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学位授与の日付	2016 年 9 月 25 日
論　　文　　名	「Developing General Video Game Playing Artificial Intelligence Based on a Multilayer Architecture （多層構造アーキテクチャに基づく汎用ビデオゲーム AI の開発）」
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論文要旨

Artificial Intelligence (AI) is one of the important application in computer science. It is also widely used in the video games and robotic industries. AIs' performances have also been increasingly publicized; most recently the victory of Google DeepMind's AlphaGo against Mr. Lee Se-dol in March 2016 has drawn the world's attention.

In the past, AIs have been designed primarily to address specific tasks, but today's grand challenge is to create general intelligence that can resolve numerous and diverse problems. General Artificial Intelligence (GAI) is a research area particularly addressing the development of AI which can learn to perform different tasks successfully.

The initial objective of GAI research was to create AI that could successfully perform any intellectual task a human being can. The emphasis of the research was placed on the AI learning capacity and its adaptability. Beside the desire to reproduce a human mind, another goal of the GAI is to simplify the AI development process for the industry. Indeed, if an AI is able to learn by itself any task, it could be used to generate a solution to any specific problem. Doing so would automate the AI development process and allow the developers to easily create different AIs.

General Video Game Playing Artificial Intelligence (GVGPAI) is a branch of the GAI research addressing the development of a controller which can play more than one video game

successfully. In GVGPAI, the AI must work out how to play and win games that it has never seen before. To do that, the AI is given the game's state and basic information including the applicable actions and the number of players. The advantage of focusing on video games is that they provide a large set of challenging tasks with relatively low cost.

In video games, the main part of the game's program deals with all data representing the game's information. These data include information such as the position and size of the enemies, the player's life points and so forth. The set of all these data at a specific iteration of the game is called a game state. At every game iteration, the agent must decide on its action. After the action decision made by the agent, the game will update the game state considering the actions of all the agents and the game physics.

The recent research has particularly focused on two ways to address such challenges. The first one is to design knowledge-free AIs that make total abstraction of the game's characteristics. These AIs play the game without being aware of its objectives and game-play. Such solutions are based mostly on tree search algorithms and often require simulation features integrated to the game. A popular planning algorithm for such general AI is Monte Carlo Tree Search (MCTS). This algorithm produces great results, and nowadays there are a number of variations of MCTS algorithms. Its main weaknesses arise from complex games with high branching trees and games requiring long-term planning beyond the planner's horizon. The second way is to create AIs that are able to learn the characteristics of the game to improve itself. The solutions based on a Neuro-Evolution of Augmenting Topology algorithm (NEAT) are strong candidates in that category. These AIs use the evolved neural network to assimilate the game-play's features and to give back actions depending on the game state. In many games, algorithms of these kinds were found to be superior to planning algorithms. However, these methods tend to discover and to use game loopholes instead of playing the way intended by the game-play.

This thesis proposes a multilayer architecture and concrete implementations of AI based on this architecture. Unlike the aforementioned solutions, our approach introduces AI with a more human-like mode of thinking. Generally, humans do not act without a purpose. Their acts are not merely a sequence of uncorrelated actions chosen one at a time, but are chosen as a whole to accomplish a particular strategy. We suggest a solution to imitate such a process using AI designed to ascertain a strategy before choosing the actions required to accomplish it. Strategies comprise a sequence of sub-objectives which represent the AI's purpose. These sub-objectives are based on domain-specific knowledge. The implemented AI provides an automated method to extract the sub-objectives from the games. The proposed architecture consists of three layers. The first layer is responsible for computing the global strategy of the AI. The second layer's purpose is to convert this strategy's sub-objectives into a sequence of actions that are directly usable by the agent. Finally, the third layer overrides the first and the second layers to handle emergency cases endangering the agent.

The main benefit of the solution proposed in this thesis is to avoid the shortcomings encountered by the other GVGPAI solutions. First, enabling a more human-like mode of thinking allowed the AI to play more consistently and to use the intended game-play. In addition, generating the strategies before choosing the actions forces the AI to step back from the game, thus preventing the AI to lose its efficiency on complex games with high branching trees. Furthermore, the proposed architecture is designed to optimize the adaptability of the AI to all kinds of video games.

As for the content of the thesis, it is organized as follows.

Chapter 1 essentially introduces our work. It describes the topics related to the current research and the context within which it was developed. Then, the concept and stakes of our research field are explained along with some technical details about video games. Those details are required for a better understanding of the current work. Afterward, the state of arts is given in order to fully understand the benefits and position of the proposed solution. Finally, the contents and improvement made by the proposed solution are summarized.

Chapter 2 starts by explaining the main objectives and the motivation of the current research. It also explains the concepts of sub-objectives and actions on which the proposed solution is build. These concepts are used throughout this thesis and some understanding of them, as well as the terminology involved, is essential to read through this thesis. Then, it describes the architecture on which the proposed GVGPAI is based. While it does not recommend any particular algorithm, the AI's design directly impacts its performance and its ability to achieve the objective set by our study. Each of the three layers composing the architecture is detailed separately and a description of the architecture's global mechanism completes these explanations. Afterward, a few practical examples on which our solution could be applied are depicted. These examples suggest the proposed solution's adaptability to various games. Finally, we present the results obtained during a single-game based competition using an AI partially based on the current design.

Chapter 3 details how to ascertain the set of sub-objectives for a particular game. Sub-objectives are the unitary blocks composing the strategies generated by the AI. They represent what the AI tries to accomplish and each sub-objective defines a target which needs to be reached before to start the next one. Because each game's content and game-play is different, the related sub-objectives are different. In addition, the list of available sub-objectives may change from a game iteration to another. Therefore it is critical to be able to automatically ascertain the set of sub-objectives related to a game and to identify which of these sub-objectives are available in the current game iteration. In our work, sub-objective's representation is highly related to the game data representation. Hence this chapter starts by introducing the game data representation used by our solution. This representation describes how the game information is formatted before being sent to the AI. Secondly, the concept of sub-objective and the representation that are proposed by us are described in detail. Then the discovery procedure, which is composed of two processes, is explained. The first process is used to discover the sub-objective related to the game. The purpose of the second process is to select the list of sub-objectives available in the current game iteration. Finally the results obtained by the AI on a set of games are presented to validate the proposed procedure.

The penultimate chapter details two different AI implementations and their performance evaluation. An implementation requires decisions on which algorithms are used and how they are interconnected. Each implementation uses different algorithms but is based on the architecture proposed in this thesis. Furthermore, the second implementation was developed to overcome the flaws observed in the first implementation. This chapter is organized as follows. In the first section, the motivations and the preliminary study which led to choose the first implementation are described. Then, these algorithms and their use within the architecture are explained. This section ends by stating a list of the drawbacks arising from the chosen implementation. The following section describes the second implementation of the AI. It explains the choices made to overcome the flaws observed in the first implementation and how the new algorithms were used within the architecture. Then, the performance of both implementations was assessed in the third section. The computational experiments were conducted on the same games as in the previous chapter. This performance evaluation addresses two points. First it shows that the proposed solution was able to achieve the goals set by our study. Then, it ascertains that this solution is suitable to compete with other GVGPAI solutions. Afterward our main future works are introduced.

Finally, we conclude by summarizing the main points of this thesis.

審査結果の要旨

本論文では，汎用的な人工知能の構築において，どのようなエージェント構成が有用であるかを調査するという観点に立ち，特にビデオゲームにおいて汎用な人工知能エージェント構造を検討し，以下の成果が得られたことを確認した．

（１）環境情報から行動を決定するシステムのための階層構造を提案した．この意思決定構造により，大局的な戦略の意思決定，具体的な直近行動決定，緊急事態が発生した場合の行動決定という３つのレベルの意思決定が可能となった．

（２）大局的な戦略決定に加えて，副目的を設定することが最終目的を達するために重要であることを提案し，そのための意思決定を階層構造に加え，数値実験によりこの提案の有効性が明らかとなった．

（３）副目的の表現方法としてユニタリ形式のデータ構造を基にする方法について検討し，エージェントに実装した．この方法により，自動的に副目的を生成することがより効率的に行われることが数値実験により示された．

（４）これまでに検討されたエージェント構造に基づいて意思決定を行う汎用人工知能を計算機上に実装し，適用範囲をビデオゲームとして実装された人工知能エージェントの汎用性について検討した．大規模な数値実験の結果，提案する階層構造形式をもつ人工知能は，階層構造を持たない形式の人工知能と比較してビデオゲームへの適用がより汎用的であることが明らかとなった．国際会議が開催する汎用人工知能ゲーム大会に提案する人工知能を提出した結果，優秀な結果を収めたことからも提案手法の有効性がより明らかとなった．

以上の諸成果は，将来の汎用的な人工知能実現のための技術に関する重要な知見を与えるとともに，その導入に向けての現状の人工知能における意思決定構造に対する優位性を定量的に示したものであり，本分野の学術的・産業的な発展に貢献するところ大である．また，申請者が自立して研究活動を行うのに必要な能力と学識を有することを証したものである．