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論文内容の要旨
Summary of thesis contents

Title: Studies on Learning Dynamics of Systems from State Transitions

In recent years, there has been a notable interest in the field of Inductive Logic Programming to learn from state transitions as part of a wider interest in learning the dynamics of systems. Learning system dynamics from the observation of state transitions has many applications in multi-agent systems, robotics and bioinformatics alike. Knowing the dynamics of its environment can allow an agent to identify the consequences of its actions more precisely. This knowledge can be used by agents and robots for planning and scheduling. In bioinformatics, learning the dynamics of biological systems can correspond to the identification of the influence of genes and can help the understanding of their interactions.

In this thesis, we study a method called learning from interpretation transition. The purpose of this method is to automatically construct a model of the dynamics of a system from the observation of its state transitions. In this method the dynamics of a system is represented by a logic program that is a set of transitions rules. The learning settings can be summarized as follows. We are given a set of state transitions and the goal is to induce a logic program that realizes the given transition relations.

In the first chapter we recall the background of the three main fields of research which our contribution belongs to, that are: Machine Learning, Logic Programming and Inductive Logic Programming. In the second chapter we introduce the preliminaries notions needed for the understanding of our contribution.

In the third chapter we introduce the basis of our framework for learning dynamics of system from state transition. We firstly tackle this induction problem by learning from synchronous state transitions. Given any Boolean state transitions diagram, we propose an algorithm that can learn a logic program that exactly captures the system dynamics. Then, we focus on the minimality of the rules learned. Our goal is to learn all minimal conditions that imply a variable to be true in the next state. In bioinformatics, for a gene regulatory network, it corresponds to all minimal conditions for a gene to be activated/inhibited. For this purpose, we propose another version of our algorithm which guarantees that all rules learned are minimal. In the fourth chapter, we provide several extensions of our framework. Here, we start to consider how our framework can contribute to model more complex Biological system.

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In some biological and physical phenomena, effects of actions or events appear at some later time points. We extend our framework by designing an algorithm that builds a logic program which captures the delayed dynamics of a system. So far, the systems that our algorithms could handle were restricted to Boolean variables. Boolean values are not sufficient to capture the complexity of some systems. That's why we extend our algorithms to handle multi-valued networks. Finally, the last contribution of this thesis is to learn dynamics of non-deterministic systems. We extend our framework to learn probabilistic dynamics by proposing an algorithm for learning from uncertain state transitions. This algorithm learns the probability of the value change of each variable of the system.

In the fifth chapter, we discuss related work and compare our approaches to others. Here we point out similarities and differences, assess advantages and weak points of the method we propose. Finally, in the last chapter, we conclude the thesis by summing up what have been done and discuss possible future works and perspectives.

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博士論文の審査結果の要旨
Summary of the results of the doctoral thesis screening

博士論文本審査は審査委員 6 名全員出席の下，論文内容について出願者が約 45 分間の口頭発表を行った後，審査員や他の出席者からの公開質問・応答および口頭試問を約 20 分間行った．

出願者による口頭発表では，論文の記載順にしたがって各学習アルゴリズムの特徴が述べられ，全体を通して時系列データからの遺伝子調節ネットワーク学習の例を使って比較説明がなされた．また課題とされていた，k 次マルコフ系における適切な k 次数の求め方についても説明があった．審査員からの質問においては，ダイナミック・ベイジアンネットワークへの適応可能性，事前確率分布がある場合の確率付きプログラムの学習，ロボティクス応用において少数の施行例からの学習への対応，等，主として今後の課題に関する部分が問われ，出願者は現状できることと今後に対する自分の意見を的確に回答した．

博士論文記載内容については，3 章の内容が機械学習トップジャーナルである Machine Learning，さらに ILP 分野のメイン国際会議である ILP 2013, ILP 2014 両会議のポストプロシーディングスで発表済みであり，4 章の内容が Frontiers in Bioengineering and Biotechnology ジャーナルで発表済みで，ILP 2015 と ICLP 2015 両国際会議に発表予定であり，それぞれが博士論文の異なる貢献部分に対応している． さらに，審査委員から予備審査の際に指摘された，発表において統一した例を用いて分野への貢献をより明確にするべきであるなどの改善すべき点についても十分な改良が認められた．以上により，本論文は情報学分野における学術的貢献が大きく完成度が高いと評価された．これにより，6 名の審査委員全員一致で，本論文は学位を授与するのに十分なレベルであるものと判定され合格となった．