氏名	高 娜穎
学位の種類	博士（情報科学）
学位記番号	博情第 523 号
学位授与年月日	令和 6 年 3 月 22 日
論文題目	Computational Measures of Game Entertainment and Reward
論文審査委員	飯田 弘之 北陸先端科学技術大学院大学 教授
	池田 心 同 教授
	白井 清昭 同 准教授
	吉村 仁 静岡大学 名誉教授
	Masnizah Mohd Universiti Kebangsaan Malaysia 准教授

論文の内容の要旨

The Game Refinement (GR) theory, widely employed for assessing the enjoyment and intricacy of games, is herein examined through the lens of audience perception. This theory delves into the cognitive information processes occurring in our minds while engaging in strategy games, in adherence to the principles set forth by Newton's laws. Its central focus is on the uncertainty surrounding game outcomes, employing abstraction to dissect game components and assess the progression of game information based on

achievements and game duration.

The quantification of this progression leads to the measurement of informational acceleration, akin to Newton's second law (F = ma), wherein informational acceleration correlates with mental force and excitement. Changes in acceleration significantly impact game dynamics, especially in high-stress scenarios, and can be rectified using "jerk" values derived from acceleration readings. In this context, a comprehensive exploration of various physical factors influencing psychological experiences in gaming is conducted.

This study prominently emphasizes the intersection of physical and psychological elements by depicting the progression of game information within our minds. By establishing reasonable informational jerk values associated with the success rate and informational acceleration of the game process, the development of game refinement theory enhances the overall player experience.

The concept of "jerk", signifying a sudden change in acceleration, is a fascinating

phenomenon experienced by humans and possesses practical applications in mechanical

and engineering domains, such as elevator rides. The paper forges a connection between the logistical model of game progression and "jerk" measurements, particularly in games with incomplete information, typified as AD values (representing addiction and the propensity for repeated gameplay).

To investigate the implications of AD values concerning GR metrics and its ex- tension, the motion in mind model, several popular card games, including Wakeng, Doudizhu, Winner, Big Two, and Tien Len, are utilized. Self-playing simulations con- ducted by artificial intelligence (AI) agents validate these findings with empirical data,yielding valuable insights into game design and gameplay experiences.

Players of varying skill levels may encounter and endure diverse reward frequencies denoted as N and jerk values during the progression of game information. Thus, an exploration into the interplay between the player's performance level (k), reward frequency (N), and jerk values is undertaken.

The inherent game risk, often represented as "m" is a well-acknowledged factor. To overcome these challenges, players must skillfully devise strategies. Exceptionally skilled players can navigate uncertainties with ease, characterized by a game velocity represented as $\vec{v}_0 = 1 - m$.

However, players possess differing abilities, resulting in varying levels of proficiency in dealing with uncertainties. Prior research employs "k" as a measure of performance, where higher values indicate lower performance. For imperfect players, the game velocity can be calculated as $\vec{v}_k = (1 - km)\vec{v}_0 = (1 - km)(1 - m)$.

In the realm of reinforcement learning, "N" often signifies the "number of steps" or "time steps", representing the interval for acquiring rewards. In games with perfect information, players possess complete knowledge of moves, while imperfect information games entail partial insights or educated guesses. In such instances, "N" can symbolize the number of actions considered during decision-making, akin to the Monte Carlo Tree Search algorithm.

In this study, the Game Refinement (GR) theory is explored from the perspective

of the audience. The theory focuses on the cognitive processes that occur while playing strategy games, emphasizing the uncertainty of game outcomes and how it affects player experience. It introduces the concept of "jerk" to measure sudden changes in acceleration in games. The study investigates the relationship between "AD" values, representing addiction and repeat gameplay, and GR metrics in various card games. Additionally, it delves into the interplay of player performance (k), reward frequency (N), and unpredictability (AD) in gaming. This research provides valuable insights

into game design and gameplay experiences.

Keyword: Game refinement theory;Motion in mind;Perfect information game;Imperfect

information game;Card game;Jerk;Addiction;

論文審査の結果の要旨

本博士論文は，ランダム報酬における変動比率強化スケジュール VR(N) に基づいてゲーム進捗速度を定義し，ゲーム洗練度理論（Iida et al.）の拡張を試みた．ゲーム洗練度理論では，ゲームの結果を認識するプロセスを思考の世界における自由落下運動とみなし，ニュートン力学のアナロジーとして，力学における重力加速度に相当する心の重力の値（a）をゲーム洗練度の指標（$GR=\sqrt{a}$）としたとき，その指標が適切な値（GR ゾーン）のときに心地よいスリル感が得られることが知られている．これに対し本研究では，加速度の変化分である加加速度（jerk; $j=AD^3$）に着目し，心の重力と加加速度のバランスの指標（$\phi=GR/AD$, ただし $0 \leqq \phi \leqq 2$）が遊戯性の重要な側面を表すことを提案し，様々なゲームを題材として実際のデータ収集，または，複数レベルの AI を作成し自己対戦実験によるデータ収集およびその解析を通して提案仮説の妥当性検証を試みた．具体的には，任意のゲームが心の重力と加加速度の融合として表され，一回の試行により解決される不確定性の量に対して，当該ゲームを繰り返すことで結果の客観性が達成される．十分な客観性を得るために繰り返し実施することの要求は，当該ゲームに没入する主要な要因となることから，ゲームの性質とその依存性（addiction）との関係について新たな知見を得た．特に，$\phi=1$ の場合に遊戯性が高まることは重要な発見と言える．これはトランプや麻雀のような不完全情報ゲームの場合に相当し，囲碁や将棋などの伝統的な思考ゲームに比べると運の要素が強く，それが故に多くの人が夢中になってプレイする傾向があることを説明する．また，思考ゲーム，スポーツ競技，ビジネスや教育におけるゲーム要素（ゲーミフィケーション）など様々な文脈において，ϕ の値に着目しながら遊戯性と加加速度の関係を探求した結果，ゲーミフィケーションや思考ゲームは $1<\phi \leqq 2$ となり，運の要素の強いゲームは $\phi \leqq 1$ となることを突きとめた．さらには，加加速度に着目した本研究の分析手法を思考の世界での運動（motion in mind）への応用を試みた．具体的には，プレイヤモデルである報酬獲得率 v_k のパラメータ k について考察を深め，プレイヤのレベルがどのような影響をもたらすかを考察した．

以上，本論文は，遊戯性について思考の世界での加加速度の影響が重要であるという新たな知見を提示したものであり，学術的に貢献するところが大きい．よって博士（情報科学）の学位論文として十分価値あるものと認めた．