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A Study on Dynamic Epistemic Logic and its Application to the Precedents of Criminal Law

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JAPAN ADVANCED INSTITUTE OF SCIENCE AND TECHNOLOGY

Doctoral Dissertation

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Abstract

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 (we call it $\texttt{DEMO}^{+\mathcal{A}}$). 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

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List of Abbreviations

AF	**A**rgumentation **F**ramework
DA	**D**ynamic epistemic logic with **A**wareness
DEL	**D**ynamic **E**pistemic **L**ogic
DEMO	**D**ynamic **E**pistemic **MO**deling
GUI	**G**raphic **U**ser **I**nterface
PA	**P**ropositional **A**vailability

List of Symbols

d	agent (the defendant)
i	an agent
j	agent (the prosecutor)
$\mathcal{L}$	language
$\mathfrak{M}$	epistemic model
p	proposition
q	proposition
r	proposition
s	proposition
α	action
φ	formula
ψ	formula
χ	formula
$\models$	valid
$\sim$	equivalence relation
$\vdash$	provable

Chapter 1

Introduction

1.1 Purpose of this study

One of the purposes of research on artificial intelligence is to enable a computer system to calculate the decision by the real human or to predict the result by the actual action of the human. Toward this goal, beside the newly developing research of machine learning which uses mass data and finds the answer based on the probability, the research about the reasoning based on the knowledge states of an agent and the logical calculation of them is also important. But the phenomena which can be seen in the knowledge states of an agent in the actual world is too complicated and highly diversified to simulate in formal models. When we try to describe the knowledge states of an agent, we face the frame problem to describe the huge background knowledge or the different conclusion between the one which an actual person makes and the one which an agent calculates, due to some imperfectness.

One of these difficulties lies in the limitation of the knowledge and the reasoning which the actual person has. When we formalize a logic about the knowledge of an agent, we often regard the agent as "logical omniscient" [1]. However this assumption is idealized too much and has a problem when this is applied to a reproduction of an agent in the real world. An agent in the real world cannot make a reasoning based on all the information which the agent knows logically and this leads to the difference of the conclusion. To overcome this issue, it is the one of the ways which can be utilized to remove this assumption by restricting the knowledge of an agent as in the real world.

In general, we cannot make a reasoning from the propositions which are not recognized by us. For example, when we hear an announcement about the flight in an airport, we can understand the meaning when the announcement is about the flight which we take. On the other hand, when about the one which we do not take, we listen to it in the absent-minded way or do not construe. This describes well the fact that being aware is different from knowing in case of decision making. We think if we can formalize this difference, we can follow the actual process of an agent in a real world. We set our purpose on the description of the prediction (or predictability) of an agent in the real world and the reproduction of this in a machine through this research.

[1] assuming that an agent knows all conclusions which can be derived from the hypothesis. It can be described as the following by using the modal operator 'K'
if $\Gamma \vdash \alpha$ then $K(\Gamma) \vdash K(\alpha)$.

1.2 Our proposal

In this study, we focus on the precedents in the criminal law expecting that the decision process of a judge is clear according to the criminal law and target knowledge is restricted to the elements of the domain.

To determine criminality specified in the penal code [2], at first, the judge examines whether the action of the defendant comes under the external elements of a crime defined by the penal code (*Tatbestand*)[3] in the court. Then, the judge tries to determine if the defendant is responsible for the external elements by evaluating whether its action is taken by intent (*Mens rea*)[4] or by negligence[5] [24, 39]. We think the intention is strongly influenced by the prediction of the defendant about the results. However it is difficult to describe the prediction logically.

Therefore, we propose to use awareness logic and dynamic epistemic logic to describe the knowledge states of an agent, and to use the awareness of his/her knowledge to explain the prediction/predictability. And we also propose the revised semantics of awareness logic to describe the epistemic action in a versatile way. This enables us to infer the new information in the awareness of an agent. Further in this study, we introduce the epistemic action like `infer`, `consider`, `implicitly observe`, `explicitly see` according to the inference process we assume. By these actions, we think we can model or describe each inference or consideration process of an agent.

At last, we propose the classification criteria to explain about the degree of the strength of an intention in the criminal case, which can categorize the precedents according to the one aspect of a crime.

1.3 Thesis outline

The rest of this paper is organized as follows. In Chapter 2, we introduce some related works concerning the legal reasoning and the modal logic. We also remark about the issues when we try to use them to describe the criminal precedents. And in Chapter 3, we explain about DEL and awareness logic briefly as a preliminary. This includes the action model and updating of knowledge model by an action model.

In the following chapter (Chapter 4), we provide the basic concept of precedents of the criminal law. In this explanation, the conditions of guilt authorization, the concept of intention, negligence etc. are included. We also pick up the typical precedents for each case.

Then we try to apply simple dynamic epistemic logic to the dynamic change of the knowledge states of an agent in Chapter 5. We also apply this model to the selected precedents and evaluate the results as we did in our previous paper [11, 12]. We focus on the predictability of the result (external elements of a crime) and formalize the reasoning process of judgment by action model in DEL, but the frameworks is still clumsy to describe these affairs. This makes hard to implement a concrete system or use the system in cases where the predictability is an issue.

[2] http://www.japaneselawtranslation.go.jp/law/detail/?id=3130&vm=02&re=02&new=1

[3] The guilty acts or typified criminal acts sometimes called as the objective element of a crime.

[4] A guilty mind or an intention to commit a crime.

[5] A failure to take reasonable care when they act by taking account of the potential harm to other people, sometimes called as delinquency or negligence [8].

To overcome this issue, we have assumed that our conscious knowledge is restricted to some externt. And we propose the use of DEL with awareness [32] whose semantics are revised [13, 10] and we propose the inference process of agent in Chapter 6. Then we provide the concrete action models with awareness to describe the mentioned inference process by our revised semantics. We also show the soundness and the completeness of this new language.

In the following chapter, we explain our extension of DEMO [34] program, we call it "$\texttt{DEMO}^{+\mathcal{A}}$" [9], that can capture the notion of both knowledge and awareness. We also show input/output GUI for $\texttt{DEMO}^{+\mathcal{A}}$ which makes easier to set the calculation conditions and to examine the result.

At last, we analyze some typical precedents which possess a different degree of intention to commit a crime and confirm and evaluate the results in Chapter 8.

Finally we wrap up our study, our contributions and conclude with further remarks. We also add some supplemental information about the implementation of the program and the result of calculation as appendices.

Chapter 2

Related works

2.1 Legal reasoning

Concerning the researches on legal reasoning, the expert system is studied from 1980s also in Japan (for example, Yoshino [40], Nitta [22]). A legal expert system has the structured information on the knowledge of a legal expert at the law and is expected to judge or assist the judge based on this knowledge in a computer system. For example, LES-2 [40] stores a legal knowledge as a logical structure of a legal norm or sentences, which consists of the conditional sentence of legal requirement and the legal effect. It also has the hierarchical structure reaching from the abstract to the concrete level and has the meta-data which describe the priority between the rules. It is equipped with two types of inference engines, such as the substantial law inference which provides the case and the procedural law inference which provides the judgment. The new HELIC-II [22] is a software tool for legal reasoning which consists of two functions (argumentation function and debating function). Argumentation function is programmed with generalization of rules and reasoning based on the priority of rules. This function consists of two modules, one is 'making argument' and the another is 'selecting argument'. The 'making argument' module makes all the arguments which achieve the conclusion and all the counter-arguments against them, when the user inputs the desired conclusion. Then the 'selecting argument' module selects the best suitable argument for the user based on the prioritized rules. The knowledge in the new HELIC-II is represented by the element of 'object', 'event' and 'property'. They have the partial order relation in each type ($>_o$, $>_e$, $>_p$). The rule consists of a unit name, consequence part and condition part as follows.

$$U :: A \leftarrow B_1, B_2, ..., B_n$$

Here, A or B is represented by a structure which has a root symbol and a list of event or property. Some rules may be generalized when applied to a new case.

Recently some systems were coded by the logic programming (for example Satoh [29]). Concerning PROLEG [29], it is a rule-based system based on the theory of presupposed ultimate facts ("Yoken-jijitsu-ron" in Japanese) , which separate a positive condition part resulting in a conclusion and a negation part resulting in an exceptional situation. According to this 'openness' of the exceptional category, a judge can make a decision using normal rules to reach a conclusion when exceptional facts are not explicitly known. PROLEG also has this separated category and it can incorporate the burden of proof.

Concerning an attempt to apply logical methods to the legal reasoning, we can find the study of "Argumentation framework" (recent examples like Wyner et al. [38], Araszkiewicz [2]) or the application of belief revision to the defeasible reasoning (for example, Governatori

[14]). A part of these logical methods is used for the background theory of the logical expert system mentioned above. Their aims are to overcome the difficulty of non-monotonicity of legal reasoning, because the knowledge or information changes according to the testimony of the defendant or the prosecutor and the inference is defeated according to this new information.

Argumentation framework is suitable for this non-monotonicity reasoning. Toulmin [30] suggested that a dialectical model of an argument. He noticed that good, realistic arguments typically would consist of the following six parts.

Claim : A statement that is in an argument.

Data : The backing facts or evidence used to prove the claim

Warrant : The link between the claim and the data, which is general, hypothetical logical statements.

Backing : Supporting statements for the warrant or arguments that do not necessarily prove the main point being argued, but which do prove the warrants are true.

Qualifiers : Statements that limit the strength of the argument or statements that propose the conditions under which the argument is true.

Rebuttal : Counter-arguments or statements indicating circumstances when the general argument does not hold true. i.e. exceptions to the initial claim

Here we show an example of Tulmin's argumentation framework as in FIGURE 2.1.

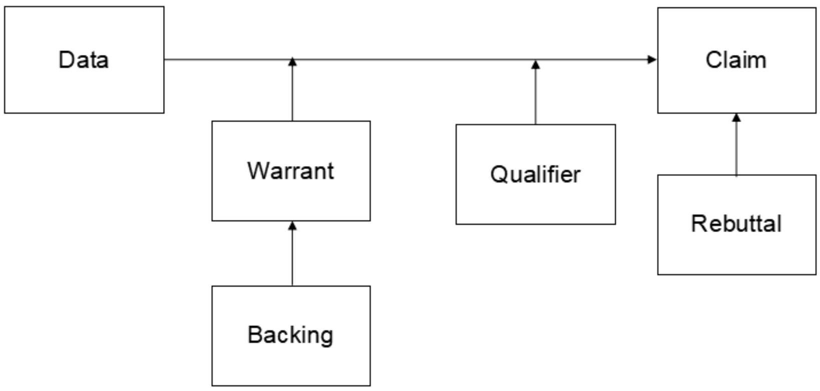

FIGURE 2.1: Example of Tulmin's argumentaion framework

Dung [5] proposed the general framework based on the argumentation theory. The notion of argument is abstract and defined as the one which attacks other arguments and which it is attacked by. Given a set of arguments and the attack relations between them, it is possible to determine which arguments are acceptable. i.e. an argument which is not attacked will be acceptable or the one will be acceptable only if it can be defended against these attackers by acceptable arguments which in turn attack those attackers. This framework is used in the study of the argumentation of legal reasoning. For example, Prakken [27] investigated the role of burden of proof in legal argument and found that the allocations of burden of proof determine the strength of counterarguments. And he showed how the dialectical models of defeasible reasoning could be adapted to the legal reasoning. He also proposed the three level model in the legal argument [26]. These are a monotonic underlying logic, a declarative theory for assessing the status of conflicting arguments, and a procedural model of how to fairly and rationally conduct a dispute. He assumes the non-monotonic logic as the first level, and as the third level, an argument framework explained by a heuristic model which is inspired by the Tulmin model. He says that the declarative and procedural models of argumentation can work together and says that a protocol for dispute which regulates how the input of an argumentation framework can be changed and then an argumentation framework is used to determine the effect of the change and reassesses the resulting state of the dispute.

Defeasible logic which is started by Nute [23] is a rule based non-monotonic reasoning which can derive a plausible conclusions under the conflicting conditions. Its language consists of facts, rules and superiority relation. The rules are divided into strict rules, defeasible rules and defeaters. Strict rules are that their conclusion cannot be disputed when the premises are indisputable (e.g., facts) and defeasible rules are rules that can be defeated by contrary evidence. Defeaters are used to prevent some conclusions and the superiority relation in a binary relation defined over the set of rules, which determines the relative strength between conflicting rules.

Johnston and Governatori [18] used this defeasible logic in the legal reasoning. For example, he proposed the rule set for a criminal law as follows in TABLE 2.1. Here $\Rightarrow$ represents the

TABLE 2.1: Hypothetical Criminal Law Theory

No.	Rule	Comment
$r1$	$\Rightarrow \neg guilty$	Innocence is presumed
$r2$	$evidence \Rightarrow guilty$	Evidence can show guilt
$r3$	$\neg motive \leadsto \neg guilty$	Lack of motive can suggest innocence
$r4$	$alibi \Rightarrow guilty$	An alibi can prove innocence
$r4 > r3, r3 > r2, r2 > r1$		

defeasible rule and $\leadsto$ indicates the defeater. Governatori also suggested the belief revision by using the defeasible logic [14].

Even though we can represent the rules or the cases and can reason based on them, it is still difficult to describe the knowledge states of each agent like a defendant or a judge in addition to the facts which can be described in an argument. And even in such an area, there are many issues concerning the various types of the precedents in the actual world. To understand the legal reasoning, especially in case of the criminal law, we have to describe the knowledge states of the stakeholders in addition to the reproduction of the argumentation in the court.

2.2 Modal logic

2.2.1 Modal logic

Modal logic is the logic about the *modality*, that is the "mode of truth" of a proposition, like p is true 'necessarily ' or 'possibly'. However, the "modal logic" has a family of logic with similar rules and a variety of different symbols. The basic modal logic uses the following modal symbols.

- $\Box$ It is necessary that ...
- $\Diamond$ It is possible that ...

Here the $\Diamond$ is defined as $\neg\Box\neg$. The basic modal logic is called **K**. The symbols of **K** usually include $\neg$ (not), $\rightarrow$ (implication) in addition to the modal operator above. System **K** consists of the axioms and rules of propositional logic and the following rule and axiom.

$$\Box(\varphi \rightarrow \psi) \rightarrow (\Box\varphi \rightarrow \Box\psi) \quad \text{Distribution Axiom}$$
$$\text{If } \varphi \text{ is a theorem, then so is } \Box\varphi \quad \text{Necessitation Rule}$$

Kripke [19] gave the semantics to the modal logic. Kripke's models are built out of the following three things.

1. Possible worlds: A set of state, which is called as "world".
2. Accessibility relation: A world is "accessible" from a given possible world if there is an accessibility relation between these worlds. The form "Necessarily φ" is true in w only if φ is true in all accessible possible worlds.
3. Valuation: The valuation determines for atomic propositions whether they are true or false in a possible world.

The **K** is too weak to describe various things and usually some more axioms or rules are added.

$$\begin{array}{ll} \mathbf{T} & \Box\varphi \rightarrow \varphi \\ \mathbf{4} & \Box\varphi \rightarrow \Box\Box\varphi \\ \mathbf{5} & \neg\Box\varphi \rightarrow \Box\neg\Box\varphi \end{array}$$

This system which has the rules mentioned above is called **KT45** or **S5** (=**KT5**) according to the names of rules or axioms. This frame characterizes the equivalence relation in possible worlds and is often used to represent the simple knowledge of an agent.

2.2.2 Epistemic logic

Epistemic logic can describe the reasoning about knowledge in an agent. Most epistemic logics are modal logic, whose language contains knowledge operators and whose semantics is given in terms of Kripke models, containing epistemically possible worlds related to one another by epistemic accessibility relations. Hintikka [16] developed a modern epistemic logic by studying Kripke semantics for epistemic notions and appropriate axioms for knowledge. His epistemic logic uses the one modal operator K and $K\varphi$ reads the agent knows that φ is true. This K has the same semantics as the $\Box$ in the Kripke semantics mentioned before. The semantics of epistemic logic is as follows. For multi-agent system, the operator has an index i of agent like K_i and $K_i\varphi$ reads the agent i knows that φ is true. The semantics is defined as follows.

$$\mathfrak{M}, w \models K_i\varphi \text{ iff all } v \text{ such as } wR_iv,\ \mathfrak{M}, v \models \varphi$$

To represent the simple knowledge states of an agent, the frame **S5** mentioned in the previous subsection and the modal operator K is often used. However, it is said the axiom **T** is too strong to assume, because this means all things which an agent knows is true.

The term 'epistemic logic' is sometimes used to the logic which has the related notions, like doxastic logic which studies the reasoning about belief and uses **D**, i.e. $\Box\varphi \rightarrow \neg\Box\neg\varphi$, instead of **T**. So the system of the doxastic logic of **KD45** can be described as follows in addition to the ones of propositional logic by using the modal operator B ($B\varphi$ reads the agent believes that φ is the case).

Distribution Axiom	$B(\varphi \rightarrow \psi) \rightarrow (B\varphi \rightarrow B\psi)$
Necessitation Rule	If φ is a theorem, then so is $B\varphi$.
D	$B\varphi \rightarrow \neg B\neg\varphi$
4	$B\varphi \rightarrow BB\varphi$
5	$\neg B\varphi \rightarrow B\neg B\varphi$

Here we show the soundness and the completeness of the epistemic logic in the frame **S5** (For details, refer to an example [33]), because later we use these for the proof of the soundness and the completeness of our revised language. The proof system **S5** is shown as follows. Here P, Q and R are the atomic propositions.

$$P \rightarrow (Q \rightarrow P) \tag{2.1}$$
$$(P \rightarrow (Q \rightarrow R)) \rightarrow ((P \rightarrow Q) \rightarrow (P \rightarrow R)) \tag{2.2}$$
$$(\neg P \rightarrow \neg Q) \rightarrow ((\neg P \rightarrow Q) \rightarrow P) \tag{2.3}$$
$$K_i(\varphi \rightarrow \psi) \rightarrow (K_i\varphi \rightarrow K_i\psi) \tag{2.4}$$
$$K_i\varphi \rightarrow \varphi \tag{2.5}$$
$$K_i\varphi \rightarrow K_iK_i\varphi \tag{2.6}$$
$$\neg K_i\varphi \rightarrow K_i\neg K_i\varphi \tag{2.7}$$
$$\text{if } \varphi \text{ and } \varphi \rightarrow \psi \text{ then } \psi \tag{2.8}$$
$$\text{if } \varphi \text{ then } K_i\varphi \tag{2.9}$$

Definition 1 (Provable).
We say φ is *provable* within an axiom system **X** and remark $\vdash \varphi$ when there is a finite sequence of formulas $\varphi_1, ..., \varphi_m$ such that,

- φ_m is φ.

- every φ_i in the sequence is either
  1. one of the axioms in **X**
  2. the result of the application of the one of the rules in the axiom system **X**.

Definition 2 (Valid).
$\mathfrak{M}, w \models \varphi$ iff φ is true at state w in $\mathfrak{M}$.
$\mathfrak{M} \models \varphi$ iff φ is true at every state w in $\mathfrak{M}$.
We say φ is *valid* and remarks as $\models \varphi$, when at all models, $\mathfrak{M} \models \varphi$.

Theorem 1 (Soundness).
if φ has a proof using the axiom system, then φ is valid, i.e. $\models \varphi$.

Proof. Regarding the soundness, here we omit the proof for the propositional axioms.
Case for $\Box(\varphi \to \psi) \to (\Box\varphi \to \Box\psi)$ (Distribution): Assume $\models \Box(\varphi \to \psi)$ and $\models \Box\varphi$. Fix the state w. At this time, $\mathfrak{M}, w \models \varphi$ and $\mathfrak{M}, w \models \varphi \to \psi$. So $\mathfrak{M}, w \models \psi$. Since w is an arbitrary one, $\models \psi$.

Case for $\varphi \to \Box\varphi$ (Necessitation): Assume φ is valid. So for every model, $\mathfrak{M} \models \varphi$. So clearly for all states, $\mathfrak{M}, w \models \varphi$, i.e. $\models \Box\varphi$.

Case for $\Box\varphi \to \varphi$ (**T**): Assume $\Box\varphi$, Since R_i is an equivalence relation, it has a reflexive relation wRw. So $\mathfrak{M}, w \models \varphi$.

Case for $\Box\varphi \to \Box\Box\varphi$ (**4**): Assume $\Box\varphi$. Since R_i a transitive relation, for every $v \in \{v \mid wRv\}$ and $t \in \{t \mid vRt\}$, wRt exists. Since $\mathfrak{M}, w \models \Box\varphi$, $\mathfrak{M}, v \models \varphi$ and also $\mathfrak{M}, t \models \varphi$. This is equivalent to $\mathfrak{M}, v \models \Box\varphi$ and therefore, $\mathfrak{M}, w \models \Box\Box\varphi$.

Case for $\neg\Box\varphi \to \Box\neg\Box\varphi$ (**5**): Assume $\neg\Box\varphi$. So there is at least one world where $\neg\varphi$ is the case (v). Since R_i a transitive relation, if $v\{v \mid vRt\}$, wRt. It is clear that $\mathfrak{M}, t \models \neg\varphi$ and then $\mathfrak{M}, v \models \neg\Box\varphi$. So $\mathfrak{M}, w \models \Box\neg\Box\varphi$.

For completeness, we can use the maximal consistent set of formulas.

Definition 3 (Maximal consistent).
Γ is maximal consistent iff

- Γ is consistent, i.e. $\Gamma \nvdash \bot$
- Γ is maximal, if there is no $\Gamma' \subseteq \mathcal{L}_{\mathbf{S5}}$ such that $\Gamma \subset \Gamma'$ and $\Gamma' \nvdash \bot$

Definition 4 (Canonical model).
The canonical model $M^c = \langle S^c, \sim^c, V^c \rangle$ is defined as follows.

- $S^c = \{\Gamma \mid \Gamma \text{ is maximal consistent}\}$
- $\Gamma \sim_i^c \Delta$ iff$\{K_i\varphi \mid K_i\varphi \in \Gamma\} = \{K_i\varphi \mid K_i\varphi \in \Delta\}$
- $V_p^c = \{\Gamma \in S^c \mid p \in \Gamma\}$

Lemma 1 (Lindenbaum).
Every consistent set of formula is a subset of a maximal consistent set of formulas.

Proof. Assume that Δ is a consistent set of formulas and now take an enumeration of $\mathcal{L}_{\mathbf{S5}}$. Let φ_n be the n-th formula in this enumeration. We consider the following sequence of sets of formulas.

$$\Gamma_n = \Delta$$
$$\Gamma_{n+1} = \begin{cases} \Gamma \cup \{\varphi_{n+1}\} & \text{if } \Gamma_n \cup \{\varphi_{n+1}\} \text{ is consistent} \\ \Gamma_n & \text{otherwise} \end{cases}$$

And take $\Gamma = \bigcup_{n \in N} \Gamma_n$. At first $\Delta \subseteq \Gamma$. Then we show that Γ is consistent by induction on n. Γ_0 is consistent because Δ is consistent. We assume that Γ_n is consistent. Then Γ_{n+1} is consistent because it is derived from the finite formulas, so Γ is also consistent.

Finally we show Γ is maximal. Let φ_n be an arbitrary formula such that $\varphi_n \notin \Gamma$. Then $\varphi_n \notin \Gamma_n$ and $\Gamma_n \cup \{\varphi_n\}$ is inconsistent and also $\Gamma \cup \{\varphi_n\}$ is inconsistent. Therefore there is no Γ' such that $\Gamma \subset \Gamma'$ and Γ' is consistent.

Lemma 2 (Truth).
For every φ and every maximal consistent set Γ,

$$\varphi \in \Gamma \text{ iff } (\mathfrak{M}^c, \Gamma) \models \varphi \tag{2.10}$$

Proof.
By induction on φ.

Let φ be a propositional variable p. Then $p \in \Gamma$ iff $\Gamma \in V_p^c$ acording to the definition of V_p^c. This is equivalent to $(\mathfrak{M}^c, \Gamma) \models p$.

Suppose $\varphi \in \Gamma$ iff $(\mathfrak{M}^c, \Gamma) \models \varphi$. Following cases are the induction cases.

Case for $\neg\varphi$: Since $\neg\varphi \in \Gamma$, $\varphi \notin \Gamma$, because $\neg\neg \notin \Gamma$ from the consistency. According to the induction hypothesis, this is equivalent to $(\mathfrak{M}^c, \Gamma) \not\models \varphi$. This is equivalent to $(M^c, \Gamma) \models \neg\varphi$.

Case for $\varphi \cap \psi$: $(\varphi \cap \psi) \in \Gamma$ is equivalent to $\varphi \in \Gamma$ and $\psi \in \Gamma$. By the induction hypothesis, these are equivalent to $(\mathfrak{M}^c, \Gamma) \models \varphi$ and $(\mathfrak{M}^c, \Gamma) \models \psi$. From them, $(\mathfrak{M}^c, \Gamma) \models \varphi \cap \psi$

Case for $K_i\varphi$: From left to right. Suppose $K_i\varphi \in \Gamma$. Let Δ be an arbitrary maximal consistent set. Suppose $\Gamma \sim_i^c \Delta$. Therefore $K_i\varphi \in \Delta$ by the definition. In **S5**, $\vdash K_i\varphi \to \varphi$ and Δ is closed, $\varphi \in \Delta$. By the induction hypothesis, this is equivalent to $(\mathfrak{M}^c, \Delta) \models \varphi$. Since Δ is an arbitrary set, this is equivalent to $(\mathfrak{M}^c, \Gamma) \models K_i\varphi$. From right to left. Suppose $(\mathfrak{M}^c, \Gamma) \models K_i\varphi$. If $\Gamma \sim_i^c \Delta$, $(\mathfrak{M}^c, \Delta) \models \varphi$. We show that $\{K_i\chi \mid K_i\chi \in \Gamma\} \vdash \varphi$ by the contradiction. Let Λ be the set as follows.

$$\Lambda = \{\neg\varphi\} \cup \{K_i\chi \mid K_i\chi \in \Gamma\}$$

Suppose Λ is consistent. Λ is a subset of a maximal consistent set Θ. Since $\{K_i\chi \mid K_i\chi \in \Gamma\} \subseteq \Theta$, $\Gamma \sim_i^c \Theta$. Because when $K_i\varphi \in \Theta$, $\neg K_i\varphi \notin \Theta$ and therefore $K_i\neg K_i\varphi \notin \Theta$. It is clear that $K_i\neg K_i\varphi \notin \Gamma$ and by negative introspection $\neg K_i\varphi \notin \Gamma$ and so, $K_i\varphi \in \Gamma$. From this $\Gamma \sim_i^c \Theta$. Since $\neg\varphi \in \Lambda$ and Θ is maximal consistent, $\varphi \notin \Theta$. By the induction hypothesis, this is equivalent to $(M^c, \Theta) \not\models \varphi$. This contradicts the assumption and $\{K_i\chi \mid K_i\chi \in \Gamma\} \vdash \varphi$. Therefore $\Gamma \vdash K_i\varphi$.

Now we show the completeness of $\mathcal{L}_{\mathbf{S5}}$

Theorem 2 (Completeness).
For every $\varphi \in \mathcal{L}_{\mathbf{S5}}$,

$$\models \varphi \text{ implies } \vdash \varphi$$

Proof. We show $\nvdash \varphi$ implies $\not\models \varphi$ (contraposition). Suppose $\nvdash \varphi$. Then $\{\neg\varphi\}$ is a consistent set. By the Lindenbaum Lemma $\{\neg\varphi\}$ is a subset a maximal consistent set Γ. Therefore $(\mathfrak{M}^c, \Gamma) \models \neg\varphi$ from the Truth Lemma and $\not\models \varphi$.

2.2.3 Other modal logics

Concerning modeling, modal logic is used for the model checking tools. If the modality is regarded as the one of time, it can describe the behavior of a system or a model over time. The temporal logic was proposed by Prior [28], which has two modal operators, i.e. G for the future, and H for the past. G is read "It will be always that" and F is also defined as "it will be the case that". On the other hand, H is read as "it was always that" and also P as "it was the case that". The axiom system is consist of the ones of K and the interaction.

$$\begin{aligned} \text{Necessitation } & \varphi \rightarrow G\varphi \\ & \varphi \rightarrow H\varphi \\ \text{Distribution } & G(\varphi \rightarrow \psi) \rightarrow (G\varphi \rightarrow G\psi) \\ & H(\varphi \rightarrow \psi) \rightarrow (H\varphi \rightarrow H\psi) \\ \text{Interaction } & \varphi \rightarrow GP\varphi \\ & \varphi \rightarrow HF\varphi \end{aligned}$$

In a (normal) linear temporal logic, operators are provided for describing events along a single path. In a branching-time logic, the temporal operators quantify over the branching paths that are possible from a given state. Emerson [6] extended the linear temporal logic to the branching time. The temporal operators quantify over the paths that are possible from a given state and indicate the possible future. We show one example of the branching-time path in FIGURE 2.2. So this logic has two more modal operators as the path quantifier in addition to

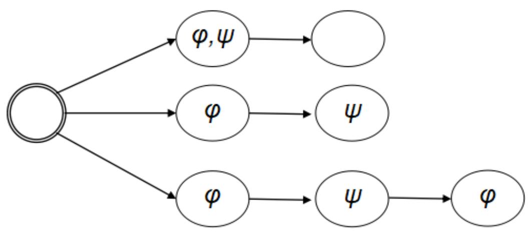

FIGURE 2.2: Example image of the branching-time

the linear-time operator of the temporal logic.

$$\begin{aligned} A: & \text{ for every path} \\ E: & \text{ there exists a path} \end{aligned}$$

By using these branching operator in addition to the temporal operators, we can describe the future of the past as some examples below.

$AG\varphi$ On all paths from this point, φ is always true.

$EG\varphi$ On some path from this point, φ is always true.

$AF\varphi$ On all paths from this point, φ is true sometime in the future.

$EF\varphi$ On some path from here, φ is true sometime in the future.

2.3 Dynamic epistemic logic and belief revision

On the other hand, the research about dynamic epistemic logic (DEL) (Section 3.2) includes the study of application for the belief revision [1] of an agent (for example [31, 35]). Baltag et. al. extended the epistemic actions which had been limited to the "public announcement" [25] to the general ones and proposed an action model, which can be used to update or change the epistemic status of an agent. However the kind of action is restricted to an epistemic one and the fact cannot be updated or changed by an action model. J.van Benthem et. al. [31] proposed the post condition function which enables to describe the change of a fact. It uses the postcondition function to define the state after an action. By using this function, an action model other than the epistemic one can be defined. Concerning DEL, van Eijck developed the model checking tool called DEMO (Dynamic Epoisteic MOdeling) in 2004. We extend this program to analyze the precedents in the succeeding chapters.

Awareness logic was proposed by Fagin and Halpern [7] and it distinguishes the explicit knowledge and the implicit knowledge. And then some researches on its dynamics and explicit knowledge were conducted. There are some variations about the definitions of the explicit knowledge and the implicit knowledge. For example, van Benthem and Velázquez-Quesada [32] defined the explicit knowledge Ex as follows.

$$\mathrm{Ex}\varphi := K(\varphi \wedge A\varphi)$$

Van Benthem and Velázquez-Quesada [32] also proposed updating the model by the concrete action. In this study, the update by an action model with awareness which is described later uses the post condition function to define the awareness status after an action. Velázquez-Quesada [36] extended this updating and proposed the model with a set "PA" of atomic propositions of which the agent is aware and a set "R" of inference rule in addition to the awareness column $\mathfrak{M} = \langle W, R, \mathrm{PA}, \mathbf{A}, \mathrm{R}, V \rangle$. In this Velázquez-Quesada's model, the awareness does not restrict the knowledge of an agent after it knows and requires some specific rules for every state of a model to be defined. He proposed the proof theory of DEL with awareness [36] by providing the reduction axioms and showed the completeness theorem for that. He also extended brief revision with awareness [37]. His concept of awareness includes the implicit and explicit information and this is different from our model. According to our definition of the awareness, this is included in the implicit knowledge.

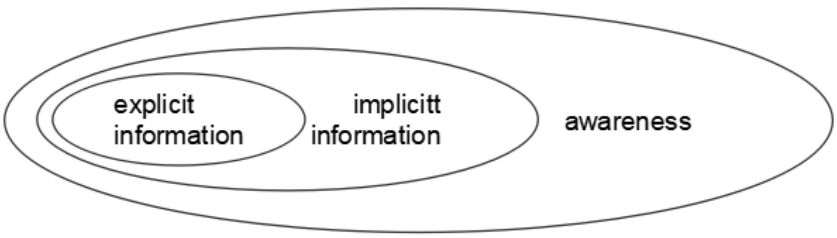

FIGURE 2.3: The awareness model by Velázques-Quesada

These DEL with awareness mentioned above cannot be applied to reproduce the event in the real world like precedents where the prediction is the important factor, because the 'general' (this means that it is not specific to the action or the state) action model is not defined based on the consideration process of an agent. We have to define each action for each states, if we try to calculate the precedents. As in the following sections, we propose the revised DEL with awareness which can be calculated in a program and which can describe the prediction or the predictability of an agent. Further their logic cannot infer the new formula in an action model and on the other hand, our model has the action '`infer`' to derive the new formula.

Chapter 3

Preliminaries

3.1 Why dynamic epistemic logic?

As described in Chapter 1, we are interested in the issue to reproduce the knowledge state of an agent in the real world and are focusing on the field of the precedents in the criminal law. In this research, we take the approach to this issue of using a logic and language to reason about the thought of an agent. We intend to follow the deduction process of the judge in the court or to clarify step by step the thought or intention of a man who commits a crime, however we do not intend to simulate the discussion itself in a court or to calculate only the result (judgment). So it is not enough to answer that the crime might happen in a high probability according to the statistics or from the feature values, or answer that the argument is done like this and the judgment is decided. We need the answer to the question why the defendant does such a thing or makes such a decision.

Among various kinds of logic, we employ dynamic epistemic logic by the following reasons.

- The judgment is determined according to the epistemic states of the defendant. DEL is one of the modal logic and can describe the epistemic states of an agent.
- The most important thing is how the judge knows about the defendant's intention and how the judgment is decided according to the defendant's knowledge or consciousness states compared with the prosecutor's knowledge states. This requires not a global objective view of an issue but a local view, from the specific world along with the relation specific to each agent.
- The judge's knowledge state changes dynamically according to the testimonies from the defendant and the prosecutor in the court.
- It is necessary to use a common model to simulate each precedent in a unified manner. If we have a specific action like "after he knows about φ, ψ ...", we can describe it as "$[\varphi]\psi$" in DEL. However if we do not use DEL, we have to define each change of an epistemic model.

We adopt the action model to update the epistemic model dynamically. For example, Plaza [25] developed DEL with an epistemic action "Public announcement" and described how the epistemic state changes according to the communication of information. However this version of dynamic epistemic logic is specific for the action "Public announcement" and cannot be applied to other epistemic actions like 'read a document' or 'message to an agent'. In simulating the precedents, it is necessary to handle the other actions than "Public announcement" which means sending any information to a specific group and all people know about it. Therefore, in this research, we adopt the action model to update the epistemic states dynamically.

3.2 Dynamic epistemic logic

3.2.1 DEL and action model

Knowledge and belief of an agent are not static because of the communication between agents or the interaction with an environment. Dynamic epistemic logic is an extension of epistemic logic [16] with dynamic operators "[ ]", and $[\pi]\varphi$ is read as "successfully executing program π yields a φ state" [15]. Namely, given a model $\mathfrak{M}$ and a possible world w,

$$\mathfrak{M}, w \models [\pi]\varphi$$

iff $\mathfrak{M}$ is properly changed by the execution of π and as a result φ holds. Public announcement logic [25] is an example of DEL where the epistemic action is only restricted to public announcement. Action model [3] is used to describe epistemic actions. In this research, we use the enhanced dynamic epistemic logic which can handle the multi-agents. Therefore, the relations defined in the following model have a label i which indicates the agent i and R_i means the relation for an agent i.

Definition 1 (Action model).
Let $\mathcal{L}_D$ be any logical language for given parameters agents I and atoms P. An **S5**[1] action model E is a structure $\langle \mathrm{S}, \sim, \mathrm{pre} \rangle$ where S is a domain of action points and for each agent i, $\sim_i$ is an equivalent relation in S, stating that the two states are indistinguishable for i. pre : S $\rightarrow \mathcal{L}_D$ is a preconditions function that assigns a formula in $\mathcal{L}_D$ to each $s \in$ S. A pointed **S5** action model is a structure (E, s) with s ∈ S

An epistemic state can be changed by an epistemic action, so the new state after updating is described as a pair of an old world with an action that has taken place in that state. The expression (w, s) indicates that action s is executable in the state w.

$$\mathfrak{M}, w \models \mathrm{pre}(\mathrm{s})$$

The two factual states are indistinguishable, if the following relation exists, where index i indicates for agent i.

$$(v, \mathrm{s}) \sim_i (w, \mathrm{t}) \text{ iff } v \sim_i w \text{ and } \mathrm{s} \sim_i \mathrm{t} \text{ (in S5 action model)}$$

Example1: Read [33]
There are two epistemic states (0/1) where the proposition P [2] is true (p) or false ($\neg p$) respectively and P is true actually. At first the agent a and b didn't know whether the value of P was true or false, so there is a link between 0 and 1 for a and b. This means that they cannot distinguish these states. A letter came to a that told p and a read it and knew that but b couldn't distinguish an action "p" (a reads a letter which tells p) from an action "np" (a reads a letter

[1]The accessibility relation which satisfies KT5, an equivalence relation.
[2]Large P stands for the proposition and small p is the value of it.

which tells ¬*p*), but b knew that *a* knew *p* or ¬*p*. In action model defined as below, this can be interpreted as a relation between these epistemic action points. The new epistemic state is built from the product of the epistemic actions and the epistemic states before these action as in TABLE 3.1, where only two cases can happen. The epistemic state after updating by the epistemic

TABLE 3.1: Product of epistemic model and action model (Example 1)

Before updating	Action model	After updating	Possibility
0: ¬*p*	np	(0, np)	can happen
0: ¬*p*	p	(0, p)	cannot happen
1: *p*	np	(1, np)	cannot happen
1: *p*	p	(1, p)	can happen

action (Read, p) is expressed as the right figure of FIGURE 3.1 where there is no link for agent *a* between state0 and state1 and the link for agent *b* remains.

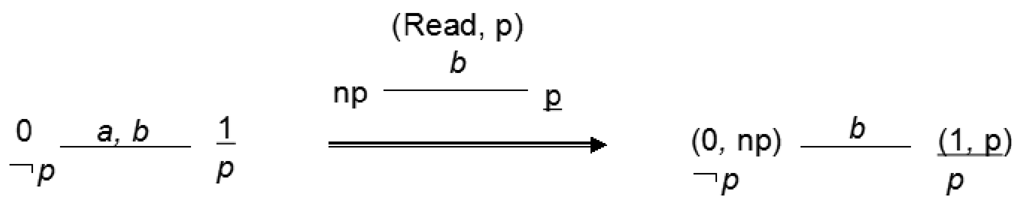

FIGURE 3.1: State transition by an action Read

Example2: MayRead [33]
Agent *b* has left the table for a while, and when come back, suspect *a* of having read the letter. There are two epistemic states (0/1) where the proposition P is true (*p*) or false (¬*p*) respectively and P is true actually. In fact, agent *a* did not read the letter which tells P is true and doesn't know whether *p* is or is not true. Agent *b* cannot know that agent *a* read or did not read it so he cannot distinguish the three action points, i.e. *a* reads the letter and it contains *p* (p), *a* reads the letter and it contains ¬*p* (¬p) and *a* does not read (t), in addition to that he does not know whether *p* holds.

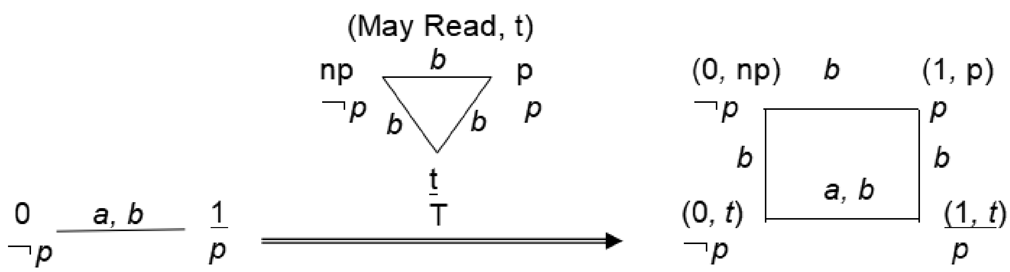

FIGURE 3.2: State transition by an action 'MayRead'

The new epistemic state after updating by the epistemic action (MayRead, t) is expressed as the right figure of FIGURE 3.2 where there is no link for agent *a* between the upper two states which represents the a's action "read the letter", and there is a link for both agent a and b between the lower two states which represents that agent a did nothing. The left vertical link represents that agent b cannot distinguish the state where $\neg p$ holds and agent a did not read the letter from the state where $\neg p$ holds and agent a read the letter containing $\neg p$, so there are two states where $\neg p$ holds. Similarly the right vertical link represents that agent b cannot distinguish the state where p holds and agent a did not read the letter from the state where p holds and agent a read the letter containing p. There are also two p states. There are only four states according to the precondition of each action (TABLE 3.2), i.e. the precondition of action np is $\neg p$, p is for p and p or $\neg p$ for t.

TABLE 3.2: Product of epistemic model and action model (Example 2)

Before updating	Action model	After updating	Possibility
0: $\neg p$	np	(0, np)	can happen
0: $\neg p$	p	(0, p)	cannot happen
0: $\neg p$	t	(0, t)	can happen
1: p	np	(1, np)	cannot happen
1: p	p	(1, p)	can happen
1: p	t	(1, t)	can happen

The language of DEL $\mathcal{L}_D$ consists of a finite set of propositional variable Prop, a set of agent I, operator $\neg, \wedge$ and modal operator K, dynamic operator [ ] and an operator for an action ";". The syntax of DEL with action model can be defined recursively as follows, using formula φ and action α.

Definition 2 (Syntax of DEL with action model language $\mathcal{L}_D$).

$$\begin{aligned} \varphi &::= p \mid \neg\varphi \mid \varphi \wedge \varphi \mid K_i\varphi \mid [\alpha]\varphi \\ \alpha &::= (\mathrm{E}, \mathrm{s}) \mid \alpha;\alpha \end{aligned}$$

i is an agent, p is a proposition, E is an action model, S is a set of actions and s is an element of this set (action point).

And the semantics of DEL are as follows. The epistemic model for multi-agent $\mathfrak{M}$ is a structure of $\langle W, \sim_i, V\rangle$, where W is a set of knowledge state w, $R_i \subseteq W \times W$ is an accessibility relation for an agent i, if we assume **S5**, this can be described by the equivalence relation $\sim_i$, V Prop $\rightarrow \mathcal{P}(W)$ is a valuation function. The action model E is the structure $\langle \mathrm{S}, \mathrm{R}_i, \mathrm{pre}\rangle$ [3]. Since we also assume **S5** relation, R is defined as $\sim_i$ and this means that the two actions cannot be distinguished by the agent i. pre : S $\rightarrow$ $\mathcal{L}_D$ is the precondition function which assign the formula of $\mathcal{L}_D$ to s. If any arbitrary model $\mathfrak{M}$ and possible world w are given, the satisfaction condition $\mathfrak{M}, w \models \varphi$ is defined as follow.

Definition 3 (Semantics of Action Model).
$\mathfrak{M}, w \models p$ iff $w \in V(p)$,
$\mathfrak{M}, w \models \neg\varphi$ iff $\mathfrak{M}, w \not\models \varphi$,

[3] In this thesis, we use Italic font to describe the epistemic model and its elemt and use romantic font to describe the action model, according to [33]

$\mathfrak{M}, w \models \varphi \wedge \psi$ iff $\mathfrak{M}, w \models \varphi$ and $\mathfrak{M}, w \models \psi$,
$\mathfrak{M}, w \models K_i\varphi$ iff for all $w' \in W, w \sim_i w'$ implies $\mathfrak{M}, w' \models \varphi$,
$\mathfrak{M}, w \models [(\mathrm{E}, \mathrm{s})]\varphi$ iff $\mathfrak{M}, w \models \mathrm{pre}(\mathrm{s})$ implies $\mathfrak{M} \otimes \mathrm{E}, (w, \mathrm{s}) \models \varphi$
$\mathfrak{M}, w \models [\alpha'; \alpha]\varphi$ iff $\mathfrak{M}, w \models [\alpha'][\alpha]\varphi$
where $\mathfrak{M} \otimes \mathrm{E}$ is the updated epistemic model by an epistemic action and this updated model $\mathfrak{M}'(= \mathfrak{M} \otimes \mathrm{E})$ is a restricted modal product ($\otimes$) of an epistemic model and an action model, which is defined as an structure $\langle W', \sim_i', V' \rangle$ where
$W' = \{(w, \mathrm{s}) \mid w \in W, \mathrm{s} \in \mathrm{S}$ and $\mathfrak{M}, w \models \mathrm{pre}(\mathrm{s})\}$,
$(w, \mathrm{s}) \sim_i (w', \mathrm{s}')$ iff $w \sim_i w'$ and $\mathrm{s} \sim_i \mathrm{s}'$,
$(w, \mathrm{s}) \in V'(p)$ iff $w \in V(p)$

The new epistemic model is defined as the product of the old epistemic model and the action model. The updated state (w, s) which consists of the pair of the epistemic state and an action point describe an epistemic state.

Here we show the completeness of the dynamic epistemic logic $\mathcal{L}_D$ according to Ditmarsch [33].
The proof system $\mathcal{L}_D$ is shown as follows.

$$\text{All instantiations of propositional tautologies.} \tag{3.1}$$
$$K_i(\varphi \to \psi) \to (K_i\varphi \to K_i\psi) \tag{3.2}$$
$$K_i\varphi \to \varphi \tag{3.3}$$
$$K_i\varphi \to K_iK_i\varphi \tag{3.4}$$
$$\neg K_i\varphi \to K_i\neg K_i\varphi \tag{3.5}$$
$$[(\mathrm{E}, \mathrm{s})]p \leftrightarrow (\mathrm{pre}(\mathrm{s}) \to p) \tag{3.6}$$
$$[(\mathrm{E}, \mathrm{s})]\neg\varphi \leftrightarrow (\mathrm{pre}(\mathrm{s}) \to \neg[(\mathrm{E}, \mathrm{s})]\varphi) \tag{3.7}$$
$$[(\mathrm{E}, \mathrm{s})](\varphi \wedge \psi) \leftrightarrow [(\mathrm{E}, \mathrm{s})]\varphi \wedge [(\mathrm{E}, \mathrm{s})]\psi \tag{3.8}$$
$$[(\mathrm{E}, \mathrm{s})]K_i\varphi \leftrightarrow (\mathrm{pre}(\mathrm{s}) \to \bigwedge_{s \sim_i t} K_i[(\mathrm{E}, \mathrm{t})]\varphi) \tag{3.9}$$
$$[(\mathrm{E}, \mathrm{s})][(\mathrm{E}', \mathrm{s}')]\varphi \leftrightarrow [(\mathrm{E}, \mathrm{s})]; [(\mathrm{E}', \mathrm{s}')]\varphi \tag{3.10}$$
$$\text{if } \varphi \text{ and } \varphi \to \psi \text{ then } \psi \tag{3.11}$$
$$\text{if } \varphi \text{ then } K_i\varphi \tag{3.12}$$

These axioms can be translated into the case before an action as follows.

Definition 4 (Translation).

$$t(p) = p \tag{3.13}$$
$$t(\neg\varphi) = \neg t(\varphi) \tag{3.14}$$
$$t(\varphi \wedge \psi) = t(\varphi) \wedge t(\psi) \tag{3.15}$$
$$t(K_i\varphi) = K_i t(\varphi) \tag{3.16}$$
$$t([(\mathrm{E}, \mathrm{s})]p) = t(\mathrm{pre}(\mathrm{s}) \to p) \tag{3.17}$$
$$t([(\mathrm{E}, \mathrm{s})]\neg\varphi) = t(\mathrm{pre}(\mathrm{s}) \to \neg[(\mathrm{E}, \mathrm{s})]\varphi) \tag{3.18}$$
$$t([(\mathrm{E}, \mathrm{s})](\psi \wedge \chi)) = t([(\mathrm{E}, \mathrm{s})]\varphi \wedge [(\mathrm{E}, \mathrm{s})]\psi) \tag{3.19}$$
$$t([(\mathrm{E}, \mathrm{s})]K_i\psi) = t(\mathrm{pre}(\mathrm{s}) \to K_i[(\mathrm{E}, \mathrm{s})]\varphi) \tag{3.20}$$
$$t([(\mathrm{E}, \mathrm{s})][(\mathrm{E}', \mathrm{s}')]\varphi) = t([(\mathrm{E}, \mathrm{s}); (\mathrm{E}', \mathrm{s}')]\varphi) \tag{3.21}$$

We define the complexity to prove by induction as follows.

Definition 5 (Complexity).

$$c(p) = 1 \tag{3.22}$$
$$c(\neg\varphi) = 1 + c(\varphi) \tag{3.23}$$
$$c(\varphi \wedge \psi) = 1 + \max(c(\varphi), c(\psi)) \tag{3.24}$$
$$c(K_i\varphi) = 1 + c(\varphi) \tag{3.25}$$
$$c([\alpha]\varphi) = (4 + c(\alpha)) \cdot c(\varphi) \tag{3.26}$$
$$c(\mathrm{E}, \mathrm{s}) = \max(c(\mathrm{pre}(\mathrm{s}))) \tag{3.27}$$

We can say the reduction of the complexity.

Lemma 1. For all φ and ψ:

$$c(\psi) \geq c(\varphi) \text{ if } \varphi \in Sub(\psi) \tag{3.28}$$
$$\text{where } Sub(\psi) \text{ means the set of sub-formula of } \psi$$
$$c([(\mathrm{E}, \mathrm{s})]p > c(\mathrm{pre(s)} \to p) \tag{3.29}$$
$$c(\ [(\mathrm{E}, \mathrm{s})]\neg\varphi) > c(\mathrm{pre(s)} \to \neg\ [(\mathrm{E}, \mathrm{s})]\varphi) \tag{3.30}$$
$$c(\ [(\mathrm{E}, \mathrm{s})](\varphi \wedge \psi)) > c(\ [(\mathrm{E}, \mathrm{s})]\varphi \wedge\ [(\mathrm{E}, \mathrm{s})]\psi) \tag{3.31}$$
$$c(\ [(\mathrm{E}, \mathrm{s})]K_i\varphi) > c(\mathrm{pre(s)} \to K_i\ [(\mathrm{E}, \mathrm{s})]\varphi) \tag{3.32}$$
$$c(\ [(\mathrm{E}, \mathrm{s})][(\mathrm{E}', \mathrm{s}')]\varphi) > c(\ [(\mathrm{E}, \mathrm{s});(\mathrm{E}', \mathrm{s}')]\varphi) \tag{3.33}$$

Proof. Refer to Section 6.3.3 for the details.
Formula (3.28): Induction of the length of ψ.
Formula from (3.29) to (3.33): From the definition of dach formula in Defitiion 5

We can prove the lemma saying that every formula is provably equivalent to its translation.

Lemma 2.
For all formulas $\varphi \in \mathcal{L}_D$ it is the case that

$$\vdash \varphi \leftrightarrow t(\varphi)$$

Proof. By induction on $c(\varphi)$.
If φ is a proposition, it is clearly $\vdash \varphi \leftrightarrow t(\varphi)$, since $t(p) = p$.

We assume that for all φ such that $c(\varphi) < n, \vdash \varphi \leftrightarrow t(\varphi)$.

Case for $\neg\varphi$: Immediately from the formula (3.28) in Lemma 1 and the induction hypothesis.

Case for $\varphi \wedge \psi$: Immediately from the formula (3.28) in Lemma 1 and the induction hypothesis.

Case for $K\varphi$:

$$\begin{aligned} K\varphi &\leftrightarrow Kt(\varphi), \text{ since the induction hypothesis} \\ &\leftrightarrow t(K\varphi) \text{ from the formula (3.16) in Definition 4} \end{aligned}$$

Case for [(E, s)]p:

$$\begin{aligned} &\text{From left to right} \\ &[(\text{E}, \text{s})]p \rightarrow \text{pre(s)} \rightarrow p \text{ from the formula (3.6) of } \mathcal{L}_D \\ &\quad \rightarrow t(\text{pre(s)} \rightarrow p) \text{ from the formula (3.29) of Lemma 1} \\ &\qquad \text{and the induction hypothesis} \\ &\quad \rightarrow t([(\text{E}, \text{s})]p) \text{from the formula (3.17) in Definition 4} \\ &\text{From right to left} \\ &t([(\text{E}, \text{s})]p) \rightarrow t(\text{pre(s)} \rightarrow p) \text{ from the formula (3.17) in Definition 4} \\ &\quad \rightarrow \text{pre(s)} \rightarrow p \text{ from the formula (3.29) of Lemma 1} \\ &\qquad \text{and the induction hypothesis} \\ &\quad \rightarrow [(\text{E}, \text{s})]p \text{ frm the formula (3.6) of } \mathcal{L}_D \end{aligned}$$

Case for [(E, s)]$\neg\varphi$: From (3.30) of Lemma 1, we can say $\vdash$ [(E, s)]$\neg\varphi \leftrightarrow t$([(E, s]$\neg\varphi$), because of the induction hypothesis and axiom (3.7) of $\mathcal{L}_D$.

Case for [(E, s)]$\varphi \wedge \psi$: From (3.31) of Lemma 1, we can say $\vdash$ [(E, s)]$\varphi \wedge \psi \leftrightarrow t$([(E, s]$\varphi \wedge \psi$), because of the induction hypothesis and axiom (3.8) of $\mathcal{L}_D$.

Case for [(E, s)]$K_i\varphi$: From (3.32) of Lemma 1, we can say $\vdash$ [(E, s)]$K_i\varphi \leftrightarrow t$([(E, s]$K_i\varphi$), because of the induction hypothesis and axiom (3.9) of $\mathcal{L}_D$.

Case for [(E, s)][(E′, s′)]φ: From (3.33) of Lemma 1, we can say $\vdash$ [(E, s)][(E′, s′)]$\varphi \leftrightarrow t$([(E, s][(E′, s′)]$\varphi$), because of the induction hypothesis and axiom (3.10) of $\mathcal{L}_D$.

Now we can prove the completeness.

Theorem 1 (Completeness).
For every $\varphi \in \mathcal{L}_D$

$$\models \varphi \text{ implies } \vdash \varphi$$

Proof. Suppose $\models \varphi$. By the soundness of the proof system of $\mathcal{L}_D$ and Lemma 2, $\models t(\varphi)$. The formula $t(\varphi)$ does not contain any action model, so **S5** $\models t(\varphi)$. By the completeness of **S5**, **S5** $\vdash t(\varphi)$. Therefore, $\mathcal{L}_D \vdash t(\varphi)$, because **S5** is a subsystem of $\mathcal{L}_D$. Since $\vdash \varphi \leftrightarrow t(\varphi)$, it follows that $\mathcal{L}_D \vdash \varphi$.

3.3 Limited reasoning by awareness

Awareness logic [7] is an extension of epistemic logic [16] and it distinguishes between "implicitly known information" (an agent knows eventually, but is not conscious of) and "explicitly known information" (an agent knows and is conscious of). That is, an agent infers its decision according to his/her "explicit known information" and leaves "implicit information" as unconscious. Accordingly, the logic of awareness has the operator A and a formula $A\varphi$ stands for "an agent is aware of φ".

Now, let us recall the awareness logic. A language $\mathcal{L}_A$ of awareness logic consists of the following vocabulary: a finite set of (atomic) propositional variables Prop, Boolean connectives $\neg, \wedge$ and modal operators K and A. The set of formulas of the language $\mathcal{L}_A$ is defined as follows:

$$\varphi ::= p \mid \neg\varphi \mid \varphi \wedge \varphi \mid K\varphi \mid A\varphi.$$

where $p \in$ Prop. As usual, $K\varphi$ stands for "an agent knows that φ."

An awareness model is a tuple $\mathfrak{M} = \langle W, R, \mathbf{A}, V\rangle$ where W is a non-empty set of worlds, $R \subseteq W \times W$ is an accessibility relation, $\mathbf{A} : W \to \mathcal{P}(\mathcal{L}_A)$ is an awareness function and V : Prop $\to \mathcal{P}(W)$ is a valuation function. Here, awareness function $\mathbf{A}$ is introduced to return a set of formulas which an agent is aware of in the corresponding knowledge state. An epistemic model is the result of dropping an awareness function from an awareness model. Given any awareness model $\mathfrak{M} = \langle W, R, \mathbf{A}, V\rangle$ and any possible world $w \in W$, the satisfaction relation $\mathfrak{M}, w \models \varphi$ is defined as follows:

$$\begin{array}{lll}
\mathfrak{M}, w \models p & \text{iff} & w \in V(p), \\
\mathfrak{M}, w \models \neg\varphi & \text{iff} & \mathfrak{M}, w \not\models \varphi, \\
\mathfrak{M}, w \models \varphi \wedge \psi & \text{iff} & \mathfrak{M}, w \models \varphi \text{ and } \mathfrak{M}, w \models \psi, \\
\mathfrak{M}, w \models K\varphi & \text{iff} & \mathfrak{M}, w' \models \varphi \text{ for all } w' \in W \text{ with } wRw', \\
\mathfrak{M}, w \models A\varphi & \text{iff} & \varphi \in \mathbf{A}(w).
\end{array}$$

This language can be extended to the multi-agent system by using the modal operator for multi-agent like K_i, A_i, where $i \in I$ means an agent i of a set of agent I. Concerning the semantics, the model is defined like $\mathfrak{M} = \langle W, (R_i)_{i\in I}, \mathbf{A}_{i\in I}, V\rangle$, where $(R_i)_{i\in I}$ is a relation for agent i and $\mathbf{A}_i$ is an awareness function which assigns the formula agent i is aware of at the state.

3.4 Dynamic epistemic logic with awareness

Van Benthem et al. extended dynamic epistemic logic [3, 33] to include the dynamics of awareness [31, 32]. They defined action model [3] which includes the post condition function to update the epistemic state of agents with awareness by an epistemic action.

The syntax of the language $\mathcal{L}_{DA}$ of DEL with awareness is based on that $\mathcal{L}_A$ of awareness logic. Besides Boolean connectives $\neg, \wedge$, and modal operators K and A, the language $\mathcal{L}_{DA}$ has action operator ";" and "[ ]." Given a non-empty finite set I of agents, the set of formulas and the set of actions of this language are defined by simultaneous induction as follows:

$$\begin{array}{lll} \varphi & ::= & p \mid \neg\varphi \mid \varphi \wedge \varphi \mid K_i\varphi \mid A_i\varphi \mid [\alpha]\varphi \\ \alpha & ::= & (\mathrm{E}, \mathrm{s}) \mid \alpha;\alpha' \end{array}$$

where $i \in I$, $\alpha;\alpha'$ means a continuous execution of the action α' after α, and (E, s) is an (pointed) action model defined as follows.

Definition 6 (Action Model with Awareness).
An action model with awareness is a tuple $\mathrm{E} = \langle \mathrm{S}, (\mathrm{R_i})_{\mathrm{i} \in \mathrm{I}}, \mathrm{Pre}, \mathrm{Pos} \rangle$ where S is a non-empty finite set of actions, $\mathrm{R_i} \subseteq \mathrm{S} \times \mathrm{S}$ is a relation for agent i, $\mathrm{Pre} : \mathrm{S} \to \mathcal{L}_{DA}$ is a precondition function, $\mathrm{Pos} : I \times \mathrm{S} \times \mathcal{P}(\mathcal{L}_{DA}) \to \mathcal{P}(\mathcal{L}_{DA})$ is a post condition function.

Definition 7 (DEL with Awareness).
Given any awareness model $\mathfrak{M}$ and any possible world $w \in W$, the satisfaction relation $\mathfrak{M}, w \models \varphi$ is defined as follows:

$$\begin{array}{lll} \mathfrak{M}, w \models p & \text{iff} & w \in V(p), \\ \mathfrak{M}, w \models \neg\varphi & \text{iff} & \mathfrak{M}, w \not\models \varphi, \\ \mathfrak{M}, w \models \varphi \wedge \psi & \text{iff} & \mathfrak{M}, w \models \varphi \text{ and } \mathfrak{M}, w \models \psi, \\ \mathfrak{M}, w \models K_i\varphi & \text{iff} & \mathfrak{M}, w' \models \varphi \text{ for all } w' \in W \text{ with } wR_iw' \\ \mathfrak{M}, w \models A_i\varphi & \text{iff} & \varphi \in \mathbf{A}(i, w), \\ \mathfrak{M}, w \models [(\mathrm{E}, \mathrm{s})]\varphi & \text{iff} & \mathfrak{M}, w \models \mathrm{Pre}(s) \text{ implies } \mathfrak{M} \otimes \mathrm{E}, (w, \mathrm{s}) \models \varphi, \\ \mathfrak{M}, w \models [\alpha;\alpha']\varphi & \text{iff} & \mathfrak{M}, w \models [\alpha][\alpha']\varphi \end{array}$$

where $\mathbf{A}$: $I \times W \to \mathcal{P}(\mathcal{L}_{DA})$ returns a set of formulas which an agent i is aware of at the state w and updated model $\mathfrak{M} \otimes \mathrm{E} = \langle W', R', \mathbf{A}', V' \rangle$ is defined as:

- $W' := \{ (w, s) \mid \mathfrak{M}, w \models \mathrm{Pre(s)} \}$,
- $(w, \mathrm{s})R'_i(w', \mathrm{s}')$ iff wR_iw' and $\mathrm{s}R_i\mathrm{s}'$,
- $\mathbf{A}'(i, (w, \mathrm{s})) := \mathrm{Pos}(i, \mathrm{s}, \mathbf{A}(i, w))$,
- $(w, \mathrm{s}) \in V'(p)$ iff $w \in V(p)$.

Chapter 4

Precedent of the penal code

In this chapter, we explain the legal concepts which are used in the criminal precedents according to the penal code. To determine the criminality specified in the penal code, the followings are examined by a judge [20].

1. The defendant's action comes under the external elements (*Tatbestand*) of a crime defined in the penal code.
2. There is no justifiable reason to dismiss the illegality[1].
3. There is no justifiable reason to dismiss the responsibility[2].

If these conditions are matched, the criminality is decided. Note that, in this thesis, we deal mainly with the process of verifying the correspondence with the external elements of a crime.

4.1 Handling of predictability in the penal code

External elements of a crime defined in the penal code In general, external elements of a crime are roughly divided into the subjective and the objective one [4]. (There are also several opposite theories [17] against this, such that both intent and negligence are regarded as the responsibility and should not be included in the external elements of a crime.) The objective element contains action, result and causality between an action and a result. The subjective element is comprised of intent and negligence.
Intent in the penal code Intent is "an intention to commit a crime". (The Penal Code Article 38 paragraph 1 [3]). At least, the consciousness of an objective external element such as an action, a causal relation and a prediction of a result is needed. Further, in general, the probability of occurrence or the admittance of the results by the defendant [4] are taken into account by the judge. As a kind of intent, there is an uncertain intent, for example the willful negligence (*dolus eventualis*)[4] is classified as this type.
Negligence in the penal code The negligence is defined in the Penal Code Article 38 paragraph 1 as "The action without awareness to commit a crime is not punishable. However, if there is a special provision in the code, this shall not be applied to" [3]. The negligence is applied in the case where the defendant did not foresee the result which might have been able to predict.

[1] A reason that there is no illegality about the act that illegality is usually estimated

[2] A reason to deny the responsibility of the act that responsibility is accepted as a general rule

[3] The Penal Code of Japan. http://www.japaneselawtranslation.go.jp/law/detail/?id=1960

[4] The defendant is uncertain about the realization of crime but knowing that crime may be implemented and he has accepted it.

Recently the duty of the defendant to avoid the criminal results is more emphasized. [8]
Causality/Causal relation A relationship between an action and a result is called the causality. In order to affirm the causality, there should be not only a conditional relationship (without that there should not be this) between an action and a result, but also it is required to be regarded reasonable from the experience of the social life of ordinary people (Legally sufficient cause [39]).

4.2 Evaluation process of correspondence to external elements of a crime

To determine whether the defendant's action conforms to the external elements of a crime specified in the penal code, the objective and the subjective elements are examined [24]. (FIGURE 4.1)
1. Consciousness about the objective elements constituting a crime At first, the defendant's

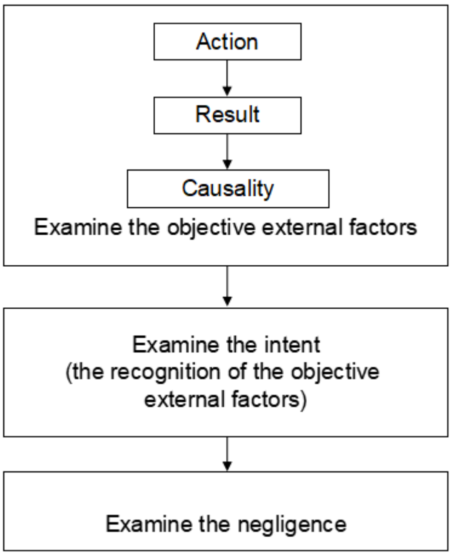

FIGURE 4.1: Evaluation process

recognition of the objective external elements such as an action, a result and a causality between them is verified. If the recognition is different from the actual fact, it is considered that there occurred a mistake in interpretation of facts [39].
2. Consciousness of subjective elements Secondly, the intent (the awareness, the prediction and the possibility of occurrence of the result, *etc.*) and the negligence (the breach of the duty of predicting the result, the breach of the duty of avoiding the criminal result) are examined.

4.2.1 Description of the Issues in the Precedents by DEL

From the above, in order to represent a process of deciding a judgment of precedents dealt in this paper, the following descriptions are required.

- Description of facts (action, result, causality) constituting a crime

- Description of the fact in the recognition and the intention to commit
- Description of predictability about the result

4.3 Selection of precedents

According to the evaluation process written in the previous section, there are three main points where predictability or recognition is the issue in the judgment. The first point is the recognition of the objective facts which include the problem of intervention of unexpected actions and a mistake in recognizing causality. The second is the intent of the defendant and the problem of *dolus evantualis* (willful negligence) occurs at this point. The third is the negligence which includes the problem of predictability and possibility of avoiding the criminal results. From precedents often cited [21], some typical examples are listed below and they are classified into 6 categories from the point of view of the awareness and the predictability as follows and these cases are mapped to the three points in the evaluation process (FIGURE 4.2). The six patterns are the unexpected action by the accuser or the third person (aggravation of punishment), misunderstanding of the causality, *dolus eventulas*, generalized intention, negligence and innocence.

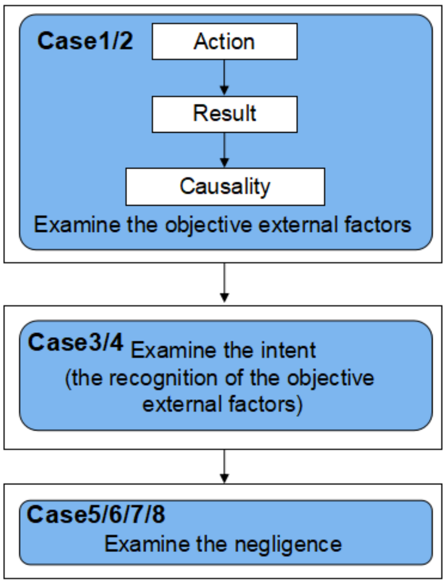

FIGURE 4.2: Evaluation process

Case 1 The intervention of the unexpected action by the victim or the third person (Aggravation of punishment)
Accused of injury resulting in death case (No. A35, 2003) Four people assaulted the victim repeatedly. He was so frightened that he ran away without wearing his shoes. Then he ran into the highway nearby to escape from the violence. He was run over by a car and died. The judge recognized a causal relationship between the assault and the victim's death, because the victim was very frightened and it was not so unnatural to escape into the highway. And the judge applied the aggravated punishment resulting in death. Concerning the aggravation of punishment, the prediction about the result is not required.

Case 2 Misunderstanding of a process or a causality
Accused of murder case (No. RE 517, 1923) The defendant tried to murder the victim by strangulation and made a mistake that the victim was then dead and attempted to conceal the crime by burying him in the sand of the coast. However he was still alive and died because of sand absorption. The judge determined there was an intention because the defendant recognized the outline of the causal relationship and the details are not required, even thought the defendant misunderstood the causal relation.

Case 3 *Dolus eventualis* **(Willful negligence)**
Dealing with stolen goods case (No. RE238, 1947) The defendant bought stolen clothes without knowing that they were originally stolen, when the suspicious person came to sell clothes. The defendant dare to buy the clothes from this unknown and suspicious person doubting that they might be stolen, because the defendant did not have a conviction that they were stolen. The judge admitted the uncertain intention by the defendant and applied the crime of illegal acquisition of the stolen goods.

Case 4 Generalized intention
The Stimulant Drug Control Law violations (No. A1038, 1998) The defendant was threatened to carry the stimulant, however he was said that they were cosmetics. He returned to his homeland carrying the stimulant drug without his conviction that the material is a stimulant. However he doubted about this. The judge declared that the defendant is conscious of carrying drugs including the stimulant and admitted his intention to violate the stimulant drug control law.

Case 5 Negligence (Delinquency of duty of care)
Hokkaido University electric scalpel case (No. U219, 1974) The nurse had mistakenly connected the cables of the electric scalpel and the doctor operated by using this electric scalpel and the patient's right foot was heavily damaged by the abnormal electronic current. Finally the patient's leg was cut due to this damage later. The judge ruled professional negligence resulting in bodily injury.

Case 6 Negligence (Delinquency of duty of care)
Involuntary manslaughter by the traffic accident (No. A193, 1986) The defendant drove his truck at over 65 km/h in a narrow road where the maximum speed is limited under 30 km/h. When he found that a car was coming from the opposite direction, he was upset and made a mistake of his handling and crushed into the footpath. Two people happened to be on the back of the truck and were dead by this crush. The defendant might not approve their ride on the back explicitly, however the judge applied the involuntary manslaughter, because the defendant should take care when he made such a dangerous driving and the judge conclude that the defendant could predict the risk.

Case 7 Innocent case
The use of HIV contaminated blood in Teikyo University hospital (No. WA1879, 1996) The doctor used unheated blood medicine to stop the hemophilic bleeding. However the unheated blood was contaminated by HIV virus and the patient becomes HIV positive. The

judge applied the innocence to the doctor. It was usual to use unheated blood medicine for the hemophilic patients at that time. And it is hard to recognize that the probability of infection is high, even though the doctor might be able to predict the possibility of the infection of HIV by the unheated blood medicine.

Case 8 Innocent case

Innocence case of the traffic accident (No. A183, 2002) The defendant drove his taxi with two passengers and went into the crossing point without slowing down. Suddenly the other drunken person drove a car at over 70 km/h from the left side into the crossing point and crashed into this taxi. The one passenger was dead and another was seriously injured. The judge declared innocence to the defendant, because another crushed car was driven abnormally at the dangerous high speed and it was hard to verify that the accident might be avoided if the defendant slowed down to 10 km/h or 15 km/h at the crossing point.

Chapter 5

Application of simple DEL to the precedents

As the first step, we try to apply the simple DEL with action model to the selected precedents, evaluate them and clarify the issues in this chapter.

5.1 Application to the precedents

From precedents often cited [21] and listed in the previous chapter, some typical examples (Case 1, Case 2, Case3, Case5 and Case 7) are listed to model. To describe the precedents by simple DEL, we define issues in the process of a trial as follows.

Action α_a an action point of an action model by agent a

Predictability The predictability is described as a possibility of link cut between epistemic states. We describe that agent a cannot predict state t from s when there is a's link between state s and state t.

Possibility of avoidance This is represented as a link cut between the states of preconditions for the alternative action in an action model of DEL.

Intent This is represented as the predictability about the result of his/her action, so there is no link for the agent between an actual state (the precondition is true) and states where the precondition is false.

Negligence Negligence is described as no intent by the defendant, the predictability and the possibility of avoidance from the view point of a usual person or a judge.

Updating the status of epistemic model is executed in two steps. The first step is by the defendant's actions through a crime (or by the start of a trial where the judge has no prejudice) and the second step is by the judge's actions from the start of a trial to the final judgment. In updating, the epistemic actions as follows are employed. Since an action of action model is corresponding the knowledge and the agent knows about something by an epistemic action, we assume knowing something can be regarded as messaging to himself/herself.

message which notifies propositions to the particular persons and the others may or may not know whether the message has reached. This corresponds to the situation that a prosecutor gives new evidence and the judge examines this evidence and the others don't know the knowledge change in the judge's mind.

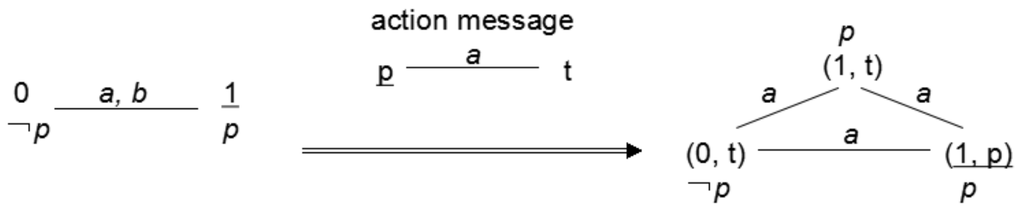

FIGURE 5.1: Update by message

public which is the same as public announcement. This is used to describe the common sense which influences the criminal actions.

For example, (message b p) indicates that agent b knows p but agent a may or may not know what is going on. (FIGURE 5.1) The product of two states and two action points consists of four states after updating, but there are only three states according to the preconditions of each action. We use the 'DEMO' [34], which is the modeling tool of DEL and is programmed by using Haskell [1], which can validate our modeling and can calculate the final epistemic model when the judgment is decided. In this implementation, the accessibility relations are restricted to **S5** relation.

5.2 Implementation and Result

When we define the propositions, we take "p" as the primary factor (or the external element of a crime) and "$q, r, ...$" as the subsidiary ones (the extraneous factor).

5.2.1 Case 1 The intervention of the unexpected action

The precedent is as follows. The defendant assaulted the victim repeatedly. So he ran away into the highway nearby and was run over by a car and died. In this case, the defendant is accused of the crime of inflicting injury and the cause of the victim's death is an issue.

- Proposition p: The victim is injured.
- Proposition q: The victim is driven to the emotional corner.
- Agent a: The defendant (in the following all cases in this chapter)
- Agent b: The judge (in the following all cases in this chapter)

We set the proposition p (external element of a crime) as the injury and q (substantial element) as the cause of a successive action. Four epistemic states are set where the value depends on these two propositions and it's true/false binary values respectively.

As the things in this crime go, the defendant takes actions. We interpret these non-epistemic actions as concerned (whose precondition is the same) epistemic actions which are points of an action model. In this case there are two non-epistemic actions.

- "injure the victim" whose precondition is p (getting injured)

[1]Haskell 98 Language and Libraries. http://www.haskell.org/onlinereport/

- "run into highway" whose precondition is q (so threatened to run into the highway)

It is necessary to update the epistemic states by two corresponding epistemic actions concerning these two non-epistemic actions described above. The defendant can recognize his own action of injuring the victim, so we update the states by the action of sending a message to himself whose precondition is the same as for the precondition of his non-epistemic action "injure". FIGURE 5.2 is an image of updating by this action "message a p", where the p states (the states agent a believes p) are copied for agent b because he cannot distinguish these states. These added states and links are represented as shaded states and dotted lines in FIGURE 5.2.

On the other hand, the casualty's action "run into the highway" cannot be predicted by the defendant, so no additional information is sent to himself and the links between states where q is true or false ($\neg q$) remain unchanged. That is the state at the time of the crime has happened. A part of the program code is as follows.

```
intervent  = initE[P 0, Q 0] --defines initial epistemic states
initInt = upds intervent [message a p] --updating
```

Then we update this epistemic state by the action of the judge. This process is regarded as the processing of the trial at the court. The actions for the final state (FIGURE 5.4) are as follows.

message b **(**p**)** The judge knows the defendant injured the victim.
The result of updating by this action is shown in FIGURE 5.3. The shaded states and dotted lines describe the added ones by this updating. For the defendant (agent a), this message p and the states where nothing happens cannot be distinguished and the new states are added. However, the links with label a remain between them. On the other hand, the judge knows that p is true and there is no link with label b between p and $\neg p$.

message b **(Disj [**$\neg p, q$**])** The judge is informed that the victim was cornered by the defendant's action. (If there is a causal relation, the precondition of the action (assault) implies the result state under the occurrence of this defendant's action. And an implication can be represented by the disjunction ($p \rightarrow q \Leftrightarrow \neg p \vee q$). In the following cases, an implication is translated to a disjunction.

message b **(K** a p**)** The judge is informed that the defendant knows he injured the victim.

5.2.2 Case 2 Misunderstand of the causal relation

The precedent is as follows. The defendant tried to murder the victim by strangulation and then made an attempt to conceal the crime by burying him in the sand, but he did not die at that time and died because of sand absorption.
The propositions and the states are as follows.

- Proposition p: The victim is dead.
- Proposition q: The victim survives the defendant's strangulation.

The defendant's actions which update the epistemic states through the crime

message a **(**p**)** "The defendant is conscious of his own action (strangulation)." (But the defendant does not know that the victim survives.)

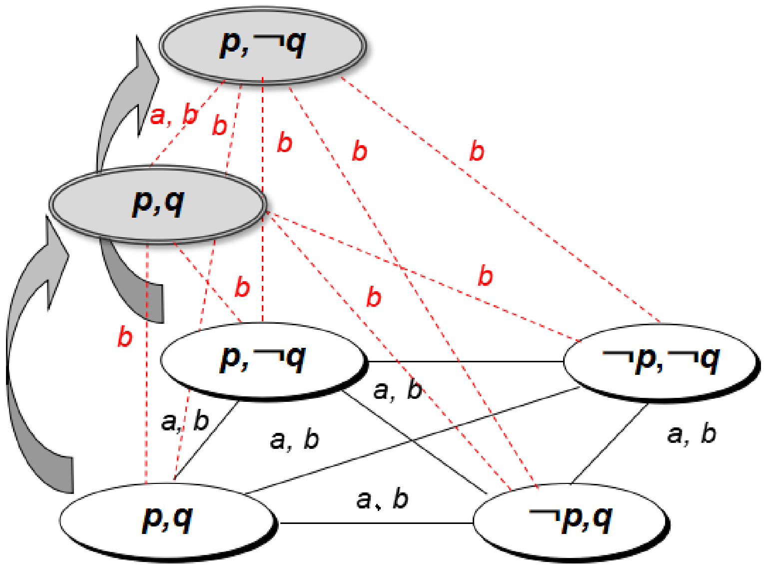

FIGURE 5.2: Case1 Updating by message a p

The judge's actions which update the epistemic status during the trial

message b **(**p**)** "The judge knows the defendant strangulated the victim."

message b **(Disj [**$\neg q, p$**])** "The judge is informed that the concealment is a part of the process of strangulation."

message b **(K** a **(**p**))** "The judge is informed that the defendant knows he strangulated the victim."

The the final state is the same as Case 1 except the value of q.

5.2.3 Case 3 *Dolus eventualis*

The precedent is as follows. The defendant bought stolen clothes without knowing that they were originally stolen.. He is accused of paid acquisition of stolen goods.
The propositions and the states are as follows.

- Proposition p: The goods are stolen.
- Proposition q: The probability of being stolen is high.
- State four states (0..3) 0:$\neg p, \neg q$, 1:$p, \neg q$, 2:$\neg p, q$, 3:p, q. Agent a, b cannot distinguish these states.

The defendant's actions which update the epistemic states through the crime.

public (Disj [Neg q, p**])** "It is known that the probability is high then the goods are perhaps stolen."

message a q "The defendant is informed that the probability of being stolen is high."

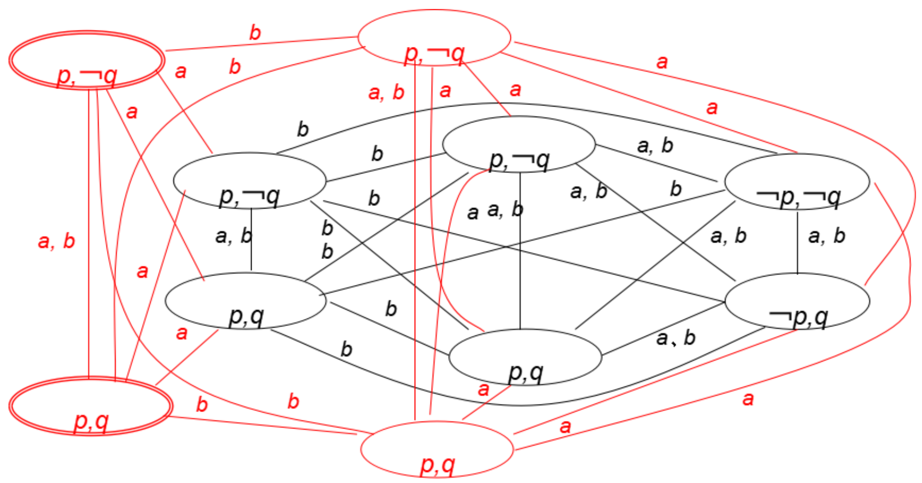

FIGURE 5.3: Case1 Updating by message $b\ p$

The judge's actions which update the epistemic status during the trial

message $b\ p$ "The judge is informed that the goods are stolen."

message b **(K** $a\ q$**)** "The judge is informed that the defendant knows the probability is high."

The final state becomes like FIGURE 5.5. The shaded circles (states) indicate the actual state and states which can be reached from the actual state by the agents' links.

After these updates, the judge knows that the defendant knows the illegality, which deserves a punishment for the defendant's intention. This can be checked by DEMO, too.

```
*DEMO> isTrue (upds initWilneg [message b p, message b (K a q)])
(K b (K a p))
True
```

5.2.4 Case 5 Negligence

The precedent is as follows. The doctor and the nurse made a mistake of connecting the cable of the scalpel incorrectly, and the patient's right foot below knee was damaged and resulted in an amputation. The nurse is accused of professional lapse resulting in bodily injury.
The propositions and the states are as follows.

- Proposition p: The patient is injured.
- Proposition q: The wrong connection highly tends to result in injury.
- Proposition r: The cables are connected wrongly.
- State eight states (0..7) : Respectively binary values of P, Q, R

The defendant's actions which update the epistemic states through the crime

public (Disj [Neg q**, Neg** r, p**])** "It is common sense that if the cable is connected wrongly and the wrong connection tends to result in injury, then the patient is damaged."

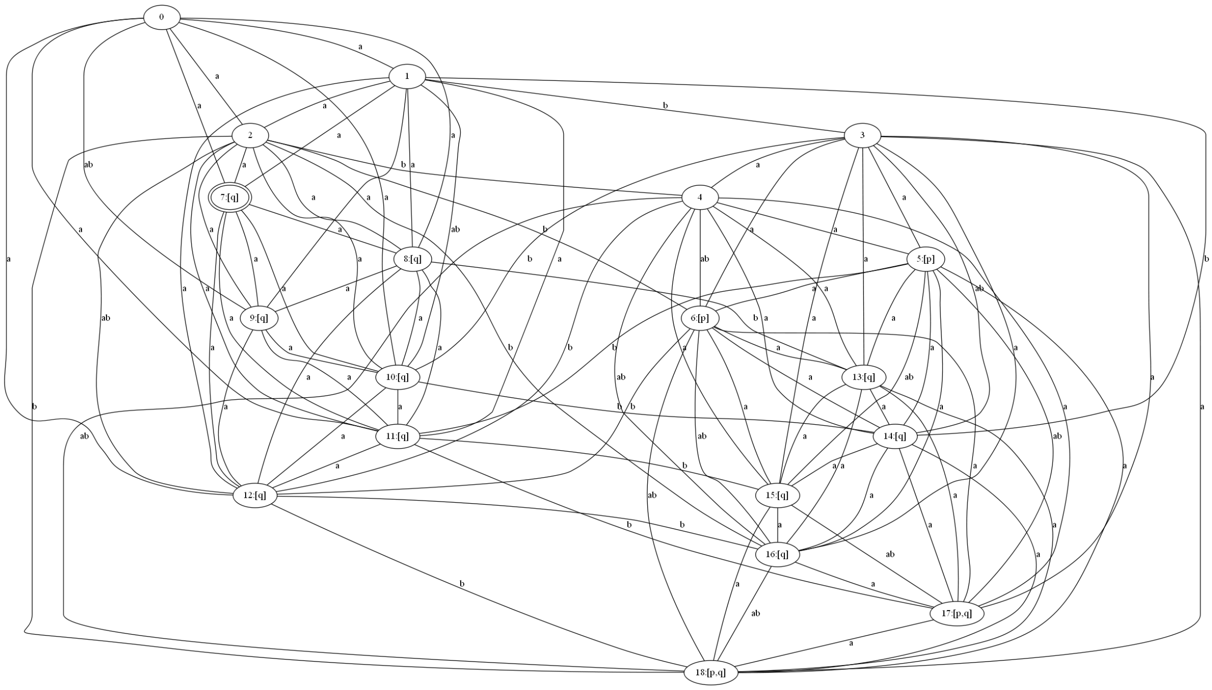

FIGURE 5.4: Case1 The final state after the trial

The judge's actions which update the epistemic status during the trial.

message b p "The judge knows the patient is injured."

message b q "The judge is informed that the probability is high."

message b r "The judge knows the cable is connected wrongly.'

5.2.5 Case 7 The innocent case

The precedent is as follows. The doctor used an unheated blood and the patient becomes HIV positive. The doctor is innocent.
The propositions and the states are as follows.

- Proposition p: The medicine is infected with HIV.
- Proposition q: The probability of infection with HIV is high.
- Proposition r: Cryoprecipitate is better than unheated blood for the patient.
- State eight states (0..7), binary values for P, Q R respectively

The defendant's actions which update the epistemic states through the crime

public (Disj [Neg q, r**])** "It is common sense that if the probability is high, the doctor should give the patient cryoprecipitateis."

message a **(Neg** q**)** "The defendant is informed that the probability of infection isn't high."

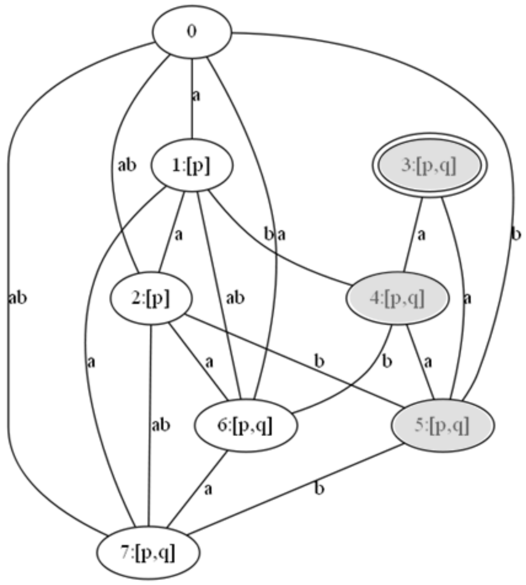

FIGURE 5.5: Case3 The final state after the trial

message a **(Neg (Neg** r**))** "The defendant doesn't know it isn't better and easy to give cryoprecipitate than unheated blood." (The opposite of the precedent, because the defendant becomes innocent in the precedent,)

The judge's actions which update the epistemic status during the trial

message b p "The judge knows the patient is infected with HIV."

message b **(Neg** q**)** "The judge knows the probability isn't high."

message b **(Neg** r**)** "The judge is informed that it isn't better and easy to give cryoprecipitate than unheated blood."

The final state after the trial
Model is consists of 32 states and the actual state is one where the defendant cannot distinguish p from $\neg p$ and r from $\neg r$. (he has the possibility of taking other action.). The judge can distinguish p, q, r.

5.2.6 Patterns of the final states

The final states of five cases after updating can be categorized into three graphical patterns according to the actual state and the links from this state.

- Intentional case (Case 1,2,3)
  - Agent b can distinguish an actual world from others and there is no link between the value of a primary proposition p and $\neg p$ for agent a. For the subsidiary proposition q, there is a link between worlds where q or $\neg q$ for agent a.(Case 1, 2) (FIGURE 5.6)

- Agent b can distinguish an actual world from others and for the agent a, there is some links between the actual world and other worlds, however the values of main proposition p and the subsidiary proposition q are respectively unique in these worlds. (Case 3) (FIGURE 5.7)

- Negligent (Lapse) case (Case 5, 7)
  - Agent b can access to worlds where the primary proposition is unique. But p is not decidable for agent a (the defendant) at the actual world. The subsidiary propositions q/r take respectively a monolithic value in these worlds. (Case 5, 7) (FIGURE 5.8)

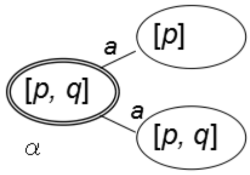

FIGURE 5.6: Pattern 1

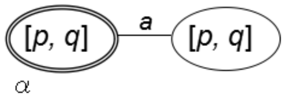

FIGURE 5.7: Pattern 2

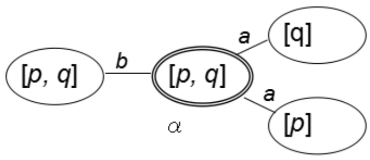

FIGURE 5.8: Pattern 3

5.2.7 Legal interpretation of patterns

For the cases where the crime is committed by the defendant intentionally, the final states can be classified as the first two patterns mentioned in the previous subsection where p is decidable (distinguishable from the $\neg p$ states).

- The judge knows the defendant's knowledge about his intention (p)

- The judge can distinguish an actual world from others.

- The defendant can distinguish (know) the intention of p.

The first pattern is concerning the judge's awareness about facts (Case 1, 2) where the judge can know the defendant's intention about p. The judge decides according to his knowledge (q).

The second is concerning the defendant's awareness of the meaning of his actions (Case 3) where the judge can find the defendant's intention about p, because he knows that the defendant knows both p, q.

On the other hand, the cases where the crime is committed by the defendant's lapse, the final states can be classified as the third pattern in which the judge knows that the defendant cannot distinguish p from $\neg p$. (Both worlds (p or $\neg p$) are reachable by the defendant's relation.) The subsidiary element (q or r) is not distinguishable for the defendant from the actual world, too. But the judge thinks p is distinguishable from $\neg p$ based on q or r (Case 5, 7).

As these cases indicate, the simple DEL cannot well describe the prediction of the indeterministic result or the degree of consciousness or predictability. We add the proposition like 'may ...' or 'likely to ...' , which describes the probability of the occurrence and classify the precedents according to the link patterns between the epistemic status or possible world, i.e. the predictability can be described by the link patterns between the status and agent a cannot predict the result when there exists a link between state v and w. This means that agent a or b cannot predict the result at state w when he is in a state v. However, this interpretation raises the issues like the arbitrary introduction of a new proposition or the intuitive interpretation of the classification.

Further it is hard to describe the intention of the defendant. We propose the observation of a link between the state where the non-epistemic action can be taken and the state where the non-epistemic action cannot be taken, regarding the link as the distinction between the precondition of the non-epistemic action. In addition to this hardness of interpretation, it is hard to distinguish the innocent case from the negligence case by using only the knowledge states. To overcome these issues, we propose the revised semantics of DEL with awareness in the next chapter.

Chapter 6

Application of DEL with awareness to the precedents

6.1 Revised Semantics for Action Model with Awareness

According to the evaluation of Chapter 5, we employ DEL with awareness whose language is $\mathcal{L}_{DA}$[13, 10]. We can refer to the existing logics mentioned in Section 3.4 to describe the change of an epistemic state. However, the existing semantics of the action model with awareness cannot infer the new formula by an action and it is also hard to implement the concrete system, because the action model of the original one does not have the inference or reasoning process and the post condition function in the original model maps a set of all awareness formulas before an action with a set of all awareness formulas after the action. It is required to define the function for each state respectively which has the different set of formulas of awareness. This prevents from defining the general action models listed in Section 6.2. In this section, we provide a revised semantics for action model with awareness $\mathcal{L}'_{DA}$. We use the same syntax and action model of DEL with awareness as shown in Section 3.4.

Definition 1 (Action model with awareness E).
Our action model E is defined as a tuple of $\langle$S, $\sim_i$, Pre, Awc $\rangle$, where
S: A set of actions,
$\sim_i \subseteq$ S $\times$ S: Equivalence relation for agent $i \in I$,
Pre: S $\rightarrow \mathcal{L}_{DA}$ Precondition function,
Awc: $I \times$ S $\rightarrow \mathcal{L}_{DA}$ Awareness condition function

Then, we also use the same satisfaction relation $\mathfrak{M}, w \models \varphi$ defined in Section 3.4 where the definition of updated model $\mathfrak{M} \otimes \mathrm{E} = \langle W', R', \mathbf{A}', V' \rangle$ is revised as follows, using an awareness condition function Awc: $i \times \mathrm{s} \rightarrow \mathcal{L}'_{DA}$, which returns a formula in $\mathcal{L}'_{DA}$.

Definition 2 (Update of knowledge and awareness).
Updated model $M \otimes$ E is a tuple $\langle W', R', A', V' \rangle$ where

$$\begin{array}{lll} W' & := & \{ (w, \mathrm{s}) \mid \mathfrak{M}, w \models \mathrm{Pre}(s) \}, \\ (w,\mathrm{s})R'_i(w',\mathrm{s}') & \text{iff} & wR_iw' \text{ and } \mathrm{sR_is'}, \\ \mathbf{A}'(i,(w,\mathrm{s})) & := & \mathbf{A}(i,w) \cup \mathrm{Awc}(i,\mathrm{s}), \\ V'(p) & := & \{ (w,\mathrm{s}) \in W' \mid w \in V(p) \}. \end{array}$$

In this definition, we assume that the awareness is not lost or is not forgotten immediately after some actions. In the real world, such actions as 'forget' or 'become not aware of' might

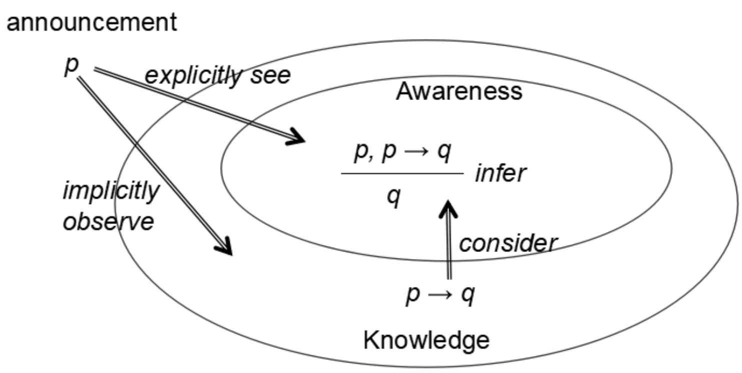

FIGURE 6.1: The model of consideration process of an agent

be taken after a while, but it is better to begin with this assumption to estimate the effect of the knowledge limitation by applying the dynamic epistemic logic with awareness. Based on this, we can discuss the intention (e.g. the consciousness of the cause, the causal relation and the prediction about the result) as mentioned in Chapter 4. According to this assumption, for example, a formula $A\varphi \rightarrow [\mathrm{E}, \mathrm{s}]A\varphi$ becomes valid in this semantics, but is not the case in the original semantics. This implies that our revised semantics is actually different from the original one. Then, to avoid unnecessary rise of the number of states and links, we also assume that the accessibility relation is an equivalence relation.

6.2 Modeling and implementation of consideration process

In this section, we introduce a set of concrete epistemic actions into our DEL with awareness. First in FIGURE 6.1, we roughly depict our reasoning actions, where an agent hears an announcement p in an absent-minded way. Also, the agent vaguely recognizes $p \rightarrow q$. In this occasion, once the agent becomes conscious of this cause and causality, the agent comes to be aware of q by an inference by *Modus Pones*[1] . In this research, we restrict the resolution rule to *modus ponens*.

Now we distinguish the following epistemic actions. Three of them are the same ones as were proposed by van Benthem and Velázquez-Quesada [32].

- *consider* [consider(χ)] is the same as [$+\chi$] by van Benthem. If a proposition resides deeply in the agent's mind and he/she is not conscious of it, he/she *consider*-s it to his/her awareness domain.
  $\mathfrak{M}, w \models [+\chi]\varphi$ iff $\mathfrak{M}_{+\chi}, w \models \varphi$. Let $\mathfrak{M}_{+\chi}$ be $\langle W, R, \mathbf{A}', V\rangle$ where
  $$\mathbf{A}'(w) = \mathbf{A}(w) \cup \{\chi\} \text{ for every } w \in W.$$
- *implicit observation* [observe(χ)] is the same as [$!\chi$] by van Benthem. If an agent *observes p implicitly*, then p enters Knowledge domain but not in the awareness domain.
  $\mathfrak{M}, w \models [!\chi]\varphi$ iff $\mathfrak{M}, w \models \chi$ implies $\mathfrak{M}_{!\chi}, w \models \varphi$. Let $\mathfrak{M}_{!\chi}$ be $\langle W', R', \mathbf{A}', V'\rangle$ where

[1] An inference rule: p and $p \rightarrow q$ imply q.

- $W' = \{w \in W \mid \mathfrak{M}, w \models \chi\}$
- $R' = R \cup (W' \times W')$
- $\mathbf{A}'(w) = \mathbf{A}(w)$ for every $w \in W'$
- $V'(w) = V(w)$ for every $w \in W'$

- *explicit seeing* [see(χ)] is the same as [!χ;+χ]. If an agent *explicitly sees p*, *p* enters the awareness domain.
- *infer* if two premises of *Modus Ponens* reside in his/her awareness domain (aware of them), employ the inference.
$\mathfrak{M}, w \models [\text{inf}(\tau, v)]\varphi$ iff $\mathfrak{M}, w \models A\tau$ and $\mathfrak{M}, w \models A(\tau \to v)$ implies $\mathfrak{M}_{\text{inf}(\tau,v)} \models Av$ and $\mathfrak{M}_{\text{inf}(\tau,v)} \models \varphi$. Let $\mathfrak{M}_{\text{inf}(\tau,v)}$ be $\langle W, R, \mathbf{A}', V\rangle$ where

$$\mathbf{A}'(w) = \mathbf{A}(w) \cup \{v\} \text{ for every } w \in W.$$

In our implementation, we also define *deep inference* "[infer$^{(+)}$]" which means to apply *Modus Ponens* recursively and exhaustively, a sufficiently large number of finite times. By these actions, $A_i(\varphi)$ and $A_i((\varphi \wedge \psi) \to \chi)$ results in $A_i(\psi \to \chi)$, since $((\varphi \wedge \psi) \to \chi) \leftrightarrow (\varphi \to (\psi \to \chi))$, by a single inference. If $A_i\psi$ also exists in the awareness domain, the agent obtains $A_i\chi$ by a deep inference. Here, we assume that the formulas in the awareness domain exist necessarily in the knowledge domain (the formulas are known to the agent.).

6.3 Proof theory

6.3.1 Axiom system of $\mathcal{L}'_{DA}$

At first, we examine the reduction axiom to treat the action models with the awareness defined in this chapter.
(1) observe (*implicitly observe*) This action does not have any influence on the awareness of an agent. As we define in this Chapter, the awareness condition function can be defined as Awc(i, s)=$\top$. And the reduction axiom can be described as

$$[(\text{E, s})]A_i\varphi \leftrightarrow A_i\varphi$$

(2) consider (*consider*) The awareness condition function can be defined as Awc(i, s)=ψ and the reduction axiom can be described as

$$[(\text{E, s})]A_i\varphi \leftrightarrow \text{pre(s)} \to A_i\varphi \qquad \text{(in case of } \varphi = \psi)$$
$$[(\text{E, s})]A_i\varphi \leftrightarrow A_i\varphi \qquad \text{(in case of } \varphi \neq \psi)$$

(3) see (*explicitly see*) The awareness condition function can be defined as Awc(i, s)=ψ and the reduction axiom can be described as

$$[(\mathrm{E},\mathrm{s})]A_i\varphi \leftrightarrow \mathrm{pre(s)} \rightarrow A_i\varphi \qquad \text{(in case of } \varphi = \psi\text{)}$$
$$[(\mathrm{E},\mathrm{s})]A_i\varphi \leftrightarrow A_i\varphi \qquad \text{(in case of } \varphi \neq \psi\text{)}$$

(4) infer (*infer*) The awareness condition function can be defined as follows.

$$\mathrm{Awc}(i,\mathrm{s}) = \psi \qquad \text{(in case of } \chi, \chi \rightarrow \psi \in \mathbf{A}(w)\text{)}$$
$$\mathrm{Awc}(i,\mathrm{s}) = \top \qquad \text{(in other cases)}$$

According to the above definition of Awc, we can define the reduction axioms for this action model as the following.

$$[(\mathrm{E},\mathrm{s})]A_i\varphi \leftrightarrow \mathrm{pre(s)} \rightarrow A_i\varphi \qquad \text{(in case of } \varphi = \psi\text{)}$$
$$[(\mathrm{E},\mathrm{s})]A_i\varphi \leftrightarrow A_i\varphi \qquad \text{(in case of } \varphi \neq \psi\text{)}$$

Now we show the reduction axioms for the defined DEL with awareness and action models. Proof system of $\mathcal{L}'_{DA}$ consists of the tautology of propositional logic and the reduction axioms of DEL [33] and the newly added reduction axioms for an action model with awareness above. Here P, Q and R are the atomic propositions.

$$P \rightarrow (Q \rightarrow P) \tag{6.1}$$
$$(P \rightarrow (Q \rightarrow R)) \rightarrow ((P \rightarrow Q) \rightarrow (P \rightarrow R)) \tag{6.2}$$
$$(\neg P \rightarrow \neg Q) \rightarrow ((\neg P \rightarrow Q) \rightarrow P) \tag{6.3}$$
$$K_i(\varphi \rightarrow \psi) \rightarrow (K_i\varphi \rightarrow K_i\psi) \tag{6.4}$$
$$K_i\varphi \rightarrow \varphi \tag{6.5}$$
$$K_i\varphi \rightarrow K_iK_i\varphi \tag{6.6}$$
$$\neg K_i\varphi \rightarrow K_i\neg K_i\varphi \tag{6.7}$$
$$[(\mathrm{E},\mathrm{s})]p \leftrightarrow (\mathrm{pre(s)} \rightarrow p) \tag{6.8}$$
$$[(\mathrm{E},\mathrm{s})]\neg\varphi \leftrightarrow (\mathrm{pre(s)} \rightarrow \neg[(\mathrm{E},\mathrm{s})]\varphi) \tag{6.9}$$
$$[(\mathrm{E},\mathrm{s})](\varphi \wedge \psi) \leftrightarrow [(\mathrm{E},\mathrm{s})]\varphi \wedge [(\mathrm{E},\mathrm{s})]\psi \tag{6.10}$$
$$[(\mathrm{E},\mathrm{s})]K_i\varphi \leftrightarrow (\mathrm{pre(s)} \rightarrow \bigwedge_{s \sim_i t} K_i[(\mathrm{E},\mathrm{t})]\varphi) \tag{6.11}$$
$$[\mathrm{E},\mathrm{s}]A_i\varphi \leftrightarrow A_i\varphi \text{ for } \mathrm{Awc}(i,\mathrm{s}) \neq \varphi \tag{6.12}$$
$$[\mathrm{E},\mathrm{s}]A_i\varphi \leftrightarrow \mathrm{pre(s)} \rightarrow A_i\varphi \text{ for } \mathrm{Awc}(i,\mathrm{s}) = \varphi \tag{6.13}$$
$$[(\mathrm{E},\mathrm{s})][(\mathrm{E}',\mathrm{s}')]\varphi \leftrightarrow [(\mathrm{E},\mathrm{s})];[(\mathrm{E}',\mathrm{s}')]\varphi \tag{6.14}$$
$$\text{if } \varphi \text{ and } \varphi \rightarrow \psi \text{ then } \psi \tag{6.15}$$
$$\text{if } \varphi \text{ then } K_i\varphi \tag{6.16}$$
$$\text{if } \varphi \text{ then } [(\mathrm{E},\mathrm{s})]\varphi \tag{6.17}$$

6.3.2 Soundness of $\mathcal{L}'_{DA}$

We show the soundness of this axiom system. We show only of the reduction axioms concerning the awareness.
In case of Awc(i, s) = φ,

$$\begin{aligned}
\text{from left to right}&\\
&\mathfrak{M}, w \models [(\mathrm{E}, \mathrm{s})]A_i\varphi\\
\text{from the definition}&\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow \mathbf{A}(i, (w, \mathrm{s}))\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow \mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s})\\
\text{since Acw}(i,\ \mathrm{s}) = \varphi&\\
&\mathfrak{M}, w \models (\mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s})) \ni \varphi\\
\text{we can say}&\\
&\mathfrak{M}, w \models A_i\varphi\\
\text{so}&\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow A_i\varphi\\
\text{from right to left}&\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow A_i\varphi\\
\text{from the definition of } A,&\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow \mathbf{A}(i, (w, \mathrm{s}))\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow \mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s})\\
\text{since Awc}(i, \mathrm{s}) = \varphi&\\
&\mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s}) \ni \varphi\\
\text{so}&\\
&\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow (\mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s}) \ni \varphi)\\
\text{we can say}&\\
&\mathfrak{M}, w \models [(\mathrm{E}, \mathrm{s})]A_i\varphi
\end{aligned}$$

In case of Awc(i, s) $\neq \varphi$,

From left to right

$$\mathfrak{M}, w \models [(\mathrm{E}, \mathrm{s})]A_i\varphi$$

from the definition,

$$\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow (\mathbf{A}(i, (w, \mathrm{s})) \ni \varphi)$$
$$\mathfrak{M}, w \models \mathrm{pre(s)} \rightarrow (\mathbf{A}(i, w) \cup \mathrm{Awc}(i, \mathrm{s}) \ni \varphi)$$

since Awc(i, s) $\neq \varphi$,

$$\mathfrak{M}, w \models \mathbf{A}(i, w) \ni \varphi$$
$$\mathfrak{M}, w \models A_i\varphi$$

From right to left,

the action does not affect on the awareness.

6.3.3 Completeness of $\mathcal{L}'_{DA}$

Then we show the completeness of this axiom system by using the transformation of the dynamic operator '[ ]' [31, 33]. The transformation including awareness is defined as follows in Definition 3.

Definition 3 (Translation).

$$t(p) = p \quad (1)$$
$$t(\neg p) = \neg t(p) \quad (2)$$
$$t(\varphi \wedge \psi) = t(\varphi) \wedge t(\psi) \quad (3)$$
$$t(K_i\varphi) = K_i t(\varphi) \quad (4)$$
$$t([(\mathrm{E}, \mathrm{s})]p) = t(\mathrm{pre(s)} \rightarrow p) \quad (5)$$
$$t([(\mathrm{E}, \mathrm{s})]\neg\varphi) = t(\mathrm{pre(s)} \rightarrow \neg [(\mathrm{E}, \mathrm{s})]\varphi) \quad (6)$$
$$t([(\mathrm{E}, \mathrm{s})](\psi \wedge \chi)) = t([(\mathrm{E}, \mathrm{s})]\varphi \wedge [(\mathrm{E}, \mathrm{s})]\psi) \quad (7)$$
$$t([(\mathrm{E}, \mathrm{s})]K_i\psi) = t(\mathrm{pre(s)} \rightarrow K_i [(\mathrm{E}, \mathrm{s})]\varphi) \quad (8)$$
$$t([(\mathrm{E}, \mathrm{s})][(\mathrm{E}', \mathrm{s}')]\varphi) = t([(\mathrm{E}, \mathrm{s});(\mathrm{E}', \mathrm{s}')]\varphi) \quad (9)$$
$$t(([(\mathrm{E}, \mathrm{s})]A_i\varphi)) = t(\mathrm{pre(s)} \rightarrow A_i\varphi) \ \ (\text{in case of } \mathrm{Awc}(i, \mathrm{s}) = \varphi) \quad (10)$$
$$t(([(\mathrm{E}, \mathrm{s})]A_i\varphi)) = t(A_i\varphi) \ \ (\text{in case of } \mathrm{Awc}(i, \mathrm{s}) \neq \varphi) \quad (11)$$

By the soundness of this proof system, this translation preserves the semantics of a formula. And we define the complexity concerning awareness as Definition 4.

Definition 4 (Complexity).

$$c(p) = 1 \tag{1}$$
$$c(\neg\varphi) = 1 + c(\varphi) \tag{2}$$
$$c(\varphi \wedge \psi) = 1 + \max(c(\varphi), c(\psi)) \tag{3}$$
$$c(K_i\varphi) = 1 + c(\varphi) \tag{4}$$
$$c(A_i\varphi) = 1 + c(\varphi) \tag{5}$$
$$c(\mathrm{E}, \mathrm{s}) = \max(c(\mathrm{pre(s)}), c(\mathrm{Awc(i, s)})) \tag{6}$$
$$c([(\mathrm{E}, \mathrm{s})]\varphi) = (4 + c(\mathrm{E}, \mathrm{s})) \cdot c(\varphi) \tag{7}$$

Concerning our action models defined in Section 6.2, we can assume $c(\mathrm{pre(s)}) > c(\mathrm{Awc(i, s)})$. By considering the complexity of each formula and using the induction on this complexity, the complexity of awarenss in Definition 3 is reduced and $\vdash \varphi \leftrightarrow t(\varphi)$ is proved in an inductive way.

Lemma 1 (Decrease of complexity).

$$c(\psi) \geq c(\varphi) \text{ if } \varphi \in Sub(\psi) \tag{1}$$
$$\text{(where } Sub(\varphi) \text{ is the set of subformulas of } \varphi)$$
$$c([(\mathrm{E}, \mathrm{s})]p > c(\mathrm{pre(s)} \rightarrow p) \tag{2}$$
$$c(\ [(\mathrm{E}, \mathrm{s})]\neg\varphi) > c(\mathrm{pre(s)} \rightarrow \neg\ [(\mathrm{E}, \mathrm{s})]\varphi) \tag{3}$$
$$c(\ [(\mathrm{E}, \mathrm{s})](\varphi \wedge \psi)) > c(\ [(\mathrm{E}, \mathrm{s})]\varphi \wedge\ [(\mathrm{E}, \mathrm{s})]\psi) \tag{4}$$
$$c(\ [(\mathrm{E}, \mathrm{s})]K_i\varphi) > c(\mathrm{pre(s)} \rightarrow K_i\ [(\mathrm{E}, \mathrm{s})]\varphi) \tag{5}$$
$$c(\ [(\mathrm{E}, \mathrm{s})][(\mathrm{E}', \mathrm{s}')]\varphi) > c(\ [(\mathrm{E}, \mathrm{s});(\mathrm{E}', \mathrm{s}')]\varphi) \tag{6}$$
$$c([(\mathrm{E}, \mathrm{s})]A_i\varphi) > c(\mathrm{pre(s)} \rightarrow A_i\varphi))(\varphi = \psi, \text{ where } \mathrm{Awc}(i, \mathrm{s}) = \psi) \tag{7}$$
$$c([(\mathrm{E}, \mathrm{s})]A_i\varphi) > c(A_i\varphi)(\varphi \neq \psi, \text{ where } \mathrm{Awc}(i, \mathrm{s}) = \psi) \tag{8}$$

Proof. **Lemma 1** (1) The subformulas are less complex than the parent formula. This can be said from $c(p) = p$ and the induction of the length of a formula.
Lemma 1 (2)

$$\begin{aligned} & c([(\mathrm{E}, \mathrm{s})]p \\ =& (4 + c(\mathrm{E}, \mathrm{s}))\dot{c}(p) \\ =& 4 + c(\mathrm{pre(s)}) \end{aligned}$$

on the other hand,

$$\begin{aligned} & c(\mathrm{pre(s)} \rightarrow p) \\ =& 1 + \max\ (1 + c(\mathrm{pre(s)}), c(\neg p)) \\ =& 2 + \max\ (c(\mathrm{pre(s)}), 2) \\ =& \begin{cases} 4 \\ 2 + c(\mathrm{pre(s)}) \end{cases} \end{aligned}$$

therefore $c([(\mathrm{E}, \mathrm{s})]p > c(\mathrm{pre(s)} \to p)$.
Lemma 1 (3)

$$\begin{aligned}&c([(\mathrm{E}, \mathrm{s})]\neg\varphi)\\=&(4+c(\mathrm{E},\mathrm{s}))\cdot c(\neg\varphi)\\=&(4+c(\mathrm{E},\mathrm{s}))\cdot(1+c(\varphi))\\=&(4+c(\mathrm{pre(s)}))\cdot(1+c(\varphi))\\=&4+c(\mathrm{pre(s)}))+4\cdot c(\varphi)+c(\mathrm{pre(s)})\cdot c(\varphi))\end{aligned}$$

on the other hand,

$$\begin{aligned}&c(\mathrm{pre(s)} \to \neg\, [(\mathrm{E}, \mathrm{s})]\varphi)\\=&1+1+\max(c(\mathrm{pre(s)}), c(\ [(\mathrm{E}, \mathrm{s})]\varphi))\\=&2+\max(c(\mathrm{pre(s)}), 4+c(\mathrm{pre(s)})\cdot c(\varphi))\\=&\begin{cases}2+c(\mathrm{pre(s)})\\2+4\cdot c(\varphi)+c(\mathrm{pre(s)})\cdot c(\varphi)\end{cases}\end{aligned}$$

therefore $c(\ [(\mathrm{E}, \mathrm{s})]\neg\varphi) > c(\mathrm{pre(s)} \to \neg\, [(\mathrm{E}, \mathrm{s})]\varphi)$
Lemma 1 (4)

$$\begin{aligned}&c(\ [(\mathrm{E}, \mathrm{s})](\varphi\wedge\psi))\\=&(4+c(\mathrm{pre(s)}))\cdot c(\varphi\wedge\psi)\\=&(4+c(\mathrm{pre(s)}))\cdot(1+\max\ (c(\varphi), c(\psi)))\\=&\begin{cases}4+c(\mathrm{pre(s)})+4\cdot c(\varphi)+c(\mathrm{pre(s)})\cdot c(\varphi)\\4+c(\mathrm{pre(s)})+4\cdot c(\psi)+c(\mathrm{pre(s)})\cdot c(\psi)\end{cases}\end{aligned}$$

on the other hand,

$$\begin{aligned}&c(\ [(\mathrm{E}, \mathrm{s})]\varphi\wedge\ [(\mathrm{E}, \mathrm{s})]\psi)\\=&1+\max\ ((4+c(\mathrm{pre(s)}))\cdot c(\varphi), (4+c(\mathrm{pre(s)}))\cdot c(\psi))\\=&\begin{cases}1+4\cdot c(\varphi)+c(\mathrm{pre(s)})\cdot c(\varphi)\\1+4\cdot c(\psi)+c(\mathrm{pre(s)})\cdot c(\psi)\end{cases}\end{aligned}$$

therefore $c(\ [(\mathrm{E}, \mathrm{s})](\varphi\wedge\psi)) > c(\ [(\mathrm{E}, \mathrm{s})]\varphi\wedge\ [(\mathrm{E}, \mathrm{s})]\psi)$
Lemma 1 (5)

$$\begin{aligned}&c(\ [(\mathrm{E}, \mathrm{s})]K_i\varphi)\\=&(4+c(\mathrm{pre(s)}))\cdot c(K_i\varphi)\\=&(4+c(\mathrm{pre(s)}))\cdot(1+c(\varphi))\\=&4+4\cdot c(\mathrm{pre(s)})+4\cdot c(\varphi)+c(\mathrm{pre(s)})\cdot c(\varphi)\end{aligned}$$

on the other hand,

$$\begin{aligned}&c(\text{pre(s)} \rightarrow K_i\,[(\text{E, s})]\varphi)\\=&2+\max\,(c(\text{pre(s)}), c(\neg K_i\,[(\text{E, s})]\varphi))\\=&2+c(\neg K_i\,[(\text{E, s})]\varphi)\\=&2+1+1+c(\,[(\text{E, s})]\varphi)\\=&4+(4+c(\text{pre(s)}))\cdot c(\varphi)\\=&4+4\cdot c(\varphi)+c(\text{pre(s)})\cdot c(\varphi)\end{aligned}$$

therefore $c([(\text{E, s})]K_i\varphi) > c(\text{pre(s)} \rightarrow K_i\,[(\text{E, s})]\,\varphi)$.
Lemma 1 (6)

$$\begin{aligned}&c([(\text{E, s})][(\text{E}', \text{s}')]\varphi)\\=&(4+c(\text{pre(s)}))\cdot c([(\text{E}', \text{s}')]\varphi)\\=&(4+c(\text{pre(s)}))\cdot((4+c(\text{pre(s)})\cdot c(\varphi))\end{aligned}$$

on the other hand,

$$\begin{aligned}&c([(\text{E, s});(\text{E}', \text{s}')]\varphi)\\=&(4+1+\max(c(\text{pre(s)}), c(\text{pre(s}'))))\cdot c(\varphi)\end{aligned}$$

therefore $c(\,[(\text{E, s})][(\text{E}', \text{s}')]\varphi) > c([(\text{E, s});(\text{E}', \text{s}')]\varphi)$.
Lemma 1 (7)

$$\begin{aligned}&c([(\text{E, s})]\,A_i\varphi)\\=&(4+c(\text{E,s}))\cdot(1+c(\neg\varphi))\\=&(4+\max(c(\text{pre(t)}), c(\text{Awc}(i,\text{s}))))\cdot(1+c(\varphi))\\=&(4+c(\text{pre(t)}))\cdot(1+c(\varphi))\\=&4+c(\text{pre(t)}))+4\cdot c(\varphi)+c(\text{pre(t)})\cdot c(\varphi)\end{aligned}$$

on the other hand,

$$\begin{aligned}&c(\text{pre(s)} \rightarrow A_i\varphi)\\=&1+1+\max(c(\text{pre(s)}), c(\neg A_i\varphi))\\=&2+\max(c(\text{pre(s)}), 2+c(\varphi))\\=&\begin{cases}2+c(\text{pre}(s))\\4+c(\varphi)\end{cases}\end{aligned}$$

therefore $c([(\text{E, s})]A_i\varphi) > c(\text{pre(s)} \rightarrow A_i\varphi))$.
Lemma 1 (8)

$$\begin{aligned}&c([(\text{E, s})]A_i\varphi)\\=&4+c(([(\text{E, s})])\cdot c(A_i\varphi)\end{aligned}$$

therefore $c([(\text{E, s})]A_i\varphi) > c(A_i\varphi)$.

By using these properties, we can show that every formula is provably equivalent to its translation.

Lemma 2 (Equivalence to translation).

$$\vdash \varphi \leftrightarrow t(\varphi).$$

Proof. We can say by induction on $C(\varphi)$.
Base case $\vdash p \leftrightarrow p$.
Induction hypothesis for all φ such that $c(\varphi) \leq n, \vdash \varphi \leftrightarrow t(\varphi)$.
Induction step for all translation cases, we can reduce the complexity by using **Lemma**1.

By using the above, if $\models \varphi$ then $\vdash \varphi$ can be derived.

Theorem 1. $\models \varphi$ implies $\vdash \varphi$

Proof. Suppose $\models \varphi$, therefore $\models t(\varphi)$ by the soundness we show in this chapter and the equivalence of translation Lemma 2. We can reduce our revised $\mathcal{L}'_{DA}$ to the static epistemic logic with awareness which are sound and complete.
From the completeness of awareness logic, $\vdash_{\mathcal{L}_D} t(\varphi)$.
Since $\mathcal{L}_D$ is a subsystem of $\mathcal{L}'_{DA}$, $\vdash_{\mathcal{L}'_{DA}} t(\varphi)$.
Since $\vdash \varphi \leftrightarrow t(\varphi)$, we can say $\vdash_{\mathcal{L}'_{DA}} \varphi$.

Chapter 7

Implementation of $\texttt{DEMO}^{+\mathcal{A}}$

7.1 Development of $\texttt{DEMO}^{+\mathcal{A}}$

DEMO [34] is a modeling tool for dynamic epistemic logic and it is programmed by using Haskell. It enables to simulate an update of an epistemic model, to display an action model and to evaluate a formula in these models, so DEMO can be used to check the semantic intuitions of what is going in the updating situations.

We extended DEMO to handle the language with awareness and call it $\texttt{DEMO}^{+\mathcal{A}}$. The awareness function is added to the epistemic model in the program as a list of a tuple which consists of an agent, a state and a set of formula. And the precondition for the awareness is added to the awareness condition function. It is implemented as a list of a tuple which has an agent, an action pint, a precondition and a result as an element. We show the definition of these data types in Appendix B.

Further, the related functions in the program which handles these epistemic and action models are replaced to match the newly defined models which is implemented by these data types. The updating functions in the program are also replaced for the new one to change the awareness state according to the conditions of the previous awareness state. In addition to these extensions, we develop the GUI of input and output of $\texttt{DEMO}^{+\mathcal{A}}$ to confirm the calculated result easily.

Concerning the program structure, $\texttt{DEMO}^{+\mathcal{A}}$ consists of the following modules.

- module `ActEpist`: Defines the basic data structure for formulas and action models. This module also includes supplemental handling functions.
- module `Callbacks`: Includes all the functions which are triggered when the GUI parts are operated to raise events.
- module `DEMO`: Includes the domain specific functions to describe the consideration process of an agent defined in Chapter 6 and the useful function to describe the precedents.
- module `DemoGuiMain`: Includes all GUI input and output components.
- module `Display`: Defines the output functions of the relation, the calculated model and the dot graph.
- module `DPLL`: Includes the common parts to calculate the propositions.
- module `Main`: The main module which creates GUI screens and set events to each widget.

TABLE 7.1: Definition of actInfer

actInfer a	
Action points	0,1 (underlined number indicates the actual action state.)
Precondition	0: $\varphi, \psi, A\varphi \rightarrow \psi, A\varphi$ 1: [ ]
Awareness condition	i 0 : ψ, 1 : [ ]
	other than i 0:[ ], 1:[ ]
Relation	i[0],[1] other than i[0,1]

i: agent, [ ](blank) in 'Aware condition' means no formula
The number in relation [ ] indicates the action which cannot be distinguished.

- module `MinAE`: Contains a few common functions to handle the action model to make it minimum by the refinement.
- module `MinBis`: Includes the functions which wrap up the state by using bi-simulation and minimize the epistemic model.
- module `Models`: Defines the basic data structure for an agent and epistemic model.
- module `Semantics`: Defines the updating mechanism.

7.1.1 Implementation of Epistemic Actions

In DEMO$^{+\mathcal{A}}$, for example, the action model for "infer" (infer) mentioned in the previous chapter is defined as follows (TABLE 7.1, "actInfer"). In the definition of actInfer(*agent*, φ, $\varphi \rightarrow \psi$), the awareness condition function makes the agent aware of ψ, if he/she is aware of φ and $\varphi \rightarrow \psi$. The other agents do not know the fact that this agent becomes aware of it.

The definitions of other action models to describe the epistemic actions ("explicitly see", "implicitly observe" and "consider") assumed in the considering process model of an agent (FIGURE 6.1) are showed in TABLE 7.2. In TABLE 7.2, i indicates agent, [ ](blank) in "Awareness condition" means no precondition and the number in [ ] of "Relation" indicates the action which cannot be distinguished by the corresponding agent.

By using these defined action models, the actions in the consideration process are programmed. In this implementation, we assume that the information comes to the agents in a group who know it or are aware of it at the same time. According to this assumption, we implemented the simplified action models of "explicitly see" and "implicitly observe" to enable for the user to treat the agents as one group as follows.

However other action "infer" or "consider" than "explicitly see", "implicitly observe" seem that they are specific to each agent and does not happen in the internals of all agents of a group. Because these actions are completely internal events, and we should calculate the updating one by one for each agent. And the definition of these function would be like the following. We attach the definition code for these actions in Appendix B.

- *infer* `infer(agt: agent, m: an awareness model)` :refer to Algorithm 1
- *deeply infer* `infer`$^{(+)}$ `(agt: agent, m: an awareness model)`: refer to Algorithm 2

TABLE 7.2: Each Action Model

actConsider i φ	
Action points	0, 1 (underlined number indicates the actual action state)
Precondition	0: $K_i\varphi$, 1: [ ]
Awareness condition	i 0: φ, 1: [ ]
	other than i 0: [ ] , 1: [ ]
Relation	i [0],[1] other than i [0, 1]
actSee i φ	
Action points	0, 1 (underlined number indicates the actual action state)
Precondition	0: φ, 1: [ ]
Awareness condition	i 0: φ, 1: [ ]
	other than i 0: [ ], 1: [ ]
Relation	i [0],[1] other than i [0, 1]
actObserve i φ	
Action points	0, 1 (underlined number indicates the actual action state)
Precondition	0: φ, 1: [ ]
Awareness condition	i 0: [ ], 1: [ ]
	other than i 0: [ ], 1: [ ]
Relation	i[0],[1] other than i[0, 1]

- *consider* `consider(agt: agent, m: an awareness model, p: a formula)` := `update(m, actConsider(agt, p))`
- *explicitly see* `see([a list of agent], m: an awareness model, p: a formula):= update(m, actSee(agt, p))`
- *implicitly observe* `observe([a list of agent], m: an awareness model, p: a formula):= update(m, actObserve(agt, p))`

We show the outline of the implementation of "infer" in Algorithm 1. We also implement the

Algorithm 1 inference

infer (agt: agent, m: an awareness model))
Require: $i \leftarrow agt$
$m' \leftarrow m$
while a state unchecked exists in W **do**
  if $p,\ p \rightarrow q \in A_i$ at some states ▷ modus ponens can be applied.
  and p, q are True at the states
  and $q \notin A_i$ **then**
    $m' \leftarrow$ update(m, actInfer($p, p \rightarrow q$))
  end if
end while
return m' ▷ need not be updated in other cases

variant of "infer" which repeats the inference and we show the outline of the implementation in Algorithm 2.

Algorithm 2 deep inference

infer(+)(agt: agent, m: an awareness model)
Require: $i \leftarrow agt$
$m' \leftarrow m$
while there exists a state, where not null (A_i@infer(agt, m) - A_i@m) **do**
▷ If a new formula can be acquired by updating, do the updating.
$m' \leftarrow$ infer$^{(+)}$(agt, infer(agt, m))
end while
return m' ▷ need not be updated in other cases

The algorithm of the function "update" which are used in the definitions of these actions to update the epistemic model with awareness by an action model is as follows in Algorithm 3.

Algorithm 3 update(m@$\langle W, R, V, A\rangle$: an awareness model, a@$\langle$E, R, Pre, Awc$\rangle$: an action model, i: agent)

Require: $i \leftarrow agt$
for all w such that $w \in W$ **do**
for all s such that s $\in$ E **do**
$W' \leftarrow \{(w, \mathrm{s}) | w$ is a world of m
where Pre(s) is *True*$\}$
$R' \leftarrow \{uRv | u, v \in W'\}$
$V' \leftarrow V$
if pre-condition $sub(\mathbf{A}(i, w))$ is defined **then**
$newA \leftarrow$ Awc(i, s)
end if
$A' \leftarrow A \cup newA$
end for
end for
return m'@(W', R', V', A')

7.1.2 GUI for Input and Output

We developed new GUI of input and output interface of DEMO$^{+\mathcal{A}}$ to set the conditions and to confirm the calculated result easily. The main screen is in FIGURE 7.1. We use FLTKHS [1], which is a Haskell binding to FLTK GUI library.
At the beginning of calculation, the following is required to be set (FIGURE 7.2).

- The propositions : The number of propositions and their descriptions which are used to describe the precedents. (Ex. in Case 3 of Section 4.3, 3 propositions, p, q, r)
- The common background: Describe the common background knowledge for the defendant and the prosecutor from the ordinal people's view. These background knowledge can be set as "explicitly see" (is aware of at the same time) or as "implicitly observe" (is not aware of) based on their statements at the court. (Ex. in Case 3 of Section 4.3, $q \rightarrow r$

[1] Haskell bindings to FLTK GUI toolkit https://github.com/deech/fltkhs

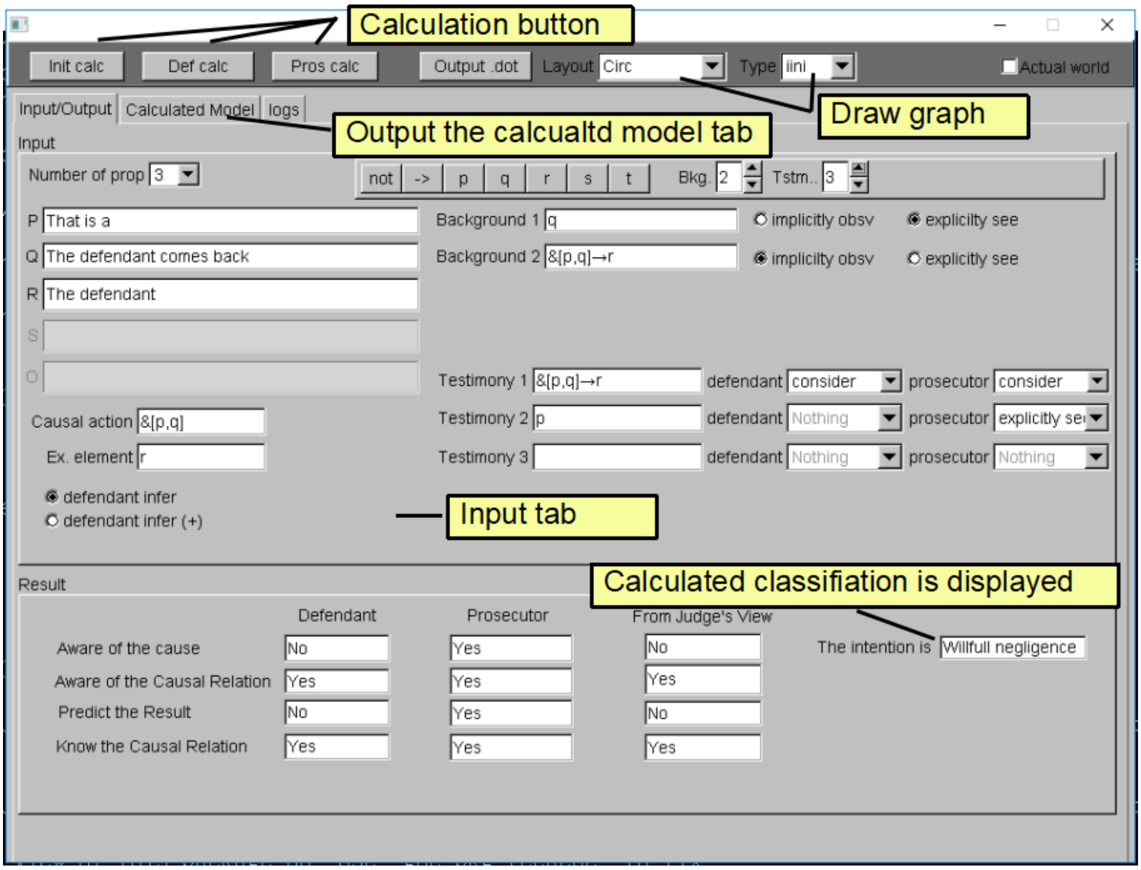

FIGURE 7.1: Input/Output main screen

is set as explicitly seeing for both the defendant and the prosecutor, describing that they are conscious of the danger of an electric abnormal current.)

- The individual epistemic actions which change the awareness or knowledge states: Describe the individual (a defendant or a prosecutor respectively) knowledge or awareness based on their testimony at the court. These knowledge or awareness is required to be set with their acquiring action ("explicitly see", "implicitly observe" or "consider"). (Ex. in Case 3 of Section 4.3, p is set as explicitly seeing only for the prosecutor, describing that "The prosecutor is conscious of the mistake.)

- The defendant's depth of inference : Can be set as once (infer) or many times (infer$^{(+)}$). (Ex. in Case 3 of Section 4.3, this parameter is set as infer (*inference*).)

- The cause and the external elements : To calculate the predictability about the external element from the cause, they are required to be set in advance. (Ex. in Case3 of Section 4.3, p (wrong connection) is set in the cause and r (patient's injury) is set in the external element.)

After the calculation of the updated model, DEMO$^{+\mathcal{A}}$ can output the following.

- The predictability: Indicate whether the defendant is aware of the cause or the causal relation from his own and the prosecutor's view and the classification of the judgment

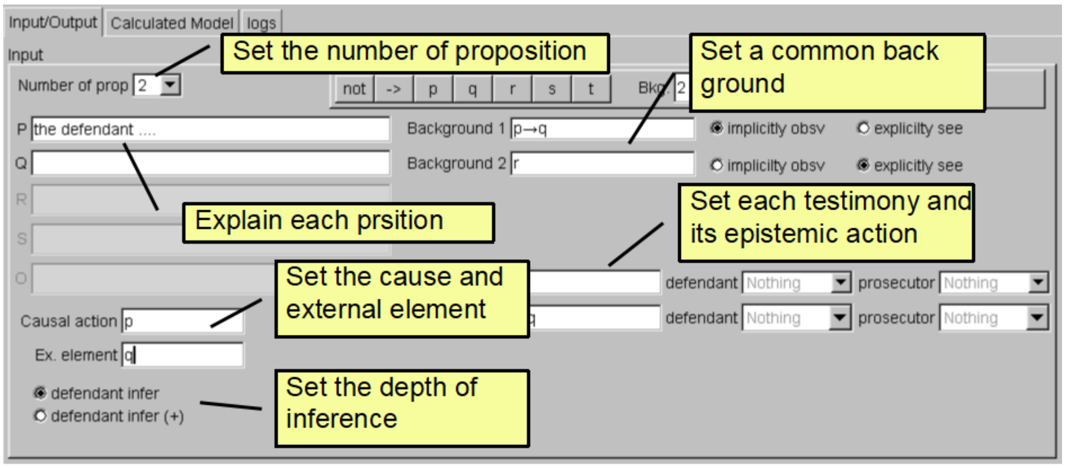

FIGURE 7.2: Input field

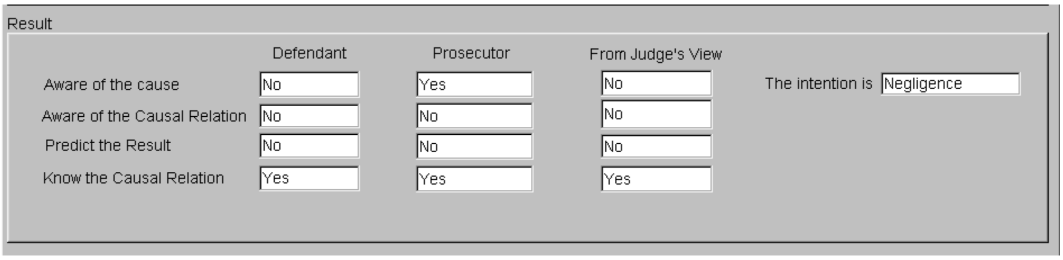

FIGURE 7.3: Output field

like "Deterministic intention", "In-deterministic intention", "Miss-recognition of causal relation","Negligence" and "Innocence" (FIGURE 7.3). These classification is calculated according to the criteria which is describe later in Chapter 8. Here we regard the judge's states the same as the prosecutor's one, because they know well the crime and the prosecutor investigates carefully the crime to get the correct information and provide all to the judge at the court. In the screen, "from judge's view" indicates the result at the all states where the prosecutor can access from the actual world.

- The knowledge states of a model: Output the calculated final states of knowledge and awareness of both the accused and the prosecutor (FIGURE 7.4).
- Dot-graph: DEMO$^{+\mathcal{A}}$ can also output the dot graph of the final knowledge states of the model (FIGURE 7.5). The dot graph format can be selected from ".circ" or normal ".dot" graph. The ellipse indicates the epistemic state and the link between the states means the accessibility relation for an agent.
- The inference logs: To follow up the inference, the log is output (FIGURE 7.6).

7.1.3 Calculation Flow

DEMO$^{+\mathcal{A}}$ calculates the final knowledge and awareness states according to the following steps.

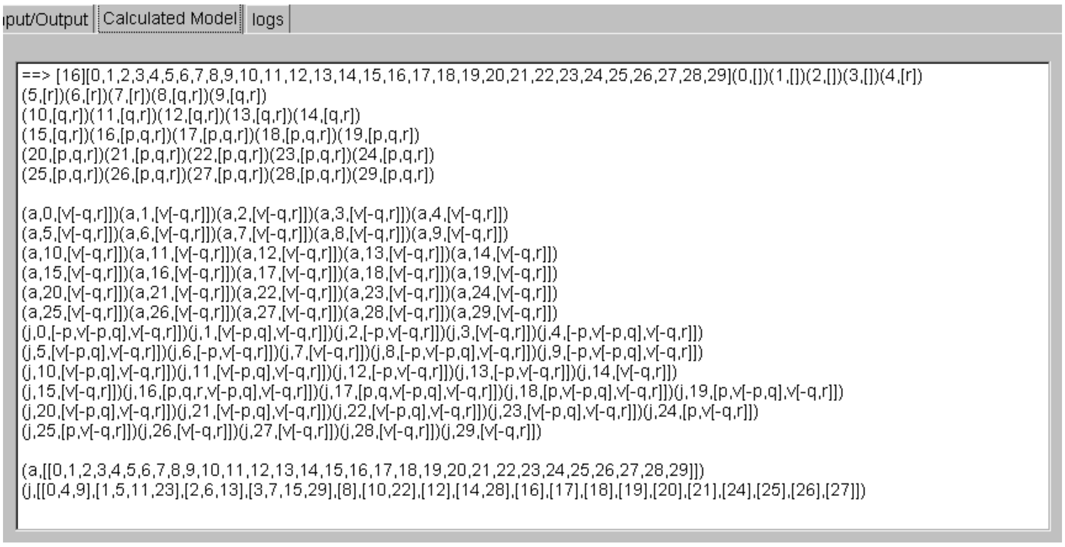

FIGURE 7.4: Output of a calculated model

1. Creates an initial model according to the designated propositions.
2. Updates the initial model by the knowledge or awareness of common background for both a defendant and a prosecutor by using the defined actions.
3. Updates the model which reflects the common knowledge by the actions derived from their testimony of each person respectively.
4. Checks the awareness about cause and the causal relation of a defendant at the actual states from the view point of the judge.
5. Checks the awareness about the external element (result) of a defendant at the actual states from the view point of the judge.
6. Classifies the precedent according to the knowledge states and the awareness states about the cause, the causal relation and the external elements.
7. Displays the calculated final model.
8. Draws the dot graph of this model.

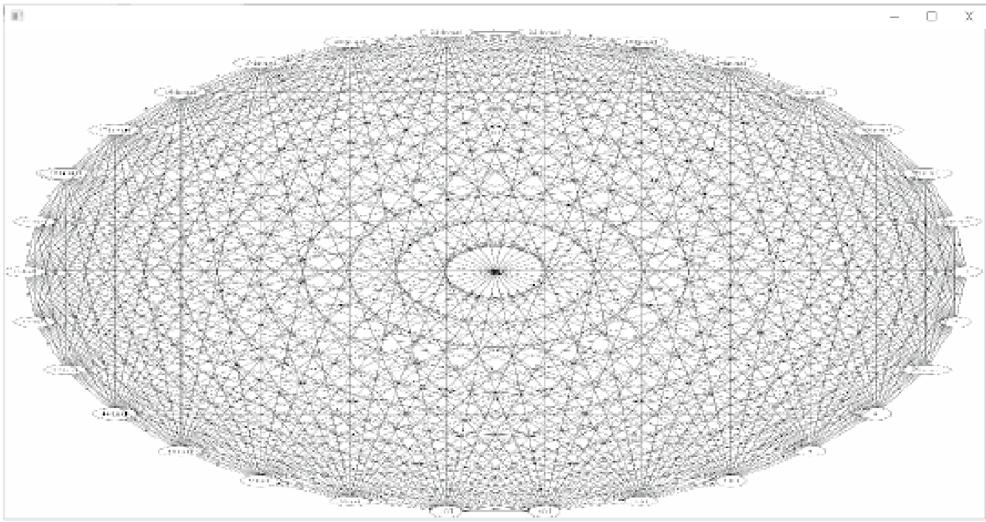

FIGURE 7.5: Example of dot graph (.circ format)

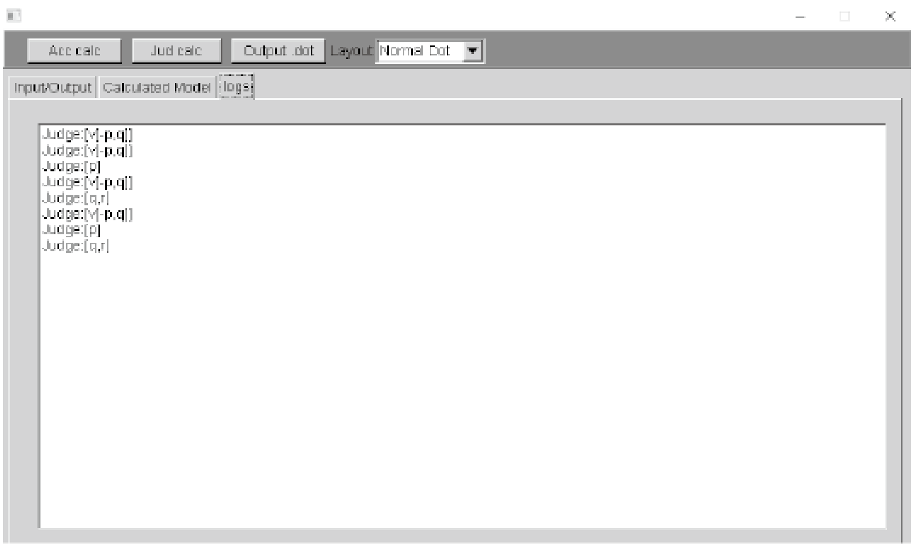

FIGURE 7.6: Output of the log of inference

Chapter 8

Representation of precedents by DEL with awareness

In this chapter, we analyze the epistemic model of selected precedents which are updated by the defendant's testimony and the statement of the prosecutor and show the comparison of the knowledge and the awareness states in its final model. We assign the propositions for each precedents and use the action model according to the following policies.

1. One testimony/statement by the defendant/the prosecutor is treated as one proposition.
2. If the knowledge can be regarded as a common wisdom, it is known to both the defendant and the prosecutor implicitly but not necessary in their consciousness.
3. We treat other information according to the testimony/statements respectively by the defendant or the prosecutor.
4. We describe the action of the defendant or the prosecutor by using the defined action models of the inference process in Chapter 6. The actions can be described by the combination of these epistemic actions and we assume their knowledge or awareness can be changed or updated by these epistemic actions.
5. We assume that the final knowledge states of the prosecutor and the judge is the same, because the prosecutor investigate the crime cautiously to get the correct information and they provide all of them to the judge at the court. And we omit the calculation for the states of the judge.

We explain the calculation of each selected precedents in Chapter 4, Case 1, 3, 4, 5, 6, 7, 8 by using $\texttt{DEMO}^{+\mathcal{A}}$. We omit Case 2, because this case includes the misunderstanding of the causal relation and it is better to handle in the logical language in **KD45**[1] in the future work.

8.1 Aggravation of punishment (Unawareness of the causation) (Case 1)

The precedent is as follows. The four criminals assaulted the casualty again and again. To escape from the violence, the victim ran away into the highway nearby, however the car happened to come and he was run over by the car and dead. The prosecutor admitted a causal

[1]The accessibility relation which satisfy D ($K\varphi \to \neg K \neg \varphi$) instead of T ($K\varphi \to \varphi$) and other 4, 5 are the same as KT45.

relationship between the assault and the death of the victim and applied the guilty of injury resulting in death.

We set the propositions as follows.

p : The defendants assaulted the victim repeatedly.

q : The victim ran away to escape from their violence.

r : The victim ran into the highway.

s : The victim was run over by a car and died.

And then we update the initial knowledge states by their common knowledge or consciousness according to their testimony. In DEMO$^{+\mathcal{A}}$, the corresponding formula should be entered in the background fields (`Background`) and the action should be selected (`implicitly obsv/explicitly see`).

- The defendants and the prosecutor explicitly saw that the defendants assault the casualty repeatedly. (`see`$[d, j]\ p$)
- It is commonly known that running into the highway is very dangerous and might lead to the traffic accident by a car. (`see`$[d, j]\ r \to s$)
- A casualty may tries to escape from assault against him/her. (`observe`$[d, j]\ p \to q$)

The updated model at this moment consists of 3 states and there is no difference in these states between the defendant and the prosecutor (FIGURE 8.1). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicate that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge state in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent a and j get the information that p, $\neg p \vee q$, $\neg r \vee s$ is the case, p, q, $(\neg r \vee s)$ are true at the actual worlds.

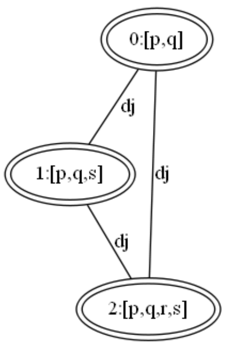

FIGURE 8.1: The epistemic model after update by the common background

Then update this epistemic model according to the testimony of the defendant.

- The defendant knew that the casualty was trying to escape from his/her assault. (`consider` $d\ (p \to q)$)
- The defendant gave a testimony that he/she could not consider that the victim ran away into the highway. (`infer` d)

At this moment, the defendant becomes aware of $p,\ q,\ p \to q,\ r \to s$, however he/she is not aware of $q \to r$ and he/she cannot become aware of s by his/her "inference" action. This action creates new worlds/states which are copied and the prosecutor cannot distinguish these newly created states, because the 'inference' is an internal event.

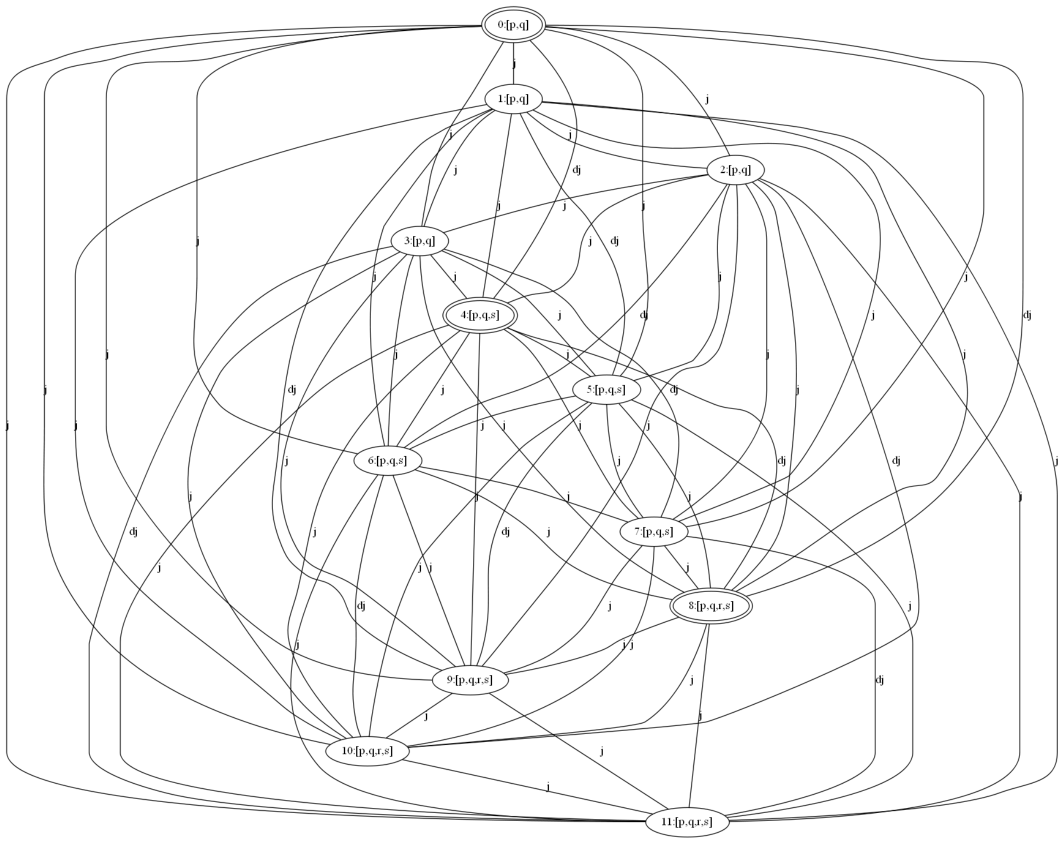

FIGURE 8.2: The epistemic model after update by the testimony

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. The judge also has the same updating. These actions update his epistemic model. In $\texttt{DEMO}^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button "`Pros calc`".

- The prosecutor also knows that the casualty was trying to escape from the assault by the defendant. (`consider` $j\ (p \to q)$)
- The prosecutor knows that the beleaguered casualty might escape into the highway. (`see`$[j]\ q \to r$)
- The prosecutor considered repeatedly. ($\texttt{infer}^{(+)}\ j$)

The result consists of 69 states and at the actual state (No. 18), $p,\ q,\ r,\ s$ are true and the defendant is aware of $p,\ q,\ p \to q,\ r \to s$ and the prosecutor is aware of $p,\ q,\ r,\ s,\ p \to q,\ q \to r,\ r \to s$. In this final epistemic model, there are two actual worlds which the prosecutor cannot distinguish (No. 35, 62). In both worlds, the defendant is not aware of the causal relation ($p \to q, q \to r, r \to s$) nor knows. The prosecutor described that the defendant could not predict the result of his action and the judge applied the aggravation of punishment, which does not require the awareness of the causal relation. There is a difference of the epistemic state between the defendant and the prosecutor as follows in TABLE 8.1.

TABLE 8.1: Comparison of epistemic status of defendant and prosecutor (Case 1)

	Defendant	Prosecutor
The cause (p)	aware know	aware know
The causal relation ($p \to s$)	not aware not know	aware know
The external element (s)	not aware not know	aware know

8.2 *Dolus eventualis* (Willful negligence) case (Case 3)

The precedent is that the defendant bought clothes without knowing that they were originally stolen. He thought the person who came to sell was suspicious, however he dared to buy. The prosecutor applied the crime of illegal acquisition of the stolen goods.

At first, we set the propositions as the following. In DEMO$^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as three and set the explanation for each proposition.

p : The clothes were stolen.

q : The defendant bought the clothes.

r : The defendant got the stolen clothes.

And then we update the initial knowledge status by their common knowledge or consciousness according to their testimony. In `DEMO`$^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsv/explicitly see`).

- Both the defendant and the prosecutor *explicitly know* the defendant bought the clothes. (`see` $[d,j]\ q$)
- It is common but *implicitly known* that an defendant who buys the stolen goods shall be punished. (`observe` $[d,j]\ p \wedge q \to r$)

The updated model at this moment consists of 3 states and there is no difference in these states between the defendant and the prosecutor (FIGURE 8.3). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge states in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent a and j acquire the information that $q,\ \neg p \vee \neg q \vee r$ is the case, $q,\ (\neg p \vee s)$ are true at the actual worlds.

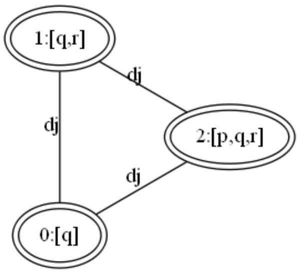

FIGURE 8.3: The epistemic model after the common background is set (Case 3)

Then we update this epistemic model according to the testimony of the defendant.

- The defendant *consider*-ed that if the clothes were stolen, he should be punished.(`consider` $d\ \ (p \wedge q \to r)$)
- The defendant *infer*-red that these might be stolen, because of the situation. (`infer` d)

At this moment, the defendant becomes aware of $\neg p \vee \neg q \vee r,\ q$, however since he/she is not aware of p, he/she cannot become aware of r by his/her "inference" action. This action creates new worlds/states which are copied and the prosecutor cannot distinguish them (FIGURE 8.4).

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. By this "inference" action, the prosecutor becomes aware of r as follows.

$$A_j p \wedge q \to r \qquad \text{before inference} \qquad (8.1)$$
$$A_j q \wedge p \to r \qquad (8.2)$$
$$A_j q \to (p \to r) \qquad (8.3)$$
$$A_j q \qquad \text{before inference} \qquad (8.4)$$
$$A_j p \to r \qquad (3), (4)\ \textit{modusponens} \qquad (8.5)$$
$$A_j p \qquad \text{before inference} \qquad (8.6)$$
$$A_j r \qquad (5), (6)\ \textit{modusponens} \qquad (8.7)$$

In `DEMO`$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor *consider*-s that if the defendant buys the stolen goods, he shall be punished. (`consider` $j\ \ (p \wedge q \to r)$)

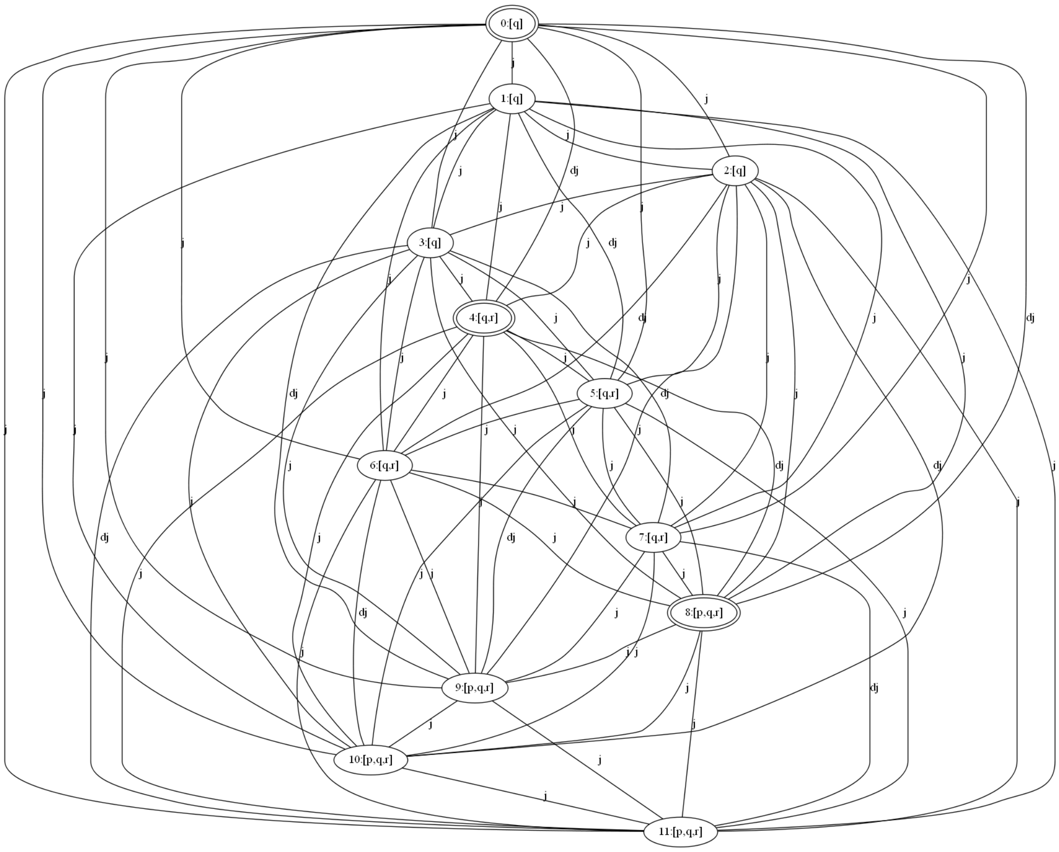

FIGURE 8.4: The epistemic model after update by the testimony (Case 3)

- The prosecutor *explicitly see*-s the clothes were stolen. (`see` $[j]$ p)
- The prosecutor *infer*-red carefully and repeatedly. (`infer`$^{(+)}$ j)

In the final epistemic model, there is one actual world where the proposition p, q, r are true and the defendant is aware of q, $p \wedge q \rightarrow r$, $p \rightarrow (q \rightarrow r)$, $q \rightarrow (p \rightarrow r)$. On the other hand, the prosecutor is aware of p, r, $q \rightarrow s$ in addition to the formulas of which the defendant is aware. We attach the final model in Appendix C. This is too complicated to see and intuitively understand.

There are 2 states where the prosecutor can access from the actual world and in these 2 worlds, the prosecutor is aware of r, however the defendant is not aware of this. the prosecutor thinks there is a possibility of the prediction of r and he/she also knows the defendant is not aware of $\neg r$. The judge concludes the defendant has the intention. There is a difference of the epistemic state between the defendant and the prosecutor as follows in TABLE 8.2.

8.3 Generalized intention (Case 4)

The precedent is that the defendant who carried the stimulant drug without deterministic conviction that they are the stimulant drug is accused of the violation of stimulant drug control law.

TABLE 8.2: Comparison of epistemic status of defendant and prosecutor (Case 3)

	Defendant	Prosecutor
The cause ($p \wedge q$)	not aware not know	aware know
The causal relation ($p \wedge q \to r$)	aware know	aware know
The external element (r)	not aware not know	aware know

At first, we set the propositions as follows. In `DEMO`$^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as three and set the explanation for each proposition.

p : The thing the defendant carried was the stimulant.

q : The defendant returned to his country carrying something.

r : The defendant carried the stimulant.

And then we update the initial knowledge states by their common knowledge or consciousness according to their testimony. In `DEMO`$^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsv/explicitly see`).

- Both the defendant and the prosecutor *explicitly know* the defendant carried something. (`see`$[d, j]\ q$)
- It is commonly but *implicitly known* that a defendant who carries the stimulant shall be punished. (`observe`$[d, j]\ p \wedge q \to r$)

The updated model at this moment consists of 3 states and there is no difference in the links between these states for the defendant and the prosecutor (FIGURE 8.5). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge states in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent d and p acquire the information that q, $\neg p \vee \neg q \vee r$ is the case, q, $(\neg p \vee s)$ are true at the actual worlds.

Then we update this epistemic model according to the testimony of the defendant.

- The defendant *consider*-ed that if he carried the stimulant, he should be punished.(`consider` $d\ \ (p \wedge q \to r)$)
- The defendant *infer*-red that this might be the stimulant. (`infer` d)

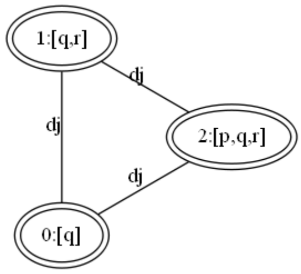

FIGURE 8.5: The epistemic model after the common background is set (Case 4)

At this moment, the defendant becomes aware of $\neg p \vee \neg q \vee r,\ q$, however he/she is not aware of p, he/she cannot become aware of r in his/her "inference" action. This action creates new worlds/states which are copied and the prosecutor cannot distinguish. Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. The judge also has the same updating. In DEMO$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor *consider*-s that if the defendant carries the stimulant, he shall be punished and *explicitly sees* the thing is the stimulant. (`consider` j $(p \wedge q \rightarrow r)$, `see` j p)
- The prosecutor *inferred carefully and repeatedly*. (`infer`$^{(+)}$ j)

In the final epistemic model, there is one actual world where the proposition $p,\ q,\ r$ are true and the defendant is aware of $q,\ p \wedge q \rightarrow r,\ p \rightarrow (q \rightarrow r),\ q \rightarrow (p \rightarrow r)$. On the other hand, the prosecutor is aware of p, r, $q \rightarrow s$ in addition to the formulas which the defendant is aware of. We attach the final model in Appendix C.

There are 2 states where the prosecutor can access from the actual world and in these 2 worlds, the prosecutor is aware of r, however the defendant is not aware of this. the prosecutor thinks there is a possibility of the prediction of r and he/she also knows that the defendant is not aware of $\neg r$. The judge concludes the defendant has the intention. There is a difference of the epistemic state between the defendant and the prosecutor as follows in TABLE 8.3. The

TABLE 8.3: Comparison of epistemic status of defendant and prosecutor (Case 4)

	Defendant	Prosecutor
The cause ($p \wedge q$)	not aware	aware
	not know	know
The causal relation ($p \wedge q \rightarrow r$)	aware	aware
	know	know
The external element (r)	not aware	aware
	not know	know

result of Case 4 is the same as Case 3.

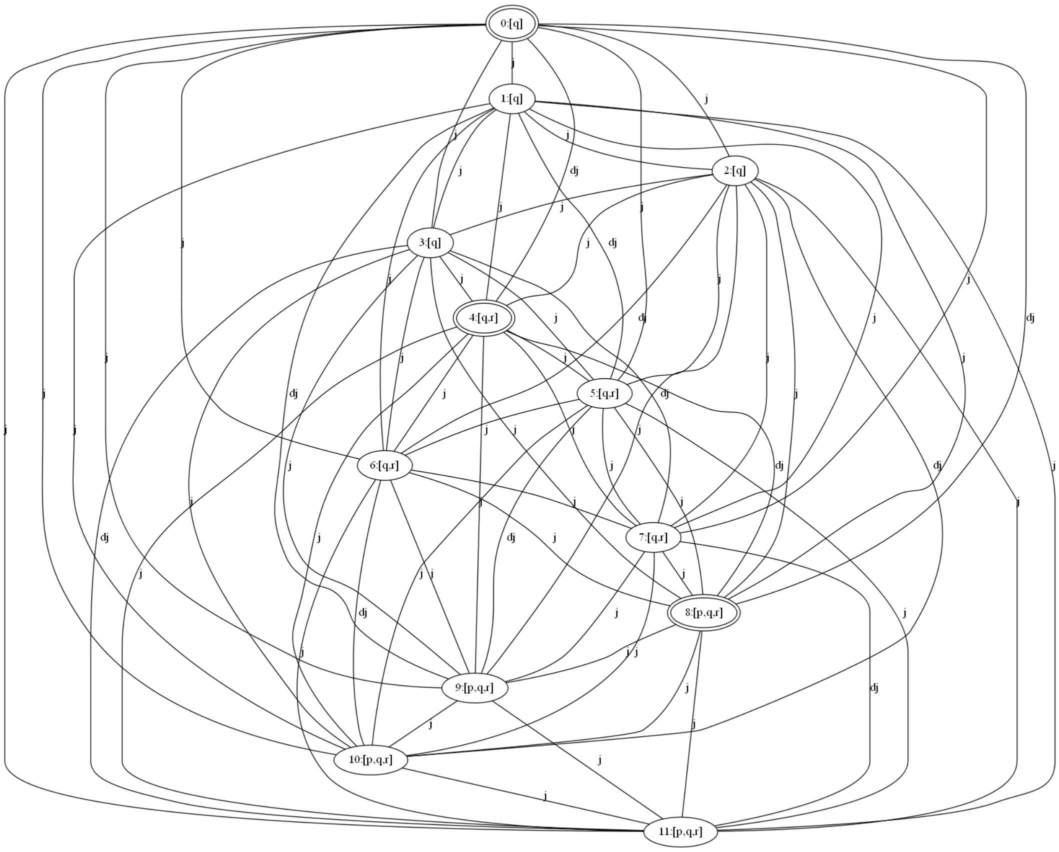

FIGURE 8.6: The epistemic model after update by the testimony

8.4 Negligence (Case5)

The precedent is as follows. The nurse had mistakenly connected the cable of the electronic scalpel. When the doctor operated using this scalpel, the abnormal electric currency occurred and the patient's right foot was damaged. The judge ruled professional negligence resulting in bodily injury, because he/she thought the defendant could predict that the abnormal electric current could harm the patient if he/she made a mistake to connect the cable wrongly.

At first, we set the propositions as the following. In DEMO$^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as three and set the explanation for each proposition.

p : The nurse connected the cables of the electric scalpel wrongly.

q : The wrongly connected cables without a breaker formed a dangerous electric circuit and abnormal electric current might occur.

r : The patient's right foot was damaged.

And then we update the initial knowledge states by their common knowledge or consciousness according to their testimonies. In DEMO$^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsv/ explicitly see`).

- The defendant and the prosecutor know the patient's leg could be damaged if an abnormal electric current occurred. (`see` $[d, j]\ q \to r$)
- It is commonly known (*implicitly observed*) that if the cables are wrongly connected, abnormal electric current may occur. (`observe` $[d, j]\ p \to q$)

The updated model at this moment consists of 4 states and there is no difference in these state between the defendant and the prosecutor (FIGURE 8.7). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge states in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent a and j acquire the information that $\neg q \vee r$, $\neg p \vee q$ is the case, in the actual worlds, p, q, r are true or p, r are true or r is true or p, q, r are not true.

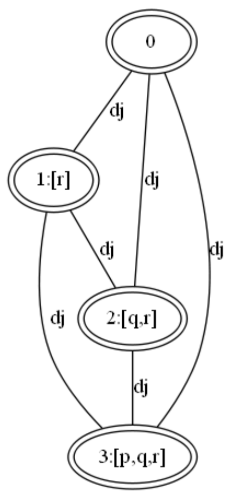

FIGURE 8.7: The epistemic model after the common background is set (Case 5)

Then we update this epistemic model according to the testimony of the defendant.

- The defendant says he/she could not predict. (`infer`$^{(+)}$ d)

There is no new information about the defendant and the defendant is not yet aware of r, because he/she is not aware of p and he/she cannot become aware of r by his action "inference". And the epistemic model states is the same as FIGURE 8.7, since there is no new formula reasoned by the defendant when he/she infers and any new world/state is not copied.

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. The judge also has the same updating. In `DEMO`$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor knows the fact that the nurse made a mistake of connecting cables wrongly (`see`$[j]\ p$).

- The prosecutor is aware of the fact that the wrong connected cables may have caused the abnormal electric current. (`consider` $j\ p \to q$)
- The prosecutor considered repeatedly. ($\texttt{infer}^{(+)}\ j$)

The result (FIGURE 8.8) consists of 22 states and the actual state is No. 8 where $p,\ q,\ r$ are true and the defendant is aware of $q \to r$ and the prosecutor is aware of $p,\ q,\ r,\ p \to q,\ q \to r$. There is no other state where the prosecutor can access from the actual state. At the actual state, the defendant is not aware of both the fact (p) and the causation ($p \to q$ and $q \to r$), however he/she knows the causation ($p \to q$ and $q \to r$) and this is the same from the prosecutor's view point. The judge can conclude if the defendant took care of the situation (p), he/she could predict the consequence (r) and the judge applied the negligence. We also attach the

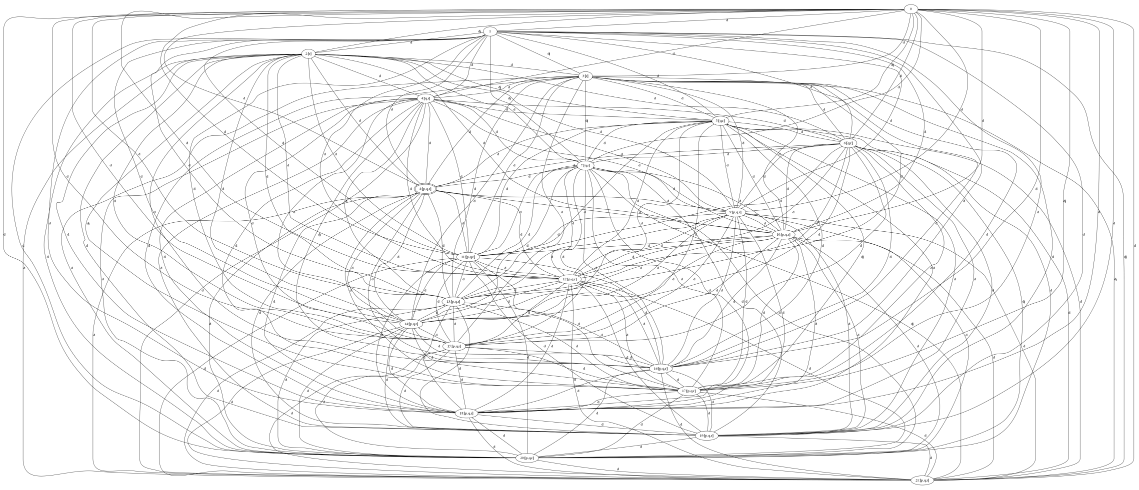

FIGURE 8.8: The final state

partially enlarged image of FIGURE 8.8 as FIGURE 8.9, because the whole state diagram is too complicated to understand. The difference of the epistemic state between the defendant and the prosecutor is as follows in TABLE 8.4.

TABLE 8.4: Comparison of epistemic status of defendant and prosecutor (Case 5)

	Defendant	Prosecutor
The cause (p)	not aware	aware
	not know	know
The causal relation ($p \to r$)	not aware	aware
	know	know
The external element (r)	not aware	aware
	not know	know

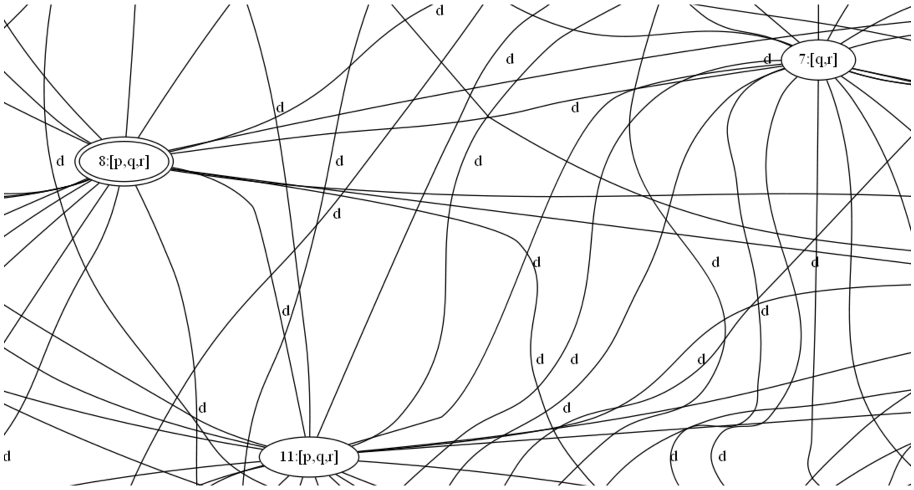

FIGURE 8.9: Partially enlarged graph of FIGURE 8.8

8.5 Negligence (Case6)

The precedent is as follows. The defendant drove his truck at over 65 km/h in a narrow road where the maximum speed is limited under 30 km/h. When he found that a car was coming from the opposite direction, he was upset and crushed into the footpath. Two people happened to be on the back of the truck and were dead by this crush. The judge applied the involuntary manslaughter.

At first, we set the propositions as follows. In `DEMO`$^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as four and set the explanation for each proposition.

p : The defendant drove a car in a very dangerous situation.

q : The car crashed into the footpath to avoid the crash with a car coming from the opposite direction .

r : The victims happened to be on the back of the truck.

s : The victims were dead.

And then we update the initial knowledge states by their common knowledge or consciousness according to their testimony. In `DEMO`$^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsve/ explicitly see`).

- The defendant and the prosecutor explicitly know the victims are dead if they are on the back of the truck and the car crashed. (`see`$[d,j]\ q \wedge r \rightarrow s$)
- It is not clear that the casualties got an approval of the defendant and were on the back of the truck. (`observe`$[d,j]\ r$)
- It is commonly known that the car may crash if the driver drives a car in a dangerous situation over the maximum speed. (`observe`$[d,j]\ p \rightarrow q$)

The updated model at this moment consists of 4 states and there is no difference in these states between the defendant and the prosecutor (FIGURE 8.10). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge state in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent d and j get the information that $\neg q \vee \neg r \vee s, \neg p \vee q, r$ is the case, in the actual worlds, $p,\ q,\ r$ are true or $p,\ r$ are true or r is true or $p,\ q,\ r$ are not true.

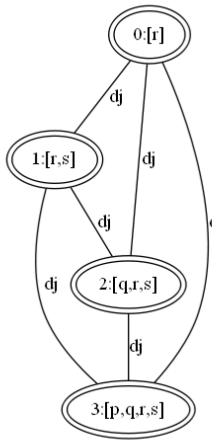

FIGURE 8.10: The epistemic model after the common background is set (Case 6)

Then we update this epistemic model according to the testimony of the defendant.

- The defendant says he/she could not predict. (`infer`$^{(+)}$ a)

There is no new information about the defendant and the defendant is not yet aware of s, because he/she is not aware of p, r and he/she cannot infer s by his action "infer". And the epistemic model status is the same as FIGURE 8.10, since there is no new formula inferred by the defendant when he/she considers and any new world/state is not copied.

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. In DEMO$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor sees the fact that the dangerous driving by the defendant caused the crash. (`see`$[j]\ p \rightarrow q$, `consider`$[j]\ p \rightarrow q$)
- The prosecutor is aware of the fact that the casualties were on the back of the truck. (`consider` $[j]\ r$)
- The prosecutor considered repeatedly. (`infer`$^{(+)}$ j)

The result consists of 98 states and at the actual state,$p,\ q,\ r,\ s$ are true and the defendant is aware of $q \rightarrow (r \rightarrow s)$, $r \rightarrow (q \rightarrow s)$, $(q \wedge r) \rightarrow s$ and in addition to these, the prosecutor is aware of p, q, r, s, $p \to q$, $q \to s$, $r \to s$. There is no other state where the prosecutor can access from the actual state. At the actual state, the defendant is not aware of both the fact (p) and the causation ($p \to q$ and $q \to r$ and $r \to s$), but he/she knows the causation ($p \to q$ and $q \to r$ and $r \to s$). So the judge can conclude if the defendant took care of the situation (p), he/she could predict the consequence (s) and applied the negligence. The difference of the epistemic state between the defendant and the prosecutor is as follows in TABLE 8.5.

TABLE 8.5: Comparison of epistemic status of defendant and prosecutor (Case 6)

	Defendant	Prosecutor
The cause (p)	not aware	aware
	not know	know
The causal relation ($p \to s$)	not aware	aware
	know	know
The external element (s)	not aware	aware
	not know	know

8.6 Innocence (Case 7)

The precedent is as follows. The doctor used unheated blood and the patient became HIV positive. The judge applied the innocence to the doctor. He/she said that Giving unheated blood medicine was not so unnatural at that time.

At first, we set the propositions as the following. In $\texttt{DEMO}^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as four and set the explanation for each proposition.

p :The medicine of unheated blood products was contaminated by HIV.

q : The patient was infected with HIV.

r : The doctor gave the medicine of unheated blood products.

s : The patient developed AIDS.

And then we update the initial knowledge states by their common knowledge or consciousness according to their testimony. In $\texttt{DEMO}^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsv/ explicitly see`).

- The defendant and the prosecutor knew the fact that the patient needed the treatment by the medicine ($\texttt{see}[d, j]\ r$).
- The defendant and the prosecutor knew that if the medicine of unheated products contaminated by HIV was given to a patient, he/she would have been infected with HIV (($\texttt{see}[d, j]\ p \wedge r \to q$).

The updated model at this moment consists of 6 states and there is no difference in these state between the defendant and the prosecutor (FIGURE 8.11). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to the line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge state in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. Since agent d and j acquire the information that r, $\neg p \vee \neg r \vee q$ is the case, r is true at the actual worlds.

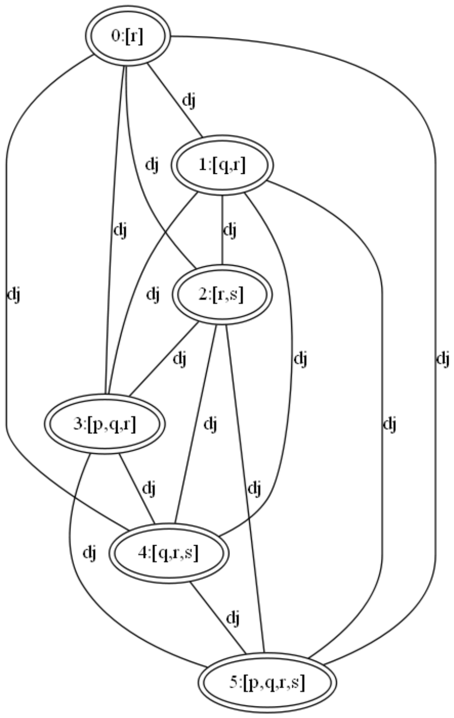

FIGURE 8.11: The epistemic model after the common background is set (Case 7)

Then we update this epistemic model according to the testimony by the defendant (FIGURE 8.12).

- The defendant said he could not avoid the result, even though he considered well. (`infer`$^{(+)}$ d).

There is no new information for the defendant and the defendant is not yet aware of s, because he/she is not aware of p nor $r \rightarrow s$ and he/she cannot "infer" s by his action.

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. In `DEMO`$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor explicitly knew that the medicine of unheated blood was contaminated by HIV (`see`$[j]$ p).

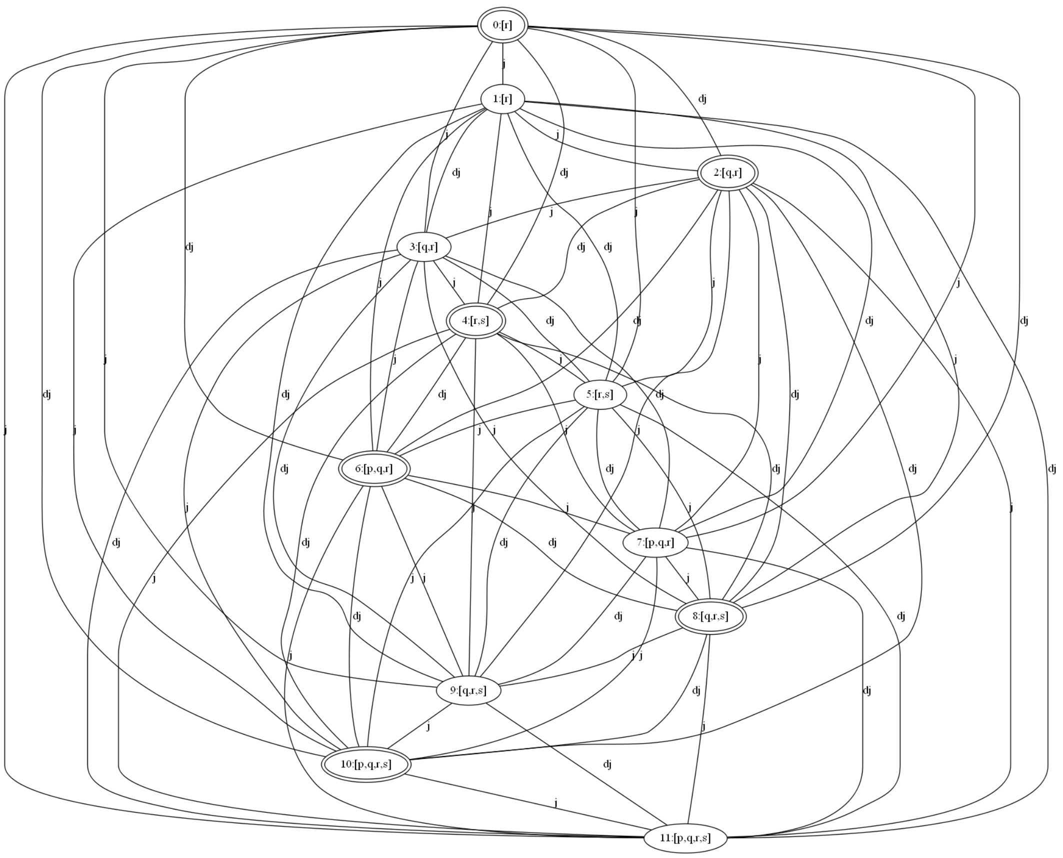

FIGURE 8.12: The epistemic model after update by the testimony (Case 7)

- The prosecutor considered repeatedly. (`infer`$^{(+)}$ j)

The result consists of 140 states and the actual state is No. 68 where p, q, r, s are true and the defendant is aware of r, $(p \wedge r) \rightarrow q$, $p \rightarrow (r \rightarrow q)$, $r \rightarrow (p \rightarrow q)$ and in addition to these, the prosecutor is aware of p, q, s, $q \rightarrow s$. There is another state (No. 104) where the prosecutor can access from the actual state. In these worlds, the defendant is not aware of both the cause ($p \wedge r$) and the causation ($p \wedge r \rightarrow q$ and $q \rightarrow s$). He/She also does not know the causation. Then the judge can conclude that it is impossible to predict and declares the innocence. The difference of the epistemic state between the defendant and the prosecutor is as follows in TABLE 8.6.

8.7 Innocence (Case 8)

The precedent is as follows. The defendant drove his taxi with 2 passengers and went into the crossing point without slowing down. Suddenly a drunken person drove a car at over 70 km/h from the left side into the crossing point and crashed with the defendant's taxi. The passengers were dead. The judge declared innocence to the defendant.

At first, we set the propositions as the following. In `DEMO`$^{+\mathcal{A}}$, we set the number of proposition (`Number of prop.`) as four and set the explanation for each proposition.

p :The defendant did not slow down when he/she should slow down.

TABLE 8.6: Comparison of epistemic status of defendant and prosecutor (Case 7)

	Defendant	Prosecutor
The cause ($p \wedge r$)	not aware not know	aware know
The causal relation ($p \wedge r \rightarrow s$)	not aware not know	not aware not know
The external element (s)	not aware not know	not aware not know

q : The person drove a car abnormally at the high speed over 80km/h.

r : The car was crashed.

s : The victim was dead by the accident.

And then we update the initial knowledge status by their common knowledge or consciousness according to their testimony. In DEMO$^{+\mathcal{A}}$, the corresponding formula should be entered in the background field (`Background`) and the action should be selected (`implicitly obsv/ explicitly see`).

- The defendant and the prosecutor think that if the driver slowed down or there was no abnormal situation, the accident could be avoided. (`observe`$[d,j]$ $p \wedge q \rightarrow r$).
- The defendant and the prosecutor knew that if the accident happened, the passenger was dead. ((`see`$[d,j]$ $r \rightarrow s$).

The updated model at this moment consists of 10 states and there is no difference in these states between the defendant and the prosecutor (FIGURE 8.13). In this graph, the circle indicates the state or world and the double circle means an actual state/world. Each state has a number as an ID and the proposition inside the square bracket in each circle indicates that the corresponding proposition is true at this state. The line between circles indicates the relation between these states and the label attached to this line expresses the agent. This means the agent cannot distinguish these states in our semantics. In this calculation, we omit the calculation of the knowledge state in the worlds which have no direct or indirect relation with the actual world to reduce the volume of calculation. The agent d and j acquire the information that $p \vee \neg q \vee r$, $\neg r \vee s$ is the case.

Then we update this epistemic model according to the testimony by the defendant (FIGURE 8.14).

- The defendant said he drove without any explicit attention to slow down. (`observe` d p).
- The defendant said he thought repeatedly, however could not avoid the crash even he slowed down at the crossing point. (`infer`$^{(+)}$ d).

There is no new information for the defendant and the defendant is not yet aware of s, because he is not aware of p nor $r \rightarrow s$ and he cannot infer s by his action.

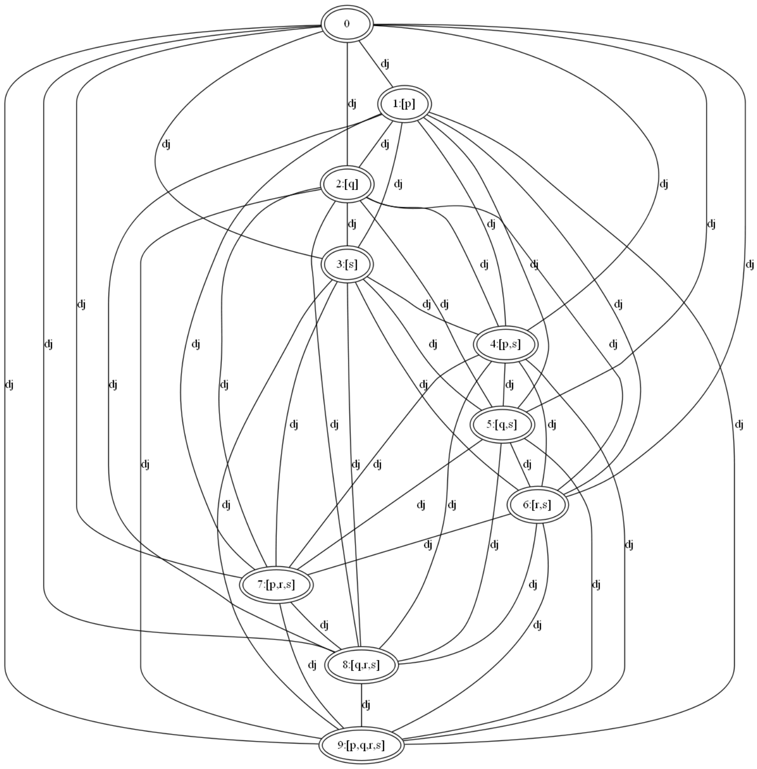

FIGURE 8.13: The epistemic model after the common background is set (Case 8)

Finally, the prosecutor investigates the fact and hears the testimony of the defendant and considers repeatedly. These actions update his epistemic model. The judge also has the same updating. In DEMO$^{+\mathcal{A}}$, the epistemic model is updated by pushing down the button `Pros calc`.

- The prosecutor explicitly sees that the defendant drove without any explicit attention to slow down. (see$[j]$ p).
- The prosecutor explicitly sees that the third person drunk and drove a car picking up his mobile phone. (see$[j]$ q).
- The prosecutor said he thought repeatedly, however he could not imagine that the defendant avoid the crash. (infer$^{(+)}$ j).

The result consists of 29 states which include one actual state where p, q, r, s are the case. The defendant is aware of $r \to s$ and in addition to this, the prosecutor is aware of p, q, $r \to s$. There is no other state where the prosecutor can access from the actual state. He/She also does not know the causal relation. Then the judge can conclude that it is impossible to predict and to try to avoid the result, so declares the innocence. The difference of the epistemic state between the defendant and the prosecutor is as follows in TABLE 8.7.

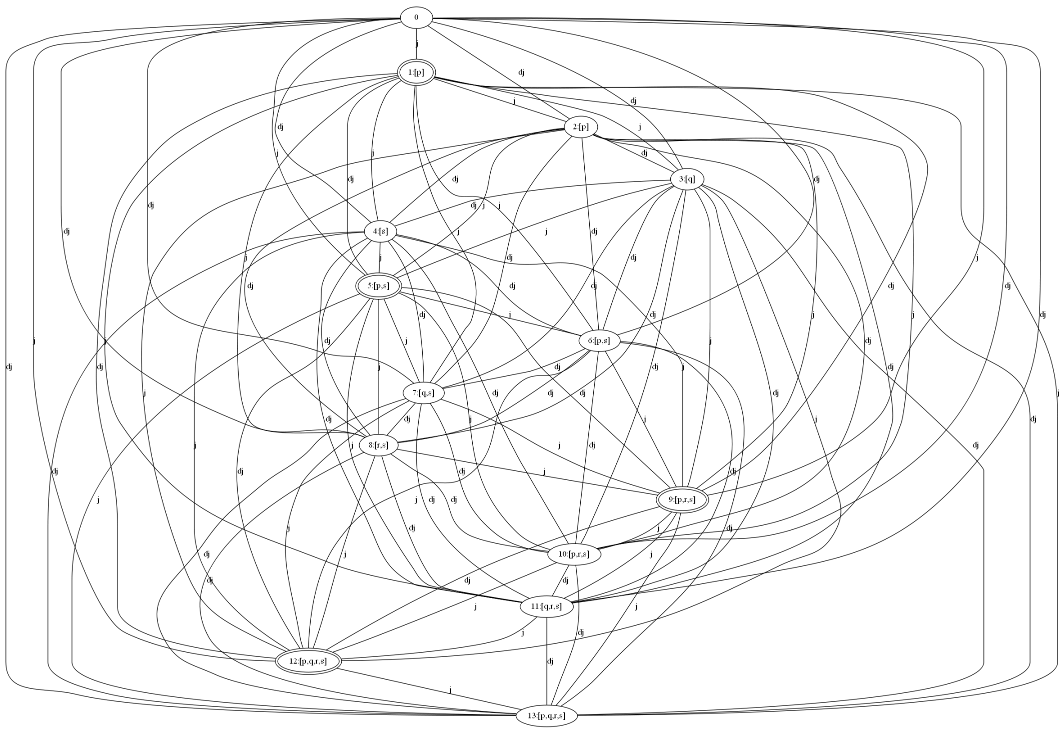

FIGURE 8.14: The epistemic model after update by the testimony (Case 8)

TABLE 8.7: Comparison of epistemic status of defendant and prosecutor (Case 8)

	Defendant	Prosecutor
The cause ($p \wedge q$)	not aware not know	aware know
The causal relation ($p \wedge q \to r$)	not aware not know	not aware know
The external element (r)	not aware not know	not aware know

8.8 Validation of the results

8.8.1 Examining the calculated results

We assume the followings when we evaluate the calculated results.

- We assume the consideration/inference model of an agent described in Chapter 6. An agent can predict the result which can be derived from the formulas that the agent is aware of.
- We define the result formula ψ which match the external element defined in the criminal law. We also define the causal relation as $\varphi \to \psi$.

And we check the calculated awareness or knowledge states of these results or the causal relations. TABLE 8.8 shows this result of the selected precedents [21].

TABLE 8.8: Awareness status in each cases

Precedents	Status
Case1: Accused of injury resulting in death case (No. A35, 2003)	Defendant is aware of the cause. Defendant is not aware of the causal relation. Defendant is not aware of the result. Defendant does not know the causal relation.
Case3: Accused of buying the stolen goods (No. RE238, 1947)	Defendant is not aware of the cause. Defendant is aware of the causal relation. Defendant is not aware of the result. Defendant knows the causal relation.
Case4: The Stimulant Drug Control Law violations (No. A1038, 1998)	Defendant is not aware of the cause. Defendant is aware the of the causal relation. Defendant is not aware of the result. Defendant knows the causal relation.
Case5: Hokkaido University electric scalpel case (No. U219, 1974)	Defendant is not aware of the cause. Defendant is not aware of the causal relation. Defendant is not aware of the result. Defendant knows the causal relation.
Case6: Involuntary manslaughter by the traffic accident (No. A193, 1986)	Defendant is not aware of the cause. Defendant is not aware of the causal relation. Defendant is not aware of the result. Defendant knows the causal relation.
Case7: The use of HIV contaminated blood in Teikyo University Hospital (No. WA1879, 1996)	Defendant is not aware of the cause. Defendant is not aware of the causal relation. Defendant is not aware of the result. Defendant does not know the causal relation.
Case8: Innocent case of the traffic accident (No. A183, 2002)	Defendant is not aware of the cause. Defendant is not aware of the causal relation. Defendant is not aware of the result. Defendant does not know the causal relation.

8.8.2 Validation of the calculation

In Case 1, the external element is s and the defendant's initial action is p. The defendant is aware of p, $p \to q$, $r \to s$, but is not aware of $q \to r$, so he cannot "infer" s in his awareness or consciousness by his action. This is the same as the states of the defendant from the view point of the prosecutor, which means in the states where the prosecutor can access. On the other hand, the prosecutor also knows p and is aware of this at the same tine, because the defendant admitted the fact of his assault p at the court. This leads to the result that the defendant is aware of the cause p in all the states where the prosecutor can access from the actual world. According to this, $A_d\varphi \wedge \neg A_d(\varphi \to \psi)$ is valid in some states to which the prosecutor can reach. On the other hand, in all states where the prosecutor can access from the actual states, $\neg A_d(\varphi \to \psi)$ is valid. So the judge can conclude that the defendant does not predict the result ψ, even if he/she took care of. However in all states to which the prosecutor has an access, the prosecutor is conscious about the causal relation ($A_j(\varphi \to \psi)$) and the judge admits this causal relation.

In Case 3 and Case 4, the external element is r and the defendant's initial action is q. The defendant is aware of q, $p \wedge q \to r$ and he cannot infer r in his awareness or consciousness by his action. This is the same as the states of the defendant from the view point of the prosecutor. On the other hand, the prosecutor also knows p and is aware of it, because the prosecutor investigated and reported it. This leads to the result that the defendant is aware of the causal relation $p \wedge q \to r$ in some states where the prosecutor can access from the actual world. According to this, $\neg A_d\varphi \wedge A_d(\varphi \to \psi)$ is valid in some states to which the prosecutor can reach. So the judge can guess that the defendant dare to do.

In Case 5, the external element is r and the defendant's initial action is p. The defendant is not aware of p, nor $p \to q$, however is aware of $q \to r$, so he cannot "infer" r in his awareness or consciousness by his action. This is the same as the states of the defendant from the view point of the prosecutor. On the other hand, the prosecutor also knows p and is aware of it, because the prosecutor investigated and reported it. He/she is also aware of $p \to q$. This leads to the result that the defendant is not aware of the cause p nor the causal relation ($p \to q$, $q \to r$) in all states to which the prosecutor has an access. According to this, $\neg A_d\varphi \wedge \neg A_d(\varphi \to \psi)$ is valid in all states where the prosecutor can access. In Case 6, we can also say $\neg A_d\varphi \wedge \neg A_d(\varphi \to \psi)$ is valid from the view of the prosecutor. And the judge can conclude that the defendant does not predict the result φ, however in all states to which the prosecutor can reach, the defendant knows about the causal relation ($\varphi \to \psi$), the judge can conclude that the defendant might be able to predict if he/she took more care of.

The Case 7 is the same as Case 5. In Case 7, the external element is s and the defendant's initial action is r. The defendant is not aware of p, nor $r \to s$, but is aware of $p \wedge r \to q$, so he cannot infer s in his awareness or consciousness by his action "infer". This is the same as the states of the defendant from the view point of the prosecutor. On the other hand, the prosecutor also knows p, $r \to s$ and is aware of them, because the prosecutor investigated and reported it. This leads the result that the defendant is not aware of the cause $p \wedge r$ nor the causal relation ($p \wedge r \to q$, $q \to r$) in all states where the prosecutor can access from the actual world. According to this, $\neg A_d\varphi \wedge \neg A_d(\varphi \to \psi)$ is valid in all states to which the prosecutor can reach. In Case 8, the judge can say that $\neg A_d\varphi \wedge \neg A_d(\varphi \to \psi)$ is valid in all states where the prosecutor can access from the actual world. However in both cases, the defendant does not know about the causal relation ($\varphi \to \psi$) and the judge can conclude that it is difficult to predict the result for the defendant.

8.8.3 Classification of prediction/predictability

We propose the description of the predictability or prediction of the external element of a crime by the awareness of the cause φ and the causal relation $\varphi \to \psi$. The predictability or prediction of the external element can be classified into 4 patterns according to the awareness of these two elements as follows.

1. $A\varphi \wedge A(\varphi \to \psi)$
2. $\neg A\varphi \wedge A(\varphi \to \psi)$
3. $A\varphi \wedge \neg A(\varphi \to \psi)$
4. $\neg A\varphi \wedge \neg A(\varphi \to \psi)$

Based on the validation above, we can match our calculated results with these four patterns.

TABLE 8.9: Matching calculation results with patterns

Intentional case	Crime by deterministic intention	$A\varphi \wedge A(\varphi \to \psi)$
	Crime by indeterministic intention (Aggravation of punishment by result)	$A\varphi \wedge \neg A(\varphi \to \psi)$
	Crime by indeterministic intention (*Dolus eventualis*, Generalized intention)	$\neg A\varphi \wedge A(\varphi \to \psi)$
Not intentional cases	Negligence	$\neg A\varphi \wedge \neg A(\varphi \to \psi)$
	Innocent case	

In addition to the awareness status in TABLE 8.9, finally we propose the following classification by using knowledge about the causal relation. In intentional cases, there is a possibility that the agent can predict the external element (φ) in his/her awareness by the internal epistemic actions like "infer", since in these cases, the agent is aware of at least the causal relation or the cause.

In unintentional cases, the agent is not aware of both the causal relation and the cause and the knowledge states of the agent about the causal relation can make an explanation of the difference between the negligence and the innocent. In negligence cases, the agent knows the causal relation implicitly. We attach the results of classification to this proposed patterns comparing with the interpretations or types of the precedents. These classification results match well with the judgment types of the precedents.

TABLE 8.10: Classification criteria for precedents

Defendant	Prosecutor	Classification
$A\varphi \wedge A(\varphi \to \psi)$	$A\varphi \wedge A(\varphi \to \psi)$	Crime by a deterministic intention
$A\varphi \wedge \neg A(\varphi \to \psi)$	$A\varphi \wedge A(\varphi \to \psi)$	Erroneous recognition of causal relation, Aggravation of punishment by result
$\neg A\varphi \wedge A(\varphi \to \psi)$	$A\varphi \wedge A(\varphi \to \psi)$	Crime by an indeterministic intention (*Dolus eventualis*, Generalized intention, Mistake of cause)
$\neg A\varphi \wedge \neg A(\varphi \to \psi) \wedge K(\varphi \to \psi)$	$A\varphi \wedge A(\varphi \to \psi) \wedge K(\varphi \to \psi)$	Negligence
$\neg A\varphi \wedge \neg A(\varphi \to \psi) \wedge \neg K(\varphi \to \psi)$	$A\varphi \wedge \neg A(\varphi \to \psi) \wedge \neg K(\varphi \to \psi)$	Innocence

TABLE 8.11: Comparison of classification with actual precedents

Precedents	Judgment	Calculated result
Case 1: Accused of injury resulting in death case (No. A35, 2003)	Aggravation by result	Aggravation by result / Misunderstanding of causal relation
Case 2: Accused of murder by strangulation (No. RE 517, 1923)	Misunderstanding of causal relation	
Case 3: Accused of buying the stolen goods (No. Re238, 1967)	*Dolus eventualis*	*Dolus eventualis*/Generalized intention
Case 4: The Stimulant Drug Control violations (No. A1038, 1998)	Generalized intention	
Case 5: Hokkaido University electric scalpel case (No. U219, 1974)	Negligence	Negligence
Case 6: Accused of resulting in death during driving a truck (No. A193, 1986)	Negligence	
Case7: The use of HIV contaminated blood in Teikyo University Hospital (No. WA1879, 1996)	Innocence	Innocence
Case 8: Not the guilty of resulting in death (No. A183, 2002)	Innocence	

Chapter 9

Conclusion and further directions

9.1 Conclusion

We have investigated the decision process of a judge in the court and picked up some typical precedents. Then we have tried to reconstruct the precedents by using DEMO which is the modeling tool for DEL by defining the concrete action models. We have faced the difficulty to describe the intention in the precedents. Then, we have employed DEL with awareness, including its action models, to address these issues and to describe the predictability of the agent. We have proposed the revised semantics of this logic to infer the new information by an action and have added an awareness condition function to the action model.

We have defined the consideration or inference process of an agent and listed the concrete epistemic actions with awareness according to our newly defined action model. By using these actions and modal operator A, we can model the deterministic or indeterministic intention, erroneous recognition of the causal relation, negligence and innocence in the precedents.

We have developed the legal reasoning system by implementing the DEL with awareness of the extended DEMO program ($\texttt{DEMO}^{+\mathcal{A}}$) and added GUI to calculate easily. In this GUI, the classification of precedents is displayed according to the proposed classification criteria. We have also described some typical variation of intentions for a crime and confirmed the availability of this criteria for the legal cases.

9.2 Further directions

In this research, we have employed **S5** as an axiomatization system and we cannot treat well the precedents which are classified as the misunderstanding of the fact or the misunderstanding of the causal relation. We have assumed that the formulas being awared reside within the domain of an agent's knowledge, however we think it is necessary to re-define the relation between awareness and knowledge in the axiom system of **KD45** to handle these problems of misunderstanding. If we can describe these issues of misunderstanding, we can handle the precedents in a wider field and a more realistic context.

For another direction, we consider to expand the classification method to apply to other cases than the legal ones. In the real world, there are many cases other than the legal cases such that the predictability would be the problem. And our tool may be able to analyze the multi-agent knowledge states where the knowledge or consciousness is limited.

9.3 Evaluation of this research

In this research, the awareness states and the knowledge states of an agent can be analyzed by using the revised DEL with awareness in case of several precedents of criminal law. By using the inference or consideration process model of an agent which is described in Chapter 6 and the newly defined action models like "infer", "consider", "explicitly see" and "implicitly observe", we can describe more easily or adequately the awareness and knowledge states of the defendant when he/she commits a crime. This can be helpful in analyzing the motivation of committing a crime or categorizing the crime according to the prediction or predictability of the defendant.

On the other hand, because we defined this logic on **S5** frame in this research, we are not able to describe well such cases as the one of misunderstanding of the fact. In addition,, we assume that the awareness is not lost immediately and do not define such an action as "forget" or "become unconscious about".

Also by using this consideration or inference process, we can reinterpret the cases of the other field in the real world than the precedents where the reasoning by an agent is limited. We provide the source code of this $\texttt{DEMO}^{+\mathcal{A}}$ in our site [1] and we expect the feedback from a lawyer or a researcher who studies the logics about the application of this program to the other precedents or the other problems than the criminal law, for example, the civil law. Concerning $\texttt{DEMO}^{+\mathcal{A}}$, it is desirable to reduce the calculation volume in the future by omitting the calculation of the states which do not have the relation to the actual world, because the number of the state increases according to updating the model by each action.

In this research, we do not mean to formalize the legal concept logically like *dolus eventualis*, "Negligence" or "Misunderstanding of causal relation", however we try to classify the precedents according to the one aspect of these legal concepts by using DEL with awareness. In this limited categorization, we can say that these methods can help visualization or understanding of the thought of the judge.

9.4 Our contributions

Based on the evaluation in the previous subsection, we can say about our contributions as follows.

- This study assists the lawyer to understand more clearly the legal concepts concerning intention to commit a crime or negligence. We have classified the precedents according to the awareness about the result and the causal relation. This matches well with the interpretation of the precedents according the predictability and provides the clear understanding of the relation between the awareness and the legal interpretations in a criminal precedents. Examining the knowledge states or the awareness states from the view point of the stakeholders deepens the understanding of these legal concepts.

- This study provides one method by DEL to describe the consideration (inference) process of an agent in the real world which includes the prediction or the limited reasoning. We have constructed the axiom system of DEL with awareness which enables us to describe the inference of a new information by an action of an agent. Using this newly defined

[1] http://cirrus.jaist.ac.jp:8080/soft/demo_plus_a

action model, we can reconstruct the limited reasoning or the inference process of an agent in the real world who is not a "logical omniscient".

- We have opened in our site the developed modeling tool $\texttt{DEMO}^{+\mathcal{A}}$ which can treat the awareness dynamically to all the users who research the multi-agent simulation in the real world. This helps the analysis and the visualization of the precedents of a crime. Further it can be applied to the other fields than the precedents of the criminal law.

Appendix A

English - Japanese translation table

We show the English translation of the Japanese legal concepts in TABLE A.1.

TABLE A.1: English - Japanese translation of the legal term

English translation	Japanese term
Aggravation of punishment according to the result	結果的加重犯
Criminal law or Penal code	刑法
Defendant	被告人
External elements of a crime or *Tatbestand*	構成要件
Generalized intention	概括的故意
Innocence	無罪
Intent or Intention	故意
Involuntary manslaughter	過失致死
Judge	裁判官
Judgment	判決
Justifiable reason to dismiss the illegality	違法性阻却事由
Justifiable reason to dismiss the responsibility	責任阻却事由
Misunderstand of a process or causality	因果関係の錯誤
Negligence	過失
Precedent	判例
Dolus eventualis or Willful negligence	未必の故意

Appendix B

Implementation of model

We show a part of our implementation of DEMO$^{+\mathcal{A}}$ concerning the important definitions or functions.

```
-- The definition of Epistemic Model with awareness (awareness model)
data Model state formula awfrm = Mo
         [state] -- a list of state/world
         [(state, formula)] -- a list of valuation as a pair
         [(Agent, state, awfrm)] -- a list of awareness state of
                                    a tuple
         [(Agent, state, state)] -- a list of relation as a tuple
         deriving (Eq, Ord, Show) -- for displaying character
-- The definition of Action Model with awareness
data ACM state = Acm
         [state] -- a list of action/event
         [(state, Form)] -- a list of precondition as a pair
         [(Agent, state, Subst)] -- a list of awareness condition
                                    as a tuple
         [(Agent, state, state)] -- a list of relation as a tuple
         deriving (Eq, Show, Ord)  -- for displaying character
```

– The definition of the action "consider" and its action model

```
consider :: Agent -> EpistM -> Form -> EpistM
consider agent m frm = upd m (actConsider agent frm)

actConsider :: Agent -> Form -> PoACM State
actConsider agent frm =
   Pacm [0,1,2] [(0,(K agent frm)),(1,(Neg (K agent frm))),(2,Top)]
    ([(agent, 0, [([Top], frm)])] ++ [(a, 0, [])|a <- all_agents
        \\ [agent]] ++ [(a, 1, [])|a <- all_agents] ++
        [(a, 2, [])|a <- all_agents])
    ([(a,0,0)| a <- all_agents] ++ [(a, 0,1) | a <- all_agents
     \\ [agent]] ++ [(a,0,2)| a <- all_agents \\ [agent]]
     ++ [(a,1,2) | a <- all_agents] ++ [(a,1,0)| a <- all_agents
     \\ [agent]] ++ [(a,1,1) | a <- all_agents] ++
    [(a,2,0)| a <- all_agents \\ [agent]] ++ [(a,2,1) | a <- all_agents]
    ++ [(a,2,2)| a <- all_agents])
```

```
    [0]
```

– The definition of the action "observe" and its action model

```
observe :: [Agent] -> EpistM -> Form -> EpistM
observe agents m form = upd m (actObserve agents form)

actObserve :: [Agent] -> Form -> PoACM State
actObserve agents frm =
   Pacm [0,1,2] [(0,frm),(1,Neg frm),(2,Top)]
    ([(a, 0, [])|a <- all_agents ] ++
     [(a, 1, [])|a <- all_agents] ++ [(a, 2, [])|a <- all_agents])
    ([(a, 0, 0) | a <- all_agents] ++ [(a, 0,1) | a <- all_agents
       \\ agents] ++ [(a, 0,2) | a <- all_agents \\ agents]
       ++ [(a,1,0) | a <- all_agents \\ agents] ++
       [(a,1,2)| a <- all_agents \\ agents] ++
       [(a,1,1) | a <- all_agents] ++ [(a, 2,0) | a <- all_agents
       \\ agents] ++ [(a,2,1)| a <- all_agents \\ agents] ++
       [(a,2,2)|a<-all_agents])
    [0]
```

– The definition of the action "see" and its action model

```
see :: [Agent] -> EpistM -> Form -> EpistM
see agents m form = upd m (actSee agents form)

actSee :: [Agent] -> Form -> PoACM State
actSee agents frm =
   Pacm [0,1,2] [(0,frm),(1,Neg frm),(2,Top)]
    ([(a, 0, [([Top], frm)])| a <- agents] ++
    [(a, 0, [])|a <- all_agents \\ agents] ++
    [(a, 1, [([Top], Neg frm)])| a <- agents] ++
    [(a, 1, [])|a <- all_agents \\ agents] ++
    [(a, 2, [])|a <- all_agents])
    ([(a, 0, 0) | a <- all_agents] ++
    [(a, 0,1) | a <- all_agents \\ agents]
    ++ [(a, 0,2) | a <- all_agents \\ agents]
    ++ [(a,1,0) | a <- all_agents \\ agents]
    ++ [(a,1,2)| a <- all_agents \\ agents]
    ++  [(a,1,1) | a <- all_agents]
    ++ [(a, 2,0) | a <- all_agents \\ agents]
    ++ [(a,2,1)| a <- all_agents \\ agents]
    ++ [(a,2,2)|a<-all_agents])
    [0]
```

– The definition of the action "infer" and its action model

```
doInfer :: Agent -> EpistM -> [(State,[Form])] -> EpistM
doInfer agent m [] = m
```

```
doInfer agent m (x:xs)
    | isInfer x x  m /= (Top, Top) = upd m (inference agent conds consq)
    | otherwise = doInfer agent m xs
    where
        conds = fst(isInfer x x m)
        consq = snd(isInfer x x m)

infer1 :: Agent -> EpistM -> EpistM
infer1 agent m@(Pmod worlds val aw rel points)
    | isIntmed awofsts' m =  doInfer agent m awofsts'
    | otherwise = m
    where
        awofsts' = totalfrm agent m

inferN :: Agent -> EpistM -> EpistM
inferN agent m
    | isIntmed (totalfrm agent m) m &&
          not(null((totalfrm agent (infer1 agent m))
          \\ (totalfrm agent m)))
          = inferN agent (infer1 agent m)
    | otherwise = m
```

Appendix C

The calculated final epistemic models of the precedents

C.1 Aggravation of punishment (Case 1)

The dot graph of this model is as follows in FIGURE C.1.

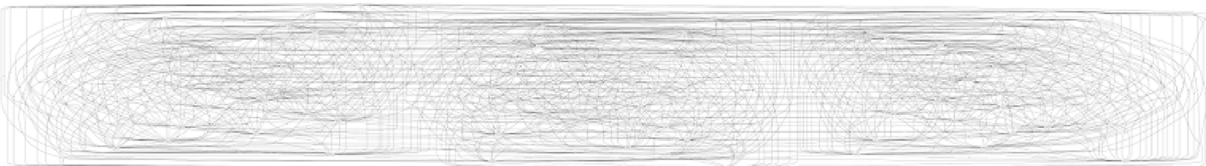

FIGURE C.1: The epistemic model after the common background is set

The model is described as follows. Here the first list [ ] next to "==>" indicates the actual worlds and the second list indicates the all states and third tuples mean the propositions which are true at the state.The forth tuple of *d* means the awareness formula for agent *d* and fifth tuple of *j* means the awareness formula for agent *j*. The sixth tuple of agent *d* indicates the equivalence relation for agent *d* and seventh tuple of agent *j* indicates the equivalence relation for agent *j*.

```
==> [36]
[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,
27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49,50,
51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,74,
75,76,77,78,79,80,81,82,83,84,85,86]
(0,[p,q])(1,[p,q])(2,[p,q])(3,[p,q])(4,[p,q])(5,[p,q])(6,[p,q])(7,[p,q])
(8,[p,q])(9,[p,q])(10,[p,q])(11,[p,q])(12,[p,q])(13,[p,q])(14,[p,q])(15,
[p,q])(16,[p,q])(17,[p,q])(18,[p,q,s])(19,[p,q,s])(20,[p,q,s])(21,[p,q,s
])(22,[p,q,s])(23,[p,q,s])(24,[p,q,s])(25,[p,q,s])(26,[p,q,s])(27,[p,q,s
])(28,[p,q,s])(29,[p,q,s])(30,[p,q,s])(31,[p,q,s])(32,[p,q,s])(33,[p,q,s
])(34,[p,q,s])(35,[p,q,s])(36,[p,q,r,s])(37,[p,q,r,s])(38,[p,q,r,s])(39,
[p,q,r,s])(40,[p,q,r,s])(41,[p,q,r,s])(42,[p,q,r,s])(43,[p,q,r,s])(44,[p,
q,r,s])(45,[p,q,r,s])(46,[p,q,r,s])(47,[p,q,r,s])(48,[p,q,r,s])(49,[p,q,
r,s])(50,[p,q,r,s])(51,[p,q,r,s])(52,[p,q,r,s])(53,[p,q,r,s])(54,[p,q,r,
s])(55,[p,q,r,s])(56,[p,q,r,s])(57,[p,q,r,s])(58,[p,q,r,s])(59,[p,q,r,s]
)(60,[p,q,r,s])(61,[p,q,r,s])(62,[p,q,r,s])(63,[p,q,r,s])(64,[p,q,r,s])(
65,[p,q,r,s])(66,[p,q,r,s])(67,[p,q,r,s])(68,[p,q,r,s])(69,[p,q,r,s])(70,
[p,q,r,s])(71,[p,q,r,s])(72,[p,q,r,s])(73,[p,q,r,s])(74,[p,q,r,s])(75,[p,
q,r,s])(76,[p,q,r,s])(77,[p,q,r,s])(78,[p,q,r,s])(79,[p,q,r,s])(80,[p,q,
```

```
r,s])(81,[p,q,r,s])(82,[p,q,r,s])(83,[p,q,r,s])(84,[p,q,r,s])(85,[p,q,r,
s])(86,[p,q,r,s])
(a,0,[p,q,v[-p,q],v[-r,s]])(a,1,[p,q,v[-p,q],v[-r,s]])(a,2,[p,q,v[-p,q],
v[-r,s]])(a,3,[p,q,v[-p,q],v[-r,s]])(a,4,[p,q,v[-p,q],v[-r,s]])(a,5,[p,q,
v[-p,q],v[-r,s]])(a,6,[p,v[-p,q],v[-r,s]])(a,7,[p,v[-p,q],v[-r,s]])(a,8,
[p,v[-p,q],v[-r,s]])(a,9,[p,v[-p,q],v[-r,s]])(a,10,[p,v[-p,q],v[-r,s]])(
a,11,[p,v[-p,q],v[-r,s]])(a,12,[p,v[-r,s]])(a,13,[p,v[-r,s]])(a,14,[p,v[
-r,s]])(a,15,[p,v[-r,s]])(a,16,[p,v[-r,s]])(a,17,[p,v[-r,s]])(a,18,[p,q,
v[-p,q],v[-r,s]])(a,19,[p,q,v[-p,q],v[-r,s]])(a,20,[p,q,v[-p,q],v[-r,s]]
)(a,21,[p,q,v[-p,q],v[-r,s]])(a,22,[p,q,v[-p,q],v[-r,s]])(a,23,[p,q,v[-p,
q],v[-r,s]])(a,24,[p,v[-p,q],v[-r,s]])(a,25,[p,v[-p,q],v[-r,s]])(a,26,[p,
v[-p,q],v[-r,s]])(a,27,[p,v[-p,q],v[-r,s]])(a,28,[p,v[-p,q],v[-r,s]])(a,
29,[p,v[-p,q],v[-r,s]])(a,30,[p,v[-r,s]])(a,31,[p,v[-r,s]])(a,32,[p,v[-r,
s]])(a,33,[p,v[-r,s]])(a,34,[p,v[-r,s]])(a,35,[p,v[-r,s]])(a,36,[p,q,v[-
p,q],v[-r,s]])(a,37,[p,q,v[-p,q],v[-r,s]])(a,38,[p,q,v[-p,q],v[-r,s]])(a,
39,[p,q,v[-p,q],v[-r,s]])(a,40,[p,q,v[-p,q],v[-r,s]])(a,41,[p,q,v[-p,q],
v[-r,s]])(a,42,[p,q,v[-p,q],v[-r,s]])(a,43,[p,q,v[-p,q],v[-r,s]])(a,44,[
p,q,v[-p,q],v[-r,s]])(a,45,[p,q,v[-p,q],v[-r,s]])(a,46,[p,q,v[-p,q],v[-r,
s]])(a,47,[p,q,v[-p,q],v[-r,s]])(a,48,[p,q,v[-p,q],v[-r,s]])(a,49,[p,q,v
[-p,q],v[-r,s]])(a,50,[p,q,v[-p,q],v[-r,s]])(a,51,[p,q,v[-p,q],v[-r,s]])
(a,52,[p,q,v[-p,q],v[-r,s]])(a,53,[p,v[-p,q],v[-r,s]])(a,54,[p,v[-p,q],v
[-r,s]])(a,55,[p,v[-p,q],v[-r,s]])(a,56,[p,v[-p,q],v[-r,s]])(a,57,[p,v[-
p,q],v[-r,s]])(a,58,[p,v[-p,q],v[-r,s]])(a,59,[p,v[-p,q],v[-r,s]])(a,60,
[p,v[-p,q],v[-r,s]])(a,61,[p,v[-p,q],v[-r,s]])(a,62,[p,v[-p,q],v[-r,s]])
(a,63,[p,v[-p,q],v[-r,s]])(a,64,[p,v[-p,q],v[-r,s]])(a,65,[p,v[-p,q],v[-
r,s]])(a,66,[p,v[-p,q],v[-r,s]])(a,67,[p,v[-p,q],v[-r,s]])(a,68,[p,v[-p,
q],v[-r,s]])(a,69,[p,v[-p,q],v[-r,s]])(a,70,[p,v[-r,s]])(a,71,[p,v[-r,s]
])(a,72,[p,v[-r,s]])(a,73,[p,v[-r,s]])(a,74,[p,v[-r,s]])(a,75,[p,v[-r,s]
])(a,76,[p,v[-r,s]])(a,77,[p,v[-r,s]])(a,78,[p,v[-r,s]])(a,79,[p,v[-r,s]
])(a,80,[p,v[-r,s]])(a,81,[p,v[-r,s]])(a,82,[p,v[-r,s]])(a,83,[p,v[-r,s]
])(a,84,[p,v[-r,s]])(a,85,[p,v[-r,s]])(a,86,[p,v[-r,s]])
(j,0,[p,q,-v[-q,r],v[-p,q],v[-r,s]])(j,1,[p,-v[-q,r],v[-p,q],v[-r,s]])(j,
2,[p,q,v[-p,q],v[-r,s]])(j,3,[p,v[-p,q],v[-r,s]])(j,4,[p,-v[-q,r],v[-r,s
]])(j,5,[p,v[-r,s]])(j,6,[p,q,-v[-q,r],v[-p,q],v[-r,s]])(j,7,[p,-v[-q,r],
v[-p,q],v[-r,s]])(j,8,[p,q,v[-p,q],v[-r,s]])(j,9,[p,v[-p,q],v[-r,s]])(j,
10,[p,-v[-q,r],v[-r,s]])(j,11,[p,v[-r,s]])(j,12,[p,q,-v[-q,r],v[-p,q],v[
-r,s]])(j,13,[p,-v[-q,r],v[-p,q],v[-r,s]])(j,14,[p,q,v[-p,q],v[-r,s]])(j,
15,[p,v[-p,q],v[-r,s]])(j,16,[p,-v[-q,r],v[-r,s]])(j,17,[p,v[-r,s]])(j,1
8,[p,q,-v[-q,r],v[-p,q],v[-r,s]])(j,19,[p,-v[-q,r],v[-p,q],v[-r,s]])(j,2
0,[p,q,v[-p,q],v[-r,s]])(j,21,[p,v[-p,q],v[-r,s]])(j,22,[p,-v[-q,r],v[-r,
s]])(j,23,[p,v[-r,s]])(j,24,[p,q,-v[-q,r],v[-p,q],v[-r,s]])(j,25,[p,-v[-
q,r],v[-p,q],v[-r,s]])(j,26,[p,q,v[-p,q],v[-r,s]])(j,27,[p,v[-p,q],v[-r,
s]])(j,28,[p,-v[-q,r],v[-r,s]])(j,29,[p,v[-r,s]])(j,30,[p,q,-v[-q,r],v[-
p,q],v[-r,s]])(j,31,[p,-v[-q,r],v[-p,q],v[-r,s]])(j,32,[p,q,v[-p,q],v[-r,
s]])(j,33,[p,v[-p,q],v[-r,s]])(j,34,[p,-v[-q,r],v[-r,s]])(j,35,[p,v[-r,s
]])(j,36,[p,q,r,s,v[-p,q],v[-q,r],v[-r,s]])(j,37,[p,q,r,v[-p,q],v[-q,r],
v[-r,s]])(j,38,[p,q,v[-p,q],v[-q,r],v[-r,s]])(j,39,[p,q,v[-p,q],v[-q,r],
v[-r,s]])(j,40,[p,v[-p,q],v[-q,r],v[-r,s]])(j,41,[p,v[-p,q],v[-q,r],v[-r,
s]])(j,42,[p,q,v[-p,q],v[-r,s]])(j,43,[p,q,v[-p,q],v[-r,s]])(j,44,[p,q,v
[-p,q],v[-r,s]])(j,45,[p,v[-p,q],v[-r,s]])(j,46,[p,v[-p,q],v[-r,s]])(j,4
7,[p,v[-p,q],v[-r,s]])(j,48,[p,v[-q,r],v[-r,s]])(j,49,[p,v[-q,r],v[-r,s]
])(j,50,[p,v[-r,s]])(j,51,[p,v[-r,s]])(j,52,[p,v[-r,s]])(j,53,[p,q,r,s,v
[-p,q],v[-q,r],v[-r,s]])(j,54,[p,q,r,v[-p,q],v[-q,r],v[-r,s]])(j,55,[p,q,
v[-p,q],v[-q,r],v[-r,s]])(j,56,[p,q,v[-p,q],v[-q,r],v[-r,s]])(j,57,[p,v[
-p,q],v[-q,r],v[-r,s]])(j,58,[p,v[-p,q],v[-q,r],v[-r,s]])(j,59,[p,q,v[-p,
q],v[-r,s]])(j,60,[p,q,v[-p,q],v[-r,s]])(j,61,[p,q,v[-p,q],v[-r,s]])(j,6
2,[p,v[-p,q],v[-r,s]])(j,63,[p,v[-p,q],v[-r,s]])(j,64,[p,v[-p,q],v[-r,s]
])(j,65,[p,v[-q,r],v[-r,s]])(j,66,[p,v[-q,r],v[-r,s]])(j,67,[p,v[-r,s]])
```

```
(j,68,[p,v[-r,s]])(j,69,[p,v[-r,s]])(j,70,[p,q,r,s,v[-p,q],v[-q,r],v[-r,
s]])(j,71,[p,q,r,v[-p,q],v[-q,r],v[-r,s]])(j,72,[p,q,v[-p,q],v[-q,r],v[-
r,s]])(j,73,[p,q,v[-p,q],v[-q,r],v[-r,s]])(j,74,[p,v[-p,q],v[-q,r],v[-r,
s]])(j,75,[p,v[-p,q],v[-q,r],v[-r,s]])(j,76,[p,q,v[-p,q],v[-r,s]])(j,77,
[p,q,v[-p,q],v[-r,s]])(j,78,[p,q,v[-p,q],v[-r,s]])(j,79,[p,v[-p,q],v[-r,
s]])(j,80,[p,v[-p,q],v[-r,s]])(j,81,[p,v[-p,q],v[-r,s]])(j,82,[p,v[-q,r],
v[-r,s]])(j,83,[p,v[-q,r],v[-r,s]])(j,84,[p,v[-r,s]])(j,85,[p,v[-r,s]])(
j,86,[p,v[-r,s]])
(a,[[0,1,2,3,4,5,18,19,20,21,22,23,36,37,38,39,40,41,42,43,44,45,46,47,4
8,49,50,51,52],[6,7,8,9,10,11,24,25,26,27,28,29,53,54,55,56,57,58,59,60,
61,62,63,64,65,66,67,68,69],[12,13,14,15,16,17,30,31,32,33,34,35,70,71,7
2,73,74,75,76,77,78,79,80,81,82,83,84,85,86]])
(j,[[0,6,12,18,24,30],[1,7,13,19,25,31],[2,8,14,20,26,32,44,61,78],[3,9,
15,21,27,33,47,64,81],[4,10,16,22,28,34],[5,11,17,23,29,35,52,69,86],[36,
53,70],[37,54,71],[38,55,72],[39,56,73],[40,57,74],[41,58,75],[42,59,76],
[43,60,77],[45,62,79],[46,63,80],[48,65,82],[49,66,83],[50,67,84],[51,68,
85]])
```

C.2 *Dolus eventualis*/Generalized intention (Case 3/4)

The model is described as follows. Here the first list [ ] next to "==>" indicates the actual worlds and the second list indicates the all states and third tuples mean the propositions which are true at the state.The forth tuple of *d* means the awareness formula for agent *d* and fifth tuple of *j* means the awareness formula for agent *j*. The sixth tuple of agent *d* indicates the equivalence relation for agent *d* and seventh tuple of agent *j* indicates the equivalence relation for agent *j*.

```
==> [36][0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,
25,26,27,28,29,30,31,32,33,34,35,36,37,38,39,40,41,42,43,44,45,46,47,48,49
,50,51,52,53,54,55,56,57,58,59,60,61,62,63,64,65,66,67,68,69,70,71,72,73,7
4,75,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95](0,[q])(1
,[q])(2,[q])(3,[q])(4,[q])
(5,[q])(6,[q])(7,[q])(8,[q])(9,[q])
(10,[q])(11,[q])(12,[q,r])(14,[q,r])(13,[q,r])
(15,[q,r])(16,[q,r])(17,[q,r])(18,[q,r])(19,[q,r])
(20,[q,r])(22,[q,r])(21,[q,r])(23,[q,r])(24,[q,r])
(25,[q,r])(26,[q,r])(27,[q,r])(28,[q,r])(30,[q,r])
(29,[q,r])(31,[q,r])(32,[q,r])(33,[q,r])(34,[q,r])
(35,[q,r])(36,[p,q,r])(37,[p,q,r])(38,[p,q,r])(39,[p,q,r])
(40,[p,q,r])(41,[p,q,r])(42,[p,q,r])(45,[p,q,r])(43,[p,q,r])
(46,[p,q,r])(44,[p,q,r])(47,[p,q,r])(48,[p,q,r])(49,[p,q,r])
(50,[p,q,r])(51,[p,q,r])(52,[p,q,r])(53,[p,q,r])(54,[p,q,r])
(55,[p,q,r])(56,[p,q,r])(57,[p,q,r])(58,[p,q,r])(59,[p,q,r])
(60,[p,q,r])(61,[p,q,r])(62,[p,q,r])(65,[p,q,r])(63,[p,q,r])
(66,[p,q,r])(64,[p,q,r])(67,[p,q,r])(68,[p,q,r])(69,[p,q,r])
(70,[p,q,r])(71,[p,q,r])(72,[p,q,r])(73,[p,q,r])(74,[p,q,r])
(75,[p,q,r])(76,[p,q,r])(77,[p,q,r])(78,[p,q,r])(79,[p,q,r])
(80,[p,q,r])(81,[p,q,r])(82,[p,q,r])(85,[p,q,r])(83,[p,q,r])
(86,[p,q,r])(84,[p,q,r])(87,[p,q,r])(88,[p,q,r])(89,[p,q,r])
(90,[p,q,r])(91,[p,q,r])(92,[p,q,r])(93,[p,q,r])(94,[p,q,r])
(95,[p,q,r])
(d,0,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,1,[q,v[-p,r],
v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,2,[q,v[-p,r],v[-p,v[-q,r]],v[
-q,v[-p,r]],v[-&[p,q],r]])(d,3,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&
[p,q],r]])(d,4,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
```

```
(d,5,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,6,[q,v[-p,v[-q,r]],v[
-q,v[-p,r]],v[-&[p,q],r]])(d,7,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]
])(d,8,[q])(d,9,[q])
(d,10,[q])(d,11,[q])(d,12,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,14,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,13,[q,v
[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,15,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,16,[q,v[-p,r
],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,17,[q,v[-p,r],v[-p,v[-q,r]]
,v[-q,v[-p,r]],v[-&[p,q],r]])(d,18,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],
v[-&[p,q],r]])(d,19,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,20,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,22,[q,v[-p,v[-q,r]],
v[-q,v[-p,r]],v[-&[p,q],r]])(d,21,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,23,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,24,[q,v[-p,v[-q
,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,25,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,26,[q,v[-p,v[-q,r]],
v[-q,v[-p,r]],v[-&[p,q],r]])(d,27,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,28,[q])(d,30,[q])
(d,29,[q])(d,31,[q])(d,32,[q])(d,33,[q])(d,34,[q])
(d,35,[q])(d,36,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,37
,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,38,[q,v[-p,r],v[-
p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,39,[q,v[-p,r],v[-p,v[-q,r]],v[-q
,v[-p,r]],v[-&[p,q],r]])
(d,40,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,41,[q,v[-p,r
],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,42,[q,v[-p,r],v[-p,v[-q,r]]
,v[-q,v[-p,r]],v[-&[p,q],r]])(d,45,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],
v[-&[p,q],r]])(d,43,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,46,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,44,[q,v[-p,r
],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,47,[q,v[-p,r],v[-p,v[-q,r]]
,v[-q,v[-p,r]],v[-&[p,q],r]])(d,48,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],
v[-&[p,q],r]])(d,49,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,50,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,51,[q,v[-p,r
],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,52,[q,v[-p,r],v[-p,v[-q,r]]
,v[-q,v[-p,r]],v[-&[p,q],r]])(d,53,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],
v[-&[p,q],r]])(d,54,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,55,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,56,[q,v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,57,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v
[-&[p,q],r]])(d,58,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,59,[q,v
[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,60,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,61,[q,v[-p,v[-q,r]],
v[-q,v[-p,r]],v[-&[p,q],r]])(d,62,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,65,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,63,[q,v[-p,v[-q
,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,66,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,64,[q,v[-p,v[-q,r]],
v[-q,v[-p,r]],v[-&[p,q],r]])(d,67,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,68,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,69,[q,v[-p,v[-q
,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,70,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,71,[q,v[-p,v[-q,r]],
v[-q,v[-p,r]],v[-&[p,q],r]])(d,72,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q]
,r]])(d,73,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,74,[q,v[-p,v[-q
,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(d,75,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(d,76,[q])(d,77,[q])(d,
78,[q])(d,79,[q])
(d,80,[q])(d,81,[q])(d,82,[q])(d,85,[q])(d,83,[q])
(d,86,[q])(d,84,[q])(d,87,[q])(d,88,[q])(d,89,[q])
(d,90,[q])(d,91,[q])(d,92,[q])(d,93,[q])(d,94,[q])
(d,95,[q])(j,0,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,1,[
q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,2,[q])(j,3,[q])
(j,4,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,5,[q,v[-p,v[-
```

```
q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,6,[q])(j,7,[q])(j,8,[q,v[-p,r],v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(j,9,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,10,[q])(j,11,[q])(j,1
2,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,14,[q,v[-p,v[-q,
r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(j,13,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,15,[q,v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,16,[q])(j,17,[q])(j,18,[q])
(j,19,[q])(j,20,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,22
,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,21,[q,v[-p,r],v[-p,v[-q,r
]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,23,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p
,q],r]])
(j,24,[q])(j,25,[q])(j,26,[q])(j,27,[q])(j,28,[q,v[-p,r],v[-p,v[-q,r]],v[-
q,v[-p,r]],v[-&[p,q],r]])
(j,30,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,29,[q,v[-p,r],v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,31,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v
[-&[p,q],r]])(j,32,[q])(j,33,[q])
(j,34,[q])(j,35,[q])(j,36,[p,q,r,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r
]],v[-&[p,q],r]])(j,37,[p,q,r,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q
],r]])(j,38,[p,q,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]]
)
(j,39,[p,q,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]])(j,40,[p,q,v[
-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,41,[p,q,v[-p,v[-q,r]],v
[-q,v[-p,r]],v[-&[p,q],r]])(j,42,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[
-&[p,q],r]])(j,45,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(j,43,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,46,[q,v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,44,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[
-p,r]],v[-&[p,q],r]])(j,47,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j
,48,[p,q])
(j,49,[p,q])(j,50,[q])(j,51,[q])(j,52,[q])(j,53,[q])
(j,54,[q])(j,55,[q])(j,56,[p,q,r,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r
]],v[-&[p,q],r]])(j,57,[p,q,r,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q
],r]])(j,58,[p,q,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]]
)
(j,59,[p,q,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]])(j,60,[p,q,v[
-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,61,[p,q,v[-p,v[-q,r]],v
[-q,v[-p,r]],v[-&[p,q],r]])(j,62,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[
-&[p,q],r]])(j,65,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(j,63,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,66,[q,v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,64,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[
-p,r]],v[-&[p,q],r]])(j,67,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j
,68,[p,q])
(j,69,[p,q])(j,70,[q])(j,71,[q])(j,72,[q])(j,73,[q])
(j,74,[q])(j,75,[q])(j,76,[p,q,r,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r
]],v[-&[p,q],r]])(j,77,[p,q,r,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q
],r]])(j,78,[p,q,v[-p,r],v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]]
)
(j,79,[p,q,v[-p,v[-q,r]],v[-q,r],v[-q,v[-p,r]],v[-&[p,q],r]])(j,80,[p,q,v[
-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,81,[p,q,v[-p,v[-q,r]],v
[-q,v[-p,r]],v[-&[p,q],r]])(j,82,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[
-&[p,q],r]])(j,85,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])
(j,83,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,86,[q,v[-p,v
[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j,84,[q,v[-p,r],v[-p,v[-q,r]],v[-q,v[
-p,r]],v[-&[p,q],r]])(j,87,[q,v[-p,v[-q,r]],v[-q,v[-p,r]],v[-&[p,q],r]])(j
,88,[p,q])
(j,89,[p,q])(j,90,[q])(j,91,[q])(j,92,[q])(j,93,[q])
(j,94,[q])(j,95,[q])
(d,[[0,1,2,3,12,13,14,15,16,17,18,19,36,37,38,39,40,41,42,43,44,45,46,47,4
8,49,50,51,52,53,54,55],[4,5,6,7,20,21,22,23,24,25,26,27,56,57,58,59,60,61
```

```
,62,63,64,65,66,67,68,69,70,71,72,73,74,75],[8,9,10,11,28,29,30,31,32,33,3
4,35,76,77,78,79,80,81,82,83,84,85,86,87,88,89,90,91,92,93,94,95]])
(j,[[0,4,8,13,21,29,44,64,84],[1,5,9,15,23,31,47,67,87],[2,6,10,18,26,34,5
4,74,94],[3,7,11,19,27,35,55,75,95],[12,20,28,43,63,83],[14,22,30,46,66,86
],[16,24,32,52,72,92],[17,25,33,53,73,93],[36,56,76],[37,57,77],[38,58,78]
,[39,59,79],[40,60,80],[41,61,81],[42,62,82],[45,65,85],[48,68,88],[49,69,
89],[50,70,90],[51,71,91]])
```

C.3 Negligence (Case 5)

The calculated model is describe as follow. Here the first list [ ] next to "==>" indicates the actual worlds and the second list indicates the all states and third tuples mean the propositions which are true at the state.The forth tuple of *d* means the awareness formula for agent *d* and fifth tuple of *j* means the awareness formula for agent *j*. The sixth tuple of agent *d* indicates the equivalence relation for agent *d* and seventh tuple of agent *j* indicates the equivalence relation for agent *j*.

```
==> [8][0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21](0,[])(1,[
])(2,[r])(3,[r])(4,[q,r])
(5,[q,r])(6,[q,r])(7,[q,r])(8,[p,q,r])(9,[p,q,r])
(10,[p,q,r])(11,[p,q,r])(12,[p,q,r])(13,[p,q,r])(14,[p,q,r])
(15,[p,q,r])(16,[p,q,r])(17,[p,q,r])(18,[p,q,r])(19,[p,q,r])
(20,[p,q,r])(21,[p,q,r])
(d,0,[v[-q,r]])(d,1,[v[-q,r]])(d,2,[v[-q,r]])(d,3,[v[-q,r]])(d,4,[v[-q,r]]
)
(d,5,[v[-q,r]])(d,6,[v[-q,r]])(d,7,[v[-q,r]])(d,8,[v[-q,r]])(d,9,[v[-q,r]]
)
(d,10,[v[-q,r]])(d,11,[v[-q,r]])(d,12,[v[-q,r]])(d,13,[v[-q,r]])(d,14,[v[-
q,r]])
(d,15,[v[-q,r]])(d,16,[v[-q,r]])(d,17,[v[-q,r]])(d,18,[v[-q,r]])(d,19,[v[-
q,r]])
(d,20,[v[-q,r]])(d,21,[v[-q,r]])(j,0,[v[-p,q],v[-q,r]])(j,1,[v[-q,r]])(j,2
,[v[-p,q],v[-q,r]])
(j,3,[v[-q,r]])(j,4,[v[-p,q],v[-q,r]])(j,5,[v[-p,q],v[-q,r]])(j,6,[v[-q,r]
])(j,7,[v[-q,r]])
(j,8,[p,q,r,v[-p,q],v[-q,r]])(j,9,[p,q,v[-p,q],v[-q,r]])(j,10,[p,v[-p,q],v
[-q,r]])(j,11,[p,v[-p,q],v[-q,r]])(j,12,[p,v[-q,r]])
(j,13,[p,v[-q,r]])(j,14,[v[-p,q],v[-q,r]])(j,15,[v[-p,q],v[-q,r]])(j,16,[v
[-p,q],v[-q,r]])(j,17,[v[-p,q],v[-q,r]])
(j,18,[v[-q,r]])(j,19,[v[-q,r]])(j,20,[v[-q,r]])(j,21,[v[-q,r]])
(d,[[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21]])
(j,[[0,2,5,17],[1,3,7,21],[4,16],[6,20],[8],[9],[10],[11],[12],[13],[14],[
15],[18],[19]])
```

C.4 Innocent case (Case 8)

The calculated model is described as follows. Here the first list [ ] next to "==>" indicates the actual worlds and the second list indicates the all states and third tuples mean the propositions which are true at the state.The forth tuple of *a* means the awareness formula for agent *a* and fifth tuple of *a* means the awareness formula for agent *j*. The sixth tuple of agent *a* indicates the equivalence relation for agent *a* and seventh tuple of agent *j* indicates the equivalence relation for agent *j*.

```
==> [21][0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,
25,26,27,28](0,[])(1,[p])(2,[p])(3,[p])(4,[p])
(5,[q])(6,[q])(7,[s])(8,[p,s])(9,[p,s])
(10,[p,s])(11,[p,s])(12,[q,s])(13,[q,s])(14,[r,s])
(15,[p,r,s])(16,[p,r,s])(17,[p,r,s])(18,[p,r,s])(19,[q,r,s])
(20,[q,r,s])(21,[p,q,r,s])(23,[p,q,r,s])(22,[p,q,r,s])(24,[p,q,r,s])
(25,[p,q,r,s])(27,[p,q,r,s])(26,[p,q,r,s])(28,[p,q,r,s])
(d,0,[v[-r,s]])(d,1,[v[-r,s]])(d,2,[v[-r,s]])(d,3,[v[-r,s]])(d,4,[v[-r,s]]
)
(d,5,[v[-r,s]])(d,6,[v[-r,s]])(d,7,[v[-r,s]])(d,8,[v[-r,s]])(d,9,[v[-r,s]]
)
(d,10,[v[-r,s]])(d,11,[v[-r,s]])(d,12,[v[-r,s]])(d,13,[v[-r,s]])(d,14,[v[-
r,s]])
(d,15,[v[-r,s]])(d,16,[v[-r,s]])(d,17,[v[-r,s]])(d,18,[v[-r,s]])(d,19,[v[-
r,s]])
(d,20,[v[-r,s]])(d,21,[v[-r,s]])(d,23,[v[-r,s]])(d,22,[v[-r,s]])(d,24,[v[-
r,s]])
(d,25,[v[-r,s]])(d,27,[v[-r,s]])(d,26,[v[-r,s]])(d,28,[v[-r,s]])(j,0,[v[-r
,s]])
(j,1,[p,v[-r,s]])(j,2,[p,v[-r,s]])(j,3,[v[-r,s]])(j,4,[v[-r,s]])(j,5,[q,v[
-r,s]])
(j,6,[v[-r,s]])(j,7,[v[-r,s]])(j,8,[p,v[-r,s]])(j,9,[p,v[-r,s]])(j,10,[v[-
r,s]])
(j,11,[v[-r,s]])(j,12,[q,v[-r,s]])(j,13,[v[-r,s]])(j,14,[v[-r,s]])(j,15,[p
,v[-r,s]])
(j,16,[p,v[-r,s]])(j,17,[v[-r,s]])(j,18,[v[-r,s]])(j,19,[q,v[-r,s]])(j,20,
[v[-r,s]])
(j,21,[p,q,v[-r,s]])(j,23,[p,v[-r,s]])(j,22,[p,q,v[-r,s]])(j,24,[p,v[-r,s]
])(j,25,[q,v[-r,s]])
(j,27,[v[-r,s]])(j,26,[q,v[-r,s]])(j,28,[v[-r,s]])
(d,[[0,2,4,5,6,7,9,11,12,13,14,16,18,19,20,22,24,26,28],[1,3,8,10,15,17,21
,23,25,27]])
(j,[[0,3,4,6,7,10,11,13,14,17,18,20,27,28],[1,2,8,9,15,16,23,24],[5,12,19,
25,26],[21,22]])
```

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