Katsumi Inoue
Ken Satoh
Francesca Toni (Eds.)

LNAI 4371

Computational Logic in Multi-Agent Systems

7th International Workshop, CLIMA VII
Hakodate, Japan, May 2006
Revised Selected and Invited Papers

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Library of Congress Control Number: 2006939322

CR Subject Classification (1998): I.2.11, I.2, C.2.4, F.4

LNCS Sublibrary: SL 7 – Artificial Intelligence

ISSN 0302-9743
ISBN-10 3-540-69618-0 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-69618-6 Springer Berlin Heidelberg New York

Typesetting: Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India
Printed on acid-free paper SPIN: 11972709 06/3142 5 4 3 2 1 0

Lecture Notes in Artificial Intelligence 4371

Edited by J. G. Carbonell and J. Siekmann

Subseries of Lecture Notes in Computer Science

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Preface

Multi-agent systems are communities of problem-solving entities that can perceive and act upon their environment to achieve their individual goals as well as joint goals. The work on such systems integrates many technologies and concepts in artificial intelligence and other areas of computing as well as other disciplines. Over recent years, the agent paradigm gained popularity, due to its applicability to a full spectrum of domains, from search engines to educational aids to electronic commerce and trade, e-procurement, recommendation systems, simulation and routing, to cite only some.

Computational logic provides a well-defined, general and rigorous framework for studying syntax, semantics and procedures for various tasks by individual agents, as well as interaction amongst agents in multi-agent systems, for implementations, environments, tools and standards, and for linking together specification and verification of properties of individual agents and multi-agent systems.

The CLIMA (Computational Logic in Multi-Agent Systems) workshop series aims at identifying synergies between computational logic and multi-agent systems, whereby computational logic methods, tools and techniques are used for representing, programming and reasoning about agents and multi-agent systems in a formal way.

The first workshop in this series took place in Las Cruces, New Mexico, USA, in 1999, under the designation Multi-Agent Systems in Logic Programming (MASLP 1999), and was affiliated with ICLP 1999. In the following year, the name of the workshop changed to Computational Logic in Multi-Agent Systems, and CLIMA 2000 took place in London, UK, affiliated with CL 2000. Further information about the CLIMA workshop series, with links to past and future events, is available at `http://centria.di.fct.unl.pt/~clima`.

The seventh edition of CLIMA (CLIMA VII) took place in Hakodate, Japan, on May 8–9, 2006, affiliated with AAMAS 2006. It received 29 regular submissions, of which only 14 were selected for presentation and inclusion in the preproceedings. About 30 delegates from 12 countries registered for the event, and many more AAMAS 2006 participants attended. More details about the event can be found at the workshop Web site `http://research.nii.ac.jp/climaVII/`

CLIMA VII also hosted the Second CLIMA Contest, following the first such contest at CLIMA VI. This competition is an attempt to stimulate research in the area of multi-agent systems by identifying key problems and collecting suitable benchmarks that can serve as milestones for testing new approaches and techniques from computational logics. Three groups participated in the second edition, and the winner was team brazil consisting of Rafael Bordini, Jomi Huebner, and Daniel Tralamazza. All results can be checked at `http://agentmaster.in.tu-clausthal.de/`.

This volume contains improved and revised versions of the 14 papers presented at CLIMA VII, as well as papers describing the 3 contest entries and a paper by the contest organizers presenting the contest and assessing its outcomes. All papers went through a thorough revision, with three to six reviews over two rounds.

The topics of the regular papers include agent reasoning, such as deontic reasoning, probabilistic reasoning, contextual reasoning, decision making and abduction, agent communication, such as argumentation and dialogue, agent architecture and verification of multi-agent systems. The contest papers describe implemented agent architectures solving the gold mining domain.

Our thanks go to the authors who responded to our initial call with very high quality submissions and revised their contribution thoroughly for inclusion in this volume. We are also grateful to the members of the CLIMA VII Program Committee for their valuable work in reviewing, discussing and re-reviewing the submitted articles. Further, we thank the organizers of the contest, Mehdi Dastani from Utrecht University, Jürgen Dix and Peter Novak from Clausthal University of Technology, for their efforts in creating a server architecture and a nice framework for the whole contest. Finally, we are grateful to our sponsor, the National Institute of Informatics, Tokyo, Japan, for providing support for some of the CLIMA VII participants.

October 2006

Katsumi Inoue
Ken Satoh
Francesca Toni

Organization

CLIMA VII took place in Hakodate, Japan.

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Acts of Commanding and Changing Obligations

Tomoyuki Yamada

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Abstract. If we are to take the notion of speech act seriously, we must be able to treat speech acts as acts. In this paper, we will try to model changes brought about by various acts of commanding in terms of a variant of update logic. We will combine a multi-agent variant of the language of monadic deontic logic with a dynamic language to talk about the situations before and after the issuance of commands, and the commands that link those situations. Although the resulting logic inherits various inadequacies from monadic deontic logic, some interesting principles are captured and seen to be valid nonetheless. A complete axiomatization and some interesting valid principles together with concrete examples will be presented, and suggestions for further research will be made.

1 Introduction

Consider the following example:

Example 1. Suppose you are reading an article on logic in the office you share with your boss and a few other colleagues. While you are reading, the temperature of the room rises, and it is now above 30 degrees Celsius. There is a window and an air conditioner. You can open the window, or turn on the air conditioner. You can also concentrate on the article and ignore the heat. Then, suddenly, you hear your boss's voice. She commanded you to open the window. What effects does her command have on the current situation?

Your boss's act of commanding does not affect the state of the window directly. Nor does it affect the number of alternatives you have. It is still possible for you to turn on the air conditioner, to ignore the heat, or to open the window. But it has now become impossible for you to choose alternatives other than that of opening the window without going against your obligation. It is now obligatory upon you to open the window, although it was not so before.

If the notion of speech acts, or more specifically that of illocutionary acts, is to be taken seriously, it must be possible to see utterances not only as acts of uttering words but also as acts of doing something more. But speech acts do not seem to affect so called brute facts directly, except for those various physical and physiological conditions involved in the production and perception of sounds or written symbols. What differences can they bring about in our life?

In attempting to answer this question, it is important to be careful not to blur the distinction between illocutionary acts and perlocutionary acts. Since Grice [10], many philosophers, linguists, and computer scientists have talked about utterers' intentions

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to produce various changes in the attitudes of addressees in their theories of communication. But utterers' intentions usually go beyond illocutionary acts by involving perlocutionary consequences, while illocutionary acts can be effective even if they do not produce intended perlocutionary consequences. Thus, in the above example, even if you refuse to open the window in question, that will not make her command void. Your refusal would not constitute disobedience if it could make her command void. Her command is effective in a sense even if she has failed to get you to form the intention to open the window. In order to characterize effects of illocutionary acts adequately, we need to be able to isolate them from perlocutionary consequences of utterances.

It is interesting to note, in this connection, that some illocutionary acts such as commanding, forbidding, permitting, and promising seem to affect our social life by bringing about changes in the deontic status of various alternative courses of actions. Thus, in the above example, before the issuance of your boss's command, none of your three alternatives were obligatory upon you, but after the issuance, one of them has become obligatory. In what follows, we will model changes acts of commanding bring about in terms of a new update logic. We will combine a multi-agent variant of the language of monadic deontic logic with a dynamic language to talk about the situations before and after the issuance of commands, and the commands that link those situations. Although the resulting language inherits various inadequacies from the language of monadic deontic logic, some interesting principles are captured and seen to be valid nonetheless.

The idea of update logic of acts of commanding is inspired by the update logics of public announcements and private information transmissions developed in Plaza [16], Groeneveld [11], Gerbrandy & Groeneveld [9], Gerbrandy [8], Baltag, Moss, & Solecki [2], and Kooi & van Benthem [13] among others. In van Benthem [4], the logics of such epistemic actions are presented as exemplars of a view of logic as "the analysis of general informational processes: knowledge representation, giving or receiving information, argumentation, communication", and used to show "how using a 'well-known' system as a vehicle, viz. standard epistemic logic, leads to totally *new issues* right from the start"(p.33). The basic idea of the update logic of acts of commanding is to capture the workings of acts of commanding by using deontic logic instead of epistemic logic as a vehicle. This may lead to a significant extension of the range of the kind of logical analysis advocated in van Benthem [4], since acts of commanding exemplify a kind of speech acts radically different from those discussed in the logics of epistemic actions.

2 A Static Base Language $\mathcal{L}_{\mathsf{MDL}^+}$ and a Static Logic MDL^+

Let's go back to Example 1. In the situation before the command is given, it was neither obligatory upon you to open the window, nor was it so not to open it. But in the situation after your boss's act of commanding, it has become obligatory upon you to open it. In order to describe these situations, we use a language $\mathcal{L}_{\mathsf{MDL}^+}$, the Language of Multi-agent monadic Deontic Logic With an alethic modal operator, MDL^+. We represent the two situations by two models M and N with a world s for $\mathcal{L}_{\mathsf{MDL}^+}$. Thus, we can describe the difference between these situations as follows:

$$M, s \models_{\mathsf{MDL}^+} \neg O_a p \wedge \neg O_a \neg p \quad (1)$$

$$N, s \models_{\mathsf{MDL}^+} O_a p \ , \quad (2)$$

where the proposition letter p stands for the proposition that the window is open at such and such a time, say t_1. The operator O_a here is indexed by a given finite set $I = \{a, b, c, \ldots, n\}$ of agents, and the index a represents you. Intuitively, a formula of form $O_i\varphi$ means that it is obligatory upon the agent i to see to it that φ. Thus:

Definition 1. *Take a countably infinite set* Aprop *of proposition letters and a finite set I of agents, with p ranging over* Aprop *and i over I. The multi-agent monadic deontic language* $\mathcal{L}_{\mathsf{MDL}^+}$ *is given by:*

$$\varphi ::= \top \mid p \mid \neg\varphi \mid \varphi \wedge \psi \mid \Box\varphi \mid O_i\varphi$$

The set of all well formed formulas (sentences) of $\mathcal{L}_{\mathsf{MDL}^+}$ *is denoted by* S_{MDL^+} *and operators of the form* O_i *are called deontic operators. For each* $i \in I$*, we call a sentence i-free if no* O_i*'s occur in it. We call sentence alethic if no deontic operators occur in it, and boolean if no modal operators occur in it. For each* $i \in I$*, the set of all i-free sentences is denoted by* $S_{i\text{-free}}$*. The set of all alethic sentences and the set of all boolean sentences are denoted by* S_{Aleth} *and* S_{Boole} *respectively.*

$\bot$, $\vee$, $\rightarrow$, $\leftrightarrow$, and $\Diamond$ are assumed to be introduced by standard definitions. We also abbreviate $\neg O_i \neg\varphi$ as $P_i\varphi$, and $O_i\neg\varphi$ as $F_i\varphi$. Note that Aprop $\subset S_{\mathrm{Boole}} \subset S_{\mathrm{Aleth}} \subset S_{i\text{-free}} \subset S_{\mathsf{MDL}^+}$ for each $i \in I$.[1]

Definition 2. *By an* $\mathcal{L}_{\mathsf{MDL}^+}$*-model, we mean a quadruple* $M = \langle W^M, R_A^M, R_I^M, V^M \rangle$ *where:*

(i) W^M *is a non-empty set (heuristically, of 'possible worlds')*

(ii) $R_A^M \subseteq W^M \times W^M$

(iii) R_I^M *is a function that assigns a subset* $R_I^M(i)$ *of* R_A^M *to each agent* $i \in I$

(iv) V^M *is a function that assigns a subset* $V^M(p)$ *of* W^M *to each proposition letter* $p \in$ Aprop .

We usually abbreviate $R_I^M(i)$ *as* R_i^M.

Note that for any $i \in I$, R_i^M is required to be a subset of R_A^M. Thus we assume that whatever is permitted is possible.

Definition 3. *Let M be an* $\mathcal{L}_{\mathsf{MDL}^+}$*-model and w a point in M. If* $p \in Aprop$*,* $\varphi, \psi \in S_{\mathsf{MDL}^+}$*, and* $i \in I$*, then:*

(a) $M, w \models_{\mathsf{MDL}^+} p$ *iff* $w \in V^M(p)$

(b) $M, w \models_{\mathsf{MDL}^+} \top$

[1] Formally there is no difference between S_{MDL^+} and $\mathcal{L}_{\mathsf{MDL}^+}$ since a formal language can be identified with the set of its sentences. Thus we have two names for the same thing here.

(c) $M, w \models_{\mathsf{MDL}^+} \neg\varphi$ *iff it is not the case that* $M, w \models_{\mathsf{MDL}^+} \varphi$ (*hereafter,* $M, w \not\models_{\mathsf{MDL}^+} \varphi$)

(d) $M, w \models_{\mathsf{MDL}^+} (\varphi \wedge \psi)$ *iff* $M, w \models_{\mathsf{MDL}^+} \varphi$ *and* $M, w \models_{\mathsf{MDL}^+} \psi$

(e) $M, w \models_{\mathsf{MDL}^+} \Box\varphi$ *iff for every* v *such that* $\langle w, v\rangle \in R_A^M$, $M, v \models_{\mathsf{MDL}^+} \varphi$

(f) $M, w \models_{\mathsf{MDL}^+} O_i\varphi$ *iff for every* v *such that* $\langle w, v\rangle \in R_i^M$, $M, v \models_{\mathsf{MDL}^+} \varphi$.

A formula φ *is true in an* $\mathcal{L}_{\mathsf{MDL}^+}$*-model* M *at a point* w *of* M *if* $M, w \models_{\mathsf{MDL}^+} \varphi$. *We say that a set* Σ *of formulas of* $\mathcal{L}_{\mathsf{MDL}^+}$ *is true in* M *at* w, *and write* $M, w \models_{\mathsf{MDL}^+} \Sigma$, *if* $M, w \models_{\mathsf{MDL}^+} \psi$ *for every* $\psi \in \Sigma$. *If* $\Sigma \cup \{\varphi\}$ *is a set of formulas of* $\mathcal{L}_{\mathsf{MDL}^+}$, *we say that* φ *is a semantic consequence of* Σ, *and write* $\Sigma \models_{\mathsf{MDL}^+} \varphi$, *if for every* $\mathcal{L}_{\mathsf{MDL}^+}$*-model* M *and every point* w *such that* $M, w \models_{\mathsf{MDL}^+} \Sigma$, $M, w \models_{\mathsf{MDL}^+} \varphi$. *We say that a formula* φ *is valid, and write* $\models_{\mathsf{MDL}^+} \varphi$, *if* $\emptyset \models_{\mathsf{MDL}^+} \varphi$.

Intuitively, $\langle w, v\rangle \in R_i^M$ means that the world v is compatible with i's obligations at w in M. Thus, according to this semantics, it is obligatory upon i to see to it that φ at w in M iff φ holds at every world compatible with i's obligations at w in M.

Note that it is not standard to relativize obligation to agents. In dealing with moral or legal obligations, for example, it is natural to work with un-relativized obligations. But we are here trying to capture the effects of acts of commanding, and commands can be, and usually are, given to some specific addressees. In order to describe how such commands work in a situation where their addressees and non-addressees are present, it is necessary to work with a collection of accessibility relations relativized to various agents. In such multi-agent settings, we may have to talk about commands given to every individual agent in a specified group, as distinct not only from commands given to a single agent but also from commands meant for every agent, e.g. "Thou shalt not kill". And even among commands given to a group of agents, we may have to distinguish commands to be executed jointly by all the members of the group from commands to be executed individually by each of them. Although we will only consider commands given to a single agent in this paper, it doesn't seem impossible to extend our analysis to commands given to more than one agents.

A word about the use of monadic deontic operators here may be in order. Monadic deontic logics are known to be inadequate to deal with conditional obligations and R. M. Chisholm's contrary-to-duty imperative paradox; dyadic deontic logics are better in this respect. But there are still other problems which are unsolved even by dyadic deontic logics, and Åqvist [1], for example, stresses the importance of temporal and quantificational machinery to viable deontic logics. The use of the language of monadic deontic logic here does not reflect any substantial theoretical commitment. It is used to keep things as simple as possible as we are in such an early stage of the development. We will discuss some shortcomings resulting from the static nature of this language and the possibility of using different languages as vehicles later.

A word about the use of alethic modal operator may also be in order. It can be used to describe unchanging aspects of the changing situations. As we have seen in the above example, even after your boss's act of commanding, it was still possible for you to turn on the air conditioner or to ignore the heat. Thus we have:

$$M, s \models_{\mathsf{MDL}^+} \Diamond p \wedge \Diamond q \wedge \Diamond(\neg p \wedge \neg q) \tag{3}$$

$$N, s \models_{\mathsf{MDL}^+} \Diamond p \wedge \Diamond q \wedge \Diamond(\neg p \wedge \neg q) \ , \tag{4}$$

where p is to be understood as before, and q as meaning that the air conditioner is running at t_1. Note that the notion of possibility here is that of alethic (or metaphysical) possibility, and not that of epistemic possibility. Suppose, for example, you obeyed your boss's command by opening the window by t_1. Then we have $N, s \models_{\mathsf{MDL}^+} p$. But we may still have, for some world w alethically accessible from s, $N, w \models_{\mathsf{MDL}^+} \neg p$. Thus, even after all the people in the office came to know that you had opened it, some of your colleagues, without noticing that you had been commanded to do so, might complain that if you hadn't opened it, they wouldn't have been disturbed by the outside noises. [2]

Now we define proof system for MDL^+.

Definition 4. *The proof system for* MDL^+ *contains the following axioms and rules:*

(Taut)	*all instantiations of propositional tautologies over the present language*	
($\Box$-Dist)	$\Box(\varphi \to \psi) \to (\Box\varphi \to \Box\psi)$	($\Box$-distribution)
(O_i-Dist)	$O_i(\varphi \to \psi) \to (O_i\varphi \to O_i\psi)$ *for each* $i \in I$	(O_i-distribution)
(Mix)	$P_i\varphi \to \Diamond\varphi$ *for each* $i \in I$	(Mix Axiom)
(MP)	$\dfrac{\varphi \quad \varphi \to \psi}{\psi}$	(Modus Ponens)
($\Box$-Nec)	$\dfrac{\varphi}{\Box\varphi}$	($\Box$-necessitation)
(O_i-Nec)	$\dfrac{\varphi}{O_i\varphi}$ *for each* $i \in I$.	(O_i-necessitation)

An MDL^+*-proof of a formula* φ *is a finite sequence of* $\mathcal{L}_{\mathsf{MDL}^+}$*-formulas having* φ *as the last formula such that each formula is either an instance of an axiom, or it can be obtained from formulas that appear earlier in the sequence by applying a rule. If there is a proof of* φ*, we write* $\vdash_{\mathsf{MDL}^+} \varphi$*. If* $\Sigma \cup \{\varphi\}$ *is a set of* $\mathcal{L}_{\mathsf{MDL}^+}$*-formulas, we say that* φ *is deducible in* MDL^+ *from* Σ *and write* $\Sigma \vdash_{\mathsf{MDL}^+} \varphi$ *if* $\vdash_{\mathsf{MDL}^+} \varphi$ *or there are formulas* $\psi_1, \ldots, \psi_n \in \Sigma$ *such that* $\vdash_{\mathsf{MDL}^+} (\psi_1 \wedge \cdots \wedge \psi_n) \to \varphi$.

The above rules obviously preserve validity, and all the axioms are easily seen to be valid. Thus this proof system is sound.[3]

The completeness of this proof system can be proved in a completely standard way by building a canonical model. Thus we have:

Theorem 1 (Completeness of MDL^+). *Let* $\Sigma \cup \{\varphi\} \subseteq S_{\mathsf{MDL}^+}$*. Then, if* $\Sigma \models_{\mathsf{MDL}^+} \varphi$ *then* $\Sigma \vdash_{\mathsf{MDL}^+} \varphi$.

[2] The notion of alethic possibility may be said to be too weak to capture the kind of possibility involved in the notion of possible alternative courses of actions. Although the possibility of interpreting $\Diamond$ and $\Box$ in terms of notions of possibility and necessity stronger than those of alethic ones is tempting, we will not pursue it in this paper.

[3] Strictly speaking, O_i-necessitation is redundant since it is derivable. It is included here just to record the fact that MDL^+ is normal.