COMENIUS UNIVERSITY IN BRATISLAVA
FACULTY OF MATHEMATICS, PHYSICS AND INFORMATICS
DEPARTMENT OF APPLIED INFORMATICS

SEARCHING FOR A STRATEGY OF MONOPOLY GAME USING COGNITIVE AND ARTIFICIAL INTELLIGENCE APPROACH

(Master's thesis)

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Title: Searching for a strategy of Monopoly game using cognitive and artificial intelligence approach

Aim:

1. To find a strategy for decision making of participants in Monopoly game using observation methods.
2. To program a simulator of Monopoly game.
3. To create a rule based agents using rules extracted from observations.
4. to program the evolution of agent-players using genetic algorithms.
5. To program learning of agent-player using reinforcement learning.

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Názov: Hľadanie stratégie v hre Monopoly využitím kognitívnovedných prístupov a metód umelej inteligencie

Cieľ:

1. Nájsť stratégiu rozhodovania participantov hry Monopoly pomocou pozorovaní.
2. Naprogramovať simulátor hry Monopoly.
3. Vytvoriť pravidlá pre agentov použitím pravidiel extrahovaných z pozorovaní.
4. Naprogramovať evolúciu agentových hráčov pomocou genetických algorithmov.
5. Naprogramovať hráčov-agentov pomocou učenia posilňovaním.

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DECLARATION

I hereby declare that this thesis is my own work and effort with guidance and advices of my supervisor.

PREHLÁSENIE

Prehlasujem, že táto práca je moje vlastne dielo, ktoré som vytvoril za pomoci vedenia a rád môjho školitela.

Date: .....

Signature: .....

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Abstract

The purpose of this work is to find and describe a strategy in Monopoly game. The work goes through several levels. The first one is my own observation of participants on the principles of behavioural experiments, the second one is drilling information from literature about strategies of players followed by a synthesis of these two through their analysis. As a result of analysis, several outcomes of strategy are offered. All is completed with a strategy model for a human player. This model is then applied to an artificial agent-player using a rule-based system. Two optimisations of the strategy were applied. The first one used an approach of genetic algorithms which through evolution of certain parameters improved the strategy of an agent-player. The second optimisation was made with an aim to specify a decision-making process of an agent from a global perspective by means of a reinforcement learning approach using a neural network as a learning system to distinguish whether a decision of the strategy is correct or not. I created a Monopoly game simulator which enabled agent-players with various strategies to play the game. At the end of this work all four strategies were compared before their next optimisation. Finally, I present the results of my experiment and discuss them. It turned out that an agent-player which uses both genetic algorithm and reinforcement learning optimisation of the strategy is the best one.

Keywords: Monopoly, observation, analysis, strategy, game dynamics, global strategy and tactics, agent-player, rule-based agent, simulator, genetic algorithm, reinforcement learning, neural network, multilayer perceptron.

Abstrakt

Cieľom tejto práce je nájsť a popísať stratégiu v hre Monopoly. Práca prechádza niekoľkými úrovňami. Najskôr je popísané moje vlastné pozorovanie participantov na princípe behaviorálnych štúdii, potom sa práca zaoberá informáciami získanými zo štúdia literatúry o stratégiach hráčov. Tieto poznatky sú analyzované a výsledkom je niekoľko záverov o stratégii hráčov. Všetko je to zakončené vytvorením modelu stratégie pre ľudského hráča. Tento model je potom na základe extrahovaných pravidiel aplikovaný do agenta-hráča. Následne boli aplikované dve optimalizácie nájdenej stratégie. Prvá používa prístup genetických algoritmov, ktoré pomocou evolúcie riadiacich parametrov zlepšili stratégiu daného agenta. Následne z dôvodu potreby špecifikovať decision-making proces agenta z globálnej perspektívy, je realizovaná druhá optimalizácia pomocou učenia s posilňovaním, ktoré ako učiaci systém používa neurónovú sieť pre presné určenie, či rozhodnutie danej stratégie je správne alebo nie. Vytvoril som simulátor hry Monopoly, ktorý umožňuje agentom-hráčom hrať túto hru s použitím rôznych stratégii. Na konci tejto práce sú porovnané štyri stratégie, každá pred jej optimalizáciou, a predložené výsledky. Ukázalo sa, že agent používajúci obe optimalizácie danej stratégie, genetický algortimus a učenie s posilňovaním, skončil ako najlepší hráč.

Kľúčové slová: Monopoly, pozorovanie participantov, analýza, stratégia, dynamiky hry, globálna stratégia a taktiky, agent-hráč, agent založený na pravidlách, simulátor, genetický algoritmus, učenie s posilňovaním, neurónová sieť, viacvrstvový perceptrón.

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1. Introduction

The Monopoly game is one of the most popular board games and it is played across the whole world. In Monopoly game it is noticeable how people make decisions, how they create their own strategy, how this strategy is changing and how they can win the game. Especially the last point is very interesting, because there are no strategies about which we can say they are the best. Many researchers specialise in mathematical and statistical models of Monopoly strategy. They generally simulate Monopoly game on computer simulations and from that they make certain conclusions. Then there are a few studies focusing on behavioural aspects of players, which observe participants during playing Monopoly game or other similar board games. My intention was to join these two approaches together. In this work I observed players, their decisions in certain situations, their strategy during the whole game, their reactions, etc. I made an analysis of collected information and then I created a model of *tactics*. It means what players should and what should not do in certain situations of a game. And then I did investigation of literatures, I used many resources, from board game studies over statistical and probabilistic models to economist studies. I offer an overview of possible strategies, which along with results from my observation, identify complex outlook of strategies in Monopoly game. According to this I have created a certain model of a global strategy which was a starting point for creating an artificial agent-player. I have implemented this model of a global strategy in combination with a model of tactics into the rule-based agent-player. In order to enable the agent-players to compete against each other I created a simulator of this game. It was possible to improve the rule-based agent-player and therefore I applied two optimisations to the found strategy. I used an approach of *genetic algorithm*s inspired by a natural evolution in order to find certain parameters which I could only estimate to be in the found model of a strategy because the observations of participants and study of literatures did not offer me a complete knowledge of some important decision-making situations. The approach of genetic algorithms allowed me to find values for these parameters by evolving them. The reason for the second optimisation was to specify the decisions of purchasing the assets from global perspective with respect to the whole state space of a game. It was done by the *reinforcement learning* approach in combination with *neural network*

allowing a generalisation, it means to know how to decide in situations which did not occur in the training process. All of this was ended with a competition of these strategies and the winner was an agent-player whose strategy combined both *genetic algorithm* and *reinforcement learning* optimization.

Monopoly is a board game created according to economic concept of monopoly, where the goal is to control whole market by a single entity. Therefore many references in this work are from economist theories. The principle of Monopoly game for a player is to have whole block of certain colour group of *street properties*. This whole block is called monopoly. The board of Monopoly contains forty boxes with twenty-eight properties as it can been seen of figure [fig1]. The word *properties* includes four *railroads*, two *utilities* and twenty-two streets of different colours. When a player lands on one of these twenty-eight properties, he can buy them if nobody owns them, or he can put them into auction, or pay a rent if somebody owns them. If a player buys a certain property, then he gets Title Deed card, which determines him as an owner of a particular property. *Utilities* are properties with a special renting system. If a player lands on them, then he has to pay to owner four times dice value if owner has only one *utility* and ten times dice value if owner has both of them. Ownership of *railroads* means to earn on rent $25 if owner has only one *railroad*, $50 if owner has two of them, $100 if owner has three of them and $200 if owner has all four *railroads*. Remaining twelve boxes of the board consist of one *Free Parking*, which is the only box where players do not do any action when they land on it, one starting box *GO*, which represents the start in the game, *Jail* which represents the prison in the game and *Go to jail* which instructs a player to go to jail, one *Luxury Tax* and one *Income Tax*, which are charges for a bank, three *Chance* boxes which instruct a player to pick up a chance card and do certain actions according to command on the card, and three *Community Chest*, which function on the same principle as *Chance*. Then player can build *houses* and *hotels* on his colour blocks and due to it earn enough money from rents, which will pay other players when they land on his *street properties*. These *houses* and *hotels* are represented as *tokens* in the game. Gradually the player should continue creating other monopolies and finally to bankrupt other players. During whole game players buy, rent and sell properties either from bank or by dealing with other players. At the beginning each

player has $1500 in cash. The game is played with two dices and player moves forward on playing board according to his throw. Then he can decide to buy or not to buy property which he landed on. If he decides to buy it, he has to pay a particular price of property or he can take mortgage for the property. If he decides to buy the property for full price then other players if they land on his property have to pay particular rent for it to him. If he decides to take a mortgage then he has to pay only a half price, but he will not be able to take money from the rent until he repays it. When he wants to repay it, he has to pay by 10% more of the price of the property. If a player decides not to buy property then the property has to go to auction. It means that other players and also the player who puts property to auction can bid the property. The property will be sold for the highest bid. Then if player owns whole block of *street properties* he can build *houses* and *hotels* on it and earn more money on rent. At the end it can be only one winner, who bankrupts all other players.

Interesting on these rules is that vast majority of people do not play this game according to them. They created their own rules for playing Monopoly, the family rules. And even more interesting is that these family rules are very similar across the world. I describe more about this phenomenon later in this work.

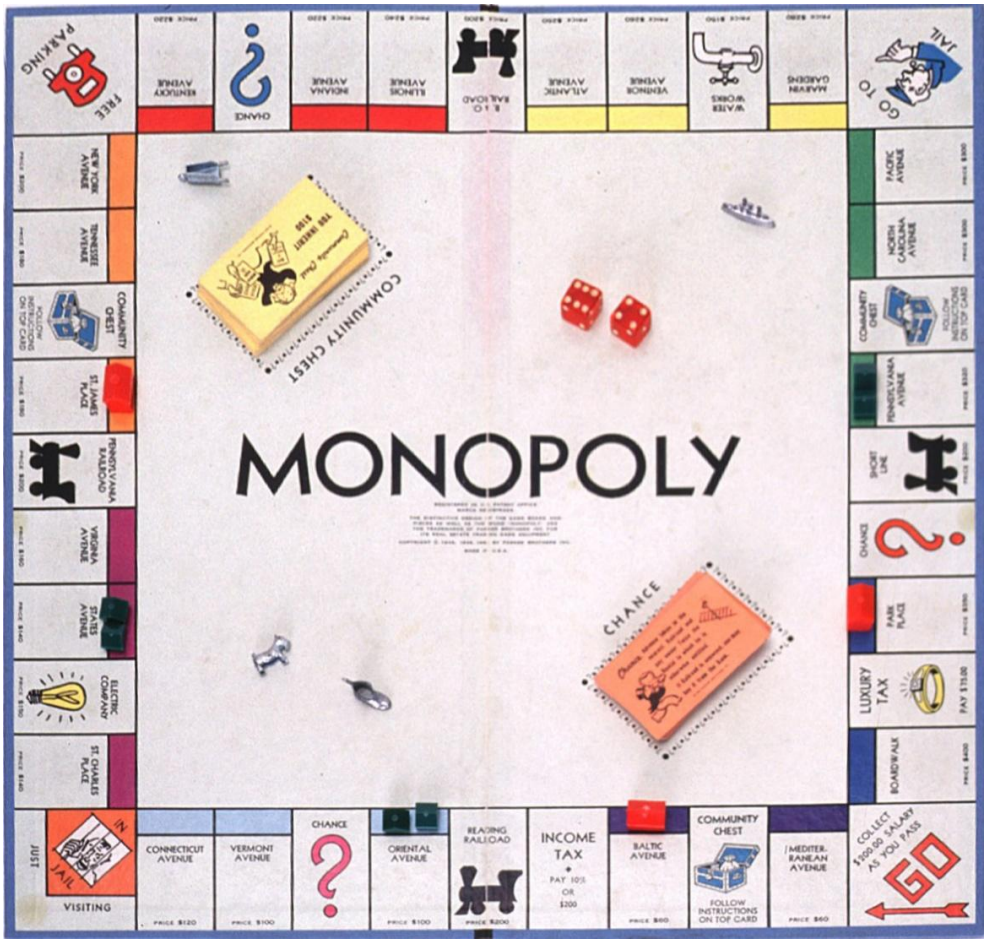

fig 1: Sample of board of Monopoly. (Figure taken from [fig1])

1.1 Strategies

This work is mainly about strategies and therefore before I will describe particular parts of this study it is needed to look at what strategy is.

According to Kumar et al. [1] there are three main factors in the process of playing games: *Chance*, *Skill* and *Strategy*.

Chance is randomness, which is embedded into game by designers. In Monopoly this randomness is represented by a roll of dice. There is a need to distinguish between randomness in game and variations in decisions of other players. Hence, decisions of other players depend on the strategy they used and this variation of decisions is mutually influenced by strategies of players together.

Skill is “the dexterity acquired by repeated playing of the game." [1]. These skills help to improve strategy of individual in the game.

Strategy is the ability to make decisions, which improves the performance of an individual in the game and also prevents the opponent or opponents from obtaining positive results.
According to Mintzberg (cited in [2]) a strategy is composed of 5P: Plans, Ploys, Patterns, Position and Perspective.
Mintzberg (cited in [2]) focused in his work on economic strategies. As I mentioned before, Monopoly game was based on economic foundations and therefore the vast majority of information can be applied from economic context to Monopoly context.

Description of 5P:

- **Plan**: Mintzberg (cited in [2]) described *plan* as consciously intended process of action that is what you want to do and how you want to do. In Monopoly this is the base for *global strategy* and *tactics*.
- **Ploy**: According to Mintzberg (cited in [2]) *ploy* means using tricks in game to cover the real intentions. This part is not so visible in Monopoly game. I realized it only due to observation of myself. For example I tried to get two *street properties* of the same colour from two players. Each of them has one of *street properties* which I needed. I had to do my tactics in such a way, that other player would not be able to know what my real intention was. Simulation of this part is quite hard, but it is necessary to mention that such point exists in strategy.
- **Pattern**: The author (cited in [2]) described *pattern* as consistent behaviour and process from strategic thinking as a result of intentional activities. In Monopoly it means to do actions according to our chosen strategy. It is consequent or resulting process.
- **Position**: As Mintzberg (cited in [2]) was interested in economics he explained *position* as an acceptable location of an organization in a business environment in consideration of a competition in this environment. In Monopoly it is very similar, it is the position to competition, how strong is a strategy to other players.

- **Perspective**: According to Mintzberg (cited in [2]) *perspective* is the vision of direction of current strategy. In Monopoly it is necessary for a player to realize when his strategy is not right or his doing of certain act is not right. For example if he bids on auction it is absolutely necessary to know what is the limit, to see that this process brings him to big troubles in future.

According to Papula [3] the absolute base for strategy is strategic thinking. He again focused on economic perspective of companies, to find and develop certain opportunities which can affect the direction of companies in future. He characterised strategic thinking by specific features which I transformed for needs of Monopoly game. The following features are:

- **long duration:** Papula [3] described *long duration* as viability and profitability of organization in the longest term. In Monopoly it means how long is player able to be long-term in profit. In Monopoly there is important to know that the principle of this game is not to have as much money as it is possible. The purpose of game is to bankrupt other players. In certain situations it is much more efficient to use money for developing *street properties* than save money for future. Players who have a lot of money but only few *street properties* without *houses* on them they will lose as first one. Therefore this feature of strategic thinking, to be long-term in profit, is very important.
- **extrovertedness**: The author [3] described it as a development of a strategy with an environment. It means to focus also in external thinking not only in inner system ability. In Monopoly it is oriented on changes in the environment of the game. If board is changed then player's strategy has to be also changed according to it.
- **competition in thinking**: According to Papula [3] *competition in thinking* means to have positive results in competitiveness among other business units. In Monopoly it means to know what is valuable, to have certain scale of valuation of importance of particular situations in game. For example to know that if player owns whole colour block of *street properties* then other players have to rival with him and try to deal among themselves to get to the same level and even be better.

- **goal orientation:** According to Papula [3] *goal orientation* means to have basic and united opinion on goals, what is the goal of current situation according to the final goal of organization. This feature is very suitable in a strategy. It is actually the base of *global strategy* in Monopoly game. If players do not know their goal, they just play Monopoly without a certain vision in future then they react only on current impulses, which from the global perspective can have a negative impact on their playing.
- **operational orientation**: The author [3] defined *operational orientation* as an adaptation on serious changes, which can occur during certain situations. In Monopoly it means if one player has a certain problem which second player can take as a big advantage and create particular pattern of strategy for it then the second player has to be able to change his pattern when the first player masters his problem. It is absolutely necessary to develop a pattern of strategies according to environment.
- **simplicity:** According to Papula [3] it means to not create a very complicated system. Endeavour to have clear and simple thinking, to choose a simple conclusion in particular situations. In Monopoly there can be a situation that player X wants *street property* 1 from player Y. He thinks that player Y needs *street property* 2, which is owned by player Z. He decides to deal with player Z and change with him certain *street property* from his own for *street property* 2. And then he wants to deal with player Y and change *street property* 2 for *street property* 1. This is absolutely complicated system. And it does not have to work. The simplicity is very important in strategic thinking.

Strategy from the **game perspective** is often described as a *player's strategy* in a game.

According to Prof. RC Chakraborty [4] *player's strategy* is "a complete plan of action for whatever situation might arise. It is a complete description of how one will behave under every possible circumstance, telling a player what to do for every possible situation throughout the game. It is a complete algorithm for playing the game."

This definition according to my opinion includes two dimensions: what to do and how to do it. These two dimensions I decided to divide into two groups. First is *global strategy* which is oriented on overall perspective of playing, on goals of players and their fulfilment. It is the

player's vision for success. And second is *tactics*, which is a set of actions in particular situations which are used to fulfil the *global strategy*. Each action is a *decision-making* in a certain situation. *Decision-making* is process to do *decision*. And *decision* is a choice between two or more possible actions. In other words the *global strategy* is a main plan, what to do. The *tactics* represent group of decisions for a player in particular situation which are significantly influenced by the *global strategy*. It means to perform action in consideration of current situation and the *global strategy*.

Monopoly game can be designed according to these three main factors in the process of playing, *chance, skill and strategy*. Graphical representation of it can be seen in image [fig2]. Kumar [1] in his work said that Monopoly can be placed between *chance* and *strategy*, but then he mentioned that deeper analysis showed the game is more about chance than strategy. According to many other resources [5][11][12][19] from this work and according to my own observation I cannot agree. I agree with his first statement, that Monopoly is between *chance* and *strategy*. It is possible to win Monopoly without suitable strategy only due to luck, because *chance* influences the playing, but on the other hand possibility to win it without suitable strategy is very low. Therefore I put Monopoly between *strategy* and *chance*. The Author [1] did not put factor of skill into Monopoly game. For him skill is something like either physical equipment acquired by a repetitive playing or mental equipment. But he identified the mental equipment with the strategy. In my opinion his own definition is correct but his understanding of it is not correct. I can say that *skill* is ability to influence strategy by acquired experience from repeated playing. Therefore I put Monopoly in place which is possible to see in [fig2]. In my opinion, Monopoly partly depends on chance, which represents a coincidence caused by a roll of dice, whilst this chance influences each player in a particular game. However the choice of strategy and decisions, which players make during their playing, leads either to success or to loss. Therefore Monopoly is closer to the factor of *strategy* than to the one of *chance*. On the other hand it is not so far away from the *chance*, representing the option of randomness, which can form the playing to such an extreme that a beginner can beat a professional. As Tim Darling [5] said: "Monopoly is a game of luck, strategy, and people skills. No strategy will guarantee you a win; that's one of the reasons why Monopoly is so

interesting. In any particular game, a newcomer can beat a lifetime champion." Skills are also very important in Monopoly game because thanks to repetition of playing a suitable strategy is developing. Strategy itself can be good or bad, only thanks to repetition of playing and searching for new ways of improvement, what to reduce or what to add, a player can achieve the level of an expert. Therefore the proportion between *strategy* and *skill* is more or less equable.

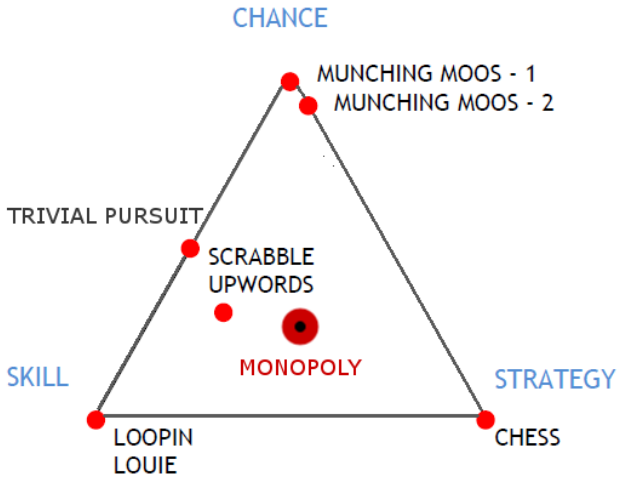

fig 2: Sample of placement Monopoly into three factors of designing game. Monopoly is game partly about chance and luck, but mainly it is game about strategy. Skill represents an ability to improve strategy through experience from repeated playing of game. On the figure there are more games for better representation and understanding of placement for Monopoly. (Figure adapted from [1])

1.2 Defining the sub-goal for the cognitive approach

According to placement of Monopoly within the triangle in [fig2] and according to dividing a strategy to *global strategy* and *tactics* I suggested my **sub-goal**:

The sub-goal of this work was to find a suitable adaptable global strategy and tactics for playing Monopoly game which can be applied for agent-player.

For acquisition of knowledge for achieving this sub-goal it is suitable to apply subsequent three steps [6] in specific manner:

The first one is to study the design, rules and mechanism of game, reports and reviews of

strategies, or alternatively communicate it with developers of particular game. The second one is to observe particular game, participants, their strategies and decision-making. And the third one is to play current game by ourselves and obtain knowledge through that way. All these methods are correct, however if the game is not played personally, it means if researcher did not play the game at all, then there is a big chance to come up with certain misunderstanding or omission of needed information. Therefore it is advisable to focus on the third step from the beginning, to play game personally and after that gradually add other two steps.

2. Observation methods

In this part I gave an introduction to observation. I applied knowledge from anthropological and sociological researches of participant observation into thirteen steps of rules and I modified it for observing players during Monopoly game.

2.1 Procedure of observation

Researchers [7][8] observe and make interview with participants to understand their behaviour, decision-making, negotiation and on the base of these information they know how to create certain model of functioning of particular society. The observation is a process, which allows researchers to learn something about activities of participants in a natural way. The observation during playing Monopoly game offers researchers a possibility to see how players interact between each other, when and how to show emotions during their decision-making, how much time they spend on various activities, etc.

The question is how to lead such an observation. Leading of observation includes diversity and attention of observer, which includes ethics in the sense to give player or other community knowledge about purpose of observation, to preserve anonymity of players, etc. Next it includes knowledge how to establish a relationship between players and observer. This process is called “hanging out”. It is actually the process of getting confidence of participants. For leading an observation it is good for researcher to know when to observe participants or what to observe on them. Also important is to make notes.

One can describe three types of observations [7]:

1) **Descriptive observation** – a researcher observes anything or everything without an engaging any questions or notes.
2) **Focused observation** – a researcher continues by adding some interview into observation, some questions about reasons of decisions of players and so on.
3) **Selective observation** – it is a systematic observation, which is focused on separated activities in detailed description.

Subsequently a question appears, how one can know what to observe. There are some proposals for researchers how to study, what is going on and how it is going on.

- How to sort regular and irregular activities, to see a situation or an event from various points of view and perspectives and take it as a whole.
- Then to search for information from similar activities and apply them to own observation.
- To discuss with other observers, etc.

The special type of observation called *participant observation* can be divided into three phases: participation, observation and asking. *Participant observation* requires a certain amount of deception which means, that observer integrates into group to such an extent, that participants stop to take him as an observer, but more likely as one of them. In Monopoly game it is easy to achieve this by participation in the game as one of the players. This however may create problems such as refusal to answer particular questions of the observer because it can be a contradictory for their strategy. But on the other hand the researcher is the closest to participants and their decisions.

Participant observation is one of the most frequent methods for observation of participants. There are four main reasons why to use the *participant observation*:

1) It allows to perceive fine activities of other players, which otherwise would not be visible or noticed.
2) It eliminates the change of behaviour of players. Because when participants know when

they are observed they start to behave in other way.

3) It allows participant to develop right questions, because he experiences the same things as other players.
4) It gives the observer a better understanding of how current play works, how a social behaviour of players works in sense of their mutual reactions and not only like individuals.

Of course there are several restrictions of *participant observation* method. But it is related mainly to particular observer in sense of various approaches of men and women, about different knowledge in current issues and also about bias caused by human interpretation.

Researchers often keep certain rules [7][8].

1) First they observe and then they ask. They try to find out some patterns through so-called *silent observation*
2) During observation of participants it is appropriate to watch needs and not only solutions. For instance if we focus on observation of players during Monopoly game then we will see that except watching the final decision-making it is also suitable to watch the need which forced the player to do it. It is for the reason that similar need can lead into other outcomes, maybe in next stage of game, maybe with other player, etc. For example if somebody has a need to buy a *street property* on violet box in Monopoly game and finally makes a decision not to buy it, then it is necessary to watch not only the outcome that the player did not buy it, ergo not only reasons why he did not buy it, but also the need which forced him to buy it. Because this need will catch him in a next stage of game and again create a similar decision-making situation.
3) Next there is appropriate to avoid an unnecessary disturbance. Because participants, in our case players, are not pleasant or happy that somebody observes them, therefore they change their original pattern and this can have an impact on observation. Therefore it is suitable to avoid unnecessary disturbances and also it is important to be unobtrusive in the sense of large number of questions, there is a need to find a balance. Also there is a need to find this equilibrium in time.

4) Other important rule during observation is to notice a body language, facial expressions, because these information can help to give some knowledge about feelings, motives and attitudes of participants.
5) When we want to use questions it is very useful to use questions with an open end, because in this way participants can answer it in their own way with their own words. And it is necessary to record their own words and not only paraphrase them, because during next analysis they can lose their original meaning.
6) It is good to look closer on decision-making of an individual. To find details which influence him. For example the environment, other players, inner problems, etc.
7) Of course an observer has to know the environment, the game rules and he has to prepare the system of observation before he starts to collect data.
8) Important is to keep an attention, to be able to change an angle of perspective from wider to narrow one. It means to be able to concentrate on an individual, his activities, interactions and then again turn the attention to the overall situation.
9) Important part of observation is making notes. It is very effective to make notes during the observation, during playing Monopoly. But if for some reason observers want to omit making notes during experiment, then it is good to focus on started and ended remarks in conversations because they are easier to remember. In this case it is appropriate to make breaks during a game and utilize the time for noticing of found information. In conversations it is suitable to focus on who speaks to whom. The observation with notes during experiment is better because an observer can be concentrated on details of game, details of behaviour and decision-making of single players.
10) It is very good to observe demographic differences among players. It is good to have information about their age, gender, etc and find out an influence of these differences on the decision-making of players, on their dealing with others, etc.
11) Observer should separate his thoughts from observed thoughts of players.
12) Important fact is to notice date, a period of time, place, etc.
13) Researcher should be always aware what he wants to find and what he observes. His aim is to create a model which helps to understand the meaning of player's decisions.

According to these 13 rules I observed my participants in *participant observation*.
First I observed participants without any questions, so it was just the *silent observation*. It was good for pre-observation because I needed to get into the game. By means of *silent observation* I found a way how to use these rules practically. It enabled me to identify where I should put my focus on in further observation, what to note down, which behaviour to observe, etc.
Then I decided for two other different approaches of observations, *participant observation* and *questionnaire observation*. As I mentioned before, the *participant observation* is very effective method for observing participants in a game like Monopoly. Because I need to be a real part of the game and also it is not so easy to find a proper amount of participants, therefore it is good to have one player (myself) in addition. On the other hand, questionnaire method gave me such information from players, which they did not want to share with other players during the game.

I decided to make notes about date, place and certain information about participants like age, education, etc. But first I decided to explain them the meaning of this observation and guarantee them discretion with respect to their names.

In my second observation I decided to ask participants the basic question: why? Why did you decide like that? It is good to use questions with open ending and this question was suitable for me.
I decided to make notes from answers to this question. Based on previous articles I knew it was good to do it in two ways: Direct notes – no paraphrase, but to try to write the same answer like player used. And also to put there my own notes about player's answers. I decided to make these notes in Slovak language for two reasons. The First was that turn of participant was fast, therefore I did not want to disturb them by a long delay of making notes. The game by itself was long and with my delaying it would have been much longer. The Second as I said, it was good to catch a direct answer of participants. This was very important for next analysis.

I decided to observe current person and also the whole situation. It is necessary to apply knowledge from observing one person considering the whole situation to ensure the generalization of acquired data from observation.

And finally I decided still to have the idea of what is my goal, what I want to do with answers of participants. Therefore I made my notes according to this goal.

2.2 First participant observation

When I used *participant observation* for the first time I observed two players during the game. One of them was I as participant and observer in the same person. Second player was 22 years old man with bachelor degree of education. He had never played the game according to the original rules. He only played according to the family rules. Therefore he was slightly stressed by this game. The game lasted only 40 minutes.

According to this *participant observation* I decided to add several other things. I found out that many times participants answered the question „WHY?" very similarly and therefore sometimes I decided to omit their answers, because I heard them already during game and instead of that I put there some my notes, what I thought was the reason for making current decision.
I found out, that it is very good to observe myself too. Because actually I am also a participant of the game, I also have to do some decision-making and therefore it is perfect to observe myself as well.

The most significant finding in this observation was the problem with original rules. People play according to their own rules. Therefore I decided to do research into this topic.

2.2.1 Original versus family rules

After first observation I realised the problem with original rules. The Monopoly game was created in 1933 [10]. Since that time millions of people all over the world have played it. And it is translated to many languages. The rules of original game have never changed. Everybody can read these rules in handbook which is the part of Monopoly game. However only few people play this game according to the original rules. Is it not weird?

Why is it like that? The explanation is simple. Monopoly is a game where people do not read rules. Rules are given in oral form through generations, from parents to children.

A question arises , what was the beginning of changing the rules. How come, that since 1933, since the first release of game, people around the world cooperatively changed the rules. What I mean is that they changed them according to nearly the same pattern, independently from each other and in different countries. The answer to this question is that Monopoly has never been a game played by gamers but by families. The most of these changed rules were created to satisfy children, who did not want to play according to rules of adults. Children prefer simple rules. And children are main players of this game, therefore the change of this rules was inevitable. These modified rules are known as family rules. [9] [10]

It is an interesting fact, when we look for instance at Italy, there are these family rules taken as the official rules. Of course the main reasons for it were financial. Italy in 1935 was ruled by „fascist law“ and when one businessman decided to bring Monopoly game to Italy, he had to modified it, because English and American products were not allowed there. First he changed the title from Monopoly to „Monópoly“ and also he changed some original rules to family rules. This way he obtained copyright on rules of Monopoly game in Italy [10].

When we better look on the family rules [9] we will understand why these rules were adapted around the world. Imagine Monopoly game played by mother, father and two children. We will look on the rule of buying properties. First child steps on a property, which the second

child needs. And according to family rules there are only two possibilities:

1) The first child decides to buy the property to make the second child angry.
2) The first child decides to ignore the property and not to buy it. This decision will please the second child because it will give him a hope to buy his wished property later.

What is important to understand is the fact, that in the first case the second child will be upset. But this agitation is not against the first player. He takes it as a destiny, because it was caused by dice. The dice made a decision.

But what will happen if this game is played by the original rules. In the official rules it is said that if player does not have any interest to buy a property then banker is required to offer this property into auction for other players. However the player who refused the property still has a chance to participate on the auction. The principle of auction is to offer such amount of money for an asset with which the player will be able to defeat other players in this trading. This rule is very important because it creates a big amount of strategic steps. For instance if a player who stays on a property sees that other players do not have enough money to purchase the property he can buy it for really small amount of money, because other players cannot compete with him. And a lot of other strategic steps may happen due to this rule.

In our case there will be three possibilities:

1) The first child decides to buy the property to make the second child upset. It means that this option is the same.
2) The first child decides not to buy the property and hence the second child is happy, because it gives him a chance to buy the property in auction.
3) However if the second option happens and father who will also want to buy the current property involves in it, the war will occur between father and second child. And if it ends with victory of father, then second child will not take it like a fact caused by random throw of dice but as injustice from father's side in this case. What will probably end with crying and family game changed to horror.

Remarkable fact in family rules is that these rules made game less cruel. For example in game there is one free box called free parking.

This „useless“ box irritated many people around the world and they figured out various innovation. One of the most frequent is that taxes which should be paid to the bank are not given to the bank but to this box. And when player steps to this box he can take the money. Problem of this is that if players have possibility to have income of money even if they do not have any properties, the time of game reaches unpleasant point and game becomes lengthy [10].

Other changed rule is the amount of money paid to a player when passing over the start box. Most people increased the original amount to double amount of money. The nature of Monopoly is to bankrupt other players. And this nature is hard to achieve when players have enough money from artificial resources.

Other rule, which allows to buy *houses* on own *street properties* anytime during game is changed to the possibility to buy *houses* on a *street property* only if a player stays on current *street property*. This rule is an absolute disaster because in this way the game becomes random game about luck. And the time is catastrophically prolonged [10].

Another important fact in game is the limited amount of *houses* and *hotels*. This originally leads to various strategic steps, e.g. to keep four *houses* instead of one *hotel* in order to make it impossible to buy a *house* for other players. This strategic rule is mainly effective for bigger amount of players. And what happens according to the family rules? The answer is ridiculous: creating new tokens of *houses* and *hotels*. Even some people complain about lack of tokens in the box [10].

Other „cruel“ rule of Monopoly game is prohibition of loans among players. If a player does not have any money and also he has sold all his properties, *houses*, *hotels* and suddenly has to pay some fine or something else, he goes bankrupt and leaves the game. The family rules

however do not like this rule and allow loans from other players or allow repayment of debt a few rounds later, what really prolongs the game.

Conclusion from this is that people around the whole world have adopted the family rules of playing Monopoly game [9]. Vast majority of people do not even know that the original rules are different than their own rules. This modification of rules created minimally two big problems. The game has become really long and the coincidence plays the main role.

2.3 Second participant observation

In the second *participant observation* I had also two players. The first was I and the second was a new one. He was 20 years old with graduation. He also played only according to the family rules before. This game lasted 1h and 50 minutes.

2.4 Third participant observation

In this observation I had four participants. I was one of them. The second one was participant from the first observation, the third one was participant from the second observation and the fourth one was a new player. He was 24 years old with graduation. He played this game for the first time. He did not play before, not even by family rules. This game lasted 3 hours and 30 minutes.

According to these observations I realized several points. Important is to notice the attitudes of players. Sometimes players have a tendency not to deal with others. And therefore if player A wants a *street property* from player B and also from player C, it is not reasonable to deal with player A if it is obvious that player B does not want to sell anything. It means to be aware of personality of players. Therefore it is necessary to notice nature of participants during the game. For example aggressive participant have one style for game, etc. In a more detailed way I focus on this topic in the part of summarizing the cognitive approach.

2.5 Questionnaire method observation

After this observation I realized that some players make irrational decisions. In a few cases they made a move which was absolutely not profitable for them, moreover, it was profitable for opponents. There was also a problem with their secret plans and therefore I decided to make another type of observations through questionnaire method, where they should not have refrained to tell me their strategies, because they would take notes privately. And also I could observe them and after game ask them about irrational decisions, if I noticed them through observation.

I created the internet webpage for noting down reasons of participants for making their decisions and expressing their emotions. The sample of this method is in figure [fig3].

After this observation I had several very important information about playing this game, which was already a base for creating certain strategy, but without studying other researches on this topic, my analysis of these observations would not have been correct, because I could make some mistakes in analysis in the sense of omission of certain important facts and therefore I decided to do research from other studies on this topic as well.

Rounds	Money +/-	Why did you decide like that?	Your emotion?	Additional events (what & why)	Your emotion?
1	-200	taxex		-	
2	-105	don't want to buy because it is only at the beginning - little money		buy on auction - but I didn't want it.	
3	-150	I bought orange middle because it has good position.		-	
4	0	parkovisko		he has both - vodarne, energ. z.	
5	0	palisady red one to acution - I wanted to buy it for less money but player gave the same prise, so I let it to him.		in auction he bought green one for 300. I didn't have enoght money, therefore I only want to deal for heist prise for him.	
6	-125 -280	I bought florianske namestie, he doesn't have none of it and it is good to have cards.		dunajska - I bought it during acution because I have one of it.	
7	0	chance - moving on start, but I was in front of start..so nothing special.		-	
8	+50	chance		-	
9	-200 -50	50 payment to player		I bought in auction green one...I didn't want it...because he has already one of it..but I wanted to deal in auction. but after I had to buy it for 200.	

fig 3: Sample of questionnaire observation method. Every player answered the question "Why did you decide like that?" after each turn. Then he also added certain additional events, which represented his decisions after opponent's turn. He also noted down his emotion after his decision and emotion after additional events. (Figure taken from own observation webpage)

3. Results from observations

As I mentioned my favourite question during observation was “why?”. I asked this question almost after each move of my participants in the game. I processed player’s answers into *tactics* rules later in analysis, but for better understanding I give example of my notes from observation of participants here:

Question: “Why did you buy this *railroad*?”
Answer: “Because *railroads* generally produce big amount of money in the first stages of game”
My note: “There are four *railroads*, to own all of them means to have possibility to earn a lot of money. Other *street properties* are effective after building *houses* and *hotels* on them, but owning of all four *railroads* is effective immediately. And probability of landing on them is high, because they are four in one round of board.”

Question: “Why did you stop bidding in auction?”
Answer: “Because I did not want current property, I just wanted the opponent to buy it for more money. And I stopped because I was afraid that the opponent would not buy it and then I would have to buy it.”
My Note: “Mentioned player could see that his opponent would want current property, but he did not have a lot of cash. Therefore he was afraid to bid more in auction. It is necessary to track on opponent’s money. ”

Question: “Why did you pay for getting out of jail?”
Answer: “Because I needed to be in game, I had a lot of money, but only a few properties.”
My note: This note came later. “The player finally lost as the first one. He did not buy properties at the beginning, he probably wanted to keep a lot of money for next stage of the game, but problem was that later there were no free properties. When other players started to build *houses* on their *street properties* he started to lose his money very quickly and he did not have any source of money, because he did not have any whole colour group. Therefore he lost as the first one.”

During game I also made notes about status of the game. For example:

My note: "Player 1 bought property for $260 and he does not have any reserve. His rest of cash is only $100. Player 2 has $1200, player 3 has $800 and player 4 has $400. We have been playing for 50 minutes."

These were examples of my taking notes, but originally this observation was in Slovak language, therefore this is a translation of it and I also substituted names by words like opponent, player 1, etc.

Example from *questionnaire observation* I have already introduced in figure [fig3]. But after this observation I asked participants certain questions:

Question 1: "Did you have a strategy you followed?"

Answer of player 1: "I played it first time. Before I played a similar game called Investor. When I saw the opponent did not have enough money then my strategy was to buy everything at low prices in auction, because he could not rival me."

Answer of player 2: "Yes, I wanted to have a lot of *houses* at the beginning. I did not realized that I did not have enough money."

Question 2: "Were there events requiring or demanding a change in your strategy? Which?"

Answer of player 1: "First I did not know how to play it in a right way so I did not have a certain strategy. But after realizing the fact that my opponent did not have enough money I created my strategy. So it was an event."

Answer of player 2: "When Player 1 bought everything at low price. I was even afraid to throw dice because I knew if I got on free property I would not be able to buy it and he would buy it at low price. After that I did not follow some special strategy. But now I know it is useful to buy *railroads* and also *utilities* because it can make a lot of money at the beginning of game."

Question 3: "How many times did you change your strategy?"

Answer of player 1: "Only one."

Answer of player 2: “I think only in that one case when I realized it is not right to spend so much money at the beginning.”

Then I asked them about irrational decisions, which I noticed.

Player 1

Question 1: “Do you remember the situation, where you did not notice that player has one of light blue cards and you bought *street property* from this colour group though you could use your not so big amount of money for other properties?”

Answer 1: “Yes, it was my lack of attention.”

Question 2: “Why did you decide like that in this situation?”

Answer 2: “Lack of attention”

Question 3: “Did it affect your strategy?”

Answer 3: “No”

Player 2

Question 1: “Do you remember the situation, when you bought every property in the first round?

Answer 1: “Yeah, now I think it was bad. I think it is more proper to keep a reserve of money during buying properties in the game.”

Question 2: “Why did you decide like that in this situation?”

Answer 2: “I don't know, it was just my wrong strategy to buy almost everything at the beginning.”

Question 3: “Did it affect your strategy?”

Answer 3: “Yes, my strategy crashed after his buying of everything at low price :)”

Findings from observations I had to analyse for getting results in the form of wanted *tactics*. Therefore, first I wanted to make an introduction to analysis, then to apply certain rules and steps for evaluation of my findings and finally offer results.

3.1 Introduction to analysis

How to construct a methodological framework for game analysis? According to Konzack [11] there are seven different layers of computer game: "hardware, program code, functionality, game play, meaning, referentiality, and socio-culture. Each of these layers may be analysed individually, but an entire analysis of any computer game must be analysed from every angle. Thereby we are analysing all technical, aesthetic and socio-cultural perspectives." [11]

To create a game like Monopoly in virtual environment it is necessary to consider and analyse all these layers. However there are three main dimensions which characterize this game according to the consideration of major elements in games with virtual environments [6]:

- **Game-play:** The dimension which includes acts of players, their strategies and motives.

- **Game-structure:** The dimension which includes rules of game and simulation of these rules.

- **Game-world:** The dimension which includes content, topology, design and environment of game as well as textures and similar details.

From this we it can be concluded, that for creation of strategy according to which players will play Monopoly it is necessary to focus on Game-play dimension. However it is always inevitable to be aware of rules, i.e. Game-structure, because without rules even if we had some virtual environment, the world, we would have only some free play or another type of interaction, but not Game-play [6]. Similarly, to simulate a player's acts, the environment, Game-world, is needed. It is important to know how changes of environment influence a

player, his actions, strategies, etc. Thus, for example, if strategy of player during Monopoly game is to gain whole block of orange colour *street properties* and subsequently one of opponents buys particular *street property*, what changes the environment of game, then the strategy of player has to be changed as well, i.e. it has to be designed to adapt to current environment, to settle with new situation.

Game-play is also possible to be divided into several sub-dimensions [6]: player's actions, player's strategies according to which he acts, social relations, player's knowledge, which also includes player's memory, communication, etc. In this work I focused on the player's strategies from global long-term perspective.

In collecting information about the game it is suitable to use as much resources as possible. Playing is essential, but it should be combined with other sources of information, advice, reviews, etc. Games are performance-oriented and our own performance might not to be always the best one, especially if we analyse it ourselves. Therefore, for analysis it is necessary to have knowledge from other resources and analyse them in the way where they came from, what they can offer, why these kinds of resources, etc. And in conclusion it is suitable to match results with empirical data.

3.2 Rules and steps for analysing findings from observations

Analysing means to take the key parts from research and observation [7]. These key parts are relevant to the purpose of strategy which will be applied to the strategy through examination of qualities of individuals and understanding the whole contribution. Of course each analysis reflects researcher's attitudes to the topic and therefore despite the fact that it will contain certain amount of subjectivity it is necessary to reduce it by offering different points of view. For example to consider similar situation through position of more players and from own perspective.

In the case study [12] they offered few basic steps to analysis:

First it is suitable to get general impression. It means to have an idea of developing individual strategies during time. If it is good or bad, how it is performed, if it is changeable, and mainly if particular player was the winner. Then it is important to concentrate on the environment of game. Which parts of game are beneficial and which cause problems. Which cause main changes in game, which produce new opportunities. And what is the character of competitive environment? Then it is important to focus on individual. What are his strategic resources, and which he should have. From this player's perspective, strategic resources mean the skills-base of playing. It means in analysis to concentrate on acquired means and consider which of them are appropriate for efficient strategy. And which of these are advantages and which disadvantages for competitors. The purpose of it is to find strengths and weaknesses of individuals and their strategies. Then it is important to evaluate it and create some options of possible strategies. Evaluation should go through following questions:

Which are the most suitable options of strategic decision making of player? Would particular player's strategies achieve competitive advantages or they just stagnate and try to endure the state of events? And which of these strategies are feasible for implementations in the sense of possible changes during play?, etc. And then it is necessary to relate own analysis to other resources. There are a lot of strategic analyses of playing games like Monopoly and therefore it is suitable to compare these analyses, take the main ideas from them, again analyse them and incorporate them in own analysis. After that if analysis gives the answer to main questions which allow to identify strategy it is already possible to deduce certain conclusion and then to build strategy.

I conducted my analysis according to mentioned advices. These advices was processed from the case study, but I took only key parts and transformed them for needs of my own analysis. I made mentioned basic steps of analysis. I had a look on decisions and strategies of each individual player. I tried to find strengths and weaknesses of players. Then I concentrated on overall process of game, I tracked environment of game, which parts of game were beneficial for players and which were not, which caused the biggest changes, etc. I used the question of the case study [12] to analyse my data and came up with following categories.

3.3 Tactics – rules for knowing how to decide in local situation

BUYING

- Buy *railroads* because there are only four in the game and it gives you high chance to make money if opponent lands on it, especially if you have all of them.
- Buy *street property* if you do not own any at the beginning of game.
- Buy *utility* if you already own one because there are only two.
- Buy *railroads* for the purpose to sell them to opponent who owns two or three of them.
- Buy *street property* from one colour group if you have one of them and nobody else has.
- Buy each property if you have a lot of money.
- Buy *street property* if it is the last one to complete opponent colour group.

SELLING

- Sell your own properties to buy *street property* for completing whole colour group.

AUCTION

- Buy property for low price in auction even if the property is not interesting for you
- If the opponent has enough money and he wants to buy the last *street property* from colour group in auction, then bid him over original price.
- Bid on auction; do not let opponents to buy property for low price.
- Put every property to auction if opponents do not have enough money to rival you.
- If other players do not have enough money and one of them tries to bid you in auction, let him to buy the property for certain price to make him very poor, especially if he is far away from start and close to your properties.

DEALING

- Deal with opponent who is going to bankrupt as much as possible, because he does not care so much about selling his properties.
- DEALING - low probability to buy some property from other players for money, high

probability to change it for another property.

- Focus on changing properties with other player and not on trying to buy from them, because they prefer to change property instead of selling them.
- Do not change properties with other players if they really need it and you have a lot of money and you are in prosperous situation.
- Do not be very merciful, because the game can turn very quickly to your disadvantage.

TOKENS

- If an opponent is near to bankrupt then bankrupt him as soon as possible by buying tokens in front of him.
- In the case you do not have enough money then sell tokens which are far away from other players.
- Buy tokens if player is in front of your *street property*.
- Do not buy tokens if you do not have sufficient reserve of money.
- Consider a problem of buying *houses* on rich *street properties* because these *houses* are very expensive there.
- Do not buy tokens if you are standing in front of opponents *street properties* with a lot of tokens on it.
- Consider the last *street property* from each colour group because it is the most expensive for renting, to have a token there means to have more money from rent.
- Buy tokens immediately when you have enough money.

JAIL

- Go out of jail in the first stages of game, because there are a lot of free properties to buy.
- Stay in jail later in game to protect yourself against landing on opponent's property.

MONEY

- Always keep some money reserve.
- Always track how much money the opponents have.
- In one observation, the first half of game, one player had a lot of money, much more

than others, but he did not have enough properties and also any completed colour group, and he bankrupted as the first one! Therefore use money, do not only keep them.

This categorisation gave me information about what to do, how to decide in certain situations. These situations are found during observations. There can be more situations, but I observed and found these ones. And this is what I called *tactics* in the game. However I needed to find also *global strategy* and therefore I started research into literature for the purpose of finding information suitable for creating *global strategy*.

4. Game dynamics

Game dynamics are factors in game which change and influence strategy of players. Before I start to speak more about game dynamics I will tell something about probabilities because I found four main game dynamics in Monopoly which are based on probabilistic evaluations.

4.1 Introduction to probabilities

In Monopoly game there are 16 cards of chance and 16 cards of community chest. Amount of money from expenses and from incomes of these 32 cards together is 485 in favour of player in the first stages of game, without tokens in board. Because with tokens there is possibility to pick up one card from chance and one card from community chest which is in big disadvantage for particular player. He would have to pay a lot of money for his used tokens.

As Stewart [13] explains, in Monopoly players throw by two dices to move from one box to another. When a player throws the same number at both of dices it means he throws double, then he has to repeat the throw and his first one will be added to other one. When player throws three times double then he has to go to prison. It follows, that maximum number of boxes, which the player can move about is 6+6, 6+6, 6+5 = 35. Every player starts from box called „GO“. Some rolls of dices occur more often than others [fig4]. For instance for roll with

number 5 there are only four possible throws: 1+4, 2+3, 3+2, 4+1. However the roll of dices with number 7 occurs more often than others: 1+6, 2+5, 3+4, 4+3, 5+2, 6+1. Number of all possible mutual rolls of dices is 36. It means that probability of 7 is 6:36 or 1:6. The higher roll of dices than 7 loses the possibility of a frequent throw due to the fact, that roll of dice contains the highest number 6. For instance for roll of dices with number 8 it is impossible to get state 1+7, it means that this option is out. For 9 it is 1+8, 2+7 what is impossible, etc. Therefore the roll of dices with number 7 is the most probable. Monopoly was created in such a way, that seventh box from the start is box with CHANCE. This little eliminates advantage of the first starting player. On the other hand the other most probable possibilities of a throw are 6 and 8 with probability 5:36, which leads to boxes with possibility to buy *street property*, what gives advantage to the first starting players, because if the first player buys one of these *street properties*, then there is a big probability that other players will land on it and they will have to pay rent from the beginning of a game. Therefore the game is design in the way that expensive *street properties* are in the second part of board.

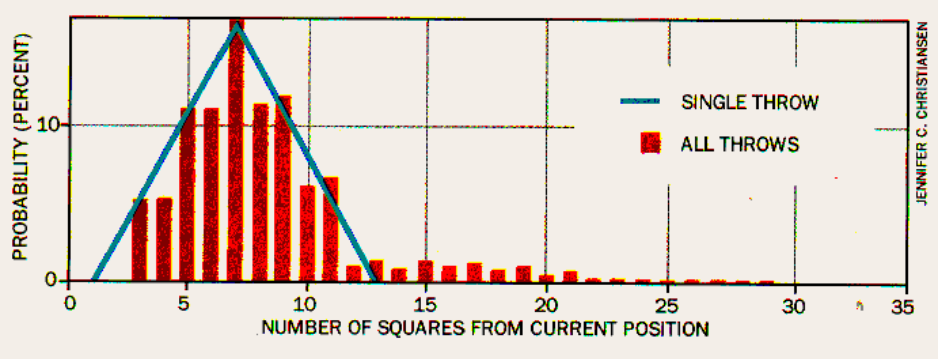

fig 4: Sample of probability of a move. Each player has to roll by two dices and this figure shows the probability of rolling particular number on these dices. If player throws the same numbers on his dices then he will have to repeat his throw. If player throws three times a double then he will have to go to prison. Therefore the longest move is only 6+6, 6+6, 6+5, what is 35. But probability of such move is very low. Number 7 has the biggest probability. (Figure taken from [13])

When we look on figure [fig4] then we can see possible specification of one decision from *tactics* which I formulated above. It was about buying tokens on *street property* if opponent stays somewhere in front of the *street property*. By the specification of this tactics I mean to know when it is the highest probability of landing on current property for an opponent from particular position. If a player stays seven boxes in front of my property then the probability of

landing on my property is the highest one, which means for me to build *houses* on the property.

4.2 Approaches to understanding Monopoly game dynamics

On the basis of probabilities it is possible to take a closer look into dynamics, which occur during playing Monopoly game. By means of literature I found four main dynamics in Monopoly: exponentiality, buying of cheap *street properties*, period of time for returning investment from buying a property, and number of players. Exponentiality shows that leaders in Monopoly, in later phases of game, become more and more wealthy and losers become more and more poor. Buying of cheap *street properties* shows how to increase wealth in the first stages of game and how this can influence whole process of playing. The period of time for returning investment shows how quickly a player gets his money back. And number of players shows how to change strategy according to how many players play Monopoly.

4.2.1 Exponentiality

Process of game for each player leads to two states. The first one is when a player goes to apparent positive infinity and the second one is when wealth is going to apparent negative infinity [14]. I used word “apparent” because in positive infinity a player can have only as much money as the bank can give him and as long as other players stay in game. And “apparent negative”, because the player goes out of game with zero wealth, which means the bankruptcy. What is even more important is the fact that stream of wealth to positive or negative infinity goes by exponential tendency.

This is also true in real life. As Shakespeare wrote in Julius Caesar before the version was changed to non-mathematical form: "There is an exponential tide in the affairs of men, which, taken at the flood, leads on to fortune; omitted, all the polynomial voyage of their life, is bound in shallows and in miseries." [14] From this it is possible to deduce also other implication: changes are happening exponentionally. For instance in Monopoly game or in

real rival business there is not generally something like linear tendency. It means that if wealth is bigger than zero and income is bigger than our expenses and even the annual income is bigger than previous one, then it is still important to be aware that our profit is an expense of somebody else, especially in competitive business. For example in Monopoly game the main profit of a player is in rents of his properties. And these rents are actually money of his opponents. It means his expenses are income for player who owns property with rent. Therefore it is necessary to take into account that somebody, in this case our competitors, whether opponents in Monopoly game or businessmen in real life want to change it very much. And if the change happens it has exponentional impact on both sides.

From this it is possible to identify feedback systems inside the Game-play and thus determine current states and changes influencing overall state of Game-play. It means that if in Monopoly leaders become more and more rich, then they can penalise other players more and more, what means, that poor players become increasingly poor [fig5] [15].

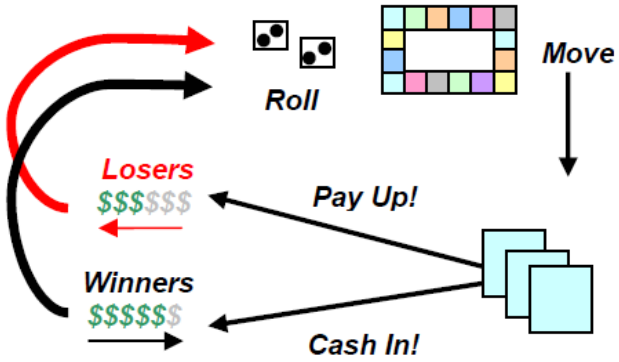

fig 5: Sample of game-play feedback system. If a player is in leading position later in game, then his amount of money will increase exponentionally. Similarly if a player is in losing position, then his amount of money will decrease exponentionally too. The reason is that leaders build more and more and losers have to pay more and more on rents. (Figure taken from [15])

We can conclude from this and also it is confirmed by observation, that it is enormously important to start with good strategy in the beginning of game. In Monopoly it makes no sense to have strategy which leads only to survival, because such a strategy sooner or later ends in bankruptcy.

4.2.2 Buying of cheap properties

According to Frayn's study [16] the landing on any *street property*, where a *hotel* is built, causes a significant hole in the player's financial budget. And the landing on *street property* two times in a row can mean the end of game. It means that it is very important to focus on cheap *street properties* because by building of *hotels* on them it is possible to achieve very quick financial rent-gathering revenue. They used evolutionary strategy for confirmation of their theory and the main result was that people are much more willing to sell cheap *street properties* in dealing process. Therefore there is no need to worry to make bids on cheap *street properties* of other players. It follows that after building of certain amount of *houses* or *hotels* it is possible to earn big amount of money. Even the player can achieve such a state, that other players have to sell their own properties in order to have enough money to pay the rent. It means that from small and cheap *street properties* at the beginning and subsequently from building on them, it is possible to get very quick financial support for buying expensive *street properties* and build on them later in game.

So as John Browne, CEO of British Petroleum said, "No advantage and no success is ever permanent. The winners are those who keep moving." [17].

The only constant in Monopoly strategy is that everything is changing [18]. The meaning of this statement is not so clear. In Monopoly game certain situations may occur when a game looks endless and absolutely not changing. But in my opinion this claim is oriented on progress. Generally it is clear that if all players are good then each of them has to progress, has to go forward. And this is that changing. Otherwise particular player will go to bankruptcy very quickly, which is also a sample of changing. For instance if we stay only in building of cheap *street properties* and we do not try to progress forward and buy also more expensive *street properties* then our initial success may end up with bankruptcy.

4.2.3 Period of time for returning the investment from buying a property

The question is how long a player has to wait for a return of his investment in a property. This question is important because answer to it is based on knowing how

advantageous it is to invest in current land. It means to know whether to buy it or not. And this is the key to understanding how to win Monopoly.

Breakeven time (# opponent rolls)

	Single Property	Last Property on Block	1st House	2nd House	3rd House	4th House	Hotel
Med/Bal	1,050.61	313.81	291.84	87.55	29.18	25.01	21.93
Or/Ver/Conn	702.31	173.97	111.01	36.32	11.71	16.02	14.53
StC/St/Vir	549.78	136.87	125.53	37.66	13.02	21.84	27.87
StJ/Tenn/NY	434.52	108.00	77.97	25.63	9.50	17.05	17.05
Ken/Ind/Ill	418.14	103.62	92.65	30.29	11.47	29.49	29.49
Atl/Vent/Marv	442.95	110.75	83.12	24.94	11.85	32.27	32.27
Pac/NC/Penn	442.51	110.63	92.84	28.23	14.71	38.48	42.07
Park/Board	381.01	120.52	81.64	23.59	12.38	35.56	35.56

	First Railroad	Second Railroad	Third Railroad	Fourth Railroad
RRs	264.61	87.10	32.56	13.01

	First Utility	Second Utility
Utilities	198.79	49.58

Table 1: Period of time for returning the investment from buying a property. It shows how long a player has to wait for a return of his investment in a property, house and hotel. (Table taken from [5])

Prices

	Price of all Titles	Titles + 1 House for whole block	2 houses	3 houses	4 houses	Hotel
Med/Bal	120	220	320	420	520	620
Or/Ver/Conn	320	470	620	**770**	920	1,070
StC/St/Vir	440	740	1,040	1,340	1,640	1,940
StJ/Tenn/NY	560	860	1,160	**1,460**	1,760	2,060
Ken/Ind/Ill	680	1,130	1,580	2,030	2,480	2,930
Atl/Vent/Marv	800	1,250	1,700	2,150	2,600	3,050
Pac/NC/Penn	920	1,520	2,120	2,720	3,320	3,920
Park/Board	750	1,150	1,550	1,950	2,350	2,750

	First Railroad	Second Railroad	Third Railroad	Fourth Railroad
RRs	200	400	600	800

	First Utility	Second Utility
Utilities	150	300

Table 2: Financial perspective of investment. How much money these properties also with houses and hotels cost. (Table taken from [5])

In study by Tim Darling [5] there is possible answer to this question. Table 1 [Table1] shows the period it takes for a player to return the investment from the probabilistic perspective. Investment into a single *street property* has no sense, whilst it does not thwart the plan of opponent to have whole colour block of *street properties*. We can see that only building of whole colour group block makes right sense for making money. According to these

evaluations from table 1 it can be inferred that the most advantageous is to own 3 *houses* on each *street property* in colour-group block. Next it can be seen that it is most advantageous to buy *street properties* from orange colour group, then red, gray and yellow.

However from financial perspective of investment according to table 2 [Table2] it is worth to buy mainly violet *street properties*, then gray, purple and orange. From combining of these two outcomes it is possible to conclude, that the best option from financial perspective of investment and from the perspective of payback time is to buy *street properties* of orange and gray colours. These lands are cheap, building three *houses* on them is also relatively cheap and return on investment is relatively fast.

Conclusion from this is that it is very advantageous to buy orange and gray lands at the beginning of game and build three *houses* on them as soon as possible. According to the tables it is also advantageous to buy *railroads*. Possession of all four *railroads* gives to player a big advantage from financial aspects in the first stages of game, because landing on these *railroads* means to pay a big rent to owner of these *railroads*.

In the table 2 [Table2] it is possible to see continuation of player's strategy in later stages of game. Blue colourations of boxes mean beneficial owning of current properties later in the game. If a player can hold this strategy then according to statistical computations he should have sufficient amount of money for buying new properties or to have good position for negotiation with opponents because they are supposed to be in financial crisis. Then, after owning gray and orange ones, it is effective to start with buying lands from red and yellow blocks and at the end lands from green colour group block and build up *hotels* on them.

In study by Hui Heng et al. [19] they tried to show that a high likelihood of landing on gray and orange boxes does not mean high expected earnings in long-term game, because these *street properties* do not collect or earn so much money from rents relative to more expensive, but less probabilistic for landing boxes of yellow and green colour. Therefore they suggest concentrating on yellow and green boxes, which however, according to observations and other

researches as I mentioned before, is not a suitable strategy in the first stages of game. This strategy should be applied in final stages of game, after sufficient amount of money and a few whole colour group *street properties*.

Regarding the time spending in jail, it is very effective to get out in the first stages of game, when it is still possible to buy new properties. However from statistical perspective there is an exception when it is reasonable to stay in jail in early stages of game and try to roll double with dices. This is when a player wants to complete the whole orange colour group, because in this way the chance to land on these boxes is increased by about 25% [5] from the reason that number 6 and 8 is most probable double roll to get out of jail.

Another very effective step is to hold a certain amount of money in reserve. The observation of participants revealed, that lack of funds can absolutely turn favour of game to opponent. Therefore it is very important to not go below a certain minimum of cash.

4.2.4 Changing strategy depending on the number of players

In study of datascope analytics [20] they noticed that during few games there were still several properties which were not purchased at the end of the game. It means that nobody had the chance to buy these properties, not even in auction, because nobody landed on them. This fact was unpleasant especially for one player there, who owned only few properties during whole game and waited for landing on particular *street property* in order to complete his colour group block. The question is, whether this player had only plain bad luck or a bad luck caused by wrong or poor strategy. The answer for this will show influence of number of players on strategy of player in game. In the study they simulated Monopoly game 1000 times with very simple strategy and with slightly changed rules like for example unlimited amount of money, what gave the opportunity to buy every property as soon as possible. Also each player tried to get out of jail as soon as possible. The sense of this was to find the fastest time which means the smallest number of turns of player, for owning all properties in game. After 1000 simulations at particular number of players from one to ten they averaged results for

finding average number of turns of individual players for owning all properties in game [fig6]. It is obvious from the graph on the figure that the number of turns of player is decreasing by number of players in game. This indication is very interesting, because it shows the average time or number of turns, which a player has available for buying properties before they run out, which depends on the number of players.

The average number of turns of a player for passing over whole board, it means one round, is 5 if player throws at least once the double and 6 if not [21]. This shows the possibility of creating a strategy for preservation of sufficient amount of cash during buying of wanted properties according to number of players in game.

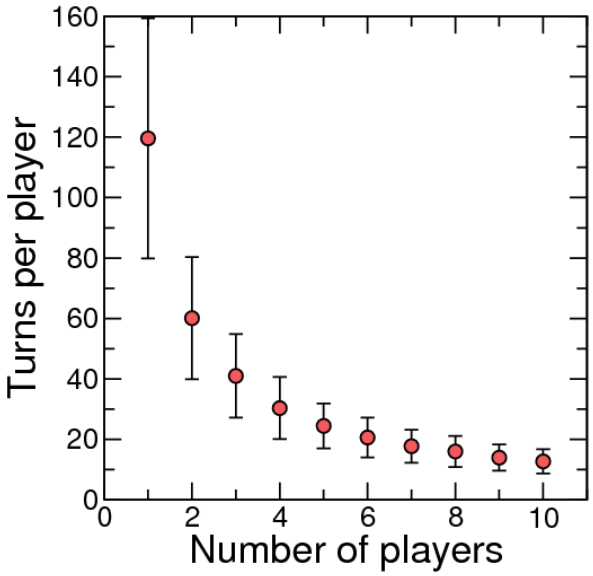

fig 6: Sample of average of player's turns to complete all Monopoly properties. For example a completion of all properties in board by two players will need statistically around 60 turns. (Figure taken from [20])

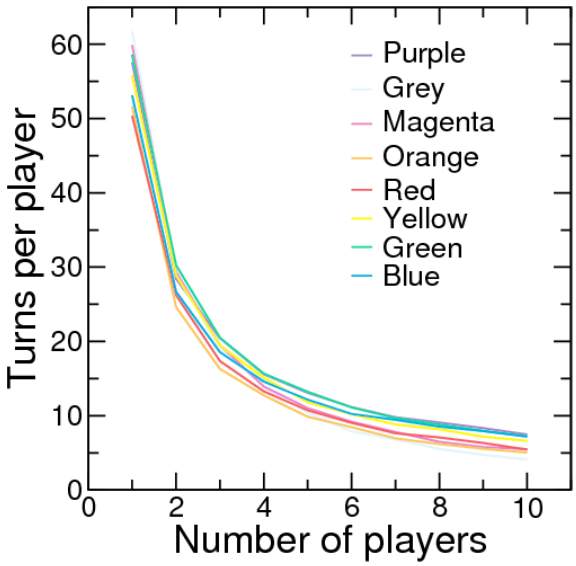

fig 7: Sample of average of player's turns to complete all Monopoly properties through perspective of colour group block. It is a continuation of the previous figure and it offers a possible change of strategy in buying of properties according to number of players. For example if there are four players in game then the orange properties will be the most visited and therefore it will be suitable to own them. (Figure taken from [20])

Next in this study [20] they computed from current simulation the number of steps for buying whole colour group block according to number of players [fig7]. From this graph it is possible to analyse a dependence of number of players on getting whole colour group block (monopoly) in game. The most beneficial is the chasing for orange *street properties* if a number of players is from 2 to 5. If a number of players is higher, then the most beneficial is to chase for gray *street properties*.

5. The sub-goal summary

There are a lot of papers, books and forums about strategies which players use. For example one of the possible strategies is to buy everything and then to start with deeper strategy which is based on trading. Because if there are more players than two, it is possible to trade with opponents to exchange some needed property for other one or for money. In this case it can be good to deal for both sides and bad for other players [22]. The goal of combination of buying everything and trading with opponents is to get a monopoly which means the whole colour block of *street properties* as soon as possible. In this type of strategy it is necessary to try to get all *railroads*. Nevertheless despite of these facts this strategy of buying everything and than dealing is absolutely bad in the game with only two players; there is a low possibility to deal with properties between two players. Considering more players it is also not the best strategy because according to observation there is a very high possibility not to have enough money to rival opponents in auction. The one conclusion from this part is that number of players is important.

Parzinskis [23] also suggests that it is not reasonable to buy each property which we land on, because in this way of playing we will be doomed. The reason is struggling for cash and inability to buy *houses* and *hotels* on *street properties*, which are needed the most to bankrupt other players and in this way to win the game. The second conclusion from this part is then always to keep a reserve of money.

During observations I found useful information for creating *tactics* in the game. During analysing of results from observation I was not able to determine the *global strategy*. I only

knew what is appropriate to do in current situation. The *global strategy* on the other hand offers vision into future, what influences decision-making in local situations very much. If for example according to *global strategy* I want to have orange *street properties*, then my decision-making will be very influenced by this fact in current local situation.

My players were not professional players, they were beginners. They did not know that orange *street properties* are the most frequent *street properties* in Monopoly, they did not have any external information. For example they did not have any special idea how to change strategy according to number of players. Their strategy was influenced only by playing a particular game. The main problem in their strategy was focusing on the most expensive *street properties*. And generally this was their way to bankruptcy. On the other hand I realized one situation in game when I observed four players that one of them just decided to buy cheap *street properties*. Nobody has problem to sell him these cheap *street properties*, to deal with him, because they think they are useless. Then he completed colour group and gradually built *hotels* on them. Suddenly his profit started to grow and he was able to buy other properties from opponents, because as I mentioned a profit for one player is a loss for other one. Other players started to have a problem with money because of often landing on his *street properties* with *hotels* and therefore they had to start to sell their properties. And according to game dynamics, the exponentiallity became apparent. This player became more and more rich and other players gradually became more and more poor. The result was that this player bankrupted all other players and became a winner.

Based on the fact which I mentioned before that some players do not want to deal with other players I decided to look closer on different types of player's personality. I found that there are four types of personality of players.

Richard Batle [24] offered an analysis of players and playing. He presented the typology of four types of players and described how interactions among these types of players influence social atmosphere in game. These four types are:

- **socialisers:** Players who enjoy the company of other players and play game for fun.

- **killers:** Players who enjoy to bother other players and cause them troubles. In Monopoly it can be buying of property, which opponent needs very much. This is of course one of possible strategy, but that's it. Here we can see that this strategy depends on particular type of personality of player.

- **achievers:** Players who loves winnings and triumphs. In Monopoly these types of players generally do not offer merciful loans or they do not forgive payments, etc. Their goal is clear, to win.

- **explorers:** Players who enjoy to observe and explore new mechanisms in game, new strategies, etc. They are players who risk.

Accordingly, it can be concluded that Bartle [24] created the general model of human behaviour during game, which is absolutely adaptable to Monopoly. This model of human behaviour is suitable to notice in observations of players. Since for creating a suitable strategy it is necessary to be aware of particular participant from who we take knowledge and to consider to which extent the information is valid.

*My **sub-goal** was to find suitable adaptable global strategy and tactics for playing Monopoly game which can be applied for agent-player.*

I can say that I found *tactics* of Monopoly, how to play Monopoly in certain situations and based on observation analysis and study of literature I identified several pillars of the *global strategy*. Now I would like to create a model of possible *global strategy* which must include decisions in local situations. These two types of strategies, *global strategy* and *tactics* are complementary to each other. They cannot be separated. *Global strategy* has clear goal and based on it influences local decision-making in particular situations where players have to decide what to do. By adaptability I mean to know how to change the strategy according to situation. For example if opponents buy wanted properties, it is necessary for player to orient on other properties which are also quite good and to try to deal with opponents.

5.1 Model of global strategy:

The goal of player is to bankrupt other players. I found out that excellent way how to bankrupt opponents is with perfect beginning of game. Therefore the first sub-plan is to have one whole colour group block as soon as possible. The most advantageous is to collect gray and orange *street properties*. As soon as the player has this colour group block, his second sub-plan is to build three *houses* on each *street property* as soon as possible. Then when the player has enough money his third sub-plan is to extend his wealth by buying red and yellow *street properties*. And finally if the player has still enough money he should continue to buy green *street properties*. Accompanied with such a progress of player is a decay of other players. This was strategy from a very rough perspective. Each sub-plan should be divided into other smaller parts. Important thing in the first sub-plan is to have these *street properties* and player should be willing to change them also for his most expensive *street properties*. For example green one for gray one. In order to have possibility to deal with opponents the player should buy *street properties* in his each turn but not for full price, but for auction. For more than three players it is absolutely suitable strategy because player will have still enough money. For fewer players it is also suitable strategy but a player has to pay a big attention to his cash. Problem with cash should be solved by definition of minimal reserve. Player should not go below this reserve. Player should bid on auction half price of *street property* plus or minus according to situation. The difference is if gray or orange *street property* is in auction. Then he can bid also for full price plus little bit more. If opponent has enough money and he needs to complete his colour group block the player should bid also little bit more than full price. As I said a player should buy *street properties* for half price if there are not more than five players. There are three exceptions. The first is for *railroads*. Player should buy *railroads* for full price. Other exception is for orange and gray *street properties*. And the third exception is if a player already owns one of *street properties* from current colour group. If a player has expensive *street properties* at the beginning he should immediately deal with them for orange and gray *street properties*, or for other *street properties* for completion of colour group block.

6. Conclusion of the cognitive approach

This was a simple model of *global strategy* which is quite dynamic and can be applied for agent-player in Monopoly game. However as I mentioned it is necessary to combine it with particular sub-decisions in certain situations which I called *tactics*. This model has plan, perspective and it is dynamic. It means that it is possible to move sub-plan into the highest position, in the position of main goal. As I mentioned as an example if wanted *street properties* e.g. orange ones are already bought, then other goal is to focus on gray ones. This model guarantees the player not to go under financial reserve which gives warranty to not fall into the trap when other players will benefit of lack of the player's funds.

This cognitive approach joins two branches of searching for the strategy in Monopoly game – the observation and the study of literature about strategies of players. I fulfilled my sub-goal and identified possible *global strategy* and *tactics* of Monopoly game.

7. Defining the final goal for the artificial intelligence approach

After finding a model of the strategy for Monopoly game and thus fulfilling the sub-goal, I defined my final goal:

The final goal of this work was to implement the found strategy from a decision-making process of human players into agent-player and optimise it.

8. Simulator

After having found the strategy for agent-player my next goal was to create a Monopoly Game Simulator. To create this simulator I followed several important steps of planning. First I defined my goal which I wanted to achieve, then I created the whole architecture of simulator and then I provided a detailed description and method of how to accomplish the given goal according to my plan and timetable. This kind of procedure is one part of *Scrum management*, which has been recently widely used by developer companies as a successful agile method.

The simulator of Monopoly game is created in *Java* as *J2EE* application. I used *MVC* (meaning model, view and controller) architecture in cooperation with *STRUTS2* framework. When I designed the simulator I decided to represent every important part of game as a separate class. Consequently each instance of such class was persistently connected with database by *Java* database framework *Hibernate*. The architecture design of simulator was slightly modified during creating the game, but the basis stayed unchanged. This architecture can be seen on figure [fig8].

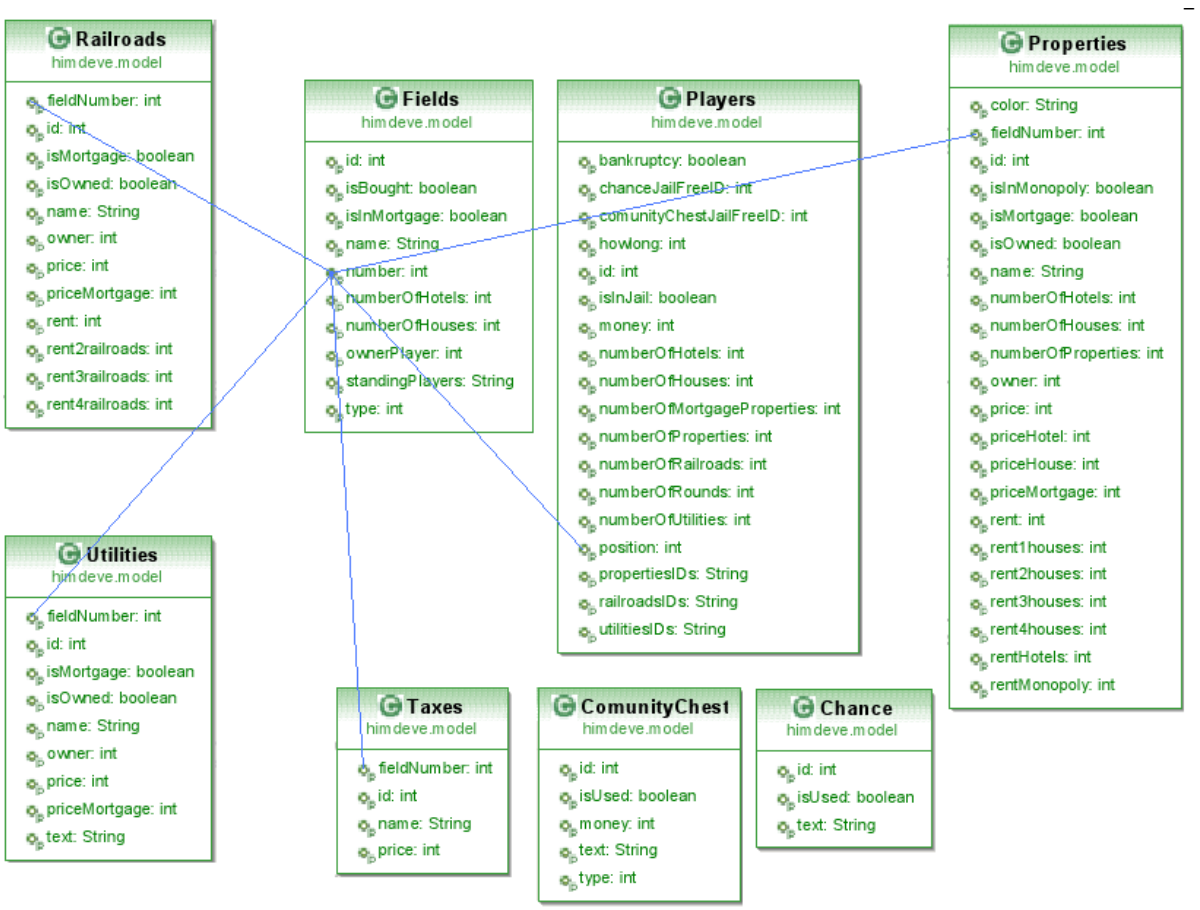

fig 8: Design architecture of simulator. Every important part of the game is represented as a separate class. Every instance of each of these classes is stored in a database. The class Fields is the main class linking the other classes together. Other important class here is Players, because its instances represent agent-players. ComunityChest and Chance are not linked to the main structure because they are independent cases which may occur during the game.

The simulator allows the game to be played by two, three and four players. The simulator at this stage does not have implemented *graphical user interface* (*GUI*) and therefore the game is

not able to be played by human players without any knowledge of programming. But on the other hand it allows an implementation of different kinds of agent-players, which makes it possible to program the new agent-players for given simulator and consequently let them play Monopoly game against each other according to their strategy.

9. Implementation of rule-based agent

Based on the acquired strategy, which consists of the *global strategy* and *tactics*, I created an agent-player in which I defined rules how to play the Monopoly game. At this stage the agent-player was not ready for launching in the simulator because it contained certain parameters, which I was not able to extract neither from observation of human players nor from study of literature. Main reasons which made it impossible to create a complete strategy for agent-player were (1) those participants who engaged in experiments and played Monopoly game were not professional players and therefore some of their decisions could not be taken as rules and (2) for acquiring all missing parameters I would have needed to perform a

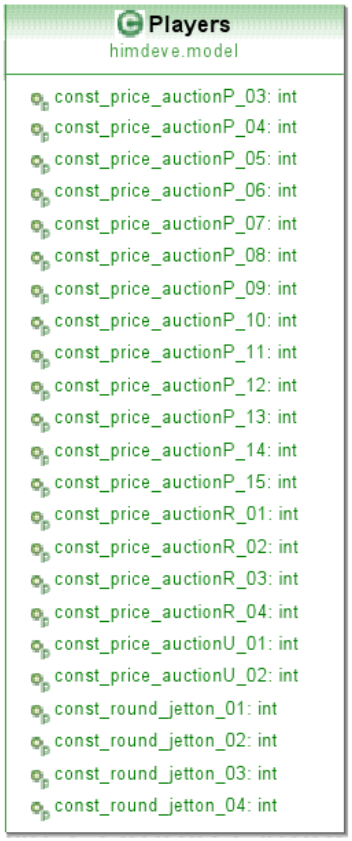

fig 9: Missing parameters of the found strategy. The values for these parameters can be found out by evolving them using a genetic algorithm.

large amount of games and observations. These parameters can be seen on figure [fig9]. They are implemented into the class *Players* and called *consts*. The majority of them focus on particular agent-player´s money. For example parameters of type *const_money_buying* define how much money should a player have left over after buying particular asset. Letters *P*, *R* and *U* in this type of parameters define whether the particular asset is a *street property*, *railroad* or *utility*. As can be seen on figure [fig9] there is a lot of parameters of this type. This is because every parameter determines a certain situation in the game or it appertains to particular situation. For example parameter *const_money_buyingP_01* determines how much money should a player have left over after buying the orange *street properties*, which belong to the elite fields in Monopoly game. This remainder of money is very important because it has significant effect on victory or loss in the game. Other Parameter *const_money_buyingP_02* belongs to gray fields. Parameter *const_money_buyingP_03* determines how much money should a player have left over after buying the current *street property* if this *street property* leads to monopoly, which means the whole colour group of the same colour *street properties*. Other parameters of this type deal with similar situations in the game. Parameters of type *const_money_jetton* determine how much money should a player have left over after buying particular token. It varies according to situation. For example according to the global strategy it is suitable to buy tokens immediately after completing whole colour group of *street properties*. But if a reserve of a current player after buying the token remains low, then he is inclined to bankrupt. Therefore it is very important to find a parameter which determines a player's minimal cash reserve after buying a token with intention to win the game. There are lots of parameters of this type and they vary according to situation. For example it is different parameter for buying tokens on orange *street properties* in comparison with buying tokens on purple ones. Purchasing of more tokens on one *street property* is defined by parameters of type *const_round_jetton*, which determine after how many rounds it is suitable to buy new tokens on current *street property* according to current situation with respect to amount of money of particular player. Parameters of type *const_price_auction* and *const_addition_auction* define the highest price for particular *street property, railroad* or *utility* in auction, which a particular player is willing to pay with respect to the position of this asset in the board. Parameter *const_diff_dealing* determines a distance between two *street*

properties in dealing process. It means a player is willing to deal with other player and get his *street property* if the distance is specified by a certain number of fields. This number of fields must be known and therefore it is set as parameter. Another parameter in the game is *const_money_jail_01*, defining a remainder, which should a player have left over after paying $50 for leaving the jail with respect to other parameter called *const_monopolies_jail_01* which represents an amount of *street properties* of other players in complete colour group. There are two more parameters, one is for mortgaging of *street properties*. It is called *const_money_mortgage_01* and it determines how much money should a player have left over after buying particular *street property* with a mortgage. The second parameter is called *const_money_mortgage_02* and it defines an amount of money necessary for taking *street property* out of mortgage.

10. First Optimization of the strategy by genetic algorithm

For acquiring these parameters and thus for the optimization of strategy, I used *genetic algorithm*, which is able to set up parameters in a proper way by using an evolutionary approach. I decided for the *genetic algorithm* due to insufficient amount of information concerning these parameters. Since *genetic algorithm*s have very good results in solving problems without need of special knowledge about target function or target goal and they are suitable methods for optimization of large variety of problems I chose them and they showed up to be good candidates for optimization of given strategy by finding values for parameters.

For better understanding of my further work it is necessary to know what *genetic algorithms* are and how they function. Therefore in this part I outlined principles of *genetic algorithms*.

10.1 Genetic algorithm

Genetic algorithms belong to a group of evolutionary algorithms inspired by nature. They imitate evolutionary processes, which are known from biology. These processes are *selection, inheritance, crossover and mutation*. In the nature there are populations of different kinds of

species, which have certain qualities. These qualities are encoded in their genes, which are parts of chromosomes. In *crossover* new individuals are forming by acquiring one part of genes from mother and another part from father. In exceptional cases in evolution of a new individual a random change of genes in chromozome may occur. Such change is then called *mutation*. *Mutation* can have positive or negative impact on further evolution of current species. According to its qualities, every new individual has a certain ability to survive in natural selection of current species and thus create a new generation. This process is constantly repetitive in the nature and genetic qualities of current species improve in the process of evolution [25].

Genetic algorithms are based on ideas of natural selection from Darwin's theory which claims that favourable inherited qualities of population become more common in subsequent generations. Whereas unfavourable inherited qualities are eliminated over time. Individuals which are able to adapt to environment survive in next generation and the other ones gradually die out [25].

In computer science the *genetic algorithm* is considered to be a search heuristic method with an effort to optimize a target function, which may represent a particular problem, in the set of available solutions. Therefore *genetic algorithm* is not a gene coding but it is the computer algorithm based on natural principles of genetics and evolution. In comparison with classical methods of tree search for optimal solution of problem in situation where set of solutions is large, *genetic algorithms* quickly converge to sub-optimal solution after examination of only a small amount of the search space. Therefore they can be successfully applied to complex optimization problems. [26]

Implementation of *genetic algorithms* begins with selection of initial population of allowable solutions. In most cases this initial population is generated randomly to ensure a diversity of possible solutions for a given problem. In combination of *genetic algorithms* with other optimization techniques exactly this part of initializing of a population is used for optimization input for *genetic algorithm*. *Genetic algorithm* applies operators of *crossover*, *mutation* and *reproduction*. In order to apply these genetic operators it is necessary to represent population in suitable form. A binary string is most frequently used for representation of an individual. Such encoding has also analogy in genetics where string corresponds to chromozome,

particular positions in string to particular genes and particular values on these positions to alleles. After creation of initial population the next task is to select individuals with best genetic information and then apply other processes of evolution such as *crossover* and *mutation*. Two primary functions are used for selection of the best individuals. The first one is called *evaluation function* and the second one *fitness function*.

As Whitley said in his article [25] the *evaluation function* "provides a measure of performance with respect to a particular set of parameters" and *fitness function* "transforms that measure of performance into an allocation of reproductive opportunities". It means that the *evaluation function* evaluates solution of particular problem from local perspective and the *fitness function* represents evaluation of solution of a particular problem in consideration of all members in population. For example, in Monopoly game it is possible to represent *evaluation function* as a result of game, which means the winner of particular game. But if population of players is four hundred and the number of players in one game is four, then the number of games will be one hundred and the number of winners will be also one hundred. It means that *evaluation function* selects a winner from particular game but *fitness function* will consider all one hundred winners.

The *fitness function* represents the ability of individuals in their environment. Here it may be worth noting that as generation gradually evolves, less able individuals according to *fitness function* are gradually eliminated and more able ones change their genetic information among each other thus producing better and better solutions. The natural selection of individuals develops into the next part of *genetic algorithm* which is called *crossover*. On molecular level in a very simplified explanation, two chromosomes hit each other, change their genetic information and continue on their way. And this process of changing information is called *crossover* because genetic material from one chromosome crosses other chromosome.

10.1.1 Crossover

The *genetic algorithm*s apply various options of *crossover*. In this work I focused on the *crossover* in a string form and therefore I omitted other types of *crossover* such as tree *crossover* etc. in this insight into *genetic algorithms*. Moreover, using string representation for

crossover is the most frequent. There are three most common types of *crossover*: *Single-point crossover*, *two-point crossover* and *uniform crossover*.

Single-point crossover

In this *crossover* there is a random selection of so-called *crossover point* and subsequently a part of one chromosome is selected from its beginning to this *crossover point* and the rest is selected from other chromosome starting from this point. This rule is applied for both chromosomes and such crossing creates two new offsprings of these chromosomes. This process can be seen on figure [fig10] [27].

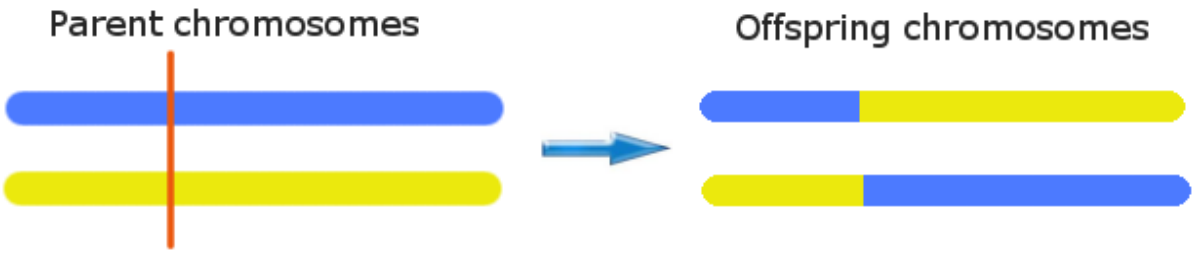

fig 10: Single-point crossover. The first part from the beginning to the point is selected from one chromosome and the second part from the point to the end is selected from the second chromosome and vice versa.

Two-point crossover

In this type of *crossover* there are two *crossover points* randomly selected and section between them is chosen and swapped between parental chromosomes. Accordingly it creates two new offsprings of chromosomes as it can be seen on figure [fig11] [27].

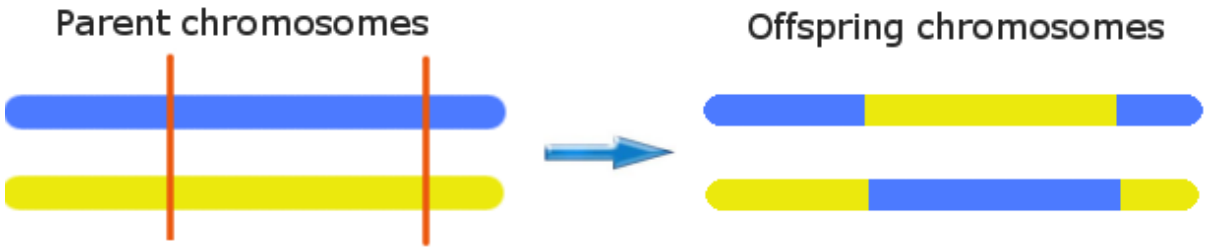

fig 11: Two-point crossover. Everything between these two points is selected and swapped.

Uniform crossover

Uniform crossover is based on random substitution of single genes and not a whole segment as it was in *single-point* and *two-point crossover*. Generally a certain ratio of substitution is used, which represents a probability of substitution of genes between two parents. If *crossover points* are used, they spread randomly depending on mixing ratio. If mixing ration is 0.5 then it is 50% chance of selecting genes from one parent and other 50% from the second parent as it can be seen on figure [fig12] [27]

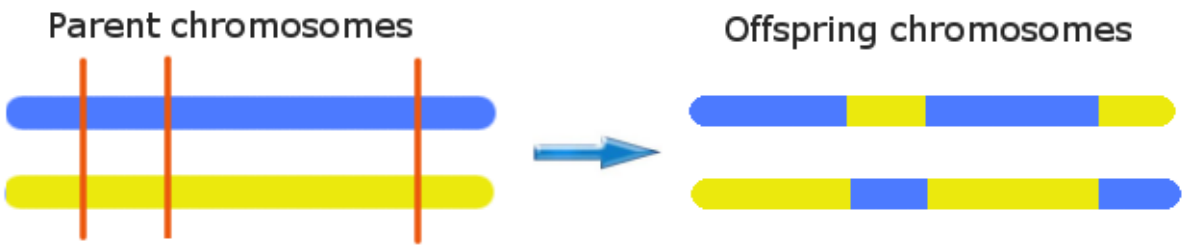

fig 12: Uniform crossover. It randomly substitutes single genes.

There are three most frequent representations of these types of *crossover*. The first is binary, where a particular chromosome is represented by a string of 0 and 1. The second is decimal, where the representation is formed by number from 0 to 9. And the third one is character representation, which uses letters of alphabet.
There is one more type of *crossover* which is used quite frequently but in a specific way. Generally it uses binary representation and it is called arithmetic crossover.

Arithmetic crossover

In arithmetic crossover a new offspring is generated by performing certain arithmetic operation between two chromosomes, which are represented by binary string. As an example I introduced arithmetic operation *AND*, which can be seen on figure [fig13] [27].

Parent chromozome 1 AND Parent chromozome 2 = Offspring chromozome

10101010 AND 01001011 = 00001010

fig 13: Arithmetic crossover - example of an arithmetic operation AND.

10.1.2 Mutation

One of great advantages of *genetic algorithms* is that they do not fall into local optimum as it can be seen on figure [fig14]. *Genetic algorithms* seek potential solutions of a certain problem in order to prevent slipping into one local optimum, it means not to let *genetic algorithms* quickly specialise and thus always keep a possibility to create new, potentially better solutions of a given problem, therefore *genetic algorithms* use a small random change of some element in chromosome. This change may influence current solution in positive as well as in negative way and it is called *mutation*. *Mutations* are very rare in the nature and they significantly interfere with genetic information of chromosome, therefore a simulation of *mutation* in *genetic algorithms* is often made with a very low probability, usually between 0.001 and 0.1. As the author Pospíchal in the article [28] said "if there were only *mutations* then genetic process would not differ from method of random search".

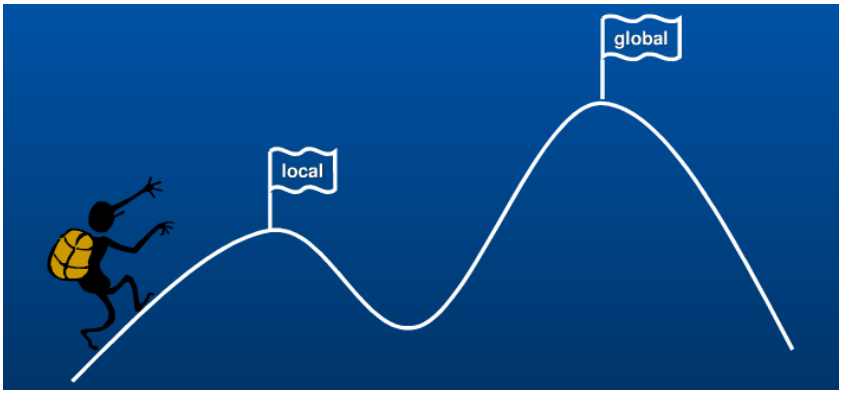

fig 14: Local and global optimum. The figure shows a difference between local and global optimum. Mutation helps to avoid slipping into local optimums. (Figure taken from [fig14])

10.1.3 Why do genetic algorithms work?

Significant efficiency of *genetic algorithms* is caused by the fact that a particular chromosome is situated in so-called schemas. As the author [29] explains the schema is "a template or pattern which is used for description of a set of strings or chromosomes, which contain certain similar sections". In the case of binary strings the schema is a string of 0 and 1 and certain metacharacter for example * (asterisk). This symbol can be substituted by 0 or 1. For example if we have a schema *000** then the instances of the given schema can be chromosomes *0000* as well as *0001*. However these chromosomes can be also instances of several other schemas. For example chromosome *0001* can be instance not only of schema *000**, but also of schemas as for example *1**** or ***01* and many others.

It means that a certain small number of chromosomes can represent a big number of schemas. These schemas may join in the process of *crossover* which leads to unification of solution, but they may also break up, which leads to creation of new schemas, in which offsprings may belong to an area where originally none of their parental chromosomes belonged to and thus provide a search of all areas defined in this way [28].

This relation is expressed by Holland's schema theorem, which represents basis for *genetic algorithms*:

Theorem: "Let *r* be a median of intensity for all chromosomes in population which contain schema; *n* be a number of these chromosomes and finally *a* be a mean value of all chromosomes in population. Then expected number of chromosomes containing the schema in the next generation is $n \cdot r/a - z$ (where *z* is the number of extinction of schemas as a result of *crossover* and *mutation*)" (cited in [28]).

In this theorem it is said that the occurrence of a schema which is more effective, is more frequent in subsequent generation and the occurrence of a schema, which is not effective, is less frequent in next generation. It means that the number of instances of frequently occurring schemas grows during time and number of instances of schemas which occur with declining tendency also decreases. In this way it will eventually produce a chromosome more or less representing a global optimal solution of a given problem.

10.2 Implementation of genetic algorithm

As I mentioned before I needed to optimise the *global strategy* and *tactics* for an agent-player because during observations I was not able to find some important information which I called parameters in decision-making process of participants. First I decided to use binary representation of chromosome. After several failure trials of this representation, where data converged to high values I decided to use decimal representation. Chromosomes were represented by four decimal numbers which almost in all cases represented financial value of a particular parameter. For example representation of parameter *const_money_buying_01* which represented amount of money after buying the orange *street properties*, could be for instance *1350* whilst this number directly meant the value of money in game. A number, for example *50*, was represented by *0050* in order to keep representation of four genes in each chromosome. At the start of the game, in the first generation of a *genetic algorithm*, all parameters were set to random values ranging from 0 to 5000. The value 5000 in Monopoly game is a considerably large amount of money and therefore I supposed that a setting of all parameters should not have exceeded this value according to acquired strategy of agent-player. In every generation one hundred games with total population of four hundred agent-players were played, whilst one game was played by four agent-players. Every parameter was represented as a separate chromosome, but all parameters together were dependent on a selected *evaluation function*. It means that every agent-player contained all parameters (70) and each of these parameters depended on *evaluation function* of a particular player. In my case the *evaluation function* represented the winner of each game. The winner of a game is a player who is able to bankrupt all other players. This way, one hundred winners were selected in one hundred games played by a total population of four hundred players.

As a *fitness function*, which was in fact a continuation of *evaluation function*, with respect to a total result of *evaluation function*, from the point of view of a total population, I chose for further genetic steps, such as *crossover* and *mutation*, a given selection of one hundred winners, in such an order, that those players whose final sum of total possession after winning the game was the highest, represented 10% of population having a higher chance of further reproduction. In the next step there was a *crossover* after which a new population of four

hundred agent-players was created. The *crossover* was set with probability of 0.9 which represented 90% chance of crossing. *Mutation* was set to value 0.03 which represented a low chance of a strong genetic change. To summarise it, the whole *genetic algorithm* ran two thousand generations whilst in one generation one hundred games with population of four hundred agent-players were played and every agent-player had seventy parameters, which had to be evolved. All in all two hundred thousand games were played to acquire the needed values of parameters. This was the first optimisation of the agent strategy.

11. Second optimization of the strategy by reinforcement learning

I was aware of few weaknesses which could arise from defining the strategy acquired by observation and therefore the second optimisation was based on the use of simplified version of *reinforcement learning* in order to find out whether a particular *street property*, *railroad*, *utility*, *house* or *hotel* should have been bought or not. The *genetic algorithm* found values of parameters which showed how much money a player should have left over after purchasing a particular *street property*, *utility* etc. However these parameters are still very general with respect to the entire course of game. *Reinforcement learning* is an appropriate method to eliminate this problem by tracking the whole state space. In this way an agent can learn whether a current *street property* is good to be purchased or not at a given moment.

Before I explain more about my implementation of *reinforcement learning* and why I speak about simpliefied implementation it must be understood what *reinforcement learning* is and how it works. Therefore I offered introduction to a concept of *reinforcement learning* in the next section.

11.1 Reinforcement learning

Reinforcement learning is a learning which focuses on taking action to maximise a reward coming from an environment. In terms of *reinforcement learning*, one who performs an action, who learns, who is a decision-maker, is called an agent. Everything what is happening around the agent is called environment [30].

Reinforcement learning defines an interaction between agent and its environment in terms of states, actions and rewards. States are a set of environment variables which the agent can observe. Actions are a set of possibilities which the agent can do in current state. The goal of agent is to maximise a total amount of rewards which it can get from the environment. These rewards actually define the agent's goal. Every reward is mapped to a current state of the environment. The value of a reward is determined by a *reward function* which represents a single number indicating a desirability of a current state [30]. It means whether the current state is good or bad for the agent in the current moment, in the immediate sense. If the current state is good for the agent then it is called a reward and if it is bad it is called a punishment.

There is another important function in *reinforcement learning* and it is called the *value function*. This function specifies what is good and what is bad in the long run. The value of this function represents a total amount of rewards, which agent can acquire from the current state by few steps into future. It is a long-term desirability of state. In fact, there are two *value functions*. The first is $Q^{\pi}(s,a)$ which means the value of taking action *a* in state *s* under policy π and it is called *state-action value function*. And second is $V^{\pi}(s)$ which means overall value of state *s* under policy π and it is called *state value function*. And $V^{\pi}(s) = max\_a\ Q^{\pi}(s,a)$ which means the *state-value function* for the current state *s* is computed as taking action *a* from current state *s* which has the best overall evaluation [31].

According to Sutton and Barto [30], rewards can be likened to pleasure and pain in biological system. And the values from *value function* can be an analogy to human judgement of how good or bad is environment residing in particular state. To make it possible for the agent to get a certain evaluation of particular state *S* in time *t* it has to pass from this state *S(t)* to other state *S(t+1)*. This transition is carried out by actions of player.

How an interaction between an agent and its environment works can be seen on figure [fig15]. The interaction runs on a sequence of time steps *t(0)* ... *t(n)*. The agent gets a certain representation of the state of an environment in its each step and based on it selects an action *a(t)*. According to this action the agent gets at time *t+1* into the new state *s(t+1)* and receives the reward *r(t+1)*. The agent maps states to a probability of selection of each possible action in each time step and this is called the policy [30]. It means the policy defines a probability of selection of an action in a particular state of the environment. The policy can be changed by

the agent according to the results from its experience. The policy can represent a table of evaluated solutions, where every solution maps the action from a particular state to another state. The most valued action has the highest probability of executing. In fact it is the evaluation of how good a particular state is which is based on estimation of how good a state is in the next step. This principle is called *bootstrapping* [30]. In *reinforcement learning, Q-learning* and *Temporal difference (TD) learning* for instance are the methods which use this principle. In *reinforcement learning* there are also methods as for example *Monte Carlo,* which do not use this principle. *Monte Carlo* methods update only a state based on value returned from performing an action in a current state.

On the other hand *TD-learning* methods use *bootstrapping* principle for estimation of mentioned *value function* i.e. what is good in a long run [32].

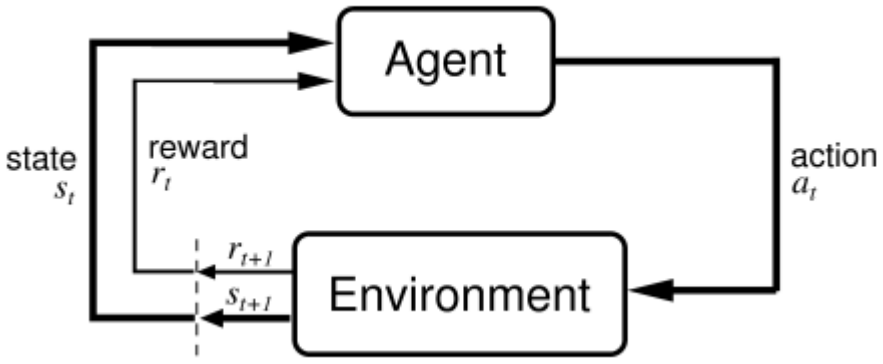

fig 15: Reinforcement learning scheme. An interaction between an agent and its enviroment. (Figure taken from [30])

The *reinforcement learning* is often interconnected with *neural networks*, which are used as a learning system of an agent. As author Farkaš [33] in his article said, the *neural network* in *reinforcement learning* is learnt by information from environment which means that it is based on evaluation from *value function*, which may include several rewards evaluation in certain sequence of steps.

If the *neural network* is trained then it is able to evaluate every action at the time *t* for a given policy [34]. Such a policy is then called *off-policy*, because the agent trained this way is able to estimate evaluation from *value function* for situations in which he was not trained.

This ability to generalise its knowledge and to react properly even in new situations is a

significant advantage of *neural networks* [33].

Beside *off-policy* there is also *on-policy* where value from a given policy is directly used for making decisions, it is not going through other complex system. None of these two policies is strict in a sense that it does not perform immediately the actions with the highest evaluation but the actions with the highest evaluation are performed with the highest probability. It gives a chance to perform actions which can lead to new solutions. This trade-off between exploitation which means to perform the highest evaluated actions and exploration which means to give a possibility to find new solutions, solves the problem of slipping into a local optimum [35].

11.2 Artificial neural networks

According to Kajan [36] the *artificial neural networks* have their origin in the activity of biological cerebral and neural structures and simulate their learning ability of understanding unknown processes. The overall knowledge of an unknown process is stored in weights of *neural networks* and the learning is based on a modification of these weights.

The basic part of *neural networks* is a neuron which can be seen on figure [fig16]. It consists of a body (*soma*), out of which one branched output (*axon*) arises. Short spurs of neuron which receive an input information (neural impulse) are called *dendrites*. The spot where a signal is transmitted from one neuron to another one is called *synapse*. In the *synapse* a signal can become more amplified or more attenuated whilst the intensity of impact from *synapse* is determined by weight of *synapse* [37].

A mathematical model of the neuron according to McCulloch-Pittsov can be seen on figure [fig17] where an analogy between neural structures and *artificial neural networks* is illustrated.

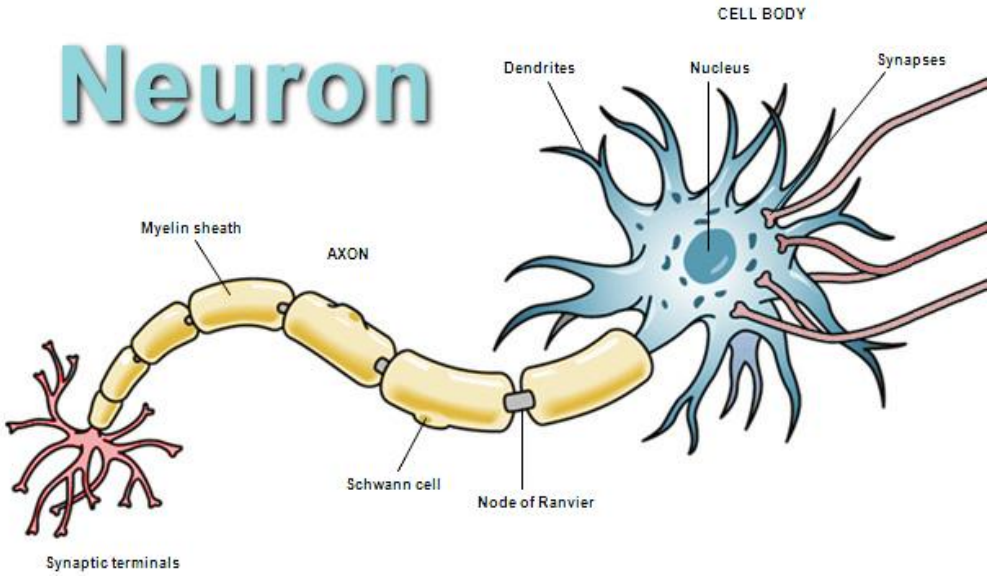

fig 16: Biological neuron. (Figure taken from [fig16])

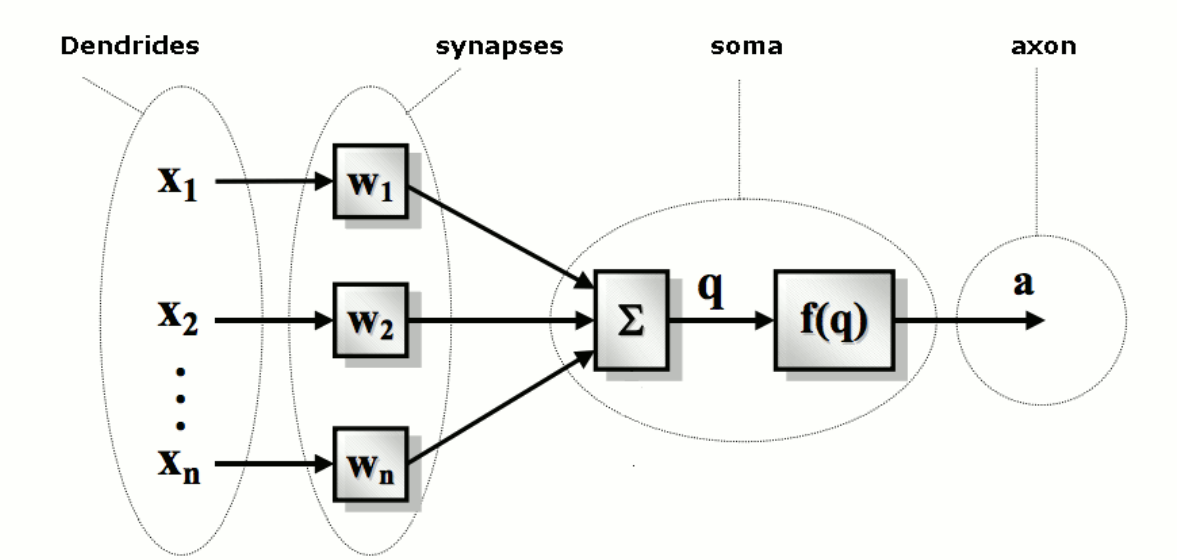

fig 17: Mathematical model of neuron with analogy to biological neuron (Figure adapted from [36])

Figure [fig17] illustrates a basic model of *neural networks* called *perceptron* consisting of input and output layers where the output layer is made by only one neuron. There exist, however, more complex models of *neural networks*. In my work I used a *multilayer perceptron* as a learning system for *reinforcement learning*.

11.2.1 Multilayer perceptron

Multilayer perceptron is a feedforward *artificial neural network* which maps input data on an appropriate output. The main difference between a simple *perceptron* and a *multilayer perceptron* is in number of layers for particular topology. *Multilayer perceptron,* besides input and output layers, contains one or more layers called hidden layers, as can be seen on figure [fig18]. Adding a hidden layer enables to solve problems which are not linearly separable. Every processed neuron in particular topology of the *multilayer perceptron* uses a nonlinear activation function which models a frequency of action potential of particular neuron. It means that the activation function determines the output of a neuron on basis of the current input. In a classic *perceptron* this function determines whether a particular neuron fires or not. But for problems which are not linearly separable a nonlinear activation function is used. One of the most common nonlinear activation function is normalizable *sigmoid function* [fig19] which can be defined by the expression: $f(x) = 1/(1+e^{-cx})$. The constant c changes the shape of a *sigmoid*, constant x represents time and e is Euler's number. Learning occurs in the *multilayer perceptron* by change of the weight after each process of data according to the error which is determined by a subtraction of the expected result and the result from the network, which is defined by an expression: $E=1/2 \sum_{i=1}^{p} ||O_i-t_i||^2$, where output O_i and target t_i wants to be identical for $i = 1,...,p$ by using a learning algorithm as it can be seen on figure [fig20]. For this process of a *supervised learning* in the *multilayer perceptron* a *backpropagation* algorithm is used, where the weights are updated based on corrections which minimise the error in the entire output. It means that after finding an overall error of the network, this error is back-propagated from up to down through the whole network and thus it determines an error for each neuron of the current network. Based on these errors, the weights between particular pairs of neurons in entire network are updated with aim to minimise this error, which can be achieved by a *gradient descent* enabling to find the change in every weight [38]. This process can be defined by the following expression: $\Delta w_{ij} = -\eta(\delta E / \delta w_{i,j})$ which represents the computation of partial derivative of E for each weight which connects a hidden node i with input j and by multiplying it by learning factor η [39].

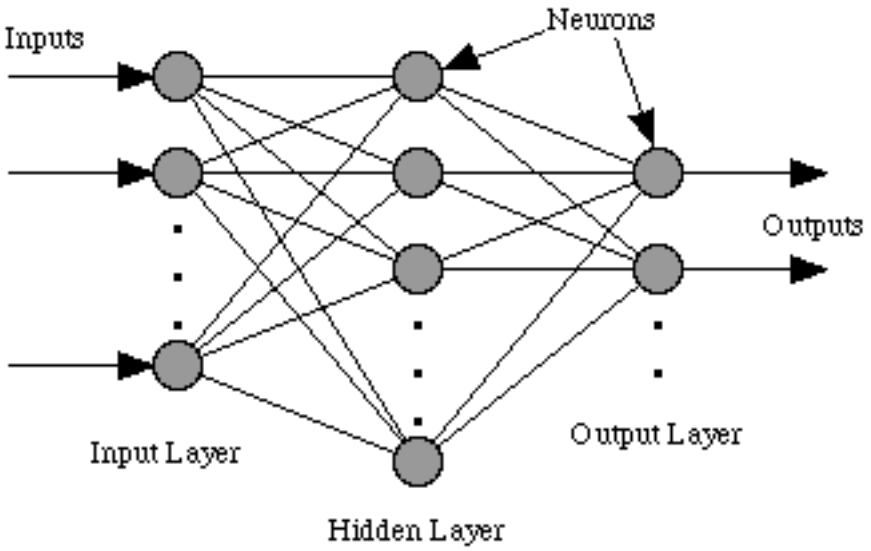

fig 18: Multilayer perceptron with one hidden layer. (Figure taken from [fig18])

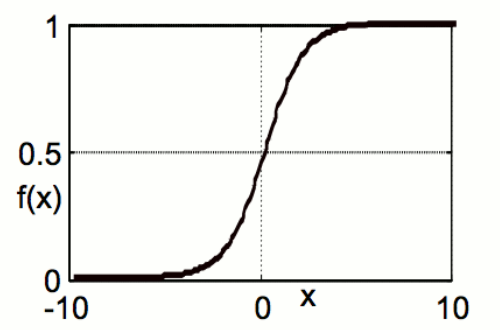

fig 19: Sample of sigmoid. (Figure taken from [fig19])

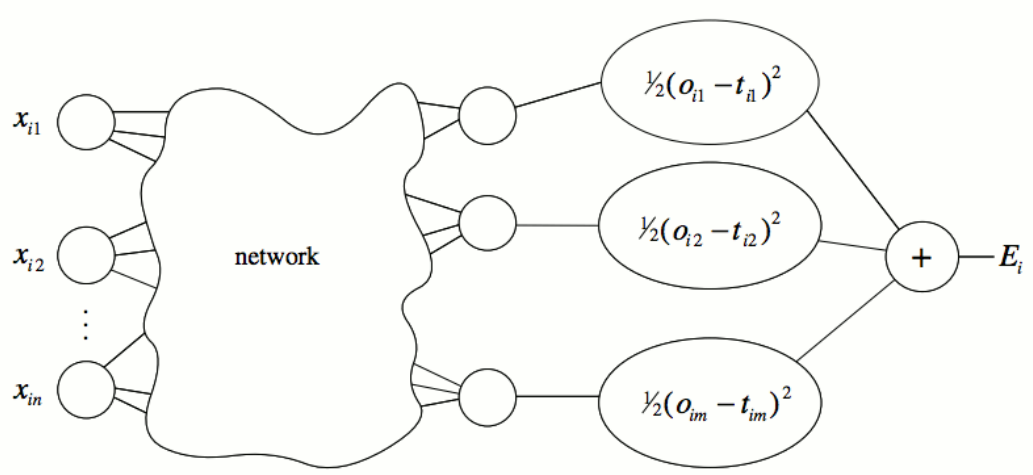

fig 20: Sample of the computation of error function in network. (Figure taken from [fig20])

Multilayer perceptron with *sigmoid* activation function and *backpropagation* learning algorithm was implemented by me using *java neural network library* as a learning system for *reinforcement learning*.

11.3 Implementation of reinforcement learning

In this work I used *reinforcement learning* as the second optimisation of the acquired strategy for purchasing *street properties*, *railroads*, *utilities*, *houses* and *hotels*. It also included mortgaging of *street properties* and purchasing of assets in auction. I omitted optimisation of some other parts as leaving the jail or dealing with players, etc. The reason why I called this optimisation simplified implementation of *reinforcement learning* is that a given policy is made up of an agent-player's decisions using its defined strategy with genetically evolved parameters from the first optimisation. It means that agent-player's policy says whether to buy or not a particular asset and thus a selection of an action is already accomplished. The reason for it is that now I do not need to use knowledge of what an agent-player learnt in *reinforcement learning* process because it will be applied into its strategy only after this optimisation. In other words the evaluation of an action in a particular state is stored and later used for training the system to make proper decisions in agent-player's strategy. And only later the policy is formed by knowledge from *reinforcement learning* and not only from the strategy with *genetic algorithm*'s optimisation. I explain it in a more detailed way later on. If the policy determines to buy current asset then the agent stores forty items which represent the current state space (for instance total money of current player and of all other players, if it is a *street property* how many *street properties* of this colour group are owned by current player and how many are owned by other players and who are these other players, how many tokens they have, etc.) and inserts this whole representation of state space into database. The most important information in this state space are total current possession of particular player and time of performing the given action. Then after every two rounds across whole playing board which is about twelve steps of a player, it adds a reward to the player based on the comparison between a total initial possession of the player in the time *t* (total possession of player before two rounds) and current total possession of this player in the time *t+1*. If the total possession

of the player in the time *t* is lower than the current total possession of the player in the time *t+1* then a reward +1 is added to the player, otherwise if the total possession of the player in the time *t* is higher than the current total possession of the player in time *t+1* then the reward for the player is *-1* which is actually the punishment for the player. There is one more condition: if the total possession of the player in the time *t* is the same as the total current possession of the player in the time *t+1* in the range of *+-200*, then the reward for the pla yer is *0*. This process is repeated after every two rounds and an example of it for one action can be seen on chart [chart1] in more detailed way. Here, it is appropriate to notice that this principle is applied for every *street property*, *railroad*, *utility*, *house* and *hotel*, which the current player buys and every purchase has its own time and from this time after every two rounds a particular reward is added based on mentioned comparison which in terms of *reinforcement learning* is called *reward function*. All this process works for every agent-player in the particular game. At the end of each game every state of player's action has positive or negative evaluation, for example *+14* or *-7*, which is represented by *value function*. As the policy was this time formed by the strategy which used only the first optimisation, the *state value function* and *state-action value function* were the same because the current agent's strategy providing the policy choose the action and the task of *reinforcement learning* system in this part was to learn whether it was good or bad action for the current state. This evaluation of the process of *TD-learning*, where the current state was evaluated based on overall game which means that it was based on nesting from one state to another, was then stored into database. It means that it mapped states with a particular action and it valued them. Then ten thousand games were executed in which this process was continually repeated. In penultimate stage all states with their parameters representing the state space in decision position of all players in ten thousand games, were assigned as inputs into a learning system which in my case was *Multi-layer perceptron* with two hidden layers whilst in the first hidden layer there were fifty neurons and in the second there were sixty neurons. This *neural network* had only one output for each set of inputs and it was the decision whether to purchase a particular asset or not. This process can be seen on figure [fig21]. In the last stage the *neural network* was trained.

After that I implemented this optimisation of *reinforcement learning* into the strategy of agent-

player. Then the agent-player was able to use both optimisation, first by *genetic algorithm* evolved values for parameters and second by confirmation of decision for buying particular asset according to global perspective of whole state space given by *reinforcement learning*.

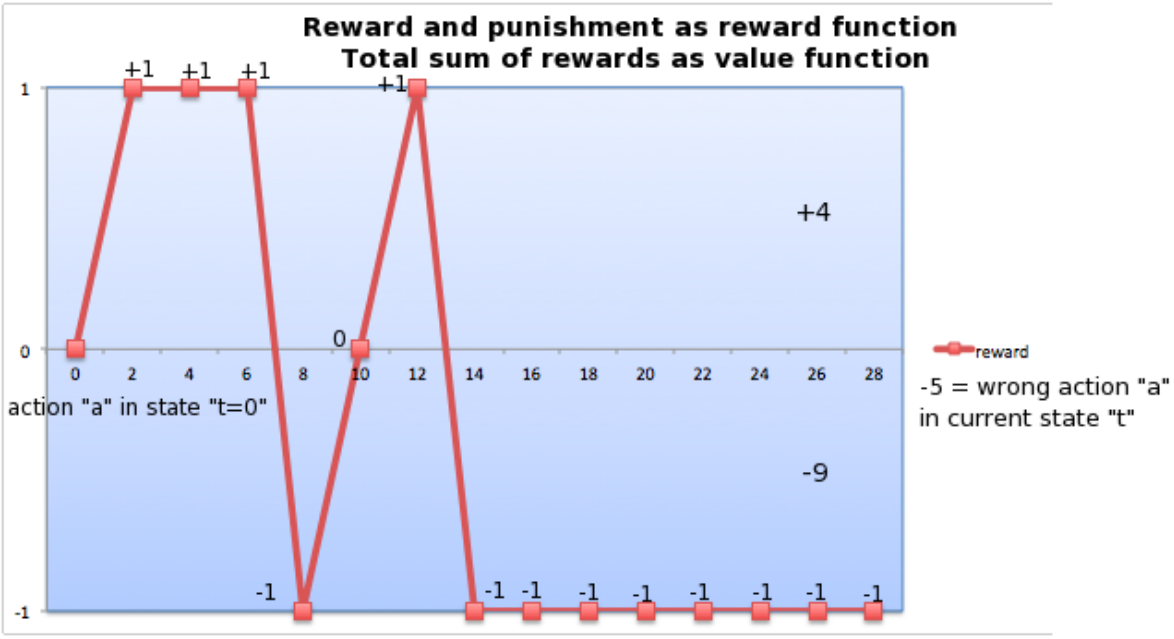

chart 1: An example of a training mechanism of the reinforcement learning for a single action e.g. buying the green street property in time t. The time t=0 represents a moment of performing the action and then after every two rounds a current reward or punishment is assigned to this action. This process is working for one whole game. At the end of a current game the rewards and punishments are added up and if the result is positive then the action is correct in time t=0 and if the result is negative then the action is not proper to perform in time t=0. This current example shows evaluation of total rewards and punishment for the action in state t=0 as a negative one (-5) and therefore this action is not proper to perform in time t=0. This process works for every action in a current game and subsequently for all ten thousand games of this learning process. It ends up with a table of 40 inputs representing a current state space in performing an action and output is positive or negative recommendation for learning system, in this case the neural network. It means that neural network has about half a milion of datas after ten thousand games.

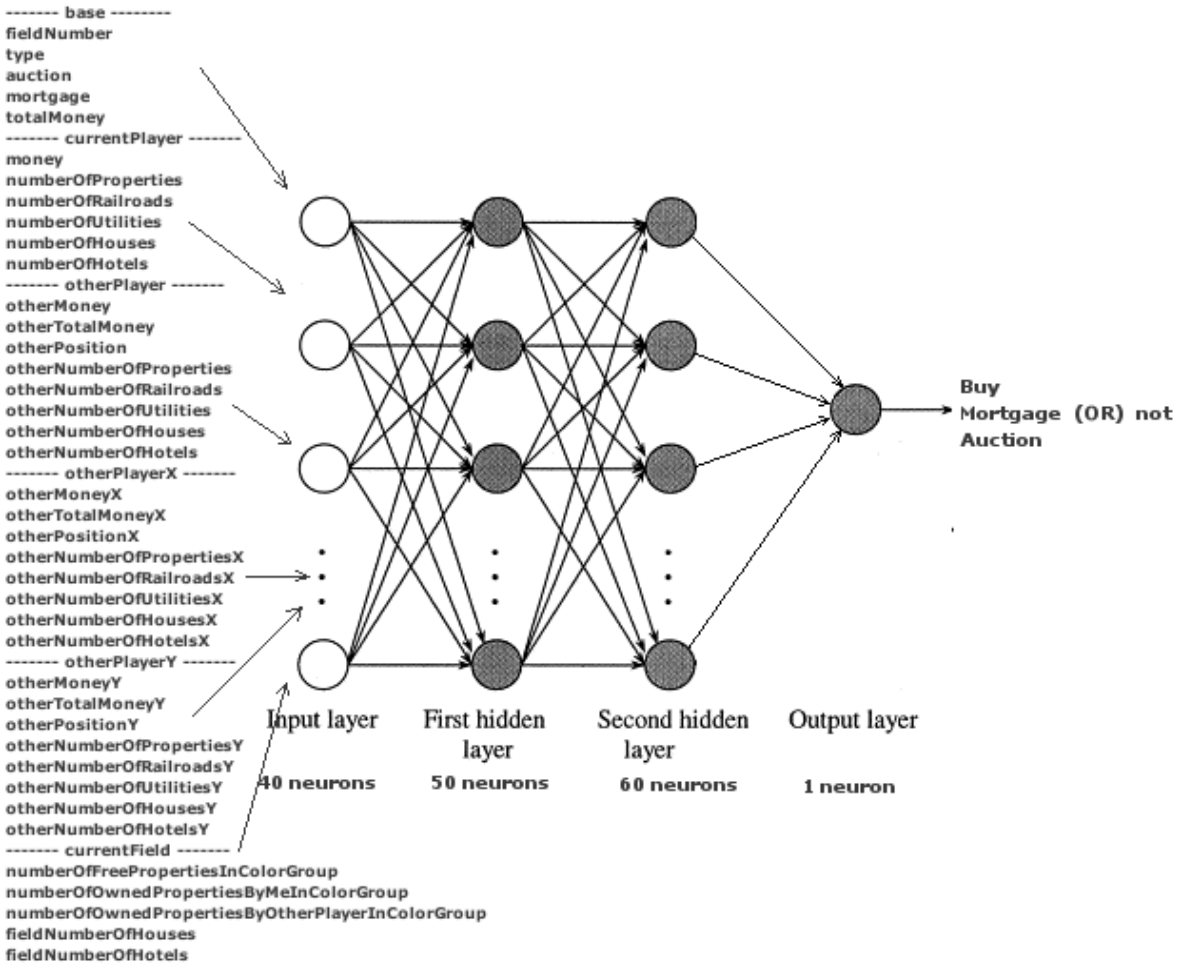

fig 21: Illustration of training the neural network (multilayer perceptron) in reinforcement learning for Monopoly game. The 40 inputs represents the state space of the game and the output is a decision for buying or mortgaging or auction a property, railroad, utility, house, hotel or not. There is only one decision and thus the choice for buying or mortgaging or auction is made by policy and represents in inputs as indicators. The multilayer perceptron contains two hidden layers with 50 and 60 neurons.

12. Limitations

- The limitations in the simulator:
    - Maximum number of players in the game is four.
    - Game is terminated if it lasts more than fifty rounds per player which is three hundred steps of a player. In this case a player who has the highest value of total possession is considered to be the winner.
    - Chance and Community cards are picked up randomly without remembering the random initial card order.

    - Number of tokens is not limited.
- The limitations in the strategy extracted from observation:
    - Agent-player deals only with a *street property* which is the last one for completing its colour group.
    - Agent-player can buy tokens on its *street properties* only in its turn but on the other hand in its every turn it can buy as much tokens as it is appropriate according to its strategy in respect to the current state and situation.
- The limitations in the first optimisation by *genetic algorithm*:
    - Assumption of maximum value for wanted parameters was five thousand.
- The limitations in the second optimisation by *reinforcement learning*:
    - Maximum number of games for training the *neural network* was ten thousand.

13. Results

At the end of my work I wanted to compare the efficiency of the given optimisation and therefore I let four agent-players play with different strategies ten thousand games against each other. Strategy of the first player-agent consisted of the rules extracted from the observation of participants whereas the missing parameters were set to random values. The values were newly generated in every game. The second agent-player was designed in a similar way as the first one but here the parameters were set according to values which I supposed were the proper ones even before I knew the results from the first optimisation. The third agent-player used the given strategy improved by the first optimisation, it means with genetically evolved values for parameters. And the last one used the strategy improved by the first and the second optimisation which means with *genetic algorithm* and *reinforcement learning*. The results were evaluated after ten thousand games. The evaluation represented the number of won games. The results can be seen on the table [Table 3] and on the chart [chart1]. The agent-player with the first and the second optimisation was the winner. The second was the agent-player with only the first optimisation. The third was agent-player with my defining parameters and the last one was the agent-player with random values of the parameters.

	Player0NN_GA	Player1_GA	Player2_myConsts	Player3_randomConsts
Number of won games	3657	3484	2064	795

Table 3: Comparison of four strategies. The first is an agent-player with parameters set to random values. The second is an agent-player with parameters set according to human estimation. The third is an agent-player with parameters set by the genetic algorithm. The fourth is an agent-player with parameters set by the genetic algorithm and optimised by the reinforcement learning.

chart 2: Competition of agent-players. The chart representing the table 3.

14. Future work

In future I plan to use the agent-players with the strategy improved by the first and the second optimisation as the training opponents for a new agent-player whose strategy will not have any knowledge about playing Monopoly game. This new agent-player will build the strategy by itself using *reinforcement learning* and *neural network*. This system is known as SARSA.

Next I would like to create a graphical user interface (GUI) for Monopoly game and hence enable human players to play this game against agent-players. From such an observation I will be able to collect results and make conclusions whether it is the human or the artificial intelligence which is better for playing a board game like Monopoly.

15. Conclusion

One of the main characteristics of the cognitive science is a multidisciplinarity. Therefore this project was carried out in this spirit. Several behavioural experiments were carried out in the beginning whose aim was to find out a decision-making process of participants in Monopoly game in respect to the goal of whole work which was to search for a strategy in Monopoly game. From observations and study of literatures I extracted the strategy which I divided into global strategy and tactics. The global strategy represented the plan or the goal of a player in Monopoly game and the tactics represented single decisions in particular moments of the game. In the next part I implemented this found strategy into an agent-player by a classical rule-based way which corresponded with a general artificial intelligence called "strong AI". To make it possible for agent-players to play Monopoly game I created the simulator of this game which enables four agent-players to play against each other. Several parameters which I was not able to extract from observation of participants and further study of optimal strategies in Monopoly game, I evolved using *genetic algorithm* inspired by natural evolution. This act improved the strategy of the agent-player and I called it the first optimisation. The second optimisation of the strategy was made by methods of *reinforcement learning*. The *neural network* was trained by this principle to decide whether it was really a proper action to purchase a particular asset from the point of view of efficiency of global perspective. *Reinforcement learning* (1) brings a concept of reward and punishment which in analogy with a human represents pleasure and pain. (2) It also brings a concept of judgement, which says how good or bad is a particular state from the perspective of a long-term evaluation of the environment. In this way I created a multidisciplinary project and I also offered options how to continue with it in future.

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Table3: own table

chart 1 – chart 2: own chart

17. Appendix A: the list of evolved parameters

PARAMETERS	EVOLVED VALUES
- BUYING	
const_money_buyingP_01	100
const_money_buyingP_02	101
const_money_buyingP_03	1010
const_money_buyingP_04	1010
const_money_buyingP_05	111
const_money_buyingP_06	10
const_money_buyingP_07	10
const_money_buyingP_08	1011
const_money_buyingP_09	1111
const_money_buyingP_10	100
const_money_buyingP_11	1011
const_money_buyingP_12	1110
const_money_buyingP_13	11
const_money_buyingP_14	1010
const_money_buyingP_15	1600
const_money_buyingP_16	100
const_money_buyingP_17	2000
const_money_buyingP_18	0
const_money_buyingP_19	0
const_money_buyingR_01	101
const_money_buyingU_01	1
const_money_buyingU_02	1001
- AUCTION	
const_price_auctionP_01	1101
const_price_auctionP_02	111
const_price_auctionP_03	0
const_price_auctionP_04	111
const_price_auctionP_05	10
const_price_auctionP_06	111
const_price_auctionP_07	1011
const_price_auctionP_08	10
const_price_auctionP_09	1001
const_price_auctionP_10	0
const_price_auctionP_11	1001
const_price_auctionP_12	1011
const_price_auctionP_13	1001
const_price_auctionP_14	1100

PARAMETERS	EVOLVED VALUES
const_price_auctionP_15	111
const_addition_auctionP_01	111
const_addition_auctionP_02	0
const_addition_auctionP_03	1011
const_addition_auctionP_04	11
const_price_auctionR_01	11
const_price_auctionR_02	110
const_price_auctionR_03	1101
const_price_auctionR_04	1001
const_addition_auctionR_01	111
const_addition_auctionR_02	1001
const_addition_auctionR_03	1010
const_addition_auctionR_04	1011
const_price_auctionU_01	1000
const_price_auctionU_02	1010
const_addition_auctionU_01	100
const_addition_auctionU_02	111
- JETTONS	
const_money_jetton_01	100
const_money_jetton_02	1001
const_money_jetton_03	1011
const_money_jetton_04	110
const_money_jetton_05	110
const_money_jetton_06	1111
const_money_jetton_07	1110
const_money_jetton_08	101
const_round_jetton_01	10
const_round_jetton_02	111
const_round_jetton_03	0
const_round_jetton_04	0
- DEALING	
const_diff_dealing_01	0
- JAIL	
const_money_jail_01	10
const_monopolies_jail_01	1
- TAKE OUT MORTGAGE	
const_money_mortgage_01	10
const_money_mortgage_02	1101

18. Appendix B: the software CD

Content of the CD:

Folder: monopolyGame

Requirements:
- Java
- Eclipse IDE for Java EE Developers
- Tomcat server
- MySQL database

Instructions:
- In MySQL create database "monopoly"
- In Eclipse import "monopolyGame" folder as existing project
- In Eclipse Project Explorer double click on "monopolyGame" folder, then "resources" folder, then "hibernate.cfg.xml" file and there set "connection.username" to your username for database and "connection.password" to your password for database.
- Into Tomcat server add particular project
- Run the project on server
- Click on button "goToMonopoly"
- There are three buttons:
    - geneticAlgorithm – it runs *genetic algorithm* for 2000 generations (200 000 games)
    - reinforcementLearningWithNN – it runs *reinforcement learning* training with *neural network* for 10 000 games
    - competition – it runs competition among agent-player with different type of strategies for 10 000 games
- For running "reinforcementLearningWithNN" or "competition" import file "FINALtabofwinnersconsts.sql" into database after clicking on button "goToMonopoly".
- The running "competition" also requires neural network file "neuralNetFINAL.nnet" which is necessary to put into your eclipse folder.
- **Files in "monopolyGame" folder:** neuralNetFINAL.nnet, FINALtabofwinnersconsts.sql

File: RobertKotrik_diplomaThesis_monopolyGame.pdf