UNO
Random turn	True/False	False	False
Initial # cards	5/7	5	7
4 colors	True/False	True	True
Color change	True/False	True	True
Decks of Cards	One/Two	One	Two
Reverse	True/False	False	True
Draw 2	True/False	False	True
Draw 4	True/False	False	True
Draw 4 Anytime	True/False	False	False
Skip	True/False	False	True
Draw till play	True/False	True	False

3. Model of Card Game[d]

We present now a computational model where N artificial agents play shedding card games to a set of specified rules. This model enables us to explore the consequences of changes in the rules on various performance indicators as discussed below.

How do we evaluate the different rule configurations of the game? For institutional rules about natural resource management equality of appropriation and overharvesting and logical indicators of performance. For card games, we have to come up with something quite different that cannot relate directly back to many institutional arrangements.

The basic assumption is that for card games, the evaluation is based on how players evaluate the game. Fortunately, some research has been done on what people enjoy in play and games. Csikszentmihalyi [5] developed the concept of "flow", which represents the feeling of complete and energized focus in an activity with a high level of enjoyment and fulfillment [3]. The flow is derived by balancing the challenges and the ability by the player to overcome it. If an activity is too challenging given the ability it generates anxiety. When an activity is not very challenging given the ability, it generates boredom. To define indicators to quantify the trade-off between challenge and ability, we first recognize that playing the shedding-type card games is not extremely challenging. It is no surprise that those card games are popular among children. We define the trade-off between boredom (length of game) and challenging (number of types of cards a player can play). The last indicator requires some explanation. If all legal cards are normal cards of the same color, it does not matter much which card to put. If one has some special cards like Draw 2 or Reverse, the number of types of cards that can be played increases. The more types of cards are available, the more important the choice of the card becomes.

We assume a simple strategy for agents to decide which card to put on the deck. First, one evaluates which cards are legal to play. We assume that with probability p_c an agent may consider to put the Wild draw 4 card when he still has cards of the same color. This is the probability of cheating.

If the amount of legal cards is equal to 1, play the card. If there are more legal cards, there is a probability p_r that a card is drawn randomly. With probability $1 - p_r$, the player will evaluate whether there is a card that one can play that can prevent the next player from playing. Note that this is the extreme case where there is perfect knowledge and the cards of the other player are known. By varying the level of p_r, we can see the impact of perfect information. It will first look at the possibilities using a normal card. If no good card is available, one will consider a card that can change the color of the cards. If that does not work, one will consider the reverse card, skip card, draw 2 card or draw 4 card.

[d] Netlogo version of the model versions used in this paper can be found at http://www. openabm. org/model-archive/sheddinggames and http://www.openabm.org/model-archive/ evosheddinggames.

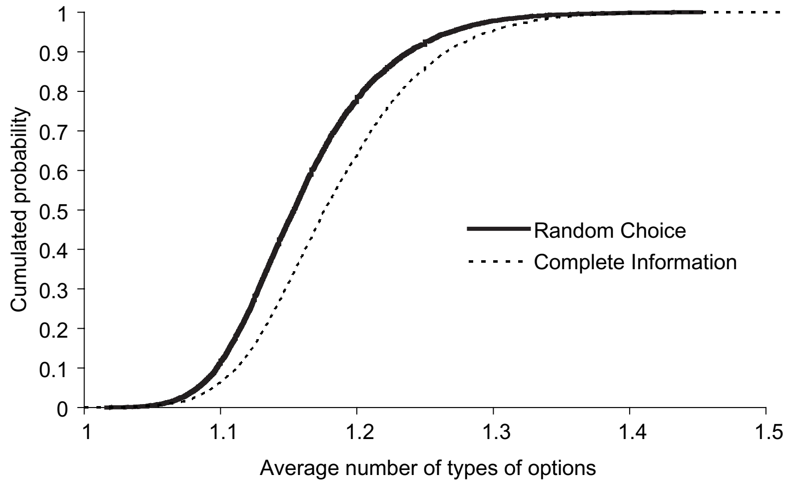

Fig. 1. The cumulated probability of the number of types of options in 10,000 games of UNO. The distributions differ if a different type of agent is used: random choice versus complete information.

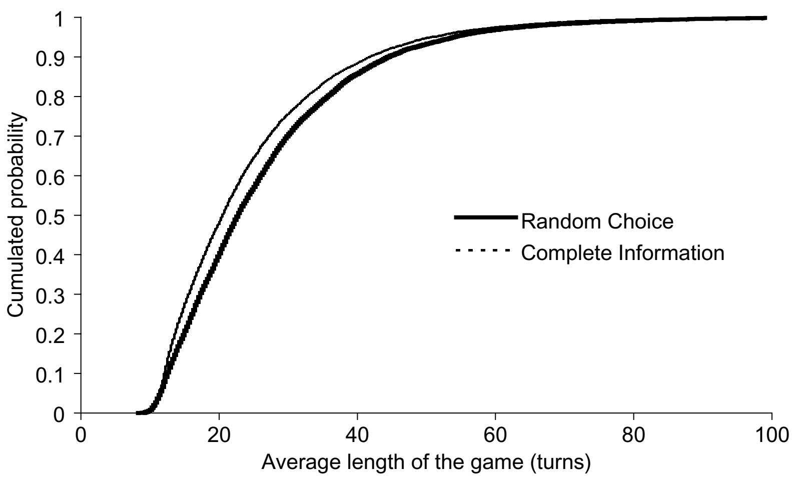

Fig. 2. The cumulated probability of the number of turns it takes to finish a game in 10,000 games of UNO. The distributions differ if a different type of agent is used: random choice versus complete information.

We use as a default strategy where p_c is 0 and p_r is 0. We also have explored different versions of the model and found that there is no major difference in the results in this section. In Figs. 1 and 2, we show the distributions of the average number of types of options and the average number of turns per person for playing the UNO game. In each figure, we show that the distribution for p_r is 1 (random choice) and p_r is 0 (complete information). The average length of the game is slightly shorter for the situation that agents play the game with full information.

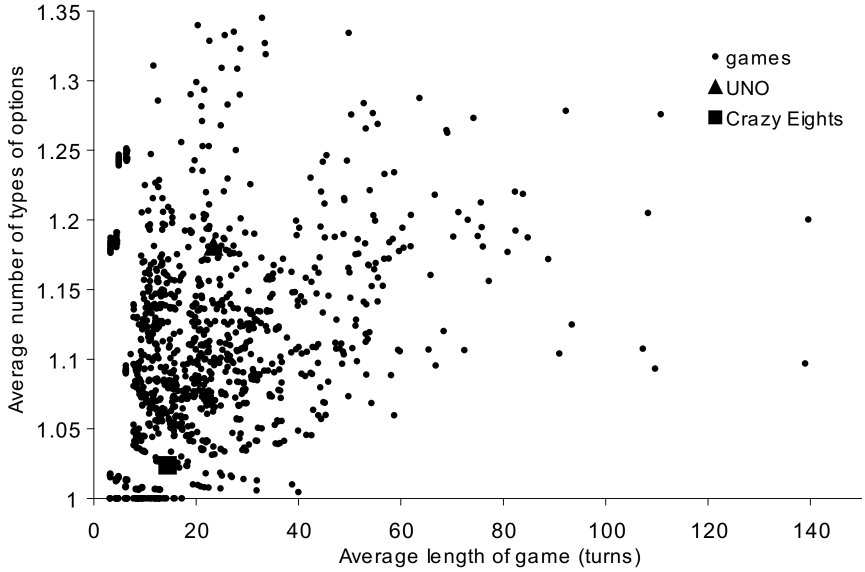

Fig. 3. The performance of all 2048 possible card games expressed among the dimensions of the number of types of options players experienced and the average length of the game per person. For each possible card game, 10,000 runs are performed for a group size of 4 players.

Furthermore, the players have more types of options during games if they have complete information instead of random choice.

However, these differences are not significant. This is not surprising since most of the time, agents have only one option to play a card legally.

There are 2048 ($= 2^{11}$) variations of the game. We run the model 10,000 times for each of the 2048 for a group size 4 (Fig. 3).[e] In these games, we assume agents have complete information ($p_r = 0$). We see a large diversity of outcomes. A few games have only one option per turn and an average length of a few turns. These are games where there are no rules that restrict players to put a card on the table. In other games, the average duration of the game is 140 turns (all including the rule "draw till play"). In some games, the duration of the game is relatively short, but the average number of types of options is around 1.35. There is no direct relation between one individual rule and the performance since it depends on the interactions with other rules.

The Crazy Eights game is relatively short and has a low average number of types of options. The UNO game has more turns on average and is more exciting (more types of options on average per turn). This is in line with the history of UNO, which is developed as a follow up of Crazy Eights.

[e]When we vary the group size between 2 and 10 players, we see an increase in the average length of the game as well as the number of types of options, but the shape of the distributions remain the same.

4. Evolution of Rules

Now we have seen the spectrum of possible games, can we simulate evolution of games? What kind of games will evolve? The simulation of rule evolution in this paper is based on cultural group selection [2]. Groups who do better — have more exciting games — are more likely to be copied. Hence successful innovations of rules will spread from group to group.

We now like to start with agents randomly throwing cards and have them evolve meaningful shedding-type of card games. We are given is a landscape of 100 cells using a regular grid of 10×10 cells. The borders are wrapped around to derive a torus and avoid border effects. Each cell contains a group of size $N(= 4)$ who plays $n(= 10)$ shedding games before evaluating their performance.

When all groups have played n games, the groups will look around to see whether there is a nearby neighboring group — eight surrounding cells — who has performed better. A better performance is considered to be a group with a higher number of types of options as long as the average length of the game is not more than x times the current game. We use x equal to 10 in the simulations discussed below. Hence this means that groups derive a small sample of possible outcomes of a set of rules.

The best neighboring group, if any, is imitated. The bigger the difference in the performance between the own group and the best neighboring group, the more likely rules of the better group are copied. For each of the 11 rules, the rule is adopted with probability $1 - O_i/O_{\max}$, where O_i is the average number of options of neighboring group i.

Independent of the imitation process, groups tinker their rules. For each of the 11 types of rules with an independent probability $\mu(= 0.01)$, a rule is changed for the next generation.

In the evolutionary process described, we will expect that groups will evolve towards card games with high number of types of options per turn. However, the variability in the outcomes of the games is high (Figs. 1 and 2). As a result, groups may experience that their neighbors had more interesting games then theirs, and imitate the rules, but will not experience an improvement in the next generation. Groups evolve their rules in a noisy fitness landscape and it is not known in advance if this leads to a convergence of a certain set of rules.

Figure 4 depicts the average performance of games evolving in the fitness landscape of possible games. The starting point is at one option per turn and about 6 or 7 turns since they just throw any card on the stack. Over time, the length increase as well as the number of types of options. The average number of types of options that evolve is similar to the UNO game, although the length of the game is shorter (Table 3). Since only 10 games are played in each generation, groups receive a noisy signal. This limits the ability of the evolutionary process to find those rule combinations that leads to the highest number of types of options in the long run.

In Fig. 5, we see for 3 examples' rule how they are adopted over time. The "four colors" as well as the ability to "change color" emerge quickly as rules in

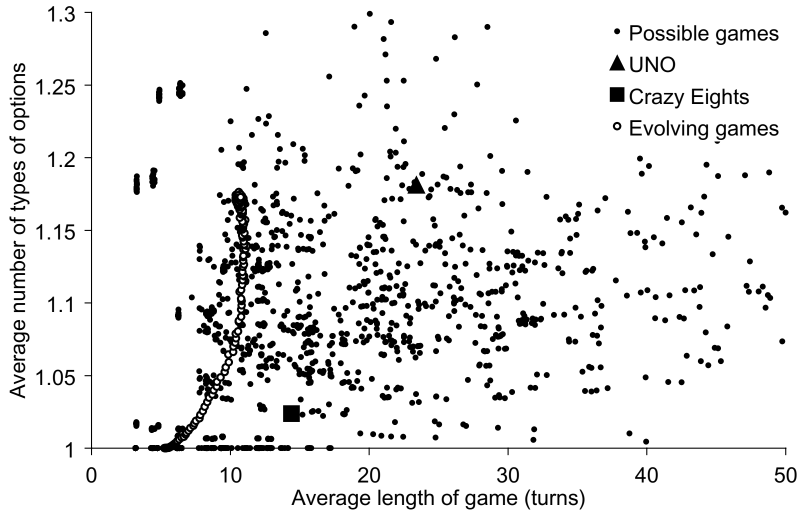

Fig. 4. The trajectory of the evolving games (open dots) starting at the left bottom of the screen and evolving to about 10 turns and 1.18 number of types of options (averaged over 10 runs). We included the fitness landscape of Fig. 3 as a reference.

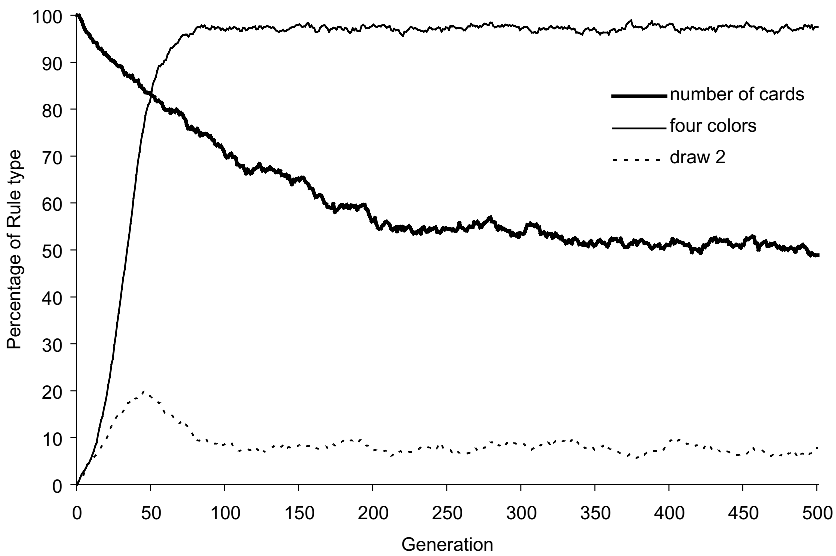

Fig. 5. Examples of three rules used by the 100 groups over 500 generations (average over 10 runs). The rule of distinguishing four colors, and the rule to use the draw 2 card.

the games. Other rules that evolve quickly are the “reverse card”, “to draws cards until one can play”, and the “skip card” as well as the “initial number of 7 cards”. Other rules such as a “draw 4 cards” or having one or two decks of cards seem not relevant for the agents. Half of the groups have such a rule, while the other half

Table 3. The evolved rule sets for two types of experiments. The standard experiment assumes that agents view which card the other puts on the stack, while in the blind case agents need to challenge the agent who put a card on the stack if one likes to check whether a valid card is used. The percentage is the percentage in the last 100 generations of the 100 groups in which groups use a particular rule.

Rules	"Crazy eights"	UNO	Evolved (standard)	Evolved (blind)
Random turn	False	False	58%	15%
Initial # cards	5	7	91% (7)	96% (7)
4 colors	True	True	98%	99%
Color change	True	True	97%	98%
Decks of Cards	One	Two	49% (two)	63% (two)
Reverse	False	True	95%	97%
Draw 2	False	True	6%	3%
Draw 4	False	True	52%	33%
Draw 4 Anytime	False	False	45%	33%
Skip	False	True	95%	96%
Draw till play	True	False	93%	41%
Options	1.03	1.18	1.17	1.51
Length	14.4	23.4	10.7	26.60
p_c				0.38
p_{ch}				0.48

have turned off such rules. After about 200 generations, the evolved rules start to converge. Compared to UNO there are a few interesting differences. The evolved game has the rule to draw cards until the agent can play, but does not include the "draw 2" cards rule (Table 3).

Since the shedding-type of card games have limited opportunities to test the monitoring and enforcement mechanisms, we also ran experiments where agents cannot directly see the card which has been put on the deck by the other agents until it is one's turn. One can challenge an agent who just put a card on the deck. If one rightly challenges the agent, the agent who cheated has to draw two cards, otherwise the challenging agent needs to draw 2 cards. An agent will only cheat when one has no valid card.

The probability of agents to cheat (p_c) and to challenge (p_{ch}) are individual attributes. These attributes evolve over time. Agents who win more games are more likely to get offspring compared to agents who win fewer games. Thus besides the rules that may change each generation, attributes of agents may change each generation. Hence we will simulate the co-evolution of agent attributes as well as the rules of the game. Figure 6 shows that initially the games become more and more lengthier and has also more types of options. After about 500 generations, the peak of the length of the game is reached. The reduction of the length of the game from 35 to 30 turns happens in the 500 next generations and then stabilizes. The number of types of cards played keeps going up slowly to 1.5 coinciding with an increase of cheating and challenging. More cheating and challenging leads to more cards and more options of cards available.

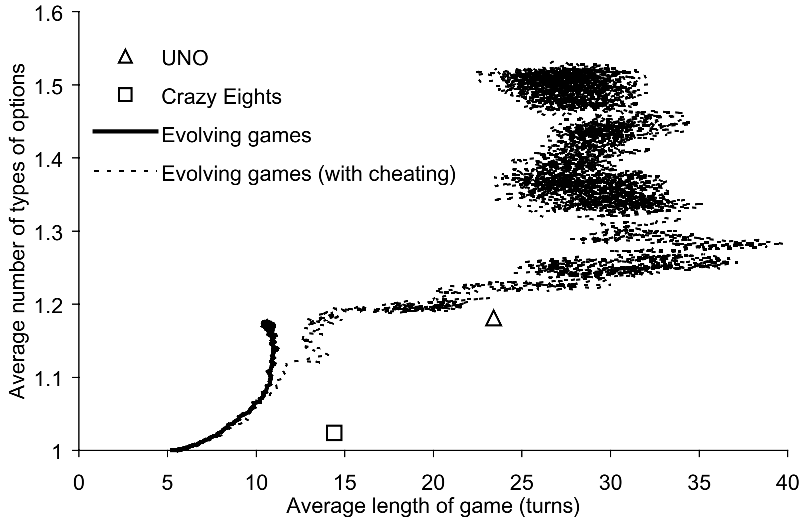

Fig. 6. The evolution of the rules when agents cannot see whether the other agents put valid cards on the stack. The small black dots represent average performance of individual generations.

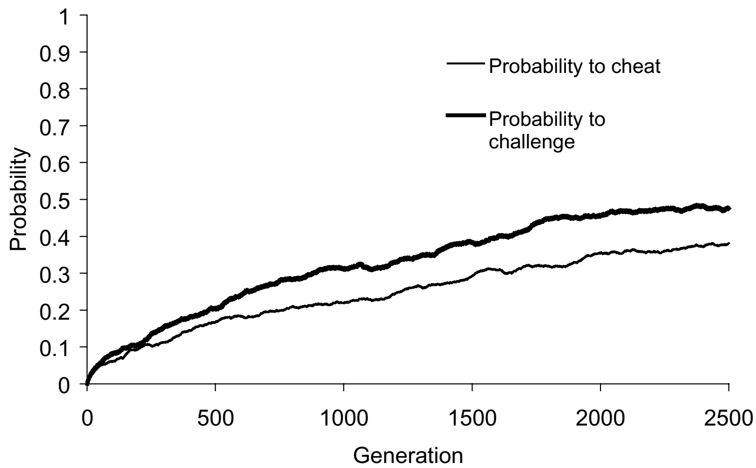

Fig. 7. The evolved probability to cheat and to challenge agents who put cards on the stack.

Figure 7 shows the average attributes of agents that evolve over time. Agents have a modest tendency to cheat, around 40% of the time they cannot play a legal card, and they have 50% probability to challenge agents. Using the indicators we defined for the performance of the games, cheating when agents run out of legal options is an evolved option to increase the number of types of cards agents can play. Groups where agents do not cheat frequently will end sooner and have a low number of types of options.

Rules evolve where agents have more options, but also agents evolve who are challenging other agents more frequently. When agents have evolved who are challenging other agents often, the rule that leads agents to draw cards until they can play becomes less important for groups. In the end of the simulations, the same type of game evolves as with the game where everybody sees which card are put on the table, except for a lower use of the rule that lead agents to draw cards until they can play and the game is more likely to follow a predefined order of play.

5. Conclusion

In this paper, we use shedding games to create a full fitness landscape of rule configurations. This enables us to explore the development of a model on the evolution of rule structures. Using cultural group selection, shedding games evolve somewhat similar to UNO, but are shorter and experience similar choices for the players. When we artificially allow agents to cheat and monitor each other, we derive a model in which agents and rules co-evolve. This leads to outcomes that were not foreseen in the original fitness landscape, since agents evolve with a large probability of cheating and challenging other agents. Such an outcome can happen since diversity of options to play was rewarded, not whether agents are honest and follow the rules.

Although this exercise is somewhat artificial, and the assumptions of performance of groups of agents drive the results, there are a number of insights we derived. Cultural group selection is a useful way to study the evolution of institutional rules. This assumes that attempts to imitate practices of other groups are important sources for innovation. Certain components of the genome of institutional rules may be found to be "junk" rules, hence are not driving the differences of outcomes between groups. The evolved rule sets led to game performance that was to be expected given that we could explore the whole fitness landscape. Therefore, we may start applying this method to more comprehensive problems for which the fitness landscape cannot fully be explored.

Most studies in the evolution of cooperation assume a static institutional landscape in which agent characteristics evolve. This paper is an initial step towards the study of the evolution of institutional rules, and its co-evolution of agent-characteristics. Agents may play social dilemma games that are defined by a simple grammar of rules [4, 6]. Changes in the rules will affect the pay-off structure, the order of play, the information agents derive, the monitoring and enforcement, etc. If we use social dilemma games related to public good provision, the level of the generated public good and the level of inequality might be used as indicators to evaluate group performance. Groups that have higher levels of public goods will do better in group competition. Groups who have higher public good levels and are more equal in the distribution of resources might be copied more frequently by neighboring groups.

The development of such comprehensive models of rule evolution enables us to start addressing questions on the emergence of complex societies in which both agent types and its institutional context evolve. What is the role of information, constitutional rules, diversity in environmental context between groups, and the level of path dependency? Furthermore, it enables us to start exploring questions on the transitions in complex societies in which not only institutions change but also the attributes of the agents. In sum, this paper provides some interesting initial steps towards a research agenda of the co-evolution of agents and institutional rules.

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