氏　　名	LORTHIOIR, Guillaume
学位(専攻分野)	博士(情報学)
学 位 記 番 号	総研大甲第 2277 号
学位授与の日付	2021年9月 28日
学位授与の要件	複合科学研究科　情報学専攻 学位規則第6条第1項該当
学 位 論 文 題 目	Plan and Goal Recognition with Application to Real-Time Strategy Games
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(Form 3)

Summary of Doctoral Thesis

Name in full LORTHIOIR, Guillaume

Title Plan and Goal Recognition with Application to Real-Time Strategy Games

Plan and goal recognition are challenging problems that were introduced by the AI community a few decades ago. Plan recognition is the task of inferring the plan, and by extension, the goal, which accounts for the observed behavior of an agent. On the other hand, goal recognition only focuses on inferring the goal of an agent when observing its behavior, and it can be seen as a sub-problem of plan recognition. There is a wide variety of applications to these tasks, for intelligent and robot assistants, automatic driving, suspect behaviors monitoring, multi-agent cooperation, or competition like for games, for instance, to obtain adaptive AIs. Although plan and goal recognition problems have existed for a while in AI, their complexity has hindered their application to real-world scenarios. But recently, with the improvement in terms of computation power and machine learning approaches, these restrictions start to fade.

There are two main contributions presented in this thesis. The first one is an online plan recognition method for RTS games. As we will see in the first chapter, RTS games are complex environments since there is uncertainty about the actions of the opponent player that are usually hidden, actions are not always deterministic, the state space of such game is by several orders of magnitude bigger than the game of Go and decision as to be taken fast. Because of this huge state space, most current plan recognition methods do not scale with the state space of such games. Moreover, for the few approaches that could scale, they often do not deal with partial observations and assume that the observed actions are ordered. However, it is not the case for most RTS games, we only get partial observations, and these observed actions are not always ordered. The plan recognition method introduced in this thesis handles all these problems and compared to previous work applied to RTS games that use machine learning to perform strategy prediction in StarCraft, our method does not use machine learning and thus does not need a set of training data, instead, it requires expert knowledge. Therefore, it makes it easier to use for games without much data from the players as the developers have expert knowledge about their game. Our method uses heuristic planning to compute in real-time different plans that the player might follow in order to achieve different goals. Then, using the partial observation that we get during the game, we will refine the different plans according to these observations, prune some plans that we consider as very unlikely and select the plan and goal that is the most likely to be followed by the player.

The second contribution is a goal recognition method that, compared to most of

the existing goal recognition methods that predict the most likely goal of the observed agent from a set of possible goals, builds this set of possible goals by observing the agent trying to achieve them. Often, previous works assume that this set of possible goals for the agent is given for the goal recognition problem or even plan recognition. However, it is usually not the case, especially in complex or unknown environments. For example, when we are not sure about all the actions that the agent can execute or if the number of possible goals is just too important. That is why we developed a method that can infer the set of possible goals of the agent. Our method allies concept learning with a representation of the environment based on propositional logic that allows us to generate a hypothesis in the form of a DNF representing the agent's possible goals. This contribution is not only related to games but much more general. We observed an agent performing some task until it eventually achieves its goal. By repeating this kind of observation, we will get a dataset that we divided into a set of positive examples, which corresponds to the states where the agent achieved a goal, and a set of negative examples, which corresponds to the states where it did not. Using the set of positive examples, we will create the concept that represents the agent's goal and refine this concept with the set of negative examples.

The thesis is organized as follows. In the first chapter, we will provide background about the plan and goal recognition problems. We will explain why we use games as a testbed and why especially RTS games and StarCraft, and then describes the organization of the thesis. Chapter 2 introduces the background knowledge that is needed for the rest of the thesis. Then chapter 3 presents the online plan recognition that we developed for the RTS game StarCraft, the different experiments that have been done to evaluate our method, and the possible improvements and extensions of the method. The second contribution of the thesis is presented in chapter 4, where we introduce the problem of inferring an agent's goals. It is not only related to games but much more general. We detail our problem and its formalization, present the experiments that we conduct to evaluate this goal recognition method, and then the possible extensions of the method. Chapter 5 concludes the thesis with perspectives of this work and discussing how to combine both contributions and conclusion.

Form8・Separate Sheet
（様式８・別紙１）

Results of the doctoral thesis screening

博士論文審査結果

Name in Full
氏 名 LORTHIOIR, Guillaume

Title
論文題目 Plan and Goal Recognition with Application to Real-Time Strategy Games

The applicant, Mr. Guillaume LORTHIOIR, has submitted the thesis for a determination of whether it is worthy of the awarding of a degree. The decision by the panel will be based on the following.

The thesis consists of the applicant's work on plan recognition and goal recognition with intended applications to Real-Time Strategy (RTS) games. Plan and goal recognition have been challenging problems in AI research. Plan recognition is the task of inferring plans of an agent, and goal recognition infers the goal from observed behavior of an agent. There is a wide variety of applications of these tasks such as intelligent and robot assistants, automatic driving, suspect behaviors monitoring, multi-agent cooperation, and computer games. This thesis has two main contributions on online plan recognition methods for RTS games and learning-based goal recognition methods, and consists of five chapters.

Chapter 1 is an introduction that explains the motivation, objectives and organization of the thesis. Chapter 2 explains the background of plan recognition as planning, which is used as the main technique for online plan recognition in the first contribution, and describes the basics of concept learning, which is used in goal recognition in the second contribution.

Chapter 3 describes one of the main contributions, and describes an online plan recognition method for RTS games. RTS games are complex environments, since there is uncertainty about the actions of the opponent player that are usually invisible, actions are not always deterministic, and the state space of StarCraft, a typical RTS game, is usually much bigger than that of the Go game and decisions must be taken fast. Because of this huge state space, most current plan recognition methods do not scale with the state space of such games. Moreover, for the few approaches that could scale, they often do not deal with partial observations and assume that the observed actions are ordered. However, this is not the case for most RTS games; players only get partial observations, and these observed actions are not always ordered. The plan recognition method introduced in this thesis tackles all these problems. Compared with previous work applied to RTS games that use machine learning to perform strategy prediction in StarCraft, the proposed method does not need much data from the players but use expert knowledge about the game. To this end, the proposed method uses heuristic planning to compute different plans in real-time that the player might follow to achieve different goals. Then, using the partial observation obtained during the game, those different plans are refined according to these observations, some plans that considered as very unlikely are pruned, and the plan and goal that are the most likely to be followed by the player

is selected. Several different experiments have been done to evaluate the proposed method, and the possible improvements and extensions are shown in this chapter too.

Chapter 4 deals with the second contribution, that is, a new goal recognition method, which is not only related to games but can be applied in more generally. Although most existing goal recognition methods predict the most likely goal of the observed agent from a set of predefined possible goals, the proposed method builds such a set of possible goals by observing the agent's behavior trying to achieve them. This is particularly useful when we are not sure about all the actions that the agent can execute. To this end, the method uses concept learning with representation based on propositional logic that allows us to generate a hypothesis in the disjunctive normal form of the agent's possible goals. For those observed successful traces of an agent performing some task, a set of positive examples is composed, while a set of negative examples corresponds to the states where the agent did not achieve any goal. A concept learner then generates the concepts that represent the agent's goals from positive examples by refining them with the negative examples.

Chapter 5 concludes the thesis with perspectives of this work and discusses how to combine both contributions and conclusion.

As for the publication related to the contents of the thesis, the work on online plan recognition (Chapter 3) has been presented as peer-reviewed papers in the AI top conference *IJCAI 2020* (Doctoral Consortium) and in the international session of the domestic conference *JSAI 2020*. Goal recognition from successful traces (Chapter 4) has been published as a peer-reviewed paper in the Q1/Q2 rated journal *Applied Sciences*.

At the public presentation, Guillaume LORTHIOIR presented his thesis work for 50 minutes in an online meeting on July, 15, 2021. Then a Q&A session was held with the thesis Evaluators. Mr. LORTHIOIR was able to answer all questions in a satisfactory way.

After the Q&A session, a review committee was held among the Evaluators. The committee members expressed their satisfaction with the quality of the PhD work, and recognized that the submitted thesis fulfilled the requirements for a PhD thesis. In conclusion, the review committee judged that this thesis was worthy of the awarding of the PhD degree.