Dynamic difficulty adjustment systems for various game genres

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Abstract: Creating a video game that is engaging for a large number of players is not an easy task. This problem is often associated with adjusting the gameplay's difficulty to the skills of a specific player. As a result, the game is neither too easy nor too difficult, so the player does not feel bored or frustrated. In recent years, a number of systems which implement the balancing procedures for dynamic gameplay have been created for different genres of games. However, in the literature, no universal understanding of the concept of difficulty has been proposed. This article is an attempt to systematize the concept (used in systems with dynamic difficulty adjustment) and the methods of its evaluation. For this purpose, this paper will present a classification of video games based on the aspects of the game that are most closely connected with the difficulty of each game genre.

Keywords: Dynamic Difficulty Adjustment (DDA), board games, video games, game typology

Homo Ludens 1(9)/2016 | ISSN 2080-4555 |

1. Introduction

One of the main tasks in the game development process is to create a game that will be engaging for a large number of players. This problem can be approached as an issue of scaling the game difficulty to match the needs of a certain player. This is the adjustment of the difficulty level that often decides whether the player is satisfied with a game and sticks to it (he or she can be bored with a too simple game or discouraged by a game which is too difficult).[1] My main goal in this paper is to explore this issue in various game genres. I am interested in difficulty as an indispensable game feature. I will discuss the idea of one coherent system of difficulty assessments which may cover different game genres. I will propose a categorization of games which is based on the game aspects linked strongly to the game difficulty.

When one thinks about designing video games, the traditional approach is to provide the possibility to select the level of difficulty (e.g. easy, medium, hard) before the play. However, it is not optimal in all cases, because there is no simple way that allows reducing the complex world of game to only one parameter, which would correspond to a level of difficulty. Additionally, this approach cannot cope with the diversity of player's skills and their unequal knowledge of the game's mechanics, different capability to learn and adapt to new situation over time (see Andrade, Ramalho, Gomes, Corruble, 2006). The new alternative is to use the Dynamic Difficulty Adjustment (DDA), which allows to create a game with dynamic changes of difficulty. Such a dynamic approach assures that

[1] Csikszentmihalyi (1990) in his theory uses the term "flow" to describe the state of mind when a person is totally focused and committed to performing an action, and this action is done purely for pleasure. This state can be achieved by the player during the game. If the main goal of the game is controlled through different levels of the challenges, the player retains within the flow, thus avoiding boredom (no challenge), or frustration (challenge too difficult). In addition, this model shows that the difficulty of the task is directly related to the person who performs them. Flow theory suggests that players can maintain in the state of flow, if game is continuously and smoothly increasing the difficulty. But perhaps it is not enough for a player to enjoy the game. It is possible that sometimes the game should be a little more difficult and sometimes a little easier, and this irregularity leads to the real enjoyment (Falstein, 2005). Irregular increase of the difficulty makes it more likely for a player to experience both failure and success. Research show that winning without losing leads to dissatisfaction of the game (Juul, 2009).

the game is not too easy nor too hard, so the player does not feel bored or frustrated. DDA systems are usually automatically varying selected parameters of the game in such a way that at a given time, the overall game difficulty level is adjusted to the skills and expertise of an individual player. To work properly, DDA has to meet at least three conditions (Andrade et al., 2006, p. 3–4):

- identify and adapt to the player as fast as possible in the early stage of the game, because the initial performance of expert and novice players may differ significantly;
- react quickly on every change in progress or regress of the player's performance;
- adapt to the player in an unsuspicious manner, so the player is not aware of the outer intervention.

Creating a well-functioning DDA system is therefore not a trivial task. In the last decade, a number of proposals to implement such systems in different genres of games (from board games to FPS games) might be observed. However, the current state of research in this field and known technologies do not allow for the creation of complex DDA systems. They cover only certain basic elements of gameplay. For example, in the AAA games the overall difficulty of the game can be affected not only by pure gameplay, but also elements like the story or the player's decisions. At the moment, these type of game elements are not included in the study of DDA.[2] We are, however, able to successfully adjust the difficulty of the games which have a mathematical model, or games in which the issue of scaling the game difficulty can be reduced to modifying a few parameters. Although all DDA systems are designed to adapt difficulty to a certain player, the specific implementation may (and should) vary depending on the game genre. Moreover, the concept of difficulty can be understood in many ways. Also, the difficulty is a common criterion used by players themselves in order to choose a game.[3] This article is an

[2] The current state of research on the DDA systems has been very well summarized in the Missura (2015) PhD thesis.

[3] Challenge, which is directly related to the difficulty of the game is often distinguished as one of the main factors of enjoyment in the game. Malone (1980) in his pioneering work on educational digital games for children identified four factors which can be used to motivate learning: challenge, fantasy, curiosity, and control. Sherry, Lucas, Greenberg

attempt to systematize the understanding of the concept of difficulty and methods that allow for its evaluation in the existing DDA systems. In the following sections I will focus on the examination of specific DDA implementations for games of different genres. The aim of this analysis is to extract the main components that may be used to build the evaluation model of the game difficulty for the purpose of future DDA systems.

2. Selected dimensions of games

There are many definitions of games, video games and the idea of playing in the literature. For decades different definitions were proposed by ludologists, game researchers and designers (see e.g. Huizinga, 1950; Salen, Zimmerman, 2003; Rogers, 2010). However, as indicated by Juul (2003), there are more similarities than differences between various definitions of games. A game can be defined as a system based on rules, which has variables and quantifiable outcomes, where players invest their effort to achieve intended results to which they are connected in some emotional way (Juul, 2003, p. 5). Such a definition covers a wide variety of game genres. It is difficult to answer the question whether and why certain game genres are more difficult than others (e.g. if it is generally more difficult to play an FPS game, or a board game than some other genre). In order to cope with this variety of games I will refer to the multidimensional typology proposed by Aarseth, Smedstad and Sunnanå (2003). This analysis will demonstrate the differences between evaluation function used in different genres of games. For this purpose, dimensions proposed in the original typology[4] were limited to three, which – in my

and Lachlan (2006) examined the reasons for playing video games and how those reasons relate to the preferences of the genre. Basing on analysis of focus groups and surveys they have identified six game uses and gratification dimensions: competition, challenge, social interaction, diversion, fantasy, and arousal. Quick, Atkinson and Lin (2012) executed a survey study which was used to develop the Gameplay Enjoyment Model (GEM), which aims to explain the overall enjoyment of the game. Authors distinguished main components of the GEM: challenge, companionship, competition, exploration, fantasy, and fidelity.

[4] A multi-dimensional typology of games proposed by Aarseth et al. (2003) includes: 1) perspective: omni-present, vagrant; 2) topography: geometrical, topological; 3) environment: dynamic, static; 4) pace: realtime, turnbased; 5) representation: mimetic, arbitrary;

opinion – have the biggest relevance to the problem of evaluating games' difficulty for DDA systems. It is worth noticing that currently there are no DDA systems which would cover all game genres. Thus, some of the dimensions from the classification proposed by Aarseth et al. (2003) do not differentiate between existing games using the DDA. My aim was to choose such dimensions (from those proposed in ibid.) that will not only help to systematize the knowledge about the DDA, but also facilitate the choice of a DDA type and the evaluation method for developers of such systems. The classification proposed in this article can be further extended with other dimensions (from the classification in ibid.), when DDA field develops sufficient tools that will allow to introduce DDA systems into other game genres. In what follows, the DDA systems will be classified according to the following dimensions:

- topography: geometrical vs. topological;
- pace: realtime vs. turnbased;
- mutability: static vs. powerups vs. experience-levelling.

The intuition behind the topography dimension is that the geometric topography allows for full freedom of movement in the game, while the topological one allows the player to move only on non-overlapping positions (ibid., p. 49–50). In the topological type of games (e.g. board games), the player is forced to choose a single move from a finite set of possible moves. What is more, the selected move should also be useful for achieving the intended goal in the game. On the other hand, in the geometrical games (e.g. FPS), a number of possible moves is unlimited.

The opposition introduced by the pace dimension is rather intuitive. When the game allows players to be active all the time and play at their own speed, regardless of the opponents' moves (if such exist), then the game can be classified as a realtime game (ibid., p. 51), whereas in turnbased games, players and their opponents play one after another, in turns (ibid., p. 50). In contrast to the realtime games, the turnbased ones give players time to rest and prepare before taking the next move.

6) teleology: finite, infinite; 7) player structure: singleplayer, twoplayer, multiplayer, single team, two team, multi team; 8) mutability: static, powerups, experience-levelling; 9) savability: non-saving, conditional, un-limited; 10) determinism: deterministic, non-deterministic; 11) topological rules: yes, no; 12) time-based rules: yes, no; 13) objective-based rules: yes, no.

The last discussed dimension (mutability) focuses on possible ways of influencing the player's behaviour by awarding her with various rewards (Aarseth et al., 2003, p. 52). Games in which there are no rewards are called static. In the second group of games, there are temporary rewards called powerups. In the last group, we find experience levelling games, where the change in the player's strength is permanent. Often, with an increasing number of opponents, also the player's equipment is improved. Thereby the game will not be too hard too soon and the perceived level of difficulty will be on a similar level through the whole game.

The summary of discussed dimensions (supplemented with examples of games) is presented in Table 1, with following labels:

- S = static games;
- P = powerups,
- XL = experience-levelling

Table 1. Game genres with examples of specific DDA's implementations classified to selected dimensions (adopted from Aarseth et al. [2003])

		Topography	
		geometrical	topological
Pace	realtime	FPS, e.g. *Hamlet* (P)	games with waves of enemies, e.g. *Tower Defence* (XL)
	turnbased	strategy, e.g. *Worms* (P)*	board games, e.g. chess (S), *Connect Four* (S)

* Although games that are both geometrical and turnbased are not popular, they do exist. One of the notable examples – indicated in the table – is called *Worms*. However, the game of this type with the implemented DDA system is not easy to be found, hence none of such games will be discussed in this article.

3. Topological and turnbased games

Games that combine topological and turnbased features are mostly board games (here considered in their digitalized versions, see Table 1).

Games of this type usually do not reward the player, thus they are classified as static ones. According to Missura and Gärtner (2008), the issue of the automatic adjustment of the difficulty in board games can be seen as a problem of interaction between the player and one (or more) agents in the game. In this approach, the natural assumption is that at any given moment the player and the agent have a set of available moves (strategies). Some of them are more effective than others. Knowing the ranking of available strategies, an agent can adapt its actions, so that they could be tuned, in terms of difficulty, to the performance level of the player.

3.1. *Connect Four*

It is a two-person board game in which players drop their stones onto one of seven columns on a 7 × 6 fields board. Each player has a different colour of stones and the winner is the player who is the first one to place four of his or her stones in a line (horizontally, vertically or diagonally). If neither of the players connects the four stones and there is no space left on the board, the game is a draw.

Missura and Gärtner (ibd.) proposed the DDA system for *Connect Four*, which is based on the ranking approach. According to the authors, the problem of adjusting the difficulty of the agent's moves can be reduced to the choice of the right strategy:

- winning (moves which lead to a win);
- neutral (moves which lead to a draw);
- losing (moves which lead to a loss).

The implementation of this approach was based on a popular algorithm known from the game theory – MiniMax, which searches through the game tree[5] in order to minimize the potential losses of the agent and maximize his chance to win (see Pinto, 2002). Winning strategies denote positive rating, while losing strategies – the negative one. In order to achieve a more diverse ranking, the authors used an additional measure, namely the number of steps the player has to make to win the game (Missura,

[5] When the game ends after a finite number of moves, you can use specific procedures to predict the results of the game. The game can be represented by the use of a tree: a structure consisting of nodes (possible positions of the pieces on the board that can be achieved after each move in the game) and lines connecting them (showing the sequence of actions taken by the players) (see Turocy, von Stengel, 2001).

Gärtner, 2008, p. 6). The game is therefore difficult when the player has to do a lot of moves to win, thereby causing the agent to perform more winning moves. The easy game occurs when the player takes many moves from the losing strategy, which affects the agent and makes him also take many losing moves. Adaptive MiniMax (AMM) algorithm proposed by Missura and Gärtner (ibid., p. 6–7) memorizes the history of player moves along with their evaluations. The algorithm uses the average performance of the player to adjust the level of performance of a game agent. The reported results show that AMM is successfully adapted to opponents (both other algorithms and players) (ibid., p. 8). However, the adaptive modification of the algorithm was designed to reduce MiniMax's efficiency when it is necessary, and that is the reason why AMM will never adapt to opponents playing better than plain MiniMax.

3.2. Chess

Another game which may be classified as both topological and turnbased is a popular two-person game, chess. With reference to it Guid and Bratko (2013) proposed their own measure of difficulty, which they called the difficulty score. Just as Misura and Gärtner (2008), they claim that the difficulty of the game depends on the depth of the game tree. However, in their approach they did not analyse the performance of the player, but the difficulty of the problem, in this case: the arrangement of pieces on the chessboard. The measure of difficulty score is based on the following assumptions (Guid, Bratko 2013, p. 861):

- a difficult problem is the one that requires many steps to resolve it (the solution is hidden in deep layers of a game tree);
- the problem will be more difficult if the available solutions are far away from each other in the game tree.

The difficulty score was developed by the use of mathematical methods only, but in order to evaluate it, the authors compared the correlation between this measure and errors in the moves made by very strong players. The assumption behind this comparison is that people will make more mistakes in case of a more difficult problem. The results showed that the difficulty score is an effective measure of difficulty for people in case of chess problems (ibid., p. 862–863). However, as the authors noted in their further studies, the algorithm based on the difficulty score was not able to deal with tactical problems very well, because it tends to choose a solution very quickly, on the shallowest layers of the game tree (Hristova, Guid, Bratko, 2014, p. 729). One more remark is in order here: the algorithm does not distinguish between different difficulty issues, while people have no problems with doing so.

4. Topological and realtime games

In games that are both topological and realtime, players' moves are limited to the predefined fields, but are not bound to any turns (see Table 1). Players may take an action whenever they want, and the effects are visible immediately. The number of player's possible moves is very high and it is not possible to determine a simple function that would evaluate the player's performance. It is necessary to create custom measures in order to help evaluate the difficulty of the game (e.g. points).

Tower Defence

Tower Defence is an RTS game in which the main goal of the player is to stop waves of enemies by placing obstacles on their way to the tower. Sutoyo, Winata, Oliviani and Supriyadi (2015) created a *Tower Defence* game with the DDA system based on a player's performance. The system evaluates the strategies of the player and if they turn out to be bad, then the system reduces the difficulty of the game. On the other hand, when the player uses a good (effective) strategy, the system increases the difficulty of the game, so it remains challenging for him or her. The DDA system proposed by the authors is based on three main parameters, which increase or decrease the difficulty of the game. These parameters are (ibid., p. 437–438):

- the number of player's lives of the player;
- health of opponents;
- passive skills (skill points).

Based on the above parameters, the game is scaled after each wave (level) is completed by the player. If the number of player's lives decrease, it means that the player is not using the optimal strategy, hence the game in the next wave will be easier. When the player retains all his lives, the game will increase its difficulty. The DDA also checks the health levels of the opponents. If the total opponents' health exceeds the fixed threshold of 50% it means that the player does not have enough towers or he / she puts them in the wrong positions (his/her strategy is bad). If so, the game will be easier in the next level. The number of opponents, their strength and the number of gold (rewards) the player receives depends also on the passive skills (offensive, defensive and supporting), which can be increased by the player as the game progresses. Changes in the passive skills are permanent, that is why the game was classified as experience levelling (see Table 1). We can speak about a difficult game of this type on the example of *Tower Defence* game, when a player has very few life points, his or her opponents spawn often and they have a lot of health, and additionally the player gets insufficient amount of gold (rewards). It is noteworthy that the DDA system proposed by the authors does not analyse the problem that the player has to solve, but the system focuses on the player's performance and uses it to scale the game.

5. Geometrical and realtime games

Games that are geometrical and paced in a realtime are the ones in which players can perform their moves at any time during the game, and the number of possible moves is unlimited (see Table 1). The FPS games may serve as a good example here. Just as in the case of games described in section 4, due to the inability to make one simple function that would evaluate the performance of the player, it is necessary to create a custom metrics to help evaluate the difficulty of the game.

Hamlet

FPS are action games in which the gameplay is seen from the first-person perspective and the main game mechanics is focused on shooting at the enemies. Hunicke and Chapman (2004) developed the DDA system for the FPS game and called their approach the probabilistic technique. The technique is based on the player's performance and estimates the difficulty of the obstacles. The authors created the Hamlet system, which is the set of libraries embedded into the Half Life engine. The aim of the

Hamlet system is to monitor the current state of the game and adjust the game difficulty if it is necessary. The system intervenes when it detects that the player begins to lose. To estimate the player's performance the system uses techniques drawn from the inventory theory (ibid., 2004, p. 91). Hamlet regulates the overall difficulty of the game based on the analysis of the supply and demand of the game inventory. The mechanics controlling supply places more health packs, ammo or weapons (Hunicke, 2005, p. 431). Due to the fact that in the FPS games players can find items that provide a temporary boost on the battlefield, this game type can be classified as a powerups type (see Table 1). The mechanics controlling the demand makes an intervention by manipulating the number and classes of enemies, and the strength of their attack (ibid.). The game is considered difficult if the player has not enough life points, ammunition, and his enemies are strong and spawn at short intervals. Just like in the *Tower Defence* described in the section 4.1, due to a large number of variables in the game the DDA system does not analyse the player's moves, but it uses a custom measure to evaluate his performance. But in contrast to *Tower Defence*, due to the nature of the FPS game, estimation of the player performance must take place all the time during the game, and not after each completed level. Therefore, authors also focused on the problem of intervention, which should be unnoticeable for the player (Hunicke, Chapman, 2004, p. 92). The purpose of this approach is to make the game interesting and constantly challenging for the player.

6. Summary

The functionality that enables automatic game difficulty scaling is important for many reasons. The adjusted game is meant to reach more players because it will suit the expectations of both experts and novices (it will not be boring or frustrating). In addition, games with the DDA systems can be used more successfully in other areas (e.g. for rehabilitation – see Goetschalckx, Missura, Hoey, Gärtner, 2010). Creating a well-functioning DDA system is not a trivial task. Perhaps the reason is that the concept of difficulty may be understood differently in different genres of games. In this paper, I suggested games' categorization based on those dimensions of games which are strongly associated with their difficulty. Such a classification may be helpful for developers when it comes to the design of choices for the DDA system. The proposed classification shows which dimensions of the game should be examined when creating such systems. Dimensions adapted from Aarseth et al. (2003) proved to be useful in showing the difference between the foundations of the DDA systems, which vary depending on the particular genre. In the board games (topological and turnbased), one may create a complete game tree. Additionally, the gameplay of this type of games is divided into small units of time. The complexity of the game can be predetermined by taking these two factors into account. It is also known if the player performs the winning or losing moves and how many moves he or she has to make to win. In the topological and realtime games it is not possible to create a complete game tree due to a large number of moves a player may make. It is therefore necessary to introduce an additional metrics to help evaluate the difficulty of the game (e.g. points). In games with waves of enemies, there are specific units of time, which constitute natural points of player's evaluation. In the last group of games discussed, FPS (realtime and geometrical games), it is not possible to create a game tree either, and, what is more, the gameplay is not divided into specific units of time. It is necessary not only to create additional measures that help estimate the difficulty of the game, but also to perform evaluation of the player on the fly, during the game. In this field, the dynamics of the adjustments is crucial. Additionally, the difficulty has to be adjusted so that the player is not aware of it. In these genres of games, in which there is no possibility to create the game tree, it is necessary to shift the analysis from terms of the game theory to the focus on players' performance in the game.

Acknowledgment

The author would like to thank Paweł Łupkowski and the anonymous reviewers for their helpful remarks and comments on a draft of this article and Wojciech Włodarczyk for his feedback in the field of computer science.

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Systemy dynamicznego wyważania rozgrywki wykorzystywane w różnych gatunkach gier

Abstrakt: Stworzenie gry wideo, która byłaby angażująca dla dużej liczby graczy, nie jest prostym zadaniem. Problem ten często wiąże się z dostosowaniem trudności rozgrywki do umiejętności konkretnego gracza. Dzięki temu gra nie okazuje się ani za łatwa, ani za trudna, przez co gracz nie czuje się znudzony czy sfrustrowany. W ciągu ostatnich lat powstało wiele implementacji systemów dynamicznego wyważania rozgrywki w różnych gatunkach gier. W literaturze próżno jednak szukać uniwersalnego rozumienia zagadnienia trudności gry. Niniejszy artykuł stanowi próbę usystematyzowania tej właściwości gier (wykorzystywanej przez systemy dynamicznego wyważania rozgrywki) oraz metod jej ewaluacji. W tym celu zostanie przedstawiona klasyfikacja gier wideo oparta na aspektach rozgrywki, które mają największy związek z trudnością poszczególnych gatunków gier.

Słowa kluczowe: dynamiczne wyważanie rozgrywki, gry planszowe, gry wideo, typologia gier