Adaptive Difficulty Scales for Parkour Games

Yi-Na Li¹, Chi Yao², Dong-Jin Li¹, Kang Zhang³
¹ School of Business, Nankai University, China
²School of Software and Microelectronics, Peking University, China
³ School of Software Engineering, Tianjin University, China

Abstract: Mobile computer games have become increasingly popular in recent years. A major factor for successful game development is the adequate control of the game’s difficulty. This paper discusses justification for dynamic difficulty adaptation for Parkour games. It presents an adaptive mechanism for difficulty adjustment in response to the player’s run-time performance in the single player mode. The mechanism is based on game content generation techniques, considering constrains for mobile screens. Both the functionality of the game’s objects and the player’s psychological and behavioral inclinations are taken into consideration. Our preliminary experiment shows that game experiences are significantly enhanced with the adaption mechanism.

Keywords: Mobile games; difficulty adaption; parkour

I. INTRODUCTION

Technological advances have made games on smartphones increasingly sophisticated. Customized methodology based on automatic content generation has been introduced into game designs to enhance interactivity and improve responsiveness.

Most mobile games provide the Player versus Environment (PvE) mode for offline scenario. A player completes the missions while progressing the game alone against given obstacles in the game environment. Comparing with Player versus Player (PvP) game mode, PvE mode has no participation from other players who may produce complex variations. Considering the time and labor costs, designing obstacles manually hinders efficient game production while missing rich diversities of obstacle patterns. Repeated game actions and tasks tend to cause boredom to players.

To maximally stimulate players, we introduce rules for automatic content generation which would also reduce the design effort, increase creativity for game content variations, and enhance playability.

Setting difficulty scales statically as in traditional game designs cannot satisfy players’ differentiated needs. With such a statically set difficulty scales, each player simply chooses easy, medium and hard, or a few more difficulty scales, before starting. Such a coarse difficulty setting is too simplistic to suit variety of game phases, scenarios and variety types of players. We therefore need to build a dynamic mechanism to keep the difficulty level just as challenging as attainable by the player.

This paper reports our design and experience with two editions of the Dragon One game, a type of Parkour games, using both a self-adaptive difficulty mechanism and a fixed difficulty mechanism. The former is developed for better user experiences. Various game scenarios and typical features are also taken into consideration. The next section reviews the related work, and Section 3 introduces the mobile Dragon One game. Section 4 analyzes various influences on a game’s difficulty. Section 5 describes our difficulty adaptation mechanism, followed by the evaluation results in Section 6. Section 7 concludes the paper.

II. RELATED WORK

A. Difficulty Scales of Game Design

Difficulty scaling is one of the most important issues in game designs [2]. Players have fun by continually attempting to overcome obstacles [22] with increasing difficulty. The enjoyment of game stems from the levels of challenge, curiosity and fantasy [8]. Challenge is the key criteria in Game-Flow Model for evaluating game enjoyment [17].

The theory of flow has been introduced into game design by Csikszentmihalyi [5]. This theory describes the mental state when a person is fully immersed in a feeling of energized focus or utterly concentrated in the process of an activity for its own sake. People would experience a distorted sense of time and a lack of self-consciousness. Such a status has become the pursuit of user-centered game design [17]. Simple and repeated tasks would lead to boredom and mindless, while excessive hardness would cause frustration. It is important to set challenging but attainable task flow adaptive to the player’s ability.

A good game design would follow an escalating difficulty curve [3] [10]. However, players’ perceived difficulties may be different from the predetermined difficulty. Assessment for game playing experiences has both objective and subjective dimensions [9]. Perceived difficulties are essentially determined by players’ learning abilities, operation strategies, preference of risks, reaction times and team cooperation. Predetermined difficulties are set by default parameters at each level, such as the maximum speed of protagonists, acceleration abilities, endurances and attritions. A difficulty
increment might be too little for a risk-taking experienced player, too challenging for a risk aversion novice. Therefore, an optimized and adaptable difficulty solution customized for different types of players would promote game experience and replayability.

### B. Procedural Content Generation

Procedural content generation (PCG) has been defined as “the algorithmic creation of game contents with limited or indirect user input” [18]. Just-in-time PCG uses a player’s run-time data during the game, rather than historical data, to generate game contents dynamically. It has become a mainstream of intelligent games with the support of customization. Previous works realized automatic mission, procedure and space generation [12], relying on users’ behavior models based on skills [7], experiences [4][13][25][14], risk preferences [6], and immersion in different difficulty scenarios. Apart from the player’s individual behavior, data from the user community are also collected and analyzed to support automatic generation [21][23].

Previous research conducted case studies in knowledge learning game [1], puzzle game [16], racing game [19], action adventure game, and etc., proposed generating, adapting, optimizing mechanism and game difficulty balancing mechanism [26][20][11][24] by introducing neural network techniques and theory of incongruently in other disciplines, paving the way to automatic generation tailoring players’ needs.

However, none of the aforementioned studies discusses the interaction and balance mechanisms between the player’s instant behavior and the difficulty level. We consider a self-adaptive difficulty adjustment mechanism, in response to the player’s dynamic performance to be extremely important. Our work introduces dynamic difficulty adjustment in response to the player’s performance, and extends the literature on 2D Parkour games for mobile devices.

III. DRAGON ONE GAME FOR MOBILE DEVICES

This section presents a simple mobile game Dragon One developed by our team for experiments. Several scenarios of the game are shown in Figure 1.

**Game objective:** The player needs to pass through all the obstacles and collect as many fortunes as possible along the way.

**Narration:** It is a type of Parkour game with a simple story line. A Chinese witch builds a food streamer of thousand layers to satisfy her gluttony. She puts all her preys in the food streamers as her food. One day, her cat, who is kind-hearted in day time, but evil at night, breaks the iron chain of a layer. One of the preys, a cute and innocent dragon, gets a chance to escape. He starts his journey through shots and obstacles to pursue his freedom and rescue other preys.

**Task and manipulation:** The player has to control the dragon’s movement in horizontal directions at a constant speed without delay, to run a long distance and earn as bonuses as possible. If killed by an obstacle, the game would restart from the same difficulty level, but not the same contents. The player needs to continuously make quick decisions by clicking he left or right arrow.

![Figure 1. Game interface and scenarios of Dragon One](image)

**Obstacles and bonuses:** Obstacles include knives, bombs and lasers shots. They are lethal once hit. The bonus objects include golden coins and white breads. Collecting as many golden coins as possible for good fortune is one of the game’s objectives. A white bread is an elixir of rebirth when killed by an obstacle. The fortune value, an indication of operation skills, could not be used to exchange for any rebirth chance or extra protection. In spite of this, players would maintain their desire for fortune, trying not to abandon any piece of fortune. The functions of obstacles and bonuses are briefly illustrated in Table 1.

<table>
<thead>
<tr>
<th>Type</th>
<th>Item</th>
<th>Function</th>
</tr>
</thead>
</table>
| Obstacle | Flying Knives | Action 1: 5 knives work in one group, reciprocating moving, falling down very fast in vertical direction.  
Action 2: The knife group revolves when falling down. |
| Bomb | Explode with thorns at a fixed height on screen.  
Two bombs set abreast with a gap through which the dragon can pass. |
| Laser Shots | Shoot from left or right side. |
| Bonus | Golden Coins | Fortune value increases when hitting it. |
| | White Bread | Get a rebirth chance when hitting it. |
Fixed difficulty experiments: The game with fixed difficulty randomly invokes 7 manually designed sessions. Each session consists of all the functions in Table 1, lasting about 7 seconds.

The game is reported to be very challenging at the beginning. Players make progress fast after practicing a while, because necessary trainings are simply about repeated patterns. Players get bored very soon after being able to handle the fixed difficulty without much effort. We, therefore, further extended the game with the difficulty levels dynamically adaptable to the player’s performance, in order to maximally engage the player and extend the playtime.

IV. ANALYSIS OF INFLUENCES ON GAME DIFFICULTY

A. A Comparative Study

We extract generally applicable rules to estimate the difficulty in a Parkour game, by comparing Dragon One with Super Mario, Man on the Next Layer 100 and the most difficult game Flappy Bird. Super Mario developed by Nintendo has been popular for almost 30 years. Mario’s adventure in Mushroom Kingdom has been considered a masterpiece of Parkour games, providing significant reference of the setting mechanism for tasks, goals, obstacles, bonuses and rebirth functions. However this game is not designed specifically for mobile devices. The Man on the Next Layer 100 is a 2D action adventure game, developed for mobile devices. Players need exquisite skills to keep on jumping down onto lower floating layers, avoiding falling to the lifeless abyss, or being crushed on the ceiling for sluggish movement. For an ordinary player, this game would last less than 3 minutes. It does not provide a scale of difficulty with step-up sessions. The fixed difficulty sometime irritates players with lower risk preference and lower adaptive ability. Similarly, Flappy Bird, a grueling difficulty game commented by game geeks in an online forum, are flocked as touchstone for game intelligence. The first two obstacles could stop more than 95% players. Parkour games tend to control the playing time for each round by setting the difficulty scale. Very brief playing time would facilitate mobile users’ fragmented time, but hard to reach the climax of enjoyment.

Game designers tend to follow the “design for segment market” principle. Games are designed for either casual players or hardcore players in a hegemonic manner. Players have to adapt themselves to follow the game rules. The dichotomy of players’ categorization ignores the diversity of players and also individual players’ prior training. An adaptive mechanism is therefore helpful to change the user-unfriendly impressions.

B. Difficulty vs End of Game

Parkour games bear remarkable resemblance between each other in terms of continual operations, penalties and rewards. Except the difference of scenes, storylines and visual traits of items, difficulty setting is the key to game experiences.

Players have to keep on making right decisions in given reaction time. Generally, a Parkour game has high risk with no sunk cost for upgrade or accumulated bonus. The attrition value is as high as 100%. One accidental failure is fatal. It is almost impossible to survive after a wrong decision.

Comparing with the game of lower attrition setting, every moment running a Parkour game is at the door of death. Players have to stay highly concentrated. Accommodating for extremely high risks, low sunk cost makes players not worried about the consequence of failure. The perceived difficulty would not increase when approaching the end of endurance. The potential influences from different stages of endurance thus are excluded.

In addition, the protagonist’s speed is constant, without acceleration or buffering actions, which further simplified the game difficulty mechanism. By eliminating possible influences, we can ascribe the difficulty into the reaction time and decision making.

C. Objective Influences on Difficulty

The objective difficulty is determined by the physical attributes of game tasks, essentially the speed and complexity. For Dragon One, the falling speeds of obstacles are basic criteria for evaluating difficulty. Mixed types of obstacles require different amounts of time for analysis and decision making. When a bonus appears, a concern to balance the risk and fortune further increases the complexity for decision making.

D. Subjective Influences on Difficulty

Subjective influences emphasize on players’ psychology and behaviors. Players who are highly tempted to purchase fortune could be terribly misled. The floating bonus items suggest seductive routes, which may lead to unpredictable risks. Moreover, players are prone to make more mistakes when they become mindless. A critically difficult task after a few easier and relaxed tasks require players to be on high alert. Those tricky conditions may deviate players’ performance from usual.

To summarize, we should employ both objective and subjective influences to estimate and adjust the difficulty scale of a Parkour game. The next section introduces the basic rules for generating game contents and constraint conditions for determining difficulty levels.

V. DIFFICULTY ADAPTATION MECHANISM

We design the adaption mechanism based on the number of obstacles passed, e.g. the difficulty level increments at every 15 obstacles as shown in Table 1.

In the flowchart in Figure 2, parameter setting and difficulty increment are the key in the adaption mechanism. We assume that the sizes of the items are fixed. Variable parameters include the falling speeds of items and the space between them.
A. Parameter Setting for Objective Difficulty

We generate game contents by randomly arranging obstacles and bonuses using a constraint condition filter. The mobile screen on which our games are implemented measures 4 inches (640×1136 pixels). The dragon’s function area is presumed to be a circle, whose diameter is 95 pixels. We defined the diameter of bomb 190 pixels, knife group 260×110 pixels, diameter of the revolving knife group 280 pixels (as shown in Figure 3). The obstacle and bonus items are lined up vertically. The initial falling speed is 384 pixels (1/4 screen) per second. The initial average reaction time on one item is about one second.

We designed an obstacle insertion rule, by inserting an obstacle into a random horizontal position. Players may take advantage of random content generation by staying at either the left or right side of the screen. Without continuing operation, the fun no longer exists. Therefore, we make an obstacle to appear to steer an active action if the dragon has been along the left or right border more than 1.5 seconds.

Expert players tend to control the dragon by flying around 1/5 of the screen height, to pre-judge the approaching danger and optimize his/her strategy according to multiple items. It means that, at each moment of decision making, players process the visual information on the screen as organized patterns, rather than independent individual objects. Therefore, we analyze various composition methods and corresponding solutions, as the determining basis for difficulty control. There are 3 kinds of obstacles, in 5 functions, as listed in Table 1. We abstract the 5 functions into geometric objects, shown in Figure 3. No two consecutive obstacles having the same function would appear in the game. The compositions of the same difficulty functions are excluded in our design. There are potentially 10 possible compositions with every two types of obstacle functions. The top-down reversal compositions obey the same rules.

We define the minimum vertical space value between two consecutive items as interval, denoted \( l \), i.e. the height of the gateway between two items, from the bottom edge of the above item to the top edge of the item below. Assume that the diameter of the dragon’s active area and the diameter of a bomb as \( x_0 \) and \( x_2 \) respectively, the length of a knife group and the length of a laser as \( x_1 \) and \( x_3 \) respectively. The \( l \) value could be calculated under the given patterns as Figure 4.

The horizontal distance between items also impacts on the minimum \( l \). If the horizontal distance is large enough, or the space between items is not the only route for the dragon, \( l \) could be any value. The patterns in Figure 4 represent the most difficulty compositions when the horizontal distance is at minimum while the interval is also at minimum. If a pair of randomly generated obstacles is eligible for the criteria of patterns in Figure 4, a smaller interval value in horizontal direction would produce higher difficulty.
For Pattern 1 in Figure 4, \( l \geq \sqrt{3 \left( x_0 + x_2 \right)^2 - x_2} \).

For Patterns 2 and 5, assume the centers of the circles are \((\alpha_1, \beta_1)\) and \((\alpha_2, \beta_2)\),
\[
l \geq \sqrt{\left( \frac{x_1 + x_2}{2} + x_0 \right)^2 - (\alpha_1 - \alpha_2)^2 - \frac{x_1 + x_2}{2}}.
\]

For Patterns 3, 4, and 6, assume that the lower left corner of the rectangular in Patterns 3 and 4, and upper left corner in Pattern 6 are \((\alpha, \beta)\), the center and radius of the circle are \((a, b)\) and \(r\) (\( r = \frac{x}{2} \)) respectively in Patterns 3 and 4; \( r = \frac{x_1}{2} \) in Pattern 6,
\[
l \geq \sqrt{(r + x_0)^2 - (\alpha - a)^2} - r.
\]

For Patterns 7-10, \( l \geq 0 \). Players have to find a chance to get through.

B. Control for Subjective Difficulty

The level of danger or risk is positively proportional to the level of awards in games and also in life. A long string of bonuses suggests a misleading route. For example, the golden coins arranged along a curve would lead to a corner where it is too late to survive by altering the trajectory. Players need more effort and skills to deal with temptations and potential risks, and foresee the exact time to give up the pursuing of bonuses that may worth maximum rewards. Both golden coins and white breads could be used as baits to elevate subjective difficulty.

Golden coins are usually organized as a line or a matrix. For obstacles, except laser, when the left side of the obstacle \((p, y_1), x_0 \geq p \geq 0\), the interval value is 0, a coin line leading to \((q, y_2), p \geq q \geq 0\), would be tricky. It works the same way for the right side.

A white bread occurs alone. As a bait, a white bread’s position is determinant. An expert player is skilled at planning the route to earn a chance of rebirth. Any white bread at an obviously fatal position would be ignored without any attempt. White breads are therefore placed in reachable positions to raise the player’s temptation as traps. The trade-off of risks and gains requires rapid and intuitive decision making with exquisite skills.

Assume the left side of the obstacle to be \((u, y_1)\), the interval value \( l \), \( 0 \leq u \leq x_0 \), the radius of the circle \( r \) (could be \( \frac{1}{2} x_1 \) or \( \frac{1}{2} x_2 \)), the horizontal speed of the dragon \( v_1 \), and the vertical speed \( v_2 \) (i.e. the falling speed of the items). The horizontal value of the critical position would be \( u + 2r - \frac{v_1^2}{v_2^2} \). The measurements on the right side are calculated similarly.

When an obstacle and a bonus item are next to each other, if \( l = 0 \), the game difficulty is raised to the maximum. The value of \( l \) mediates the difficulty for collecting the fortune.

Bonuses are introduced after the first 30 obstacles have been cleared, and then the rate of bonuses appearing will escalate to average 1 per 2 screen length. The type of subjective difficulties would be random, with coins and white breads as baits at misleading positions.

C. Difficulty Scale

We define the cases with maximum falling speed, minimum interval space, highest rate of obstacle compositions as shown in Figure 4, setting the highest frequency of misleading bonuses as the hardest level of difficulty. The difficulty of the game is measured by

Figure 4. Patterns of obstacles and dragon’s movement (blue)
where \( v \) is the falling speed of items, \( l \) is the time interval between two consecutive falling items, \( h \) is the proportion of 10 most difficult compositions in all the appeared compositions, and \( p \) is the frequency of misleading situations, \( a, b, c, \) and \( d \) are coefficients.

Assume that the difficulty is divided into \( n \) levels and set at 20 initially. Parameter \( n \) could be adjusted according to the player’s performance. Upon three times of failure in the same level, \( n \) is automatically set equivalent of 1.1 times of the original value. The amount of levels could be \( 20 \times 1.1^n \) \((20 \leq n \leq 0)\), i.e. between 20 - 120.

For each level up, the difficulty increment is

\[
\frac{1}{n} [F(x)_{\text{max}} - F(x)_{\text{min}}].
\]

The difficulty increment is therefore more delicate and sensitive to the player’s instant performance as desired. After a period of practice, players may reach their learning plateau, the game difficulty remains at the challenging status until players make another break through.

Parkour games usually do not provide tutorials or pretest level for novices due to their simple and intuitive operations. Once the fixed difficulty is no longer challenging enough, the game would be abandoned soon. Therefore, an adaptive difficulty mechanism not only serves as the guidance to the novice, but also stimulates experienced players for upgrading progress.

VI. PRELIMINARY EVALUATION

We conducted an experiment to evaluate the effects of the difficulty adaptation mechanism on different types of players and report our findings in this section.

A. Experimental Setup

We invited six volunteers as the experimental subjects whose profiles are shown in Table 2. The subjects are aged from 28 to 58, with the education levels from high school to Ph.D. The skill levels are determined by the subjects’ self-evaluation based on their previous experiences in playing similar games. There are five levels, from 1 to 5, representing “never played mobile game before”, “beginning player”, “average player”, “skilled player”, and “hardcore player”.

<table>
<thead>
<tr>
<th>ID</th>
<th>Gender</th>
<th>Age</th>
<th>Occupation</th>
<th>Skill level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Female</td>
<td>30</td>
<td>Ph.D. in Arts, Researcher</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>28</td>
<td>Graduate student in Computer Science</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Male</td>
<td>33</td>
<td>Game designer</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Male</td>
<td>30</td>
<td>Ph.D. in Biology, Researcher</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Male</td>
<td>58</td>
<td>Property company manager</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>35</td>
<td>Public security guard</td>
<td>2</td>
</tr>
</tbody>
</table>

We handed over a smart phone installed with Dragon One and asked each subject to play the game for at least 15 rounds, and recorded the score in each round.

B. Results

![Figure 5. Difficulty levels for the first 15 rounds](image)

We infer the subjects’ difficulty curves from their scores, and present them in Figure 5. The horizontal axis indicates the 15 game rounds, and the vertical axis measures the difficulty.

The six players’ difficulty curves are significantly different. The hardcore player (P3) got a high score in the first round. His difficulty value raised to 0.2. By the ninth round, his difficulty value reached 0.25. In contrast, the beginning player P5 struggled to pass the first level until the fourth round. In fact, he played for quite a long time at 0.0909 difficulty value after his extraordinary performance. The other players also got appropriate challenges after a few rounds of playing. The difficulty adaptation mechanism has satisfied the disparity of players’ expectations.

Game experiences are optimized accordingly with more delicate and sensitive difficulty increments. For example, if player P5 kept on practicing before each upgrade, his difficulty increment at level \( n \) would be \( 0.05 \times 1.1^{1-n} \), far less than the initial increment value of 0.05. The slow learner would not be too frustrated to continue.

It is increasingly difficult to upgrade after reaching the plateau adaptive to the player’s skill and ability. Therefore, the difficulty curve would be flat for many rounds to come.

The adaptive difficulty makes the difference in players’ incentives. Players in fixed difficulty scenarios are informed of their progress by the increase of the distance and fortune in each round. But in the adaptive difficulty setting, the reference criteria have to be about the upgrade information. If the player’s level setting is also customized, the incentive information could be set as the percentile among peer players apart from the player’s own experience.

VII. FUTURE WORK

Galvanic skin response, heart rate and muscle movement data have been used to assist the design of game adaption
mechanisms. Such interaction data could be used in Parkour games to generate customized experience and suit for more complicated playing modes, such as two players in competition or cooperation.

Additionally, the sizes of items in a Parkour game can be varied, as variable sized obstacles require more sophisticated strategies and generate new and exciting game experiences. The increment of item size would decrease the available safe areas, and increase the difficulty. The enhanced game difficulty adaption mechanism and its application in marketing research are our future research focus.

ACKNOWLEDGEMENT

The third author is partially supported by the National Natural Science Foundation of China (Grant number: 71372099).

REFERENCES