Computer Implementation of “Rational Pigs Game” Extended Model and Humans' Decision-Making in Related Scenarios

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Abstract*. This paper examines the well-known Rational Pigs Game (RPG) scenario from game theory where two boxed gluttons try to consume as much food as possible from a common source. In our expanded game version, we introduced a third glutton and formulated computer game for playing in the laboratory, based on our previously featured software engine called Autogenerator. Thanks to this mechanism, the game theory model of the RPG acquires the attributes of a computer game and it can run by interaction of people, players on their computers. A laboratory experiment was performed where a total of 60 players using computers were engaged in decision-making in the role of gluttons. The players’ behavior allowed us to gain useful insights into their rationalization, decision-making and learning processes.*

Keywords. computer implementation; rational pigs game; Nash equilibrium; decision making; learning styles; strategic choices; Autogenerator; clusters

1 Introduction

The problem of decision-making of rational gluttons has been described in various papers, e.g. in (Baldwin and Meese, 1979) the most relevant among which is (Hykšová, 2004). It has also been analyzed in several game theory books (McMillan, 1992), (Rasmusen, 2006). Recently, the rational gluttons scenario has been predominantly explored by Chinese scientists, e.g. in (Cheng et al., 2015), whose papers are mainly published by the CNKI scientific papers publisher.[1]

The scenario involves two pigs (gluttons) boxed in a cage and placed at its opposite ends. One glutton is large, the other one is small. By pressing the lever, one of the gluttons releases the food into the cage, but it falls far from him and close to the other (rival) glutton. According to various sources, for example in (Rasmusen, 2006), this game can be presented as a table which contains payoffs (earnings, obtained resources) for the players, as shown in Table 1. The gluttons' dilemma is whether or not press the lever and how often (in repeated games), because if they do not press the lever they will remain hungry and if they do they will cede the priority of feeding to their opponent (the other glutton).

Table 1: Rational gluttons game – payoffs

		Large glutton (LG)	
		pressure	*no pressure*
Subordinate glutton (SG)	*pressure*	15,45	1,50
	no pressure	30,30	0,0

McMillan (1992) provided an interpretation of this game, finding an analogy in the area of business, i.e. competition of oil cartels. We believe that an analog scenario can be recognized in the struggles of companies to conquer new markets, as well as in investment efforts in creating and applying innovations, and so on. RPG game elements can be identified at the opening of Chinese economy to foreign global companies. The state has allowed foreign companies to produce and sell on the Chinese market, providing them with possibility of a large income, but there is a condition - joint venture formation with some domestic company (model 50% - 50%).

Opening the pool with resources goes hand in hand with the formations of a partnerships between the big and the small “gluttons” and therefore some specific companies were formed such as: Changan Ford Automobile Co., Ltd. (joint venture between Changan Automobile and Ford Motor Company), BMW Brilliance Automotive Ltd. (BMW and Brilliance Auto), Beijing Benz Automotive Co., Ltd. (BAIC Motor and Daimler AG).

[1] http://en.cnki.com.cn

There are two Nash equilibria in the presented single-stage strategic game, and these are the solutions of this game in normal form in one stage that suggest optimal strategies. Besides, the game has a mixed-strategy Nash equilibrium, which also recommends appropriate mixed strategies, as described below.

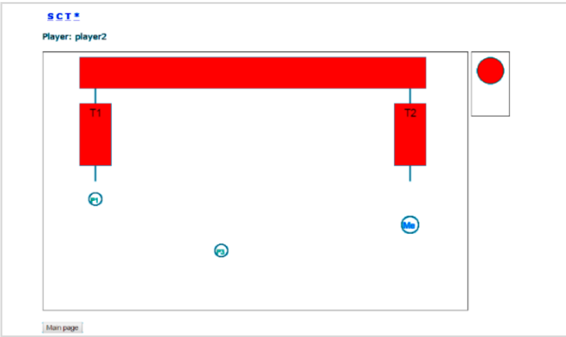

Fig. 1: Position of players – rational gluttons in extended scenario

The circumstances change in the case of a repeated game scenario. In addition, the innovative model formulated in (Fabac et al., 2014) involves a third glutton which acts asymmetrically to the benefit of the two original players. According to the formulated scenario of the game, the third player can not open the food container doors but he can and he wants to take a food. By introducing a third player, the game becomes more complex, the players' earnings are changed and the previous successful actions or the strategies needs to be re-examined. Such a rise in complexity is a common case for strategic interactions in business, military domain and other social contexts.

Table 2: Rational gluttons game (extended models) -- expected payoffs (Fabac et al., 2014)

TG (L, R)		**LG**	
		Pressure (P)	*No pressure (NP)*
SG	*P*	11,7; 35,0; 13,3 for (L) 12,0; 35,4; 12,7 for (R)	5,3; 35,4; 19,3 for (R)
	NP	20,6; 1,4; 38,0 for (L)	0; 0; 0

Furthermore, it is noteworthy that the gluttons in our model are given changed attribute values (size, speed of movement, speed of feeding and initial position in the cage). While the two gluttons who release food are positioned each at the opposite end of the cage, the third one (*tramp glutton (TG)*) is initially positioned in the middle. Although unable to release food, he moves around the open food tank to get hold of his portion. If both food tanks are open, the third glutton stops to figure out which end of the cage to go to (action L or R). The table presenting payoffs is now changed in relation to the initial one (Table 2).

Our research was aimed at establishing the behavior of humans in the roles of gluttons in a sequence of repeated games. This required setting of computer environment, i.e. an adequate game interface. The playing of a repeated game presented in tables 1 and 2 raises the question of the level of successfulness of players' strategies. As regards the finite repeated games, relevant is the term of the subgame perfect Nash equilibrium as described in, for example (Slantchev, 2004). On the other hand, unlike the well-known Prisoner's Dilemma, which was extensively studied, e.g. (Kendall et al., 2007), the studies of the iterated "rational gluttons game" almost don't exist, with the exception of the contribution of (Cheng et al., 2015).

This work attempts to contribute to the research of repeated RPG game. It is worth mentioning that according the designed rules the players/participants at first had no information on the game payoffs for various combinations of actions (strategies). Rather, they were gradually becoming aware of them through experience and learning. While the first task of this research was to enable the implementation of this game on computers, the second major task was to analyze the behavior of the game participants.

Related work was conducted in the domain of games according to the game theory models as well as in the domain of popular PC digital games. Among the numerous papers based on Iterated Prisoner's Dilemma (IPD), we highlight the research of (Burguillo, 2010) which offered a framework for using game theory and competition-based learning to increase the students' learning performance. Experimental "dictator game" was used and analyzed to determine the patterns of cooperative behavior of players, i.e. the presence of altruism, the reciprocity, the preferences for egalitarian choices, etc. (Diekmann, 2004), (Bardsley, 2008), (Engel, 2011).

In the domain online multiplayer computer games, Suznjević et al. (2011) analyzed the behavior of WoW (World of Warcraft) players based on categories of their actions. For the same game (WoW), based on certain behavioral variables, classes of player behavior were defined using clustering data methods in (Drachen et al., 2013). An empirical model of player motivations in online games was proposed in (Yee, 2006).

Concerning our first goal, computer implementation of the repeated RPG game was achieved by the simulation mechanism based on Autogenerator, which had been presented in the aforementioned work (Fabac et al., 2014). Autogenerator embeds several features that were found to be useful in the implementation of the simulation mechanism. The most important one is that it allows specification of game parameters on a high level of abstraction and is capable of receiving the modified states of these parameters, including game results. Also, Autogenerator is aimed at building web applications, which allows networking among players.

2 Simulation mechanism based on Autogenerator

This mechanism is based on the specific implementation of our SCT generator model (Radošević et al., 2011), known as Autogenerator (Magdalenić et al., 2013), as can be seen in Fig. 2.

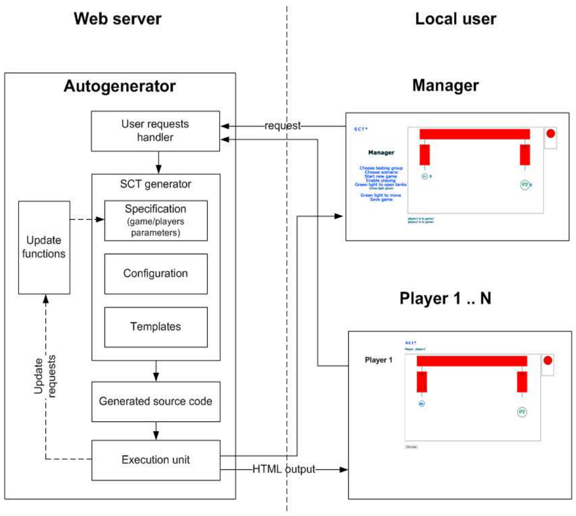

Fig. 2: Simulation mechanism used to implement strategic game

The main feature of Autogenerator is its capability to produce a demanding programming code and other application elements (such as HTML/CSS /Javascript code in the case of web application). Once created, the code is activated automatically. Autogenerator uses the option of script languages (Python in our example) to perform the programming code from variables and not just from the programming databases.

In the example of the strategic mechanism of games simulation, Specification consists of attributes that describe the generated code units (as virtual databases), the usual parameters of the game and the parameters pertaining to the tanks (of food) and players, as shown in the following example (Fig. 3):

OUTPUT:output
OUTPUT:out2
OUTPUT:out3
OUTPUT:out4
OUTPUT:out5

Output types (types of codes used for generating)

output:output/index.html
out2:output/player.cgi
out3:output/semaphore.cgi
out4:output/manager.cgi
out5:output/control_semaphore.cgi

Virtual databases used for generating

common:
+semaphore:red
+game_start:yes
+connected_tanks:yes
++fuel:60

Common parameters of the game

tank:T1
+position:1
+capacity:20
+fuel:20
tank:T2
+position:6
+capacity:25
+fuel:25

Properties of fuel tanks

player:player1
+earned:0
+player_position:1
+step:3
+size:1
player:player2
+earned:0
+player_position:6
+step:3
+size:2

Properties of players

Fig. 3: Simulation mechanism implementing strategic game

The types of outputs are associated with the highest-level templates in Configuration, as shown in Fig. 3, and are used to define the parts of the code which are generated and stored in variables (virtual databases). In the case of simulation mechanism, there are five code units to be generated; one that contains HTML and four scripts in Python. The common parameters of the game are defined under a common group, where "+" denotes subordination of attributes (for instance, parameter *fuel* is subordinated to attribute *connected_tanks*). These parameters change in the course of simulation performance in the way that attribute *semaphore* defines the current situation on the semaphore used in the simulation; *game_start* defines the current simulation stage (later it changes its value in the *game_open_tank* and *game_choose_direction* stages of the game); *connected_tanks* is an option that defines the usage of the common tank (with the capacity of 60 units) or several unconnected tanks with their respective capacities. Each tank of the group is defined by its position, capacity and current level of fuel (food) in the tanks (it is used when the tanks are not connected). Finally, the group *player* defines properties of the players, such as the current amount of fuel, speed of movement (towards attribute *step*: higher value means slower movement) and size, which defines the speed of feeding (higher value means faster feeding).

Configuration consists of configuration rules and defines the connections between Specification and Templates (Radošević et al., 2011). Each configuration rule is defined by three elements:

• **Connection**. Each connection is physically positioned in Templates, usually marked by "#" signs; for example, *#title#*, defining the position where the real content must be placed. Connection is the key element which appears only once in Configuration, but it may appear one or more times in Templates.

• **Source**. Each connection has a respective source in Specification, for example, the source for connection, *#player#*, is the value of attribute *player*. The source can be defined as: particular, tank, or group.

• **Code template**. If the source is a tank or a group, the connection has its subordinated code template. If not, this element is left out.

Connections used in code templates define inclusion of content which may be from another code template or from the source, if template code is left out. Recursive connections (the ones leading to the same template) should be avoided. Similar to Specification, Configuration is organized in a hierarchical order so as to define the structure of the trunk. Configuration of the generated application is presented in Fig. 4.

<u>*Highest-level templates*</u>

#1#,,index.template
#2#,,player.template
#3#,,semaphore2.template
#4#,,manager.template
#5#,,control_semaphore.template

<u>*Connecting with attributes from specification and subordinated code templates*</u>

#links#,player,link.template
#tanks#,tank,tanks.template
#buttons#,tank,buttons.template
#player#,player
#players#,player,players.template
#players_display#,player,players_display.template
#earned#,earned
#fuel#,fuel

. . .

Fig. 4: Configuration of Autogenerator-based simulation mechanism

The initial rows of Configuration define Templates of the upper level that are connected with the initial rows of Specification, thus defining output types (e.g. *#1#* is connected with *output*, *#2#* with *out2*, etc.). Each row of Configuration includes Connection within '#' signs; attributes from Specification; and (possibly) the used code template. If the code template is not specified, the row defines substitution of Connection (each occurrence in the template code) by the value of the specified attribute from Specification. On the other side, the specified code template is used as many times as the specified attribute occur in Specification.

The application of Autogenerator enables implementation of the rational gluttons scenario in the way that humans can participate in the game in the role of gluttons and the game can be repeated through a sequence of iterations.

In the research, an iterative repeat of the same game has been successfully performed through the series of successive time phases.

3 Humans in the role of rational gluttons

The research was conducted on a sample of 60 respondents divided in 20 groups, each consisting of three members in the role of game players. The respondents were 2nd and 4th year students of the Faculty of Organization and Informatics, both male and females. Each group of players was led by a coordinator (arbiter, manager) who created a pre-planned scenario for each game. He signalized the beginning and the end of the game (Fig. 5). The scenarios were marked by numbers 1-7, at which the scenarios from the categories 1-4 referred to the standard RPG game with two players and those in the categories 5-7 included three players, i.e. they represented variants of the extended game (RPGE).

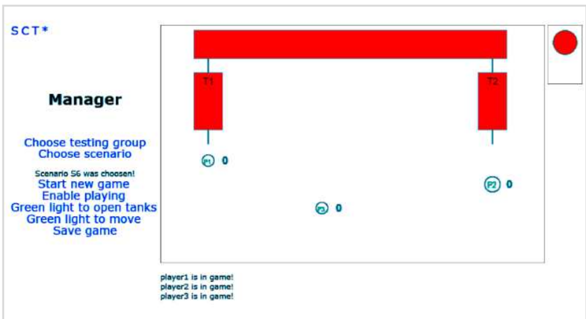

Fig. 5: The role of the game coordinator

The first 10-15 iterations of each game follow the two-player strategic model (Table 1). Further on, a third player is introduced into the same game, and the next 10-15 iterations are played following the same model, with payoffs as shown in Table 2. Because of the duration of the movement and feeding of the players (objects) in the simulation, a large number of iterations should be avoided, as it would create the saturation of people/participants.

Different game scenarios are implemented in the form of different automated generation specifications (Autogenerator). Once a new game is started, each player can see the current status of the game (Fig. 1).

In the course of the game, three persons are by their computers and the coordinator turns on the green light, thus signalizing the opening of the tank(s). Players 1 and 2 can open each tank on the opposite side (allowing the other player access to resources, i.e. food). That is action P (pressure); if there is no opening, action NP (no pressure) is chosen. It is also possible that players leave both tanks closed when given the opportunity to take action, but this option brings no gain to the players.

The players can see if one or more tanks are open, and choose to move towards one of the open food tanks. Those closer to the open tanks start feeding at once, whereas other players move over time towards the source of food and begin to feed themselves only when they reach them. One of the possible situations at the end of an iteration of the game is shown in Fig. 6.

The common food tank capacity (60 units) is distributed among the players who use them to the fullest, in keeping with this model. At the end of the game, after 25-30 iterations, the coordinator signalizes the end and stores the results. Then he can start a new game with a new group of players.

Fig. 6: A possible situation at the end of the game (payoffs).

Respondents participated in the model with two different game scenarios: the basic two-player RPG (RPG) with two players, and then the expanded game (RPGE), which includes the third player.

The main issue and aim of our analysis was to establish the behavioral characteristics of players in the computer design of the iterated "rational gluttons" model. In addition, we wanted to determine to what extent this real-life behaviour is in (in)congruity with the expected behavior. The behavior of individuals in the course of experiments as opposed to the behavior in real-life situations outside laboratories was discussed in various works, among which the most relevant are those of (Camerer, 2003), (Levitt & List, 2007) and (Benz & Meier, 2008). The topics and issues of motivation, engagement and learning in digital games have been dealt with in a number of contemporary research papers, such as (Iacovides et al., 2011).

4 Iterated RPG(E) game outcomes

Assuming the participation of rational players, the structure of payoffs (Table 1) indicates the presence of two Nash equilibria (NE) for one-stage game. According to definition, the output $x^* \in X_N$ is Nash's equilibrium from game G with n players, if the strategy x_i * of *player i* is the best response to x_{-i} * for all i = 1, ..., n, where x_{-i} * are the strategies of other players.

In this case strategy $x_i^* \in BR_i(x_{-i}^*)$ for all i = 1, ..., n. The set BR_i (BR as the "best response") form strategies that represent the best responses of (each) *player i* to the possible strategies of other participants.

NE exist for the following pairs of strategies of players SG and LG respectively:

(P, NP): $\boldsymbol{u}$(P, NP)= (10, 50), and

(NP, P): $\boldsymbol{u}$(NP, P)= (30, 30) (1)

at which $\boldsymbol{u}$ (utility) denotes players' payoffs. The third Nash equilibrium is in the domain of mixed strategies and can be recorded as follows:

S^{NE}(SG)=(6/7; 1/7) and S^{NE}(LG)=(2/5; 3/5), (2)
with associated payoffs:

$\boldsymbol{U}$ (S^{NE}(SG); S^{NE}(LG))= (12, 42.86) (3)

Thus, if the players choose their "pure" strategies "Pressure" and "No pressure" in the course of iterations of the base game with the frequency as defined in expression (2), they can expect payoffs (12, 42.9).

In the case of extended game (Table 2), payoffs change because of the third player who enters the game and wins for himself a part of the total sum (of resources, food).

This gives rise to the following question: how do the players behave when pursuing conflicting interests in the role of gluttons, which strategies do they choose, what characterizes their decision-making? All these issues are relevant in an iterated game with more than 20 repetitions. We therefore analyzed the behavior of players in 20 groups, taking into consideration several indicative elements that impact the decision-making (see description of selected variables, below): obvious errors made during the game; reciprocal behavior; activity, or lack of it, regarding the opening of food tank (resources); non-cooperative actions; change of behavior at the start of extended game.

In the following, we applied the K-means clustering method using the JMP 13 software tool. Three different clusters were found in decision-making analysis at the position of Player 1 (small glutton), as shown in Fig. 7.

For example, the red cluster (cluster 2) describes the small player who is above average successful in the game of winning points (taking food). Furthermore, he is more active in that he presses the food lever more often and tends to move towards the opposite side although he can feed himself right away (a kind of small irrationality). His behavior is more cooperative in the way that he often opens the gate with food in some iteration ***k*** after his opponent released food lever in step **(k-1)**. Approximately 1/3 of all players in the role of small glutton belong to this cluster.

Table 3 shows results of the points won by Player 1 for the categories of clusters. We can see that the results of the players from cluster 2 exceeds the expected result of the mixed-strategy Nash equilibrium, whereas in the case of cluster 1 the achieved result is slightly lower than NE payoff (expression (3)).

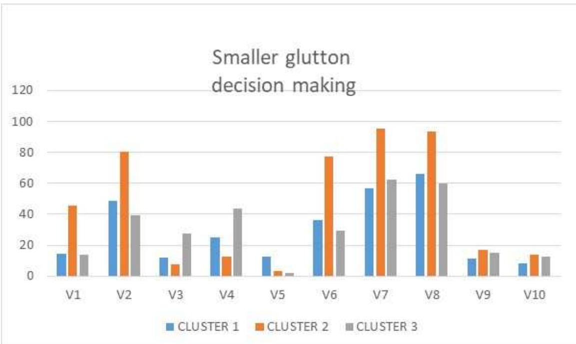

Fig. 7: Decision-making features of the player in the role of a small glutton

The characteristic *selected variables* that mark the actions i.e. the decision of the players are:

v1_ frequency of the choice to move towards the tank at the opposite end, when the one next to the player is open as well (category of mistake)

v2_ frequency of the choice to press the lever (opening) after the opponent has already pressed (opened) it in the previous iterative step (the concept of reciprocity)

v3_ frequency of the choice not to open after the opponent has already chosen to press (open) it in the previous step (no reciprocity)

v4_ frequency of the choice not to press the lever (not to open)

v5_ frequency of the event where one of the tanks is open for the player, but he chooses not to go for food (category of mistake)

v6_ frequency of situations where both players repeat the same strategies as in the previous step

v7_ frequency of pressings, i.e. openings in the second part of the game

v8_ frequency of openings throughout the game

v9_ number of the points won (payoff; resources used) throughout the game

v10_ number of the points won (payoff; resources used) in the second part of the game when the third glutton is present

Table 3: Results obtained by participants in the role of a small glutton

Cluster/ number of members	**RPG points/ standard deviations**	**Points for the 2nd part (RPGE)/ standard deviations**
1 / 5	11.07196/ 1.00011	7.990429/ 1.86532
2 / 7	17.06259/ 3.26629	13.83261/ 3.60227
3 / 8	15.33144/ 2.79018	12.32286/ 3.61995

The decision-making analysis described above was applied analogously to player 2. Fig. 8 shows three clusters and the typical decision-making of the participant in the role of large glutton (Player 2).

The blue cluster (cluster 1), performed by Player 2, turned out as the most successful one, although his result is lower than the expected result for the mixed-strategy Nash equilibrium (Table 4, expression (3)). Only about 1/7 of all players in the role of large glutton belong to this cluster.

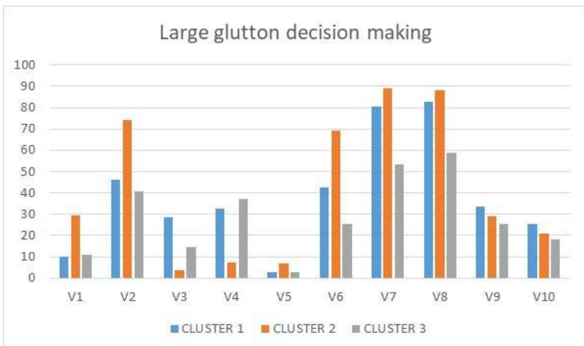

Fig. 8: Decision-making features of the player in the role of large glutton

While the aforementioned equilibrium stimulates the action of opening for Player 1 (see expression 2), a moderate activity of opening is recommended for Player 2 (in 40% of cases).

Obviously, the blue cluster (cluster 1) is not in the lead as regards the number of openings and is prone to playing with less cooperativeness and reciprocity (Fig. 8). Owing to its attributes and the constellation of the game, such attitude brings him more success.

Table 4: Results obtained by the participants in the role of large glutton

Cluster/ number of members	**RPG points/ standard deviations**	**Points for the 2nd part (RPGE)/ standard deviations**
1 / 3	33.45026/ 3.110606	25.16635/ 5.63685
2 / 9	28.79602/ 3.86564	20.95162/ 5.38918
3 / 8	25.54748/ 2.77229	18.16316/ 2.59669

The data on standard deviation indicate a statistically significant difference, especially between groups 1 and 3 in terms of the points won. The third glutton (TG) that is active in the second part of the game creates more damage to the result of the "large glutton" (Table 3 and Table 4).

5 Concluding remarks

Autogenerator makes it possible to implement scenarios of the well-known "Game of Rational Pigs", in a way that people can take the roles of gluttons and also that the game can be repeated in the same or similar form through a series of iterations. Since the previous research does not provide a systematic study of players' behavior in the model of the iterated "game of rational gluttons" this work is an original effort in that direction. Twenty groups of players participated in the computer-based gaming with two different scenarios: basic RPG in ten to fifteen repetitions and then expanded (RPGE), including third-party players, also in approximately 10-15 iterations. The analysis of players' decision-making in laboratory conditions has provided useful insights into rationality of players, the peculiarities of their decision-making and learning styles. At the beginning of each game, the participants did not have information about the payoffs (the abilities to conquer resources) for the game or various combinations of actions (strategies). Rather, they were acquiring knowledge through experience and learning through gaming. The applied behavioral analysis focuses on decision-making features leading to a greater or lesser success in the game.

It was found that among the most successful and least successful group of players, in the role of both the bigger and the smaller glutton, there was a statistically significant difference in overall success.

Preferred activities of the decision makers (players) and behavioral logic that lead toward success are different in the cases of larger and smaller players, as described earlier. Some individual players succeed in grasping and applying the right logic to success, while others fail to do so. Within the "large glutton" population, a smaller proportion of players succeed in identifying those activities that bring greater success (about one-seventh of them), unlike the situation found in the group of "small gluttons" (about one-third of them).

Why the players in the role of a "large glutton" are not so successful like players that play the role of a "small glutton"? A successful large glutton has such pattern of behavior that he is not in the lead as regards the number of openings and is prone to playing with less cooperativeness and reciprocity.

One of the key reasons for the large glutton's failure is their gaming philosophy and general approach to playing, which typically does not imply patience and persistence in postponing action. In a real-world situation, when an individual needs some resources (food and the like), he is ready to invest himself and consistently implement a strategy that may include waiting. However, in laboratory conditions, there is no struggle for survival. Instead, people are, consciously or subconsciously, aware that they are not participating in a scenario that can have actual implications.

Furthermore, through the gaming experience, the "large glutton" learned that with the same action of feeding he wins much more points than his opponent who acts as a "small glutton". He does not have a real need to take more resources than the other player, in each interaction. Therefore, his decision to open access to resources, at a particular iteration of the game is an unselfish behavior similar to the "actions of giving" recorded in the well known "dictator game". This seemingly irrational behavior of players is recorded in numerous laboratory experiments of other famous games. According to (Andreoni and Miller, 2002) "…subjects in economic laboratory experiments have clearly expressed an interest in behaving unselfishly".

The extended game RPG(E) scenario also contributes to a weaker "large glutton" result as the third player in the second stage of the game wins on average a lot more resources at the expense of a bigger than at the expense of a smaller glutton.

Finally, it should be emphasized that in this research, as well as in other works dealing with elements of game theory, social psychology, economic rationalization, the results must be considered taking into account the difference between the possible behavior in a possible real situation and the determined behavior of the examinees in the laboratory. The behavior of the respondents who play in the lab on their computers is not characterized by the same motivation that drives the (hungry) gluttons who resort to confrontation and circumvention in the cage.

Since the shown experiment can be reproduced with different groups of respondents, hence the challenging issues about motivation and rationality could be in focus of our future researches of iterated RPG(E) game playing on computers.

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