

Automated Creation of Puzzle games with Constraint Programming

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**Abstract**

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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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# Introduction

## 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](#_bookmark14)]. Sudoku, Chess, and other puzzles can be described by constraint problems and then the programmer can establish corresponding models based on these constraints [[2](#_bookmark15)]. 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](#_bookmark15)].

Besides, recently there is a tremendous 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 an AI player for puzzles [[3](#_bookmark16)]. Alpha Go had greatly promoted the solving usability of an AI player to solve puzzles. Until now, Alpha Go has been modernized to the latest version Alpha Zero and this also represents the general trend is taking advantage of technology to solve problems [[3](#_bookmark16)]. In this report, I would introduce an effective way to solve puzzles, named constraint programming. People establish constraints, describing puzzles, as corresponding models to solve puzzles. There are various kinds of puzzles and I would implement one classic puzzle named “Match Three” in this project. This project aims to solve “Match Three” puzzles and measure the difficulty of “Match Three” puzzles.

## Project Aim & Objectives

The main aim of this project is to automatically generate puzzles and create engines to solve puzzles. This project could involve formulating “Match Three” rules, implementing simulations of “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 would be divided into three difficulty levels —- easy, medium and hard. 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. Compare the results performed by computers and humans and evaluate the engine ability on classifying puzzles difficult levels.

## Motivations

As Schwab written in his book “AI game engine programming”, there are two main goals for pursuing the development of AI [[4](#_bookmark17)]. The first is to understand what intelligent entities are and meanwhile understand our humankind better [[4](#_bookmark17)]. The second is to build intelligent entities, for fun and profit for most occasions [[4](#_bookmark17)]. Because of these intelligent entities, our life has become more effective, vivid and wonderful. As a consequence, this project would be the combination of the two. 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](#_bookmark18)]:

* + 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, there are many trials for passing Turing Test which makes 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. 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 normal person wants to have fun playing against with an automatic machine player. Due to the fast development of technology, it is impossible for a normal person to win a Chess game with an automatic machine player. Because the automatic machine player has been too much powerful than human in the aspect “thinking rationally”. The machine player sorts all the possibilities out, weights all choices and then makes a rational decision. Compared to that solver, it is impossible to win for the human beings. Therefore, the aim of most humans plays Chess is for entertainment instead of any academic learning or thinking training. Most of them want to play against with a soundly player 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](#_bookmark19)]. However, it is not easy to evaluate PX using any simple device or other physical experiments [[7](#_bookmark20)].

Elisa and her group members have introduced a great experiment design and analytical method for measuring enjoyment which had been identified as a central component of the player experience [[8](#_bookmark21)]. 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 quan- titative studies into general methodological observations in an experiment. Then according to the “Purpose of the studies”, “Participants”, “Games and Genre”, “Study setting, gameplay duration and game metrics”, and “Measuring point of the critical element of experiment” these five aspects, more in-depth measures taken by the institute [[8](#_bookmark21)]. 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 [[8](#_bookmark21)]. 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.

In Chess games, what normal players need is an automatic machine player with a suitable chal- lenge rather than that automatic player overwhelm the human by always making the best move [[4](#_bookmark17)]. Such opponents would be a little bit of shortsightedness and make mistakes occasionally which are more like humans or even slightly more stupid than human normal levels. Then automatic player also needs to adjust the ability of itself to the level of human beings constantly. That occasion in a Chess game is what most people need for fun and relaxation. 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 is a simple method to improve PX greatly and also be applied to develop puzzle games in most market games today.

“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 [[9](#_bookmark22)]. 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, even the younger children or the elder people can easily understand the rules. Then these “Match Three” puzzle games 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 [[10](#_bookmark23)]. Many popular games are all based on this puzzle and the most famous series is “Candy Crush Saga”. According to the reported by Wall Street Journal in 2013, nearly 15 million people in Western countries were addicted to Candy Crush Saga [[10](#_bookmark23)] [[11](#_bookmark24)]. These data show that people enjoy playing “Match Three” puzzle games. Thus, in this project, I would also use “Candy Crush Saga” as the typical “Match Three” puzzles to implement the following experiments which could measure the difficulty levels of puzzles.

## Document Content & Scope

This project will adopt the Waterfall engineering methodology and will thus proceed in a linear fashion. More specifically, the project will proceed with sequential steps, where each step will solve a particular problem in the process. The structure will be as follows:

#### Background:

Introduce Match-three puzzle and related work

1. **Match Three:** Introduce the history of “Match Three” puzzle and simple rules.
2. **Related Work:** Introduce related work on puzzles.

#### Methodology: ...

**e) A Short Summary of Research:** Summarize the technology, ideology and working method- ology.

#### Requirements & Speciftcations:

Gives more detailed information on this puzzle game and on what needs to be prepared before experiments.

#### Design:

A section to introduce the design of this “Match Three” puzzle game and their specific components.

#### Experiment:

Get the results of human play, including time spending and the ranking of difficulty levels. .

#### Evaluation:

Get the results of machine play, including time spending and the ranking of hardness levels. .

1. **Testing:**...

#### Reflection: ...

#### Conclusion:

...

#### Appendices:

Additional information about the experiment process and complementary works completed for this project.

# Background

...

## 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 re- leased for DOS [[12](#_bookmark25)]. 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 [[13](#_bookmark26)] [[14](#_bookmark27)]. 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” [[15](#_bookmark28)]. 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 [[16](#_bookmark29)]. There are more than 150 million times of Bejeweled downloaded from App stores [[16](#_bookmark29)]. 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 [[17](#_bookmark30)]. 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” [[9](#_bookmark22)]. In the “Boarder context” part, it has four prevailing features.

* + 1. **Demographics.** Compared to traditional hardcore video games, casual games are more oriented towards women and the adults who are over 35. They have more free time and more patient playing the same game.
    2. **Distribution.** The size of causal games always smaller than 10MB, which only takes up a little space of mobile phones. Additionally, they always 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 need to be equipped with 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.** Almost “Match Three” games are free to play. Even though they are some tools needed to pay, the cost is still quite small than hardcore games.

Apart from the boarder context part, the other significant part is game design [[9](#_bookmark22)] [[18](#_bookmark31)].

1. **Allow short playing sessions.** One game could 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.** Even there are some unexpected emergency cases, players can stop games as shutting the screen or turn this application out. When players complete these cases, they could continue the game because of the auto-save.
3. **Easy control.** “Match Three” games do not require players to reply a fast response or any smooth operation.
4. **Very simple rules.** People could easily understand how to play without any knowledge and suitable for all humankind, including the young and the old.
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.
6. **Multiple levels of success.** Owing to many different levels of “Candy Crush Saga”, players could gain success easier than other hard core games. Meanwhile, it also provides some small missions during playing puzzles, such that players would get a small reward if the ranking of the contemporary game is the top one among all friends. While playing a game in “Candy Crush Saga”, players could obtain three stars if the score is much higher than the expected. Although the score is a little higher than the expected, players also could 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 could obtain experience of victory pretty early on. If players cannot find the next move, a game would provide some tips or tools to take over difficulties.
8. **Little negative feedback.** If players fail to pass, there is no any punishment for players about their mistakes.
9. **The ranking of competition.** For example, “Candy Crush Saga” has more than thousands of games, players’ accounts have been connected to their Facebook or Twitter accounts. Then players could see the ranking of all friends who are also playing “Candy Crush Saga”. It would encourage players to execute 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 [[19](#_bookmark32)]. Because categorizing is a kind of human nature and people are easier to catch three objects without any training, people have to keep categorizing gems in games.

Thus, “Match Three” puzzle games become more and more popular.

## Candy Crush Saga

“Candy Crush Saga” would be applied in this project, I would introduce this game in the following section with its rules and characters. “Candy Crush Saga”, which is developed by King Digital, is a “Match Three” puzzle game oriented from the browser website game“Candy Crush”. “Candy Crush Saga” adapts for varieties of runtime platform, such as IOS, Android, Windows Phone and Windows 10. The theme of “Candy Crush Saga” is different candies. Children, younger adults or elder adults all love candies all over the world. The basic rule is to combine three, four or five candies together by sweeping 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. 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](#_bookmark8) shown [[20](#_bookmark33)]. 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 [[20](#_bookmark33)]. 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 the first figure in Figure [1](#_bookmark9)). 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

Table 1: Introduction of Different Candies. Six regular candies and three special candies.

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

consisting the “L” or “T” shape (see the second figure in Figure [1](#_bookmark9)), 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 [1](#_bookmark9)). 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.

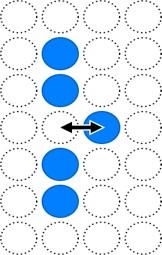
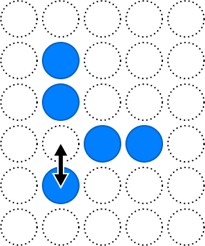
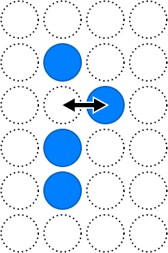


Figure 1: Possible advanced movements. Except for matching three same candies in one row or in one column, there are three kinds of possible movements.

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](#_bookmark10)) [[20](#_bookmark33)].

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 and Wrapped Candy turn into a

Striped Candy Wrapped Candy

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).

If the Colour Bomb Candy and Striped Candy exchange position, then all the candies whose

Striped Candy Colour Bomb Candy

Wrapped Candy Colour Bomb Candy

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.

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.

One coin has two sides, there is no exception of “Candy Crush Saga”. There are many doc- tors 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 [[21](#_bookmark34)]. 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 [[22](#_bookmark35)].

## 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 multiply levels of success, but also encourages players to gain a higher ranking of competitions. Moreover, great game design brings a better PX. As Elisa and her teammates reported that it is hard to evaluate PX using any simple device or other physical experiments [[7](#_bookmark20)]. However, she mentioned immersion is one of criteria which have major impact inevitably to PX. Immersion could be seen to the sum time spent on “Candy Crush Saga”. 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](#_bookmark36)]. 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](#_bookmark36)]. 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 [2](#_bookmark12). 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 has 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 the figure [2](#_bookmark12), but the number of players is decreasing as the number of level. 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 [3](#_bookmark13) 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.

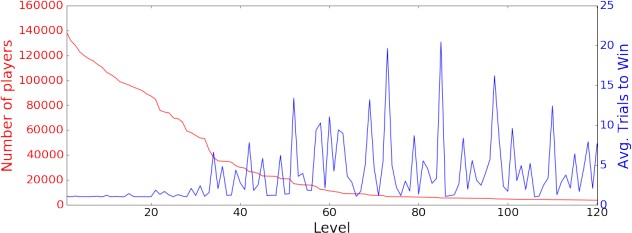


Figure 2: The retained population of players (red line) versus difficulties (blue line) by level. The red line represents, for each level, the number of players who have ever achieved it. The blue line represents the level difficulty, which is measured by 1/win rate, i.e., the average trials needed to win this level. We can observe the strong impact of difficulty on population retention, in particular for middle stage levels.

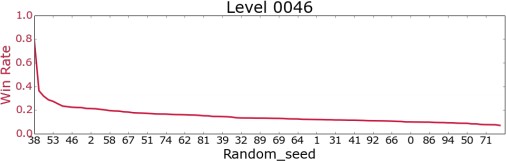


Figure 3: Difficulties of various random seeds at a level of the match-three game. Difficulty is measured by the win rate of a certain seed, i.e., the percentage out of all trials with this seed are actually wins. The variance of difficulties across seeds is large. We can see that the easiest seed (leftmost, 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. Modifica- tions would have impact to the difficulty of levels. Four significant criteria, which would affect the difficulty level, should be noted. The first is 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 total connected number/effective number of grids. And as such, if the level of elimination of the level is the same, he 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 com- plexity 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 for- mer 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. How- ever, 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 differ- ent levels of games [[18](#_bookmark31)]. 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](#_bookmark37)]. They explained how all the levels of Com- bination 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.

Why do we need to design levels with different levels of difficulty, and what impact will this have on the game? How to determine the difficulty of these levels? What criteria can be used as a reference standard?

To summarize, it is significant to design different levels of difficulty because they difficulty is related to the engagement. If there is more engagement, players could gain a better PX. The difficulty of a level would be influenced by four elements, the complexity of the terrain, the goals of the level, the special elements in the level and the restrictions of the level. There are two criteria to determine the difficulty of these levels. The first one is the win rate mentioned in Su’s experiment and the second is the time spent on solving a puzzle mentioned by Christopher Jefferson [[23](#_bookmark36)] [[24](#_bookmark37)].

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