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### 論文の内容の要旨

Game playing is widely regarded as a mentally stimulating activity. It has long served as not only entertainment but also test beds and benchmarks for artificial intelligence. Major milestones in the development of computer programs capable of playing chess over the last 60 years, to some extent, lead to the major development history of artificial intelligence (AI). In the transition from traditional games to games with AI players, it is hard to keep fairness when AI becomes stronger than human experts. Fairness stems from a respect for local goals and a desire to learn what the rules of the game are for them in that setting from individuals at different levels. In different cultures, fairness presents an interesting problem because local perceptions of fairness vary and every civilization has distinct ideas about what is fair and what is unfair. Fairness in games affects not only how a game is played, but also how the game is experienced. Previous works have interpreted the importance of fairness, called advantage of initiative (AoI), which had been previously discussed and proved through a conclusive and elegant theorem on first-player wins over second-player wins, but there have been no clear links among those interpretations. Observing the effect of the advantage of initiative in the game leads to addressing the challenge of not only keeping fairness but also maintaining the balance between competitiveness and entertainment. Inspired by classical physics, the motion in mind model was developed and adopted to better define the user experience in game-playing, where its relations in the social context were investigated from the historical development of games. The Gini coefficient  $g$  is an indicator used to quantify unfairness in  $n$ -person cooperative games (i.e., economics in society). In this thesis, the measurements of fairness and comfort, which are derived from the motion in mind concept and Gini coefficient, were used to analyze how the evolutionary trends of different games are changed to maintain the fairness and various elements of games. This thesis focuses on understanding the advantage of initiative along with its impact on game outcome and exploring the concept of play comfort, social comfort, and their culture with consideration of fairness. To achieve it, we are guided by three purposes: (1) To characterize the advantage of initiative and its impact on the evolution of game rules and game outcome, and (2) To define the gamified experience and notion of fairness (3) To develop the fairness measurement that indicates the balance between competitiveness and entertainment and establish the link between play, culture, and society. Using the motion in mind model as a measurement of fairness and comfort based on the 2-person game contexts demonstrates that it can show the link between play comfort and play culture. Furthermore, the measurement is expanded into  $n$ -person cooperative games that show social comfort which is related to play culture. For comparison, fairness indicators in  $n$ -person games with a focus on the Gini

coefficient in economics were adopted in which similarities were found, prompting the revisiting of Huizinga's Homo Ludens that identify a link between play, culture, and society decades prior. In both competitive two-person games and society, it was found that the trend of unfairness was reduced, while some enhancements to maintain fairness in classical board games and economics were discussed.

**Keywords: fairness, game progress pattern, motion in mind, Gini coefficient, economy**

## 論文審査の結果の要旨

本博士論文は、ゲームの公平性に関する問題提起に基づいて、先手の有利性といった不公平性の是正手段としてのコミの有用性とその改良策について探求した。また、公平性を担保することで得られる確かな競技性や遊戯性について議論を発展させている。さらに、公平性及び競技性の概念をベースとして競技目的ゲームと超人数ゲームの比較を試みた。具体的には、自由経済による社会での競技性と不平等の状況を競技目的ゲームにおける競技性や不公平性と対比させることで、遊び、文化、社会の観点からそれぞれの関係性を見出す試みにより、Homo Ludens (1938) において、ホイジンガーが想定した「遊び文化の社会経済への影響」を裏付ける可能性を示唆する成果となった。

ゲームや社会経済で不公平や不平等が生じる背景とその解決策について焦点を当てながら、遊戯性とのリンクについて洞察し、これまでの研究の進展を幅広くサーベイした。次に、思考ゲームを題材として先手有利性の問題の既存の解決手段について長所短所を考察した。特に、囲碁で導入されているコミの汎用性に着目し、その有用性と応用可能性について、非確定的ゲームである Scrabble を題材として AI シミュレーションによる評価実験を実施した。確定的ゲームである囲碁では静的なコミが実践的に有効であるが、Scrabble のような非確定的ゲームでは必ずしも有効でない。動的なコミの概念および実装法を提案し、その有用性を AI シミュレーションによる検証した。思考ゲームでの公平性および競技性の概念を非競技的な超人数ゲームである社会へ適用し、それぞれの比較を試みた。遊戯性評価のためにゲーム洗練度理論と思考の世界の力学を用い、不平等の評価にはジニ係数を用いた。これらの評価分析の結果、遊びの文化と社会のリンクを示唆するものであった。

当該学位論文提出者は、令和 4 年 8 月 5 日に開催された公聴会において以上の内容を簡潔にまとめ丁寧に説明した。その後の質疑においても、一つ一つの質問に対して適切に回答し、本研究での新規性や妥当性を確認することができた。

以上、本論文は、ゲーム情報学分野において、公平性・不平等・競技性の評価・改善の方法について先駆的研究を遂行したものであり、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。