論 文 内 容 の 要 旨

The study of games to develop increasingly complex and "intelligent" algorithms has been a subject of interest for years with good reason. Games provide a great "sterile" environment to study and develop intelligence. They are essentially the laboratory environments of Intelligent systems as they can provide many different levels of difficulty and varying types of challenges while still having well defined rules, precise goals and easily quantifiable rewards. Additionally, they do not have any real-world consequences so they do not pose any risk, negative effects, or responsibility problems when experimented with while still allowing to train on increasingly challenging problems.

Deep Blue's victory against Kasparov was probably the first instance of an "artificial intelligence" beating a human expert at a complex task in the eyes of the grand public and, since then "intelligent" programs have been able to surpass humans on increasingly difficult and complex tasks. Among others, AlphaGo, AlphaStar, Libratus and MuZero have been great landmarks of reinforcement learning.

At this point, AI having achieved superhuman performance in Perfect Information Games, research is increasingly concerned with Imperfect Information Games; a subset of all games that makes some information about the current game states obstructed from the players, creating a situation where, to be efficient, one has to take this uncertainty into account and be able to deal with it efficiently. Imperfect Information Games are probably most commonly card games where one does not receive information about cards possessed by an opponent. There are however many other types such as games with an inherent level of randomness like dice games or games with other types of hidden information like video games using fog of war or hidden enemy weaknesses, etc...

It is easy to see why there would be such interest in these more uncertain scenarios. In real world situations, one often does not have access to all relevant information about a problem while still needing to take action based on available information. In that sense, Imperfect Information Games are much closer to real life problems and being able to play such games efficiently with trained computer agents will be a requirement to being able to solve everyday life problems with reinforcement learning. In short, Imperfect Information Games are a key step towards using intelligent computer agents in less "sterile" environments.

However, while more research has focused on Imperfect Information Games, terminology has not yet followed the current progress. The current vocabulary has not changed from the one used to explain the challenges of Perfect Information Games despite the challenges of Imperfect Information Games being very different from the ones posed by their counterparts.

When searching for reasons why a game is studied, one oftentimes finds one of the three most common reasons listed: either the game is very popular, or it has already been studied in previous research, or it is difficult. These first two reasons are not inherently scientific and the third, while being more objective, is often explained using very basic measures of difficulty such as action space or state space size but these measures do not give any information about the specific challenges of a game, nor are they any different from the measures used to describe Perfect Information Games.

In this thesis we focus on defining new terminology and illustrating how it can be used to further classify Imperfect Information Games.

First we introduce overarching themes of Imperfect Information Games, the current vocabulary used to describe them and its weaknesses.

We then propose two new concepts specifically related to Imperfect Information: Imperfect Information Impact and Imperfect Information Visualization.

Following this we conduct two case studies, one qualitative and the other quantitative, on how these concepts appear in Imperfect Information Games.

In the first case study, we show the main overarching techniques a player can use to deal with Imperfect Information in games and illustrate how these behaviors can emerge in different games. To do so, we create multiple increasingly challenging versions of an Imperfect Information Board Game called Geister and exploit its specific rules to show variations in emerging gameplay. We then link these behaviors to the two main concepts we put forward in this work.

In the second case study we focus on a series of versions of DouDizhu, a type of card games originating from China. Using these card games, we train multiple agents with variable access to imperfect information and compare their performance as well as their ability to achieve an inner representation of the information they are missing about the game world. Their performance is then used as a way to measure both the Imperfect Information Impact and Imperfect Information Visualization of the different versions of DouDizhu. With these measures we then compare the different version of DouDizhu to analyze how they compare to our expectations.