Agents as Reasoners, Observers or Arbitrary Believers

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The work described in this paper aims at the definition of a general framework for the formal specification of agents' beliefs in a multiagent environment. The basic idea is to model both agents' beliefs and the view that each agent has of other agents' beliefs as logical theories. Consider an agent a_i having beliefs only about the world. At a very abstract level, a_i's beliefs can be modeled by a *reasoner* defined as a pair $\langle L_i, T_i\rangle$: L_i is the *language* of the reasoner and T_i are the *beliefs* of the reasoner (in the following, we abbreviate a reasoner $\langle L_i, T_i\rangle$ with R_i). Now assume that a_i has beliefs about an agent a_j and that a_j has only beliefs about the world. This situation can be easily modeled introducing two other reasoners R_j, R_{ij} —modeling a_j's beliefs and a_i's beliefs about a_j respectively— and extending R_i signature with a unary predicate B^j, used to express a_i's beliefs about a_j. R_{ij} thus plays the role of a_i's (mental) representation of a_j. R_i, R_{ij} and B^j characterize a *basic belief system*, defined as $\langle R_i, R_{ij}\rangle_{\mathrm{B}^j}$: R_i is the *observer*, R_{ij} is the *observed reasoner* and the parameter B^j is the *belief predicate* of the basic belief system. Suppose that also a_j has beliefs about another agent a_k. We model a_i's beliefs as a reasoner R_i, a_i's beliefs about a_j as a reasoner R_{ij} and a_i's beliefs about a_j's beliefs about a_k as a reasoner R_{ijk}. R_i observes R_{ij} and R_{ij} observes R_{ijk}. From this example, it is easy to see how to represent an agent with arbitrary beliefs with a family of reasoners, in which each reasoner is possibly observing other reasoners. Such configurations of reasoners are described with "belief systems". Formally, if I is a set of indices (each corresponding to a reasoner), a *belief system* is a pair $\langle\{R_i\}_{i\in I}, \mathrm{B}\rangle$ where $\{R_i\}_{i\in I}$ is a family of reasoners and B is an n-tuple of binary relations over I. If $\langle i, j\rangle$ is an element of the k-th binary relation then R_i observes R_j and expresses its beliefs about R_j using a B^k predicate (we thus assume that to the k-th binary relation there corresponds a unary predicate B^k). Following (Giunchiglia *et al.* 1993), we say that R_i is an *ideal* reasoner if T_i is closed under logical consequence. Analogously, we say that R_i is a B^k*-ideal observer* of R_j if $T_j = \{A \mid \mathrm{B}^k(\text{“}A\text{”}) \in T_i\}$. Notice that the two notions of ideal reasoner and ideal observer are independent. For instance, an ideal observer may be at the same time a real reasoner.

Consider a belief system $\langle\{R_i\}_{i\in I}, \mathrm{B}\rangle$. Both the language L_i and the beliefs T_i ($i \in I$) of each reasoner can be *extensionally* characterized as sets of formulae satisfying certain conditions. However, a belief system can be also *intensionally* characterized by multi context systems (Giunchiglia & Serafini 1994). A *multi context system* or *MC system* is a pair $\langle\{C_i\}_{i\in I}, BR\rangle$, where $\{C_i\}_{i\in I}$ is a family of axiomatic formal systems (that we call *contexts*) and BR is a set of bridge rules, *i.e.* inference rules having premises and conclusion in distinct contexts. Notationally, we write $\langle A, C_i\rangle$ to indicate the formula A in the context C_i.

Definition 1 ($\mathrm{MR}_I^{\mathrm{B}}$-) *Let I be a set of indexes, $\{C_i\}_{i\in I}$ a family of contexts and B a n-tuple of binary relations over I. $MS = \langle\{C_i\}_{i\in I}, BR\rangle$ is an MR_I^{B}- system if and only if for each $\langle i, j\rangle$ in the k-th relation in B, BR includes the following bridge rules:*

$$\frac{\langle A, C_j\rangle}{\langle \mathrm{B}^k(\text{“}A\text{”}), C_i\rangle}\ \mathcal{R}_{up.}^{\mathrm{B}^k} \qquad \frac{\langle \mathrm{B}^k(\text{“}A\text{”}), C_i\rangle}{\langle A, C_j\rangle}\ \mathcal{R}_{dn.}^{\mathrm{B}^k}$$

both restricted to the case when the premise does not depend on formulae of the same context.

We say that an $\mathrm{MR}_I^{\mathrm{B}}$- system *generates* the belief system $\langle\{R_i\}_{i\in I}, \mathrm{B}\rangle$ if $T_i = \{A \mid\ \vdash_{\mathrm{MS}} \langle A, C_i\rangle\}$ ($i \in I$).

MC systems provide the proper tools for presenting belief systems: each reasoner R_i corresponds to a context C_i. The properties of R_i (*e.g.* the language) are mapped in corresponding properties of C_i and the desired relation between the beliefs of R_i and the beliefs of another reasoner R_j can be imposed via bridge rules. The relation between $\mathrm{MR}_I^{\mathrm{B}}$- systems and some modal approaches to the problem of logical omniscience is studied in the longer version of this paper.

References

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