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Automated Creation of Puzzle games with Constraint Programming

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August 11, 2018

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University of St Andrews Dissertation MSc in Advanced Computer Science

Abstract

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Acknowledgements

I would like to extend thanks to my supervisor of this project, Christopher Jefferson, for his support and for his highly efficient replies to my emails and questions.

Also thanks to my parents for their support along the way. Thanks to my roommates and classmates for being there. Without these people, this work would not have been possible.

Declaration

I hereby certify that this dissertation, which is XXXX words in length, has been composed by me, that it is the record of work carried out by me and that it has not been submitted in any previous application for a higher degree. Credit is explicitly given to others by citation or acknowledgement.

This project was conducted by me at The University of St Andrews from June 2018 to August 2018 towards fulfillment of the requirements of the University of St Andrews for the degree of MSc under the supervision of Dr Christopher Jefferson.

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1 Introduction

1.1 Project Description

There is a history of generating puzzles using A.I., from Chess problems to Sudoku levels. Sudoku is a classic puzzle which is also named as "the Rubik's cube of the 21st century" and it became popular in Japan in 1986. Then Sudoku achieved international popularity in 2005 [1]. Sudoku, Chess, and other puzzles can be described by constraint problems and then the programmer can establish corresponding models based on these constraints [2]. Additionally, models could give an objective measure of the difficulty of a puzzle instance with grades such as from the easiest to the hardest. Then programmers apply this measuring method to problem instances for the public [2].

Recently there has been a lot of progress in generating puzzles, and also measuring the toughness of these puzzles, for a human player. In 2016, the AI player, Alpha Go, had beaten Lee Sedol and this remarkable competition also represents a result that it is nearly impossible to win against an AI player for puzzles [3]. Alpha Go greatly promoted the ability of AI players to solve puzzles. Alpha Go has since been modernized to the latest version Alpha Zero and this also represents the general trend is taking advantage of technology to solve problems [3]. In this report, I will introduce an effective way to solve puzzles using constraint programming. There are many puzzles which have been formulated as constraint problems and subsequently solved. This project aims to solve "Match Three" puzzles and measure the difficulty of "Match Three" puzzles.

1.2 Project Aim & Objectives

The main aim of this project is to automatically generate puzzles and create engines to solve puzzles. This project will involve formulating "Match Three" rules, implementing simulations for "Match Three" puzzles and performing experiments which measure how well the difficulty measure lines up with real users. Through implementing engines of solving "Match Three" puzzles, puzzles will be divided into three difficulty levels —- easy, medium and hard. Then, real users try to solve the same puzzles and record their time spent in solving puzzles and also divide puzzles into three hardness levels. The project will also involve comparing the results performed by computers and humans and evaluate the engine's ability to classify the puzzles' difficulties.

1.3 Motivations

As Schwab wrote in his book "AI game engine programming", there are two main goals for pursuing the development of AI [4]. The first is to understand what intelligent entities are and meanwhile understand our humankind better [4]. The second is to build intelligent entities, for fun and profit for most occasions [4]. This project may be seen to address aspects of both goals mentioned above. The use of constraint programming to solve puzzle games is for fun and profit and how to get such an artificial engine is exactly what we need to know about the intelligent entities.

Russel and Norvig defined AI in an article "A modern approach" in 1995 as the creation of computer programs that emulate four things [5]:

1. thinking humanly
2. thinking rationally
3. acting humanly
4. acting rationally

From these four aspects, "thinking rationally" and "acting rationally" are considered as the more important aspect so that scientists could obtain AI programs as smart as possible such as Alpha Go. Besides, many trials Turing Test trials have been conducted to show that people cannot distinguish the differences between human and machines. For the "acting humanly" aspect, people are more likely to try to make a robot that is the same as a real person than the AI player that people never win for puzzles. Indeed, people have made great progress on these aspects year by year. Considering a situation as below, in a truly enjoyable game such as Chess, a human player

may want to have fun playing against an automatic machine player. Due to the fast development of technology, it tends to be difficult for non-professional human chess players to win a Chess game against an automatic machine player, because the AI is too strong. The automatic machine player has been too much powerful than human in the aspect "thinking rationally". AI players are commonly able to consider many more combinations of moves than the human player can, thereby giving them an advantage. Therefore, many people play Chess is for entertainment instead of any academic learning or thinking training. Most of them want to play against with an opponent of similar strength rather than be beaten every time. One of the most significant aims of playing video games is to obtain a great player experience (PX) [6]. However, it is not easy to evaluate PX using any simple device or other physical experiments [7].

In Chess games, what normal players need is an automatic machine player with a suitable challenge rather than that automatic player overwhelm the human by always making the best move [4]. Such opponents would possible make mistakes occasionally which are more like humans or even worse than human normal levels. Then it may even aid human enjoyment, if an AI player could adjust its ability to that of its human opponent on occasions. Whereas in non confrontational games, such as "Candy Crush Saga", there is no automatic player so that we need to list the difficulty of initial boards and goals for normal human players. This project seeks to investigate aspects relating to using an AI to easily produce Candy Crush Saga game boards with suitable goals for human players that can be both challenging and enjoyable.

"Match Three" is a typical puzzle video game where the player manipulates tiles in order to make them disappear according to a matching criterion. The matching criterion is that there are at least three tiles of the same type adjoin each other [8]. A field has an N×M matrix of spaces, where N and M are integers greater than three, and wherein each space of the matrix includes one of a plurality of different items. Then an object is allowed to swap to the nearest object once three are three or more identical items results in the items. Finally, these items would be removed from the field.

Because "Match Three" games are very simple games with a very limited number of rules, it can be easily understood by many different age groups and appears to appeal to both young and old. Over time "Match Three" puzzle games have become more and more popular. Bejeweled, Candy Crush Jelly Saga and Ruby Blast are the most famous "Match Three" puzzle games that the number of downloads from the app store has more than billions of times [9]. Many popular games are all based on this puzzle and the most famous series is "Candy Crush Saga". According to reports by Wall Street Journal in 2013, nearly 15 million people in Western countries were addicted to Candy Crush Saga [9] [10]. These data show that people enjoy playing "Match Three" puzzle games. Thus, in this project, I aim to use "Candy Crush Saga" as the typical "Match Three" puzzles and aim to implement processes and mechanisms to aid measurement of the difficulty of puzzle levels.

2 Context Survey

In this chapter, I will introduce background and basic rules of "Match Three", review existing methods on solving "Match Three" and how to establish difficulty and explain reasons why I choose these criteria.

2.1 Introduction of "Match Three"

Match Three games are a type of casual puzzle games. The major task consists in forming lines/chains/groups of 3 or more same identical tiles. The traditional game board is square-patterned and filled with various tiles which could shift, select or rotate. Eugene Alemzhin created the first Match Three game by swapping adjacent balls named "Shariki" in 1994 which was released for DOS [11]. If there are no more possible matches in the board, then the game is over with current score shown in the screen. Then this kind of influential game led to the popularity of "Match Three" puzzle games. Nintendo published "Panel de Pon" in 1995 and "Tetris Attack" in 1996 [12] [13]. The former one is the original version released and the following one is the first game in Puzzle League series. In 2000, "Pokémon Puzzle League" developed by Nintendo which features the same gameplay as in "Panel de Pon" [14]. However, different from the predecessors, it was developed with a 3D mode instead of the traditional 2D mode. With the development of mobile phones, people realized that they would like to play more mobile games, a convenient and relaxing kind of gameplay.

In 2001, "Bejeweled", the first most famous mobile "Match Three" game released by PopCap Games [15]. There are more than 150 million times of Bejeweled downloaded from App stores [15]. The objective of this game is to swap one gem with an adjacent gem to form a horizontal or vertical chain of three or more gems [16]. If there are more than three gems connected, it provides bonus points. Once these gems are connected, they would disappear and fill new gems in. That would lead to chain reactions, called cascades, are triggered, where chains are formed by the falling gems. The cascades bring more bonus points as well. Additionally, there are two main goals for players, including complete a certain score in a limited time or limited steps. Since the great popularity of Bejeweled, more and more "Match Three" puzzle games appear in App stores, such as Candy Crush Saga, Bubble Witch Saga, Jelly Splash. Those games have long since caught on all over the playing planet. The reasons why an enormous quantity of people is addicted to "Match Three" puzzle games as noted. It contains two main parts, including "Broader Context" and "Game Design" [8]. In the "Broader context" part, it has four prevailing features.

1. **Demographics.** Compared to traditional video games, casual games are more oriented towards women and the adults who are over 35. They have more free time and more patience playing the same game.

2. **Distribution.** The size of causal games currently tends to be smaller than 10MB, which only takes up a little space of mobile phones. Additionally, most of them do not need to connect to a network. In other words, people are free to play when they take a subway without any network.

3. **Hardware.** These games do not tend to require advanced pieces of equipment or expensive external devices. Even a user's phone or computer is not the latest version, they could still play games fluently.

4. **Economic model.** "Match Three" games are often free to play. Even though they are some krypton gold in game, the cost is still quite small than most other video games.

Apart from the broader context part, the other significant part is game design [8] [17].

1. **Allow short playing sessions.**A game can often be finished in a few minutes. Most busy people, such as young child's mother or students who only have 10 minutes break during classes, would have more chances to play such games.

2. **Auto-save.** If players have some unexpected emergence cases have to deal with when they are playing, they can stop games by shutting the screen or closing the application. A commonly in-built auto-save feature makes it easy to resume playing the game.

3. **Easy control.** "Match Three" games do not require players to reply a fast response or any smooth operation. They can operate moves slowly.

4. **Very simple rules.** People tend to easily understand how to play without much much prior knowledge of the game, thereby making it.

5. **Moderate innovation.** For example, there are six regular candies in "Candy Crush Saga". However, there are more than ten kinds of different new candies or tools in "Candy Crush Saga". Thus, it has thousands of games and could develop more games as many as the company wants without having to make any substantial changes.

6. **Multiple levels of success.** Owing to many different levels of "Candy Crush Saga", players may succeed more easily than other normal video games. Meanwhile, it also provides some small missions during playing puzzles, such that players can get a small reward if the ranking of they are currently ranked top among all friends. While playing a game in "Candy Crush Saga", players can obtain three stars if the score is much higher than the expected. If the score is a little higher than the expected, players still can obtain one star. Those successes encourage players to play better every time.

7. **Much positive feedback.** Because players have to play "Candy Crush Saga" from the easiest to the hardest, players gain experience of victory pretty early on. If players cannot find the next move, a game may provide some tips or tools to help them overcome difficulties.

8. **Little negative feedback.** If players fail to pass, there is no punishment for players about their mistakes.

9. **The ranking of competition.** For example, "Candy Crush Saga" has more than thousands of games and players' accounts have been connected to their Facebook or Twitter accounts. This way, players can see the ranking of all friends who are also playing "Candy Crush Saga". This encourages players to play more games than other competitors.

10. **Categorizing is human nature.** Whether types of coffee, colours of clothes, types of fruits, trends in popular music, there is a natural human desire to categorize objects and experiences [18]. Because categorizing is a kind of human nature and people tend to find it easy to match three objects without any training, people probably enjoy categorizing gems in games.

Thus, "Match Three" puzzle games become more and more popular.

2.2 Candy Crush Saga

This section introduces the "Candy Crush Saga" game along with its rules and characters. "Candy Crush Saga", which is developed by King Digital, is a "Match Three" puzzle game and is developed from the browser website game"Candy Crush". "Candy Crush Saga" has been adapted for various platforms, including IOS, Android, Windows Phone and Windows 10. The theme of "Candy Crush Saga" is different candies and appears to appeal to many different age groups over the world. The basic rule is to combine three, four or five candies together by swapping two adjacent candies. Then candies disappear and score rises up. Players need to put different candy groups together and detonate, which will produce different effects and different scores. When one candy is moved, other candies would have chain reactions when their positions are modified. See Figure 1, the chain reaction brings Combo and Combo brings bonus to improve the current score. Then, players could gain progressively more points. Each game stage has to be unlocked one by one, and each mode is different with randomly dropping candies. There are many kinds of candies in Table 1 shown [19]. First, the basic board is made up of regular candies. Additionally, there are six regular sweets, the red candy (jelly), the orange candy (lozenge), the yellow candy (the lemon sugar), the green candy (gum), the blue candy (lollipop) and the purple candy (grape flavor candy).

Furthermore, there are some special candies, such as striped candies, wrapped candies, and colour bomb candies [19]. Striped candy has two types that there are horizontal or vertical white stripes on a regular candy. If a player sweeps two adjacent candies when one candy is moved horizontally, then four candies disappear and a new horizontal striped candy appears with the same colour (see

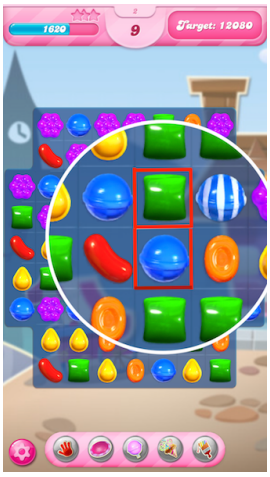


Figure 1: An Example of a chain reaction. If the player swap the selected Blue Candy and the selected Green Candy, and three blue candies in a row and blue candies would crush. Then the green candy would fall down and they will be in a column. It is an example of chain reaction process.

Table 1: Six Regular Candies And Four Special Candies.

Image	Candy Name	Origin	Image	Candy Name	Origin
	Red Candy	Jelly		Orange Candy	Lozenge
	Yellow Candy	Lemon Sugar		Green Candy	Gum
	Blue Candy	Lollipop		Purple Candy	Grape Flavor Candy
	Blue Horizontal Striped Candy			Blue Vertical Striped Candy	
	Blue Wrapped Candy			Colour bomb Candy	

the first figure in Figure 2). If the movement is vertical, then the new striped candy is vertical striped candy with the same colour. A horizontal striped candy can destroy the whole column of candies and a vertical striped candy can destroy the whole row of candies. The second special candy is wrapped candy. There are two methods to make. If there are five same colour candies consisting the "L" or "T" shape (see the second figure in Figure 2), then five regular candies disappear and the same colour wrapped candy appear. A wrapped Candy could make the 3*3 explosions twice in the game board, eliminating all nearby candies and obstacles.The last special candy is the most powerful candy named colour bomb candy. Only if there were five same colour candies in a row or in a column, and then they would be disappeared and a new colour bomb candy would be appeared (see the third figure in Figure 2). As long as the colour bomb candy is swept with any other regular adjacent candy, all the same colour candy on the board would be eliminated.

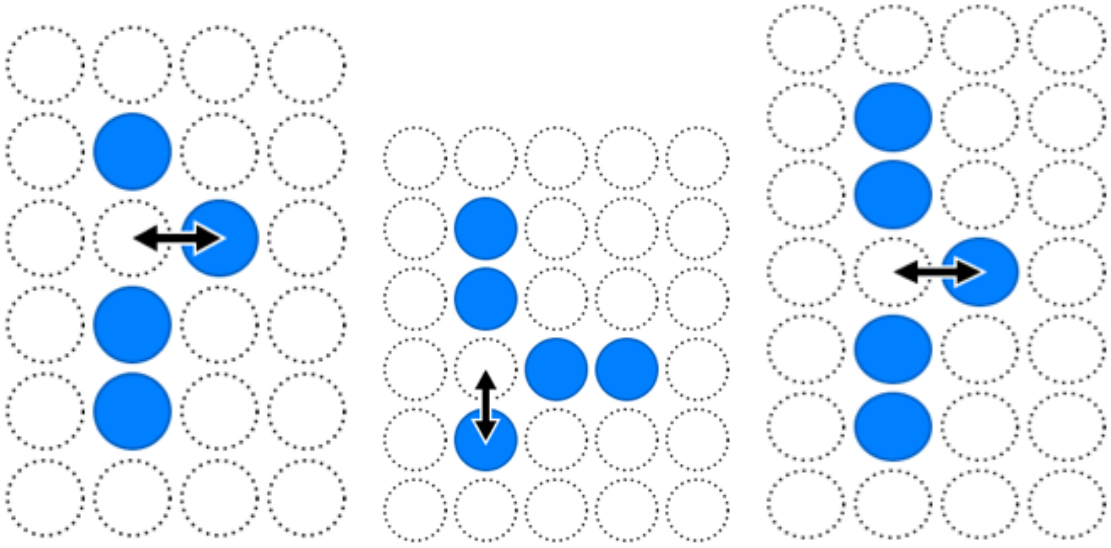


Figure 2: Except for matching three same candies in one row or in one column, there are three kinds of possible movements.

Except for these combinations, there are some hard combinations of special candies. They have high powerful effects and players could obtain much higher score after these combinations (see Table 2) [19].

One coin has two sides, there is no exception of "Candy Crush Saga". There are many doctors believe that indulging in playing the game would lead to a variety of health problems, such as presbyopia, cervical displacement, muscle inflammation and so on [20]. And Fred Richmond, the executive director of behavioral health services at Mission Hospital, pointed out that excessive indulgence in playing the game can cause a variety of psychological and physiological problems and then have a negative impact on adolescents. However, it is no doubt that this puzzle game brings much enjoyment and satisfaction. The data published by King Digital in 2013, "Candy Crush Saga is played over 700 million times a day", also proves the charming of this puzzle game [21].

2.3 Levels of Difficulty and Design

Though the background of "Candy Crush Saga" is important, each level design and its difficulty should be paid more attention. This part would bring two questions:

1. Why do we need to design levels with different levels of difficulty, and what impact will this have on the game?

2. How to determine the difficulty of these levels? What criteria can be used as a reference standard?

For the first question, it has been mentioned in the "game design" part in Section 2.1. Because "Candy Crush Saga" does not only bring multiple levels of success, but also encourages players to gain a higher ranking of competitions. Moreover, great game design brings a better PX. Elisa and her group members have introduced a great experimental design and analytical method for measuring enjoyment which had been identified as a central component of the player experience [22]. However, PX has various, overlapping concepts so that it is difficult to develop valid measures and a common understanding of game enjoyment. Firstly, they structured the review of 87 quantitative studies into general methodological observations in an experiment. Then according to the "Purpose of the studies", "Participants", "Games and Genre", "Study setting, gameplay duration

Table 2: Combinations of two special candies. Special candies can be combined together to produce special amplified effects.

Image	Candy A	Candy B	Effect
	Striped Candy	Striped Candy	Eliminate an entire line, an entire row of candies.
	Striped Candy	Wrapped Candy	Striped Candy and Wrapped Candy turn into a huge candy and destroy three whole rows and three whole columns of candies.
	Wrapped Candy	Wrapped Candy	A mass explosion created. Clears 24 candies around(5*5 explosions).
	Striped Candy	Colour Bomb Candy	If the Colour Bomb Candy and Striped Candy exchange position, then all the candies whose colour is as same as the colour of Striped Candy all randomly turn into the horizontal or vertical Striped Candy, then they all eliminate with the explosion.
	Wrapped Candy	Colour Bomb Candy	If the Colour Bomb Candy and Wrapped Candy exchange position, then all the candies whose colour is as same as the colour of Wrapped Candy all turn into the Wrapped Candy, then they all eliminate with the explosion.
	Colour Bomb Candy	Colour Bomb Candy	All candies are cleared on the board.

and game metrics", and "Measuring point of the critical element of experiment" aspects, more in-depth measures were developed by the institute [22]. Finally, the determining factors affecting the enjoyment of the game are Game System, Player and Context and Relationship between enjoyment and other PX components such as flow, presence and immersion. Thus immersion is a great critical factor of a great player experience [22]. In other words, the player has a desire to play a game, and it can prove that the player has a good game experience in the game. The more time players spend in a game, the stronger players' immersion. In other words, if players have an enjoyable experience in a game, they would like to spend more time and money on this game.

A similar experiment did by Su Xue, Meng Wu and their mates on the relationship between difficulty and engagement [23]. They convinced themselves of a causal link between the difficulty and engagement. Thus, they believed that a Dynamic Difficulty Adjustment framework with a global optimization objective of maximizing a player's engagement throughout the entire game [23]. Then they presented "Candy Crush Saga" and "Bejeweled" with Dynamic difficulty adjustment (DDA) implementations. Thereafter, they concluded two significant figures. The first shows that retained population (the red line) at a level is the number of players who have achieved this level as the highest one 3. There are players churned at each level, thus the retained population decreases as the level increases. The difficulty (the blue line) is measured by the average number of trials that are needed to win this level. The more trials it takes, the more difficult this level is. According to the win rate and the number of players, all levels have been divided into three difficulty levels, easy (<20), medium (21-80), and hard (>80). Firstly, we can easily find that the difficulty level is rising as the number of level in figure 3, but the number of players is decreasing as the number of levels. Secondly, the win rate of each level tends to be volatile. For example, there are seven peaks between 40 level and 60 level. It represents that every three levels will have a much more hard level. After that, the difficulty of the level is restored to a relatively simple or medium difficulty.

The second figure shows different initial candies board, which is affected by the random seed, have a relationship with the win rate. Because the random seed of board initialization is different, the initial candies would be different. Su and her teammates apply the random seed from 0 to 99 to the experiment, and then they conduct such figure 5 It can be clearly seen that the difficulty factor of the same game is also changing, from as low as 0.15 to as high as 0.75. This difficulty range can be said to have crossed from easy to hard. And by publishing the experiments after the game, they concluded that while existing DDA systems adapt game difficulty in a greedy manner for local benefit, our method maximizes the player engagement throughout the entire game.

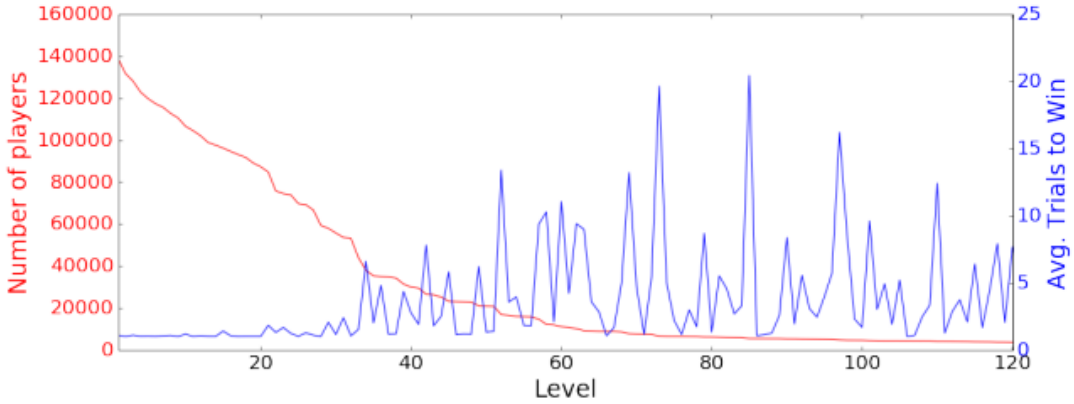


Figure 3: The retained population of players (red line) versus difficulties (blue line) by level. The red line represents, for each level, the number of players who have ever achieved it. The blue line represents the level difficulty, which is measured by 1/win rate, i.e., the average trials needed to win this level. We can observe the strong impact of difficulty on population retention, in particular for middle stage levels.

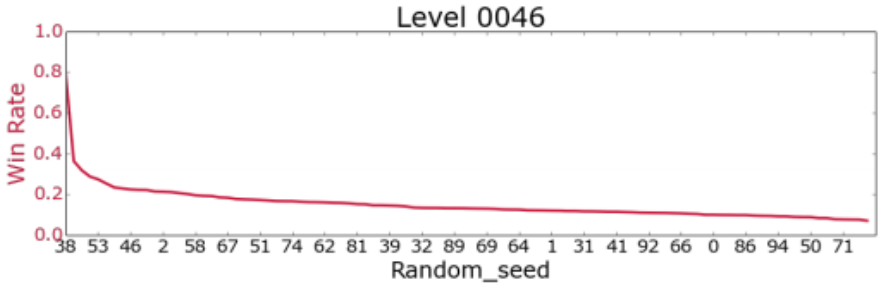
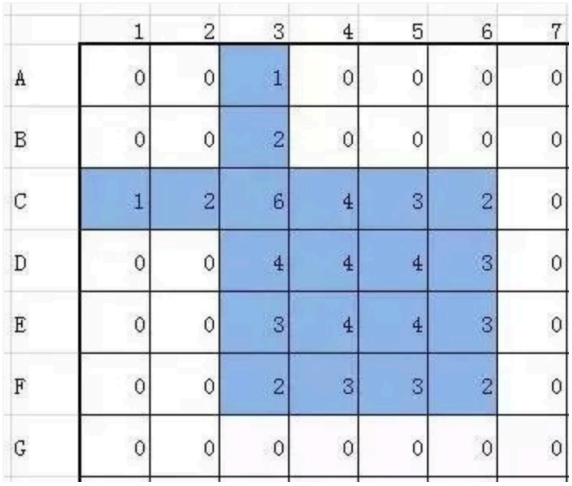


Figure 4: Difficulties of various random seeds at a level of the match-three game. The difficulty is measured by the win rate of a certain seed, i.e., the percentage out of all trials with this seed are actually wins. The variance of difficulties across seeds is large. We can see that the easiest seed (leftmost, seed 38) shows a win rate up to 0.75. In contrast, the hardest seed (rightmost, seed 71) has a win rate as low as 0.15.

In order to increase the interests of the puzzle game, it is necessary to design the game more ingeniously, such as adding some game props or changing the grid of the game board. Modifications would have an impact on the difficulty of levels. Four significant criteria, which would affect the difficulty level, should be noted. The first is the complexity of the terrain, the goals of the level. The complexity of the terrain is the most basic element of a game. This involves two core parts, static complexity and dynamic complexity. The static complexity means that the

complexity of the basic terrain itself, independent of the game process.The static complexity has a core factor: the average connected number. It is derived from the function: Grids Difficulty = Total Connected Number / Effective Number Of Grids. The Connected Number means how many possible moves on the board regardless of the colours of candies. For example, there are six possible connected "Match Three": A3-B3-C3; B3-C3-D3; C3-D3-E3; C1-C2-C3; C2-C3-C4; C3-C4-C5. The maximum connected number is 6 for such cell. Effective Number Of Grids means how many candies on the grid. And as such, if the level of elimination of the level is the same, he



	1	2	3	4	5	6	7
A	0	0	1	0	0	0	0
B	0	0	2	0	0	0	0
C	1	2	6	4	3	2	0
D	0	0	4	4	4	3	0
E	0	0	3	4	4	3	0
F	0	0	2	3	3	2	0
G	0	0	0	0	0	0	0

Figure 5: Connected Number: Owing to the function: Grids Difficulty = Total Connected Number / Effective Number Of Grids. Effective Number Of Grids means how many candies on the grid. White cell means there is no candy on the grid, and blue cell means there is a candy. "6" in C3 means there are six possible connected "Match Three": A3-B3-C3; B3-C3-D3; C3-D3-E3; C1-C2-C3; C2-C3-C4; C3-C4-C5

can divide the terrain difficulty of the game into three levels:

- High: The average connected number is >=3.6. Such a level is generally smoother and Combo is frequent.
- Medium: The average connected number is between 3.2 and 3.6. Although the number of Combos is not too large, it is not too difficult to play.
- Low: The average connected number is <3.2. In such a level, the player often has to spend some effort to find a few operational combinations on the disc, because resetting the situation is relatively frequent because there is no operation.

However, there may be a high degree of static complexity, but the actual game operation is very difficult, because it involves dynamic complexity. The dynamic complexity means that the complexity characteristic of the process of elimination and falling behavior during the actual game of the player. Dynamic complexity also has a core factor named the Combo problem. When a candy is eliminated, the fallen candies or the remaining candies will cause the chain reaction to occur. The appearance of these Combos will greatly change the difficulty of the game. These Combos are hard to predict in the game. Apart from the complexity of the terrain, the goals of the level, the special elements in the level and the restrictions of the level are also significant. The goal of the level may be a specific score, or the number of candies eliminated, or a combination of the two. Then the higher the target number or score, the more difficult it is. The special elements in the level, such as some novelty items, will increase the difficulty of the game, such as the rope and chocolate, the former is tied to the candy, while the latter will continue to increase the position occupying the candy. Level restrictions such as the number of steps and time will affect the difficulty of the game. However, these four things only affect the difficulty of the game, and can not be used as a direct basis for judgment. Consequently, a game which is designed to optimize the level of difficulty will have a profound impact on PX. This is why we need to design a reasonable game difficulty for the player.

After understanding the importance of game design, programmers could generate many different levels of games [17]. Meanwhile, here is another question about how we can identify these levels. Because the computer could generate thousands of different games artificially and mark the difficult level automatically. If the hardness of a game is determined by human beings, it may lead to more problems. On the one side, individuals have to spend a lot of time to judge the difficulty level of each game. It is inefficient, wasting time and possible to be a one-sided testing method. On the other side, different people have different standards for the same game. Thus, it must be the program itself that determines the difficulty of these different level games. This involves another matter whether the difficulty of a game determined by the program is the same as that of human beings. Therefore, an important experiment is needed for this project. The experiment requires two elements. Human and programs should divide all games into three levels, easy, medium and hard. The experiment should compare the consequences of the two groups.

Christopher Jefferson and his mates had performed an experiment on an automated generation of puzzles named Combination solved by constraints, which indicated that the fun and immersing computer games could be generated by constraints [24]. They explained how all the levels of Combination were generated, checked for correctness and rated for difficulty completely automatically through the use of constraints. Then they found that running the Constraint Programming a number of times using different variable orderings then averaging the result could provide a more satisfactory player experience. Finally, this application was released in the iTunes and gained a great commercial success and received good reviews.

2.4 Summary

To summarize, there is a substantial body of work that focuses on finding the reason why "Match Three" games so popular and how to solve "Match Three" puzzles, but limited work about how to evaluate the difficulty level of game.

Firstly, "Match Three" has two main reasons that lead to its popularity among the world, "Broader Context" and "Game Design". It allows people of all ages to play with a most basic device. The download file is small and it does not need Internet connection either. Because of these four items, the "Context" of "Match Three" games is "Broader" [8]. Players could gain multiple levels of success and much positive feedback with a few minutes. The features, such as"Auto save" and "Short playing session", allow users to play games in some gaps and stop playing when they have some emergency cases. Programmers could develop many games based on multiple special tools such as "Chocolate Candy" so that players always have a sense of freshness [8]. Then players are addicted to play such games with great immersion. The immersion is one of most significant factor on evaluating the player experience on a game [22]. Consequently, people have a great PX on "Match Three" games.

Secondly, a normal player could have a better PX if he/she has an opposite player with a suitable challenge rather than that opposite player overwhelm this normal player by always making the best move [4]. See Figure 5, "Candy Crush Saga" does not design such levels that the difficulty of level must be increased by the rising number of levels. Players would play a "Hard" difficult level after playing some "Easy" or "Medium" levels [23]. However, there is no such opposite player for "Match Three" games. Consequently, the grid map and task requirements of each level could be seen as the opposite player. This is why evaluate the difficulty of each level is important for players.

Thirdly, There are two criteria which would be used to evaluate the difficulty of these levels. The first one is the win rate mentioned in Su's experiment [23]. In addition, the second is the time spent on solving a puzzle mentioned by Christopher Jefferson [24].

3 Requirements and Analysis

This chapter gives the detailed problem statement. Then list the requirements summarized through background chapter. These requirements reflect the project objectives and the design of experiments, and provide guidelines for designing and developing the applications. There are two parts including functional requirements and non-functional requirements. The last section contains the use case diagram for this project.

My project main aim is to automatically generate puzzles and create engines to solve puzzles and then evaluate the difficulty levels of puzzles. Then real users try to solve the same puzzles and record their time spending in solving puzzles and also divide puzzles into three hardness levels. Finally, compare two results performed by computer engine and human players and evaluate the engine ability on classifying puzzles difficult levels. Consequently, there are three main tasks. The first is to develop a "Match Three" application that generate puzzles automatically. The second is to build an intelligent engine. The last one is to perform experiments on human players and the engine player. Based on these three tasks, functional requirements and non-functional requirements are listed separately according to their different uses:

3.1 "Candy Crush Saga" Java Application

1. This application shows the grids of candies, target, current score and steps left. Once players move successfully, the board should be refreshed and data should be updated.
2. This application allows player move candies if the move is valid. The move must be completed by two adjacent candies, and it would be valid if:
   - there are three or more than three same colour candies in a row or in a column.
   - there are five same colour candies consisting the "L" or "T" shape.
   - two adjacent candies are special candies or one of them is "Chocolate Candy". The result of the combination of two special candies shown in Table 2.
3. If the current score is no less than the target score when the left steps is zero. Show a message box and players could click one button to next level or click another button to close whole game.
4. Players can gain score if candies crush. The specialized score of each crushed candy as following:

3.2 Intelligent player

3.3 Project Constraints

1. The project has to be accomplished by 24rd August 2018.
2. The programming language used should be Java.
3. The application should be runnable on different operating systems, including Windows, Linux and OS X.

Table 3: The specialized score of each crushed candy.

Combination/Crush	Score	Bonus
Three regular candies	60	None
Four regular candies	120	Striped Candy with same colour
Five regular candies	200	Chocolate Candy or Bomb Candy
Vertical Striped Candy	120	Candies in the whole row of this horizontal striped candy would crush as well. Each regular candy score is 60.
Horizontal Striped Candy	120	Candies in the whole column of this horizontal striped candy would crush as well. Each regular candy score is 60.
Bomb Candy	1080	As the Bomb Candy as the centre, 5*5 candies around this candy would crush twice. Each regular candy score is 60.
Striped Candy and Bomb Candy	720	Three row and three column candies crush. Each regular candy score is 60.
Chocolate Candy and Regular Candy	0	Chocolate Candy would be seem as the regular candy. All candies which colour is same to the regular one would crush. Each regular candy score is 60.
Chocolate Candy and Striped Candy	0	Chocolate Candy would be seem as the striped candy. All candies which colour is same to the striped one would change to striped candy (It could be Horizontal and Vertical Striped Candy. This is a random choice). Each striped candy score is 120 and would lead to whole row or whole column crush. Each regular candy is 60.
Chocolate Candy and Bomb Candy	0	Chocolate Candy would be seem as the bomb candy. All candies which colour is same to the bomb candy would change to bomb candy. Each bomb candy score is 200 and would lead to 3*3 crush twice. Each regular candy is 60.
Chocolate Candy and Chocolate Candy	0	All candies on the board crush and chocolate candy is seen as a regular candy. Each regular candy is 60.
Combo[1]	0	The original Score * Combo Times

4 Design and Implementation

4.1 Application Design

4.2 Experiment Design

4.3 Experiment Implementation

5 Results Evaluation

6 Conclusions and Project Evaluation

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