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論　文　題　目	A Study on Dynamic Epistemic Logic and its Application to the Precedents of Criminal Law	
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論文の内容の要旨

　　Guilty or not guilty: the decision in court often concerns if the accused could predict the outcome via an inevitable causality from his/her initiative action. Of course, if the accused had an intention to cause the crime he or she should be punished, however, in some cases, he or she claims that the resultant crime could not be predicted. The penal code requires the prosecutor to investigate if there was the motivation or intention with the accused; even though it is negative the judge needs to certify if the causality was not recognized, that is, the result was not predictable by the accused.

　　In this study, we try to formalize if there could be the predictability. We analyze the preceding cases, and model the knowledge state of the judge, the prosecutor, and the accused in terms of Kripke semantics of modal logic, where the knowledge of each agent is represented by the accessibility to the various possible worlds in which the truth values for the constituent propositions may be different.

　　At the beginning of this study, we have formalized the reasoning process of judgment by using an action model in dynamic epistemic logic (DEL) and have attempted to describe the precedents. DEL can describe the knowledge states of each agent respectively and an action model can represent the change of these states. By using these logical tools, we have represented the final knowledge states of the defendant and the prosecutor which are updated by an epistemic action based on their testimonies at the court. However, the prediction in legal cases depends not only on the states of knowledge but also on the finite attention by the agent. For example, there are some types of crime which is caused by an indeterministic intention like ``*dolus eventualis*''. We have found that the simple DEL with an action model is not suitable for reasoning the precedent of a crime.

　　As the second step in this study, we have employed DEL with awareness for multi-agent to represent the prediction about the result and have modeled the typical criminal precedents. For example, in an airport, we can interpret the announcement about the flight which we take or wait for. However if there is no relationship between the announcement and our flight, we are not conscious of it. We think the awareness can explain the

limited reasoning which leads to a crime, and can explain the degree or the strength of an intention or a prediction about a result. We have proposed a revised semantics of an action model with awareness and defined the concrete action models like ``consider'', ``implicitly observe'', ``explicitly see'' or ``infer'' to reproduce the agent's considering or inference process. The revised language which includes these action models can describe the inference process of a new information within an awareness domain in an agent and this cannot be done by the existing semantics. We have also showed its soundness and completeness.

In addition to the formalization, we have implemented an extension program of modeling tool DEMO to include the awareness and the extended action model with an awareness DEMO^{+A}. We have also presented GUI in this program to calculate the updated epistemic model easily and to classify precedents according to the degree of prediction. We have released this modeling tool in our site to all researchers who are interested in this topic.

Then we have analyzed the final epistemic models with an awareness of some precedents of the criminal law for the defendant and the prosecutor by using this newly developed tool and estimate them. We have modeled 7 cases which represent the typical interpretation like ``*dolus eventualis*'', ``negligence'' or ``innocence'' and so on. Finally we have examined these calculated final epistemic models of the precedents and have proposed the classification criteria of the precedents according to the degree of the the predictability about the result of a criminal action, which can be described by the awareness about the cause and the causal relation. We have compared these results with the actual interpretations of the precedents and have found that the awareness can explain well the one aspect of the precedents and this can classify the precedents according to this aspect.

Keyword: Dynamic Epistemic Logic; Awareness; Action model; Multi-agent; Legal reasoning; Modeling tool

論文審査の結果の要旨

人間の知識や信念を論理のことばで表すことは，その後の推論や一貫性の検証などにおいて大変有用である．動的信念論理(Dynamic Epistemic Logic; DEL)とは，数理論理学の中の様相論理のうち，良い性質が証明されている S5 や KD45 をそれぞれ知識・信念として人間の思考を形式化する枠組みである．様相論理は Kripke による可能世界意味論でモデル化されるが，命題変数の真偽の違いの数だけ可能世界を用意した上で，世界間のアクセス可能関係をエージェントの数だけ用意する必要がある．さらに動的論理とは，このモデル（可能世界間のアクセス関係）を変更することによって信念変更を表現するという複雑な体系である．Baltag らはこの枠組みに，さらに可能世界とアクションのペアを加え，各可能世界で各エージェントが取りうるアクションを限定したアクションモデルを定義した．

動的信念論理とアクションモデルを用いては，これまで論理パズルを解くなどの応用例があるが，現実の世界へ貢献するような使用例はあまり知られていない．本研究の重要なところは，最先端の論理学の成果を法律という現実的な課題に対して応用することを試み

たことにある．刑法において争点となるのは，被告の予見可能性である．もし被告が明白な犯罪の意図を持ち，行為を行ったならば，有罪は免れ得ない．しかし，未必の故意と呼ばれる状況においては，被告が明白な意図を持たずとも，自分の行為によって犯罪となることが予見できるのであれば有罪である．本研究はこのような予見可能性を，可能世界へのアクセスと可能なアクションのペアにおいて表し，被告と検察の主張の違いを論理学的に顕在化させることを目的とする．

　本研究においては，知識・信念の様相オペレータに加えて，van Benthem と Velázquez-Quesada によるアウェアネス（自覚）という概念を導入した．すなわち，エージェント間である情報の受け渡しがあったときに，受け取る側がその情報に関心を払うかどうかによって，頭の中で演繹を行うかどうかを分けるしくみである．本研究はこのアウェアネスをアクションモデルに組み込むことにより，被告と検察の予見可能性を分離して示すことに成功した．本論理は実際に，DEMO+というコンピュータプログラムに実装され，システムとしても公開されている．

　以上，本論文は学術上も応用上も貢献するところは大きく，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．