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Labelled Sequent Calculi for Dynamic Epistemic Logics

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Abstract

Dynamic Epistemic Logic (DEL) is a field of modern epistemic logic that aims at formally expressing the change of human knowledge through modifying Kripke models which represent the state of agents' knowledge. For example, if an agent called John does not know if it will rain tomorrow and he gets information from a weather forecast on TV which informs that it will rain tomorrow, then he is now not ignorant of the condition of tomorrow's weather (i.e., his knowledge-state was changed by the information on TV). This is a typical example of public announcement (public information), and *Public Announcement Logic* (PAL) by Plaza (1989) can formally express such a situation regarding the knowledge-change of agents. PAL became the basis of other DELs and we also started to investigate labelled sequent calculus from PAL. In addition to public announcements, information is not always shared among all agents (it is not always public) and it is totally possible to imagine that some information is for only a single agent (private announcement) or for a specific group of agents. PAL can cope with only public announcement (information), but *Logic of Epistemic Actions and Knowledge* (EAK) by Baltag et al. (1989) is a logic for the formal expression of such information flows which are more delicate than public announcements. EAK is a generalized and developed version of PAL and our second target is this epistemic logic. On the other hand, the term knowledge has philosophically profound meanings, and historically, the notion of knowledge contains evidence or verification to justify one's belief. Intuitionistic epistemic logics are candidates which express knowledge in a strict sense. Based on the intuitionistic modal logic IK by Fischer Servi (1984) and Simpson (1994), *Intuitionistic PAL* (IntPAL)—an intuitionistic version of PAL—is proposed by Ma et al. (2014), and this enables us to express the change of knowledge defined in a strict sense.

In this thesis, we provide three different cut-free labelled sequent calculi for PAL, EAK and IntPAL respectively. First, we investigate an existing labelled sequent calculus for PAL and this investigation becomes an important foundation for the three labelled sequent calculi of ours with respect to the soundness theorems, the completeness theorems and the cut-elimination theorems for other labelled systems. A labelled sequent calculus **G3PAL** for PAL is provided by Maffezoli and Negri (2011), but it in

fact lacks inference rules for deriving an axiom of the Hilbert-system of PAL. So, we provide our revised calculus **GPAL**, and all the formulas derivable by Hilbert-system of PAL are also derivable in **GPAL** together with the cut rule. We also establish the cut elimination theorem. Moreover, we show the soundness of our calculus for Kripke semantics with the notion of survivence of possible worlds in a restricted domain. Then we provide a direct proof of the semantic completeness of **GPAL** for the link-cutting semantics of PAL.

Secondly, we move onto EAK based on the study of labelled sequent calculus for PAL. We also provide a cut-free labelled sequent calculus (**GEAK**) on the background of existing studies of the Hilbert-system (we call it **HEAK**) and labelled calculi for PAL. Similar to the previous procedure, we first show that all the formulas derivable by the Hilbert-system of EAK are also derivable in **GEAK** with the cut rule, and we show that the cut rule is eliminable in **GEAK**. Then we show **GEAK** is sound for Kripke semantics. After demonstrating that soundness, we derive the semantic completeness of **GIntPAL** as a corollary of these theorems

Thirdly and lastly, we introduce a labelled sequent calculus **GIntPAL** for IntPAL. Following the same manner of the construction of a labelled sequent calculus as the previous two, we show that all theorems of the Hilbert-system of IntPAL are also derivable in **GIntPAL** with the cut rule. Then we prove the cut-eliminability of **GIntPAL** and also its soundness for birelational Kripke semantics, and so its completeness for the semantics.

Keywords— Dynamic Epistemic Logic, Public Announcement Logic, Intuitionistic Public Announcement Logic, Logic of Epistemic Actions and Knowledge, Labelled Sequent Calculus, Admissibility of Cut, Validity of Sequents