Michael Wayne Barley
Nik Kasabov (Eds.)

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Intelligent Agents and Multi-Agent Systems

7th Pacific Rim International Workshop on Multi-Agents
PRIMA 2004, Auckland, New Zealand, August 2004
Revised Selected Papers

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Lecture Notes in Artificial Intelligence 3371

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Preface

Autonomous agents and multi-agent systems are computational systems in which several (semi-)autonomous agents interact with each other or work together to perform some set of tasks or satisfy some set of goals. These systems may involve computational agents that are homogeneous or heterogeneous, they may involve activities on the part of agents having common or distinct goals, and they may involve participation on the part of humans and intelligent agents.

This volume contains selected papers from PRIMA 2004, the 7th Pacific Rim International Workshop on Multi-agents, held in Auckland, New Zealand, during August 8–13, 2004 in conjunction with the 8th Pacific Rim International Conference on Artificial Intelligence (PRICAI 2004). PRIMA is a series of workshops on autonomous agents and multi-agents that focusses on the research activities in the Asian and Pacific Rim countries. PRIMA 2004 was built upon the great successes of its predecessors.

Fifty-two papers were submitted to the workshop, each paper was reviewed by three internationally renowned program committee members. After careful review, 24 papers were selected for this volume. We would like to thank all the authors who submitted papers to the workshop. We would also like to thank all the program committee members for their diligent work in reviewing the papers. We would like to thank our invited speakers, Sandip Sen and Toru Ishida. Additionally, we thank the editorial staff of Springer for publishing this volume in the series Lecture Notes in Artificial Intelligence. Lastly, we want to thank our sponsors, the Auckland University of Technology's Knowledge Engineering and Discovery Research Institute (KEDRI), and the University of Auckland's Department of Computer Science, for the financial support provided.

December 2004

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Table of Contents

A Combined System for Update Logic and Belief Revision

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Abstract. In this paper we propose a logical system combining the update logic of A. Baltag, L. Moss and S. Solecki (to which we will refer to by the generic term BMS, [BMS04]) with the belief revision theory as conceived by C. Alchouròn, P. Gärdenfors and D. Mackinson (that we will call the AGM theory, [GardRott95]) viewed from the point of view of W. Spohn ([Spohn90,Spohn88]). We also give a proof system and a comparison with the AGM postulates.

Introduction and Motivation: Update logic is a modal logic trying to model epistemic situations involving several agents, and changes that can occur in these situations due to incoming information or more generally incoming action. Belief revision theory typically deals with changes (revisions) that a database representing a belief state of a unique agent must undergo after adding conflicting information to the database. Roughly speaking, these two theories thus deal with the same kind of phenomenon. However, there are some dissimilarities. On the one hand, belief revision theory is not a logic and it deals with a single agent, unlike update logic. On the other hand, belief revision theory deals with revision (and expansion) of information unlike update logic which deals only with expansion of information. Far from being in contradiction, it seems then that these theories have a lot to give each other. So it makes sense to look for a way in which they can be merged.

In Sect. 1, we will set out the BMS theory and the AGM theory viewed from the point of view of W. Spohn. In Sect. 2 we will propose a system combining these two theories. In Sect. 3, we will give an axiomatization of it with a soundness and completeness proof. In Sect. 4, we will show that it fulfills the 8 AGM postulates.

1 Update Logic and Belief Revision Theory

1.1 Update Logic

In this section we set out the core of update logic as viewed by BMS. We split this account into three parts: 1. static part, 2. dynamic part ('dynamic' because we

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deal with actions) and 3. update mechanism. Throughout this exposition and this paper we follow a simple example called the 'coin' example taken from [BMS04]. This is the following:

"A and B enter a large room containing a remote-control mechanical coin flipper. One presses the button, and the coin spins through the air, landing in a small box on a table. The box closes. The two people are much too far to see the coin. The coin actually heads up."

1. Static Part. We classically represent the above (static) situation s by the 'epistemic model' depicted in Fig. 1.

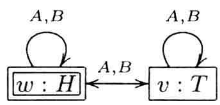

Fig. 1. BMS model for the 'coin' example.

The tokens w and v represent *possible worlds*. The double border around w means that it is the *actual world*. In this world, the coin is heads up. This last point is rendered formally by assigning the propositional letter H to w, which stands for 'the coin is Heads up'. Similarly, in the possible world v the coin is tails up. this is rendered formally by assigning the propositional letter T to v, which stands for 'the coin is Tails up'. This assignment of propositional letters to worlds is rendered formally by what we call a *valuation*: see definition below.

The *accessibility relation* $w \rightarrow_A v$ intuitively means that while A is in world w where the coin is heads up, he still considers possible that he is in world v where the coin is tails up (because he does not know whether the coin is heads or tails up). More generally, we set an accessibility relation $w \rightarrow_j v$ when 'on the basis of agent j's information in world w, the world v is a possible world'.

This epistemic representation of a particular situation is caught by the following general definition:

Definition: We call epistemic model M a tuple $M = (W, \rightarrow_j, V, w_0)$ where W is a set of possible worlds, $\rightarrow_j$ are finitely many accessibility relations indexed by the agents j, V is a valuation function which assigns a set of possible worlds to each propositional letter, and w_0 is the actual world. $\diamond$

We can then 'say things' about specific epistemic models (modeling specific situations) by introducing a language whose one of the components is a knowledge operator K_j defined like that:

$$M, w \models K_j\phi \text{ iff for all } v \text{ such that } w \rightarrow_j v,\ M, v \models \phi.$$

Intuitively $M, w \models K_j\phi$ means 'in world w, j Knows that ϕ' . We can then check with this definition that in our example, the epistemic model of Fig. 1 captures what we want (e.g. the sentence 'in the actual world, A does not know whether the coin is Heads or Tails up' is rendered by the formula $M, w \models \neg K_A H \wedge \neg K_A T$).

See [FHMV95] for an extensive account of what is just outlined here.

2. Dynamic Part. Now we consider the following epistemic action a: 'A cheats and learns that the coin is Heads up, B suspecting anything about it'. We use the term "epistemic" (in "epistemic action") in the sense that the action doesn't change facts in the world. We represent how this action is perceived by the agents (just as we represented above how a situation is perceived by the agents) by the action model depicted in Fig. 2.

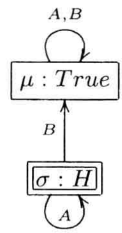

Fig. 2. BMS action model for the action 'A cheats'.

The token σ represents the *simple action* 'A looks at the coin and observes that the coin is heads up'. A double border around σ means that it is the *actual action*. For this action to be carried out in a particular possible world, the coin needs to be Heads up in this possible world. That's the intuitive meaning of the *precondition* H in the action model. The token τ represents the simple action 'nothing happens'. This action can be carried out in any possible world, hence its precondition is the tautology $True$, which is true in any possible world.

The *accessibility relation* $\sigma \rightarrow_B \tau$ intuitively means that 'while A looks at the coin and observes that it is heads up (σ), *for B* nothing actually happens (τ)'. More generally, we set an accessibility relation $\sigma \rightarrow_j \tau$ when the following condition is fulfilled: 'if σ occurs then in j's view τ is one of the action that might have happened'.

This epistemic representation of a particular action is caught by the following general definition:

Definition: We call an action model Σ a tuple $\Sigma = (\Sigma, \rightarrow_j, Pre, \sigma_0)$ where Σ is a set of simple action tokens, $\rightarrow_j$ are finitely many accessibility relations indexed by the agents j, Pre is a function which assigns preconditions to each action token, and σ_0 is the actual action. ◇

3. Update Mechanism. Now, in reality the agents update their beliefs according to these two pieces of information: action a and situation s. This gives rise to a new situation $s \times a$. This actual update is rendered formally by the following mathematical update product:

Definition: Let $M = (W, \rightarrow_j, V, w_0)$ be an epistemic model and $\Sigma = (\Sigma, \rightarrow_j, V, \sigma_0)$ an action structure. We define their update product to be the epistemic model $M \otimes \Sigma = (W \otimes \Sigma, \rightarrow'_j, V', w'_0)$ where

1. $W \otimes \Sigma = \{(w, \sigma) \in W \times \Sigma; w \in V(Pre(\sigma))\}$.
2. $(w, \sigma) \rightarrow'_j (v, \tau)$ iff $w \rightarrow_j v$ and $\sigma \rightarrow_j \tau$.
3. $V'(p) = \{(w, \sigma) \in W \otimes \Sigma; w \in V(p)\}$.
4. $w'_0 = (w_0, \sigma_0)$. $\diamond$

Intuitive Interpretation: 1. The possible worlds that we consider after the update are all the ones resulting from the performance of one of the actions in one of the worlds, under the assumption that the action can 'possibly' take place in the corresponding world (assumption expressed by the function *Pre*).

2. The components of our action model are 'simple' actions (in the sense of BMS, see [BMS04] for more precision). It allows us to state that the accessibility (or uncertainty) relations for the epistemic model and the epistemic action model are independent from one another. This independence allows us to 'multiply' these uncertainties to compute the new accessibility (or uncertainty) relation.

3. The definition of the valuation exemplifies the fact that our actions do not change facts. (That is why we call them *epistemic* actions, as already said above.)

4. Finally, we naturally assume that the actual action can 'possibly' take place in the actual world.

Let us get back to our 'coin' example. The update product of Fig. 1 and Fig. 2 yields the model depicted in Fig. 3. This model presents some flaws and will be discussed in the rest of the paper.

We have set out the core of update logic as viewed by BMS. Yet, bear in mind that in [BMS04] a genuine logical system is built out of it, that we do not expound here.

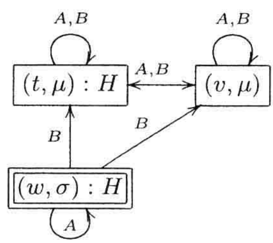

Fig. 3. BMS model corresponding to the situation after the action 'A cheats'.

1.2 Belief Revision Theory: W.Spohn's Approach

In this section, we set out a simplified account of W.Spohn's approach to belief revision theory as conceived by AGM (see [GardRott95]).

Generally speaking, belief revision theory deals with changes that must undergo a database representing a belief state of an agent after adding to the database information. (Note that it deals only with the notion of belief and not with the one of knowledge like in update logic.)

The format of the database can take two main different forms: syntactic and semantic. The former consists of a belief set K that consists of *propositional* formulas (also called sentences, representing the facts accepted in the belief state) and that is closed under logical consequences. The latter consists of a set W of possible worlds (representing the narrowest set of possible worlds in which the individual believes that the actual world is located). It can be shown that these two representations are actually equivalent.

The type of change for a state of belief which interests us most is *revision* (the other classical ones are *expansion* and *contraction*). It consists of adding to the belief set K a new sentence ϕ that is typically inconsistent with K. In order that the resulting belief set $K * \phi$ be consistent, some of the old sentences in ϕ are deleted. Now two basic questions come up to mind:

1. What general conditions this revised belief set $K * \phi$ must fulfill in order that the revision process be the closest possible to one performed by rational agents? This is the concern of the 8 AGM postulates that can be found in [GardRott95].
2. What sentences should be actually deleted from the belief set in order to form the new belief set $K * \phi$? In the literature, there are several explicit procedures that compute the new belief set $K * \phi$ after a revision. We focus on the one proposed by W.Spohn based on a possible world semantics ([Spohn90,Spohn88]). His approach satisfies moreover the 8 AGM postulates.

Definition: An ordinal conditional function is a function κ from a given set W of possible worlds into the class of ordinals such that some possible worlds are assigned the smallest ordinal 0. $\diamond$

Intuitively, κ represents a plausibility grading of the possible worlds: the worlds that are assigned the smallest ordinals are the most plausible, according to the beliefs of the individual. Then,

Definition: We define $\kappa(\phi)$ as $\kappa(\phi) := min\{\kappa(w); w \in \phi\}$.

We say that a formula ϕ is *believed* (with degree of firmness α) when $\kappa^{-1}(0) \subseteq \{w; w \in \phi\}$ (resp. and $\kappa(\neg\phi) = \alpha$).

The belief set K *associated with* the ordinal conditional function κ is the set of all propositions believed in κ. $\diamond$

Now assume the sentence ϕ is announced and the agent believes it with a degree of firmness α. We can then define the resulting ordinal conditional function $\kappa * (\phi, \alpha)$ representing the new state of belief:

Definition: Let ϕ be a proposition such that $\{w; w \in \phi\} \neq \emptyset$. We define the ordinal conditional function $\kappa * (\phi, \alpha)$ by:

$$\kappa * (\phi,\alpha)(w) = \begin{cases} \kappa(w) - \kappa(\phi) & \text{if } w \in \phi \\ \alpha + \kappa(w) - \kappa(\phi^c) & \text{if } w \in \phi^c. \end{cases} \diamond$$

Note that in this new belief state, ϕ is believed with firmness α. Finally, Proposition: If we define $K * \phi$ as the belief set associated with $\kappa * (\phi, \alpha)$, the revision function * thus defined satisfies the 8 AGM postulates. ◇

So we have set out update logic and belief revision theory as viewed by W. Spohn. Now we are going to propose a system combining these two theories and see what insights it provides us regarding information change. As in the BMS exposition, we split our account in three parts: 1. Static part 2. Dynamic part 3. Update mechanism (inspired from W. Spohn's theory).

2 A Combined System

2.1 The Static Part

Definition. Just as in the BMS system, we want to represent how a static situation is perceived by the agents from the point of view of their beliefs *and* knowledge. That is to say, we want to represent what the agents know and believe about the actual world and also about what the other agents know and believe in general. We do that thanks to what we call a belief epistemic model.

From now on and in the rest of the paper, Max is an arbitrary fixed natural number different from 0.

Definition 1. *A belief epistemic model (be-model)* $M = (W, \{\sim_j; j \in G\}, \{\kappa_j; j \in G\}, V, w_0)$ *is a tuple where:*

1. W *is a set of possible worlds.*
2. w_0 *is the possible world corresponding to the actual world.*
3. $\sim_j$ *is an equivalence relation defined on* W *for each agent* j.
4. κ_j *is an operator, ranging from 0 to* Max, *defined on the set of possible worlds.*
5. V *is a valuation.*
6. G *is a set of agents.*

Intuitive Interpretation. Points 1,2,5,6 are clear (see Sect. 1.1). It remains to give intuitive interpretations for points 3 and 4.

3. The equivalence relation $\sim_j$ intuitively models the notion of knowledge. Its intuitive interpretation is:

$$w \sim_j v \text{ iff agent } j\text{'s knowledge in } w \text{ and } v \text{ is the same.}$$

Note that this implies that j cannot distinguish world w from v (otherwise she would not have the same knowledge in w and v) and that her information is the same in w and v. This also implies that $\sim_j$ is an equivalence relation, as mentioned in the definition.

4. The plausibility assignment κ_j intuitively models the notion of belief. Among the worlds j cannot distinguish (the worlds where her knowledge is the same), there are worlds that j might consider more plausible than others. This is expressed by the plausibility grading κ_j: the more plausible a world is for the agent