Dynamic Difficulty Adjustment for Digital Games using Reinforcement Learning

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***Abstract*—This research gauges the benefits and downsides of including overarching Dynamic Difficulty Adjustment (DDA) procedures in digital games, such that the difficulty adapts automatically to the user's performance. An Artificial Intelligence Model was developed to implement and manage DDA in 'Ravenfield'. Users were asked to try both versions, through which important data was extracted. This data showed that a system which is well implemented is beneficial to players, increasing levels of enjoyment and engagement. Systems which fail to stay anonymous can instead compel the user to feel cheated. This review highlights the need for further research on the subject, as to find an ideal way of implementing a system which is beneficial for users across the board.**

***Index Terms*—Dynamic Difficulty Adjustment, Artificial Intelligence, Digital Games**

I. Introduction

Video games have become an increasingly popular form of entertainment over the last few decades. As the video game industry continues to grow, game developers are faced with the challenge of creating games that are both engaging and accessible to a wide range of players, regardless of their skill level. One solution to skill level-related inaccessibility is the implementation of Dynamic Difficulty Adjustment (DDA) in games, which involves automatically adjusting the game's difficulty level in response to the player's performance. DDA has the potential to make games more enjoyable for players by providing a customized gaming experience that is tailored to their abilities.

Recently, Artificial Intelligence (AI) has further emerged as a powerful tool, through the recognition gained by impressive Language Models which have taken the world by storm. AI techniques can be used to analyze the player's performance in real time, allowing the game to dynamically adjust the difficulty level to match the player's skill level. DDA is effective in improving player engagement and satisfaction, as well as increasing the accessibility of games for players with varying levels of experience.

The goal of this research is to explore the use of AI in implementing DDA in video games. Specifically, this research examines the effectiveness of a DDA model implemented through reinforcement learning, as well as measures the impact of the DDA procedures on player engagement, satisfaction, and accessibility.

Overall, the research seeks to contribute to the growing body of research on the use of AI in video games and to provide insights and further knowledge on the ideal way to set up an efficient and effective DDA system.

A. Research Onion

1) Research Philosophy: This research study explored the idea that social phenomena are inherently subjective and context-dependent, and can be understood through interpretation and analysis of meaning. Therefore the first layer chosen was 'Interpretivism' as this promoted understanding the subjective experience and perspective of the players. Qualitative research was used to uncover the complex and nuanced meanings that people attach to their experiences and actions.

2) Research Approach: An Inductive approach was chosen as this research's purpose is to uncover themes and patterns from the data collected. Since this topic is still relatively unexplored, this exploratory approach seemed ideal to further the topic's understanding, by arriving at a Hypothesis through the data itself.

3) Research Strategy: Data was gathered using an experiment. This experiment compared the normal version of a 'Ravenfield' match with another 'Ravenfield' match which was assisted by DDA, and managed through an AI model. The results of these two scenarios were compiled and compared with one another to produce important insight on the topic at hand.

4) Choices: The data was gathered through the use of Mixed-Methods. Participants were asked to answer several questions, some of which were closed-ended (quantitative) and some of which were open-ended (qualitative) and promoted further discussion. All data gathered was necessary to further understand underlying factors which affect enjoyment and engagement during play.

5) Time-Horizon: Data was gathered at a single point in time, therefore the Cross-Sectional method was used. The data was however gathered from different groups of people, with varying levels of skill in the topic that was tested.

6) Techniques and Procedures: The data was gathered through post-experiment interviews which gauged the difficulty, enjoyment, and engagement during play sessions, after which a number of questions are asked that directly relate

to DDA and its utility and perceived value. The sampling strategy chosen was stratified sampling. The participants were selected to represent four different sub-groups (Teenage Gamers, Teenager Non-Gamers, Adult Gamers, and Adult Non-Gamers). The researchers then analyzed the data using both content analysis and statistical analysis.

B. Researcher Positioning

The researcher has a background in digital games, both in development and in playing during leisure time. The researcher acknowledges and has experienced firsthand the emotions and detachment that can be experienced when faced with difficulty which is not in sync with the player's skill.

C. Purpose of Research

The research aims to study how DDA systems could be implemented in a way that amplifies beneficial emotions for the players without adding non-beneficial emotions such as confusion, frustration, and feeling discredited.

D. Research Questions

- Does the adjustment affect player performance?
- Do players notice when adjustments occur?
- Does adjustment significantly affect the player's enjoyment, frustration, or perception of game difficulty?

II. Literature Review

A. Game Adjustment

Game developers iteratively update game systems using feedback from playtesting, changing them until the game is balanced. While this approach cannot be automated, directed mathematical analysis can reveal deeper structures and relationships inside a gaming system, which with the right algorithms and approach, can be adjusted while the game is being played [6]. To make these transitions seamless, developers can make use of the phenomenon called "Change Blindness", which is a failure to detect changes when they occur during saccades, blinks, blank screens, movie cuts, and other interruptions [7].

B. Precautions of DDA

[6] explains that in order to adjust a game experience for a given player, without having negative impacts on well-balanced systems, it is crucial to identify and understand the systems which make it fun and how these can be adjusted to heighten this enjoyment. The author also stresses that adjusting difficulty during a play session could result in the player feeling cheated when such adjustment disrupts u degrades the core player experience. The MDA (Mechanics, Dynamics, and Aesthetics) will vary between games and genres, but must be considered and factored into DDA. Mechanics are the different player states and actions involved within the game. Dynamics refers to the variation in difficulty and rewards gained over time within a game. The Aesthetics of a game is highly influenced by its Mechanics and Dynamics. In many cases, player expectations according to genre conventions will factor into creating the overarching aesthetics of a video game [6]. Taking correct measurements where also highlighted within the study, such as taking damage reading over battle and not over the whole playing time, to retrieve a relevant damage reading in relation to battle.

C. Implementation 1

[6] used the MDA framework as a guide in order to create a system that adjusts negative feedback without changing the basic FPS genre experience. The developed system controls the game's main inventory Mechanics (health, ammunition, shielding, and weapons), which effect the game's primary exploration and combat Dynamics, while also preserving the overall cycle of activities, which in-turn maintains the game's fast-paced shooter Aesthetics. [6] used damage taken, health, mean and standard deviation of current damage rates, and time, to estimate the probability of death in a given encounter, which helps to give an indication whether intervention through difficulty adjustment is required. [6] stresses the importance of having Adjustment Goals within any DDA controller. The author mentions three different policies, first of which is the Comfort policy, which aims to keep the players reasonably safe. The Discomfort policy instead is optimized to challenge players by limiting supplies and increasing the challenge when the player reaches a pre-defined range of health. The author continues by describing the Training policy as initially comforting the player, and gradually increasing the discomfort over the course of a level or session. [6] implemented a Comfort policy, having a set threshold of 40% for the player's probability of death, which once exceeded, results in difficulty adjustments, which added 15 health points every 100 ticks.

D. Implementation 2

[8] explains that in the case of hypercasual endless games, DDA can help to keep the player engaged longer. The research shows that, while initially, most of these games are successful in effectively captivating the attention of the player, most lose the player's interest during the first 7-days of play. [8] argues that this is due to boredom or frustration brought about by an imbalance between the game's difficulty and the player's skill. Using an effective DDA system, the game can stay within the "Flow", which is when the player experiences the ideal difficulty and abilities balance. Achieving and maintaining the player's flow during the tutorial or introduction encourages the player to enter the "core loop". The research by [8] uses a hypercasual endless game which uses a Quick Progressive Difficulty (QPD) system and creates another version which implements DDA instead. The QPD works in such a way that difficulty only rises, and so once a player plateaus, frustration and anxiety start becoming a problem. The research hypothesises that tackling these elevated, negative emotions through DDA could help keep the player in the "flow", allowing the player to play longer. The normal version of the game starts the player with 5 lives and lets the player go up a level, therefore going up in difficulty, after gaining 5 consecutive points without losing a life. After this level up, the user is

then stuck at this difficulty, or harder if he/she can again gain 5 consecutive points without losing a life. The adapted version which implements DDA, allows the player to level up in the same manner, however, adds a condition that allows the player to level down to mitigate the frustration caused by the extreme difficulty. After an increase in difficulty, if the player loses a life, this indicates that the difficulty may be out of sync with the player's abilities at that point in time, which causes a decrease in difficulty.

E. Implementation 3

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H. Experiments

[6] initiated the experiment by giving subjects a description of the game and its controls, followed by at least 15 minutes of playtime. Performance data was stored for later revision and subjects were then requested to fill out an evaluation form. The experiment was single-blind, with half of the games adjusted and the other half control [6]. Adversely, [8] had participants first try one version of the game, and then try the other. This allowed the research to distinguish between the results obtained from each participant for both versions. Scores and frustration evaluations were gathered from each participant after each play session.

I. Results

The experiment conducted by [6] resulted in a significant decrease in player deaths, with post-play evaluations revealing no differences in enjoyment for novice players, whereas expert players reported slightly elevated levels of engagement. The study also highlights that no significant correlation between adjustment and difficulty evaluation was noted by the subjects. "Change Blindness" was successfully implemented as the attention of players was directed elsewhere. The results of the experiment conducted by [8] were also promising. For players of all skill types, the DDA system encouraged higher scores, and while casual players also reported a decrease in frustration, experienced players adversely reported an increase in frustration. [8] shows confidence that with further research, this too can be improved. Whereas the study by [6] implemented DDA through a change in mechanics, [8] added DDA by modifying the game's dynamics, therefore changing its structure. Both approaches are correct, however, one leaves a larger footprint on the game's aesthetics. [6]'s approach maintains the game's format, however risks becoming a nuisance for eagle eyed players which notice the adjustment. [8]'s approach does not attempt to stay anonymous and therefore, does not risk the user feeling cheated by the game. Instead, the is implemented such that it is an integral part of the game. A disadvantage to this is that it could lessen the enjoyment of the game and heavily change the experience provided by the original.

J. Recommended Reads

- R. Hunicke, "The Case for Dynamic Difficulty Adjustment in Games," pp. 429–433, Jun. 2005, doi: 10.1145/1178477.1178573.
- D. J. Simons, "Current Approaches to Change Blindness," vol. 7, no. 1–3, pp. 1–15, 2000, doi: 10.1080/135062800394658.
- Z. Yang and B. Sun, "Hyper-Casual Endless Game Based Dynamic Difficulty Adjustment System For Players Replay Ability," 2020, pp. 860–866.

III. Research Methodology

A. Game and Equipment Used

For this research, the game 'Ravenfield' was adapted such that it included DDA. This adjustment happened through changes in enemy accuracy, depending on the teams remaining unit lives and the flag control balance. A balance would mean that the set difficulty was ideal. An unbalance on either side meant that an adjustment was necessary to re-balance the teams' remaining unit lives (tickets) and/or flag balance. For all stages of this research, an ASUS ROG STRIX G15 was used with the following specifications:

- Central Processing Unit: Intel I7-11850H
- Memory / RAM: 16GB
- Graphical Processing Unit: Nvidia RTX 2060 (Laptop)

B. Dynamic Difficulty Adjustment Models

The AI Model was created using the "stablebaselines3" library available for Python. This library facilitates the creation of AI models with varying settings. For this study, it was observed that a Multi Input Policy setting would be ideal to handle the necessarily complex observations. An observation is the data which the Model associates with an action during training. Initially an observation included: the blue team's remaining tickets, the red team's remaining tickets, flag balance and current set difficulty. A class that handles logging and saving during training was created and initialised so that the model saved its best version after every 1000 steps. This allowed for detailed comparisons between models in terms of effectiveness and improvement rate. Code was added so that the models could be loaded and tested, by having the loaded model play and return the total rewards, which can be compared to other models' results. The initial Model was trained for 265000 steps and took 5 days of non stop training.

C. Reward System

This research had a number of conditions which if satisfied, return rewards to the AI Model. The first condition pertains to the difference in team tickets(unit balance), where a difference of 5 tickets or less granted the Model a reward with a value of 1. Simultaneously, another reward of the same value was earned by the Model upon satisfying another condition, which is having the flag balance of the two teams within 10% of each other. Another reward with a value of 1 was given to the Model when the previous two conditions were satisfied concurrently.

D. Gauging User Feedback

A four-phase experiment was planned and conducted, during which valuable data was collected. A number of questions for each phase were prepared with the intent of gathering as much supporting data as possible, within the boundaries presented by time. A group of 20 people were invited and accepted to take part in the experiment. As done by [8], the participants were divided into two groups, which differentiated only in the order of the phases carried out. The first group carried out phase 2 followed by phase 3, whereas the second group carried out phase 3 before moving on to phase 2. This was done to mitigate bias from the questions in phase 4, where a person's answers could have been heavily influenced by the most recent phase completed.

A number of questions were prepared for each individual phase. These questions were the main source for all the primary data collected.

E. The Experiment's Process

1) Phase 1:

- How often do you play digital games? (1-5)
- How would you rate your own skill in playing First Person Shooter Games? (1-5)
- How would you rate your adaptability to new game experiences? (1-5)
- Which of these do prefer the game to be: Easy, Challenging, or Extremely Challenging?
- Have you ever played 'Ravenfield'? If yes, give an estimation of total play-time.

The participants were all given an individual explanation of the game and its mechanics. Specifically, the rag dolling effect, the manual reloading, and the loadout selection. Subsequently, the participants were given a brief overview of the controls. It was then explained that following a number of pre-play questions, they would be asked to play a single match, after which further instructions would be given. The participants were then asked to answer the Phase 1 questions, which prompted self-assessment on skills related to the experiment and gauged the participants' expected outcome of their upcoming play session.

2) Phase 2:

- How challenging was the match? (1-5)
- How engaged were you during play? (1-5)
- How much would you say you enjoyed it? (1-5)
- How well-balanced was the game's difficulty? (1-5)
- Did you notice anything strange during the match?

The participants were equipped with an Apple Watch Series 6 which was used to gather heart rate data which could then be related to levels of engagement. Participants were then instructed to play a match using the unchanged version of the game 'Ravenfield'. They were allowed to use whatever loadout they wanted and were instructed to play until the match finished through either victory or defeat. After the play session, participants were asked to answer questions related to the current Phase. These questions measured the levels of enjoyment, engagement, and difficulty, as experienced by the participant.

3) Phase 3:

- How challenging was the match? (1-5)
- How engaged were you during play? (1-5)
- How much would you say you enjoyed it? (1-5)
- How well-balanced was the game's difficulty? (1-5)
- Did you notice anything strange during the match?

This Phase worked exactly like Phase 2 with a single and important change. During this phase, the participants played a match using the edited version of the game 'Ravenfield' which utilised Dynamic Difficulty Adjustment. After the end of the match, evaluation was carried out as done in Phase 2.

4) Phase 4:

- Could you guess which of the matches played had Dynamic Difficulty Adjustment?
- Do you feel that the adjustments were suitably balancing the game?
- Do you feel that the adjustments affected your performance?
- Did the adjustment affect your enjoyment, frustration, or perception of the game?

The final Phase started by finally explaining the research and the concept of Dynamic Difficulty Adjustment to the participant. Now that they were given clear context, they were asked whether they could identify which of the matches played had Dynamic Difficulty Adjustment. Finally, they were asked other questions related to their subjective opinions regarding the use of Dynamic Difficulty Adjustment in Digital Games.

IV. Template

- Use either SI (MKS) or CGS as primary units. (SI units are encouraged.) English units may be used as secondary units (in parentheses). An exception would be the use of English units as identifiers in trade, such as "3.5-inch disk drive".
- Avoid combining SI and CGS units, such as current in amperes and magnetic field in oersteds. This often leads to confusion because equations do not balance dimensionally. If you must use mixed units, clearly state the units for each quantity that you use in an equation.
- Do not mix complete spellings and abbreviations of units: "Wb/m^2" or "webers per square meter", not "webers/m^2". Spell out units when they appear in text: ". . . a few henries", not ". . . a few H".
- Use a zero before decimal points: "0.25", not ".25". Use "cm^3", not "cc".)

A. Equations

Number equations consecutively. To make your equations more compact, you may use the solidus (/), the exp function, or appropriate exponents. Italicize Roman symbols for quantities and variables, but not Greek symbols. Use a long dash rather than a hyphen for a minus sign. Punctuate equations with commas or periods when they are part of a sentence, as in:

$$a + b = \gamma \tag{1}$$

Be sure that the symbols in your equation have been defined before or immediately following the equation. Use "(1)", not "Eq. (1)" or "equation (1)", except at the beginning of a sentence: "Equation (1) is . . ."

B. LaTeX-Specific Advice

Please use "soft" (e.g., `\eqref{Eq}`) cross references instead of "hard" references (e.g., `(1)`). That will make it possible to combine sections, add equations, or change the order of figures or citations without having to go through the file line by line.

Please don't use the {eqnarray} equation environment. Use {align} or {IEEEeqnarray} instead. The {eqnarray} environment leaves unsightly spaces around relation symbols.

Please note that the {subequations} environment in LaTeX will increment the main equation counter even when there are no equation numbers displayed. If you forget that, you might write an article in which the equation numbers skip from (17) to (20), causing the copy editors to wonder if you've discovered a new method of counting.

BibTeX does not work by magic. It doesn't get the bibliographic data from thin air but from .bib files. If you use BibTeX to produce a bibliography you must send the .bib files.

LaTeX can't read your mind. If you assign the same label to a subsubsection and a table, you might find that Table I has been cross referenced as Table IV-B3.

LaTeX does not have precognitive abilities. If you put a \label command before the command that updates the counter it's supposed to be using, the label will pick up the last counter to be cross referenced instead. In particular, a \label command should not go before the caption of a figure or a table.

Do not use \nonumber inside the {array} environment. It will not stop equation numbers inside {array} (there won't be any anyway) and it might stop a wanted equation number in the surrounding equation.

C. Some Common Mistakes

- The word "data" is plural, not singular.
- The subscript for the permeability of vacuum μ_0, and other common scientific constants, is zero with subscript formatting, not a lowercase letter "o".
- In American English, commas, semicolons, periods, question and exclamation marks are located within quotation marks only when a complete thought or name is cited, such as a title or full quotation. When quotation marks are used, instead of a bold or italic typeface, to highlight a word or phrase, punctuation should appear outside of the quotation marks. A parenthetical phrase or statement at the end of a sentence is punctuated outside of the closing parenthesis (like this). (A parenthetical sentence is punctuated within the parentheses.)
- A graph within a graph is an "inset", not an "insert". The word alternatively is preferred to the word "alternately" (unless you really mean something that alternates).
- Do not use the word "essentially" to mean "approximately" or "effectively".
- In your paper title, if the words "that uses" can accurately replace the word "using", capitalize the "u"; if not, keep using lower-cased.
- Be aware of the different meanings of the homophones "affect" and "effect", "complement" and "compliment", "discreet" and "discrete", "principal" and "principle".
- Do not confuse "imply" and "infer".
- The prefix "non" is not a word; it should be joined to the word it modifies, usually without a hyphen.
- There is no period after the "et" in the Latin abbreviation "et al.".
- The abbreviation "i.e." means "that is", and the abbreviation "e.g." means "for example".

An excellent style manual for science writers is [7].

D. Authors and Affiliations

The class file is designed for, but not limited to, six authors. A minimum of one author is required for all conference articles. Author names should be listed starting from left to right and then moving down to the next line. This is the author sequence that will be used in future citations and by indexing services. Names should not be listed in columns nor group by affiliation. Please keep your affiliations as succinct as possible (for example, do not differentiate among departments of the same organization).

E. Identify the Headings

Headings, or heads, are organizational devices that guide the reader through your paper. There are two types: component heads and text heads.

Component heads identify the different components of your paper and are not topically subordinate to each other. Examples include Acknowledgments and References and, for these, the correct style to use is "Heading 5". Use "figure caption" for your Figure captions, and "table head" for your table title. Run-in heads, such as "Abstract", will require you to apply a style (in this case, italic) in addition to the style provided by the drop down menu to differentiate the head from the text.

Text heads organize the topics on a relational, hierarchical basis. For example, the paper title is the primary text head because all subsequent material relates and elaborates on this one topic. If there are two or more sub-topics, the next level head (uppercase Roman numerals) should be used and, conversely, if there are not at least two sub-topics, then no subheads should be introduced.

F. Figures and Tables

a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

TABLE I
TABLE TYPE STYLES

Table Head	**Table Column Head**		
	Table column subhead	***Subhead***	***Subhead***
copy	More table copy[a]		

[a]Sample of a Table footnote.

Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when

Fig. 1. Example of a figure caption.

writing Figure axis labels to avoid confusing the reader. As an example, write the quantity "Magnetization", or "Magnetization, M", not just "M". If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write "Magnetization (A/m)" or "Magnetization {A[m(1)]}", not just "A/m". Do not label axes with a ratio of quantities and units. For example, write "Temperature (K)", not "Temperature/K".

ACKNOWLEDGMENT

The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g". Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page.

REFERENCES

Please number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first ..."

Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes.

Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols.

For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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