Towards Agent-Oriented Relevant Information

Laurence Cholvy[1] and Stéphanie Roussel[1]

ONERA Centre de Toulouse
2 av.Ed.Belin, 31055 Toulouse, France

Abstract. In this paper, we give some elements about agent-oriented relevance. For that, we define a new modal operator R_a^Q so that $R_a^Q\varphi$ means that φ is relevant for agent a concerning the request Q. We discuss properties of this new operator, as well as its extensions and limits.

Keywords: information relevance, multi-agent systems, information need

1 Introduction

The general context of this work is modelling multi-agent systems i.e, systems in which some entities have to cooperate in order to achieve a given task that none of them would be able to achieve alone. In such a context, these cooperating entities (henceforth called agents) have to communicate i.e exchange information, in particular to share a common view of the current environment. However, in most systems, communication channels saturate if any agent sends to others all pieces of information he possesses. Thus, in order to be efficient, only a few information should be exchanged within agents. More precisely, the information exchanged should be the very one needed by agents in order to achieve their goals, that means *relevant information*.

Characterization of relevant information in the context of information exchange is the main object of this paper.

Following Borlund [11], relevance concept can be addressed following two different kinds of approaches: System-oriented approaches and Agent-oriented ones. System-oriented approaches analyse relevance in terms of topicality, aboutness, degrees of matching between a piece of information and a request, or independence. System-oriented approaches are the basis of Information Retrieval area ([7, 5, 9]) and Relevant Logics ([12, 3]) domain. They do not try to define a relation between some information and an informee like Agent-oriented approaches which, on the other hand, analyse relevance in terms of agent's utility, informativeness for the agent... aiming at defining relevant information according to agent's information need. According to Floridi [8], Agent-oriented Relevance lacks definition: *"The current situation can be summarised thus : some philosophical work has been done on several formal aspects of system-based or causal relevance, but the key question, namely what it means for some information to be relevant to some informee, still needs to be answered. We lack a foundational theory of agent-oriented or epistemic relevance. The warming up is over. The time has come to roll up our sleeves."*. Floridi has developed an interpretation of epistemic relevance. It is based on an analysis of the degree of relevance of some semantic information to a rational informee as a function of the accuracy of the information understood as an answer to a question, given the probability that this question might be asked by the informee.

In this present paper, our aim is to contribute, like Floridi, to the study of agent-oriented relevance. For doing so, we use a widely respected model of agents, the *belief-desire-intention* model (BDI) [10]. This model assumes that an agent is characterized by its mental attitudes, mainly belief, desire and intention. Most formal models based on BDI are modal logics whose modal operators are used to represent the different mental attitudes. The semantic of those of operators are generally given by the possible world semantics [4]. Using this kind of formalism, we aim at defining a new modal operator to represent agent-oriented information relevance.

This paper is organized as follows. Section 2 presents the formal framework we base our work on. Section 3 deals with relevance defined according to an agent's information need. In section 4, we consider a multi-agent context. Section 5 addresses a more general case of information need. Finally section 6 concludes this paper.

2 Formal framework

The formal framework on which our work is based on is the one defined in [1]. It is a propositional multimodal logic[1] whose modal operators are belief and intention.

Let $\mathcal{A}$ be the set of agents.

- **Belief.** A modal operator of belief B_a is associated to every agent a in $\mathcal{A}$. The formula B_aA is read "agent a believes that A". We will write Bif_aA instead of $B_aA \vee B_a\neg A$. Bif_aA is read "agent a knows[2] if A is true or false. Belief operator is ruled by KD45 axioms. Thus, in this framework, agents do not have inconsistent beliefs and that they are aware of their beliefs and of their disbeliefs.
- **Intention.** In [1], intention is a primitive operator. A modal operator I_a is associated to every agent of $\mathcal{A}$. I_aA is read "agent a intends that A". For this operator, nothing is supposed about logical consequence, conjunction or material implication. It is only postulated that : $\frac{A \leftrightarrow B}{I_aA \leftrightarrow I_aB}$
- **Relation between belief and intention.** As in [1], we suppose strong realism, that means we consider that one does not intend a proposition if one does not believe that this proposition is false. This is expressed by : $I_aA \rightarrow B_a\neg A$. From this postulate, it has been proven that: $I_aA \rightarrow \neg B_aA$: an agent does not intend A as soon as he believes A (weak realism); $I_aA \rightarrow \neg I_a\neg A$; $B_aA \rightarrow \neg I_aA$; $\neg B_aA \rightarrow \neg I_a\neg B_aA$

  Moreover, positive and negative intention introspection are supposed. I.e, $I_aA \rightarrow B_aI_aA$ and $\neg I_aA \rightarrow B_a\neg I_aA$

[1] The logic used in [1] was a first-order multimodal logic. We do not need the first-order here.

[2] "Knowledge" is here used instead of "belief" because in natural language, we don't say that an agent wants to belief if something is true or false

3 Relevance

3.1 Informal definition

In this part, we want to characterize what makes an information relevant.

First of all, we consider that a piece of information is relevant according to an agent. We do not conceive a piece of information to be relevant without anyone to whom it will be useful. Secondly, we consider that relevance depends on an information need this agent has and we suppose that a request models this information need. [3].

Considering these two assumptions only, we get what we call *intrinsic relevance*[4]. According to this kind of relevance, any piece of information which contributes to information need of the agent is relevant. Even false information can be relevant, which is questionable in the context of multi-agent systems.

If we add that a relevant information has to be true, then we get what we call *contingent relevance*. The term "contingent" is justified by the fact that this notion of relevance here highly depends on the current situation.

In this paper, we only focus on contingent relevance for a given agent concerning a particular information need. We will henceforth say "relevance". Thus, an information is relevant concerning an information need if the agent actually has got this information need, if the relevant information helps the agent answering his information need and if the information is true. This shows that some elements have to be seen in relevance definition: 1.the agent information need, 2.the agent beliefs (that allows him to answer his information need from the relevant piece of information) and 3. the truth value of the relevant piece of information.

3.2 Information need

In what follows, a *request* is a formula without modal operators.

We consider an agent a that needs information. For a first approach, we consider that this need is quite simple and can be expressed the following way : "agent a wants to know if Q or if $\neg Q$", where Q is a request. Thus, an agent's information need can be expressed by $I_a Bif_a Q$. This formula is read "agent a intends to know if Q".

A few comments on this information need :

- $I_a Bif_a \varphi \rightarrow \neg B_a \varphi \wedge \neg B_a \neg \varphi$ is a theorem, i.e, an agent does not intend to know if φ is true if he already believes φ or $\neg\varphi$. To say it differently, this means that an information need corresponds to a lack of information ([13]).
- If φ is a tautology and ψ a contradiction, then $\neg IaBif_a \varphi$ and $\neg IaBif_a \psi$ are theorems. It means requests are not tautologies nor contradictions.
- To know if Q comes to know if $\neg Q$. In fact, $I_a Bif_a Q \leftrightarrow I_a Bif_a \neg Q$ is a theorem.

[3] This request may be explicitly asked by the agent or not.

[4] Thanks to Robert Demolombe for proposing the two terms contingent relevance and intrinsic relevance.

3.3 Formal definition of Relevance

In this part, we give a definition for a new modal operator R_a^Q so that $R_a^Q\varphi$ means that information φ is relevant for agent a concerning request Q. When there is no ambiguity, we will say that φ is relevant.

In what follows, $\otimes$ is the exclusive disjunction generalized to n formulas i.e. if A_1, ... A_n are n formulas then $A_1 \otimes ... \otimes A_n$ is true if and only if $A_1 \vee ... \vee A_n$ is true and $\forall i, j\ \neg(A_i \wedge A_j)$ is true.

Definition 1. *Let a be an agent of $\mathcal{A}$, φ a formula, Q a request.*

$$R_a^Q\varphi \equiv I_aBif_aQ \wedge (B_a(\varphi \rightarrow Q) \otimes B_a(\varphi \rightarrow \neg Q)) \wedge \varphi$$

In this definition, the three elements that have been given in the informal definition of relevance appear :

- ***agent's information need:*** I_aBif_aQ. Relevance assumes an information need.
- ***agent's beliefs:*** $B_a(\varphi \rightarrow Q) \otimes B_a(\varphi \rightarrow \neg Q)$. From what he knows and with a relevant information φ, the agent can answer his information need Q, that means he can deduce Q or he can deduce $\neg Q$. Here, we have chosen the simplest way to represent this deduction: logical implication.
  Two points are important here :
  - First it is important that the agent uses his beliefs to answer his information need.
    For example, let's consider a doctor a that needs to know if his patient has disease d or not. This information need is formalized by I_aBif_ad. Let's suppose that if the blood formula is normal (modelled by n), then the patient does not have the disease d.
    Even if the patient has got a normal blood formula, if the doctor does not know that $n \rightarrow \neg d$, then n is totally useless to answer $\neg d$. n is relevant only if the doctor knows that $n \rightarrow \neg d$.
  - $\otimes$: if an agent, from a formula φ, can deduce Q and $\neg Q$, it means that this formula does not really answer the request as it does not allow the agent to know which one of Q or $\neg Q$ is his answer. With the $\otimes$ operator, we prevent this case to happen.
- ***truth value of*** φ : only true information is relevant as we deal with contingent relevance.

3.4 Properties

In this part, let us take a an agent of $\mathcal{A}$, Q, Q_1 and Q_2 some requests, φ, φ_1, φ_2 some formulas. The following propositions are theorems of our logic.

Proposition 1.

$$R_a^Q\varphi \rightarrow \neg B_a\varphi$$

If information φ is relevant, then the agent does not know it (otherwise, he would already be able to answer his own request).

Proposition 2.

$$R_a^Q \varphi \to \neg B_a \neg \varphi$$

If information φ is relevant, then the agent does not believe that it is false. Indeed, if a believes $\neg\varphi$, his belief set is inconsistent.

Proposition 3. *Let $*$ be an operator of belief revision satisfying AGM postulates [2]. Let Bel_a be agent a's belief set and $Bel_a * \varphi$ be a's belief set after revising Bel_a with φ by $*$. Then*

$$R_a^Q \varphi \to ((Bel_a * \varphi) \to Q) \otimes ((Bel_a * \varphi) \to \neg Q)$$

This proposition shows that the deduction operator that we have chosen, the implication, corresponds to a "basic" belief set revision operator. If a piece of information is relevant concerning a request Q, then the agent, by adding this information to his current belief set can deduce either Q or $\neg Q$.

Proposition 4.

$$I_a Bif_a Q \to R_a^Q Q \otimes R_a^Q \neg Q$$

If agent a has a request Q then either Q or $\neg Q$ is relevant.

Proposition 5.

$$(Q_1 \leftrightarrow Q_2) \to (R_a^{Q_1} \varphi \leftrightarrow R_a^{Q_2} \varphi)$$

For a given agent, two requests equivalent to each other have the same relevant information.

Proposition 6.

$$R_a^Q \varphi \leftrightarrow R_a^{\neg Q} \varphi$$

The two requests Q and $\neg Q$ are equivalent for relevant information research.

Proposition 7.

$$\neg(\varphi_1 \wedge \varphi_2) \to \neg(R_a^{Q_1} \varphi_1 \wedge R_a^{Q_2} \varphi_2)$$

Two contradictory information are not both relevant for an agent concerning some requests.

Proposition 8.

$$R_a^Q \varphi \to \neg R_a^Q \neg \varphi$$

If φ is relevant for an agent concerning a request then $\neg\varphi$ is not relevant for this agent concerning this request.

Proposition 9.

$$R_a^Q \varphi \to \neg B_a R_a^Q \varphi$$

If φ is relevant for an agent concerning a request then the agent does not know it. In fact, if a knows that an information is relevant then he knows that it is true. If he knows that the information is true, then he can answer his request. And as soon as he can answer his request, he does not have his information need anymore.

Notation. In what follows, we will note $B_a(\varphi_1, \varphi_2/Q)$ instead of $\neg(B_a(\varphi_1 \rightarrow Q) \wedge B_a(\varphi_2 \rightarrow \neg Q)) \wedge \neg(B_a(\varphi_1 \rightarrow \neg Q) \wedge B_a(\varphi_2 \rightarrow Q))$. This formula means that a believes that φ_1 and φ_2 do not allow to deduce contradictions concerning Q.

Proposition 10.

$$B_a(\varphi_1, \varphi_2/Q) \rightarrow (\varphi_2 \wedge R_a^Q \varphi_1 \rightarrow R_a^Q(\varphi_1 \wedge \varphi_2))$$

Proposition 11.

$$B_a(\varphi_1, \varphi_2/Q) \rightarrow (R_a^Q \varphi_1 \wedge R_a^Q \varphi_2 \rightarrow R_a^Q(\varphi_1 \vee \varphi_2))$$

Those two propositions show the previous definition of relevance characterizes too many relevant information.

For example, supposing that the doctor knows that $n \rightarrow d$ we have seen that n is a relevant information for doctor a who has a request d. If we consider that r is true (for instance r means that it is raining) then $n \wedge r$ is relevant for a concerning d. This is true because $n \wedge r$ contains the relevant element that really answers the doctor's request. However, we would like to say that n is more relevant than $n \wedge r$, because r is not needed to answer the doctor's need. Thus, the problem we face is to consider a hierarchy in relevance in order to characterize the most relevant information. The next section addresses this point.

3.5 Hierarchy in relevance

Let $\mathcal{R}_a^Q$ be the set of relevant formulas. We consider successively the case when such formulas are clauses, cubes, or more general formulas.

Clauses Let suppose that $\mathcal{R}_a^Q$ is a set of clauses.

Definition 2. *Let φ_1 and φ_2 be two clauses. We define $\varphi_1 \leq_{Cl} \varphi_2$ iff $\vdash \varphi_2 \rightarrow \varphi_1$.*

Proposition 12. *$\leq_{Cl}$ is a preorder.*

If we consider that relevant information are clauses, the most relevant are the maxima with this preorder. Indeed, the maxima with this preorder are the clauses that are not subsumed by any other. Those maxima formulas are the most precise. Relevance degrees can also be defined by taking successive maxima.

For example, let us suppose that $\mathcal{R}_a^Q = \{p, q, p \vee q, r \vee s, p \vee q \vee r\}$. Thus, the most relevant information set is $\{p, q, r \vee s\}$. Then, we have $\{p \vee q\}$ and $\{p \vee q \vee r\}$.

Cubes Let suppose that $\mathcal{R}_a^Q$ is a set of cubes (conjunction of literals).

Definition 3. *Let φ_1 and φ_2 be two cubes (literals conjunction). We define: $\varphi_1 \leq_{Cu} \varphi_2$ iff $\vdash \varphi_1 \rightarrow \varphi_2$*

Proposition 13. *$\leq_{Cu}$ is a preorder.*

If we consider that relevant information are cubes, the most relevant are the maxima with that preorder. Indeed, the maxima of this preorder are prime implicants [5] [6] of Q and $\neg Q$. This corresponds to information that contain only necessary elements to answer the information need. Relevance degrees can also be defined by taking successive maxima.

For example, let us suppose that $\mathcal{R}_a^Q = \{p, q, p \wedge q, r \wedge s, p \wedge q \wedge r\}$. Thus, the most relevant information set is $\{p, q, r \wedge s\}$. Then, we have $\{p \wedge q\}$ and $\{p \wedge q \wedge r\}\}$.

General formulas For general formulas, we consider them under a particular form.

Definition 4. *A formula is CNF- iff it is written under conjunctive normal form in which clauses which are tautologies have been deleted as well as subsumed clauses.*

Then we suggest the following algorithm to retrieve the most relevant formulas.

Definition 5. *Let φ_1 and φ_2 be two formulas of a set $\mathscr{E}$ which are CNF-. We consider $\mathfrak{R}_S$ a binary relation on $\mathscr{E} \times \mathscr{E}$ defined by: $\varphi_1 \mathfrak{R}_S \varphi_2$ iff $Cl(\varphi_1, \varphi_2) \geq Cl(\varphi_2, \varphi_1)$ with $Cl(\varphi_1, \varphi_2)$ a function of $\mathscr{E} \times \mathscr{E}$ in $\mathbb{N}$ and that sends back the number of clauses of φ_1 that subsume clauses of φ_2.*

Proposition 14. *$\mathfrak{R}_S$ is an ordinal preference relation.*

A formula φ_1 is preferred to φ_2 if it subsumes "globally" more φ_2 than φ_2 subsumes φ_1. For example, $Cl(a, a \vee p) = 1$ and $Cl(a \vee p, a) = 0$ so $a \mathfrak{R}_S (a \vee p)$.

From this preference, we can define an indifference relation $\mathfrak{R}_I$.

Definition 6. *Let φ_1 and φ_2 be two formulas of $\mathscr{E}$. $\varphi_1 \mathfrak{R}_I \varphi_2$ iff $\varphi_1 \mathfrak{R}_S \varphi_2$ and $\varphi_2 \mathfrak{R}_S \varphi_1$*

For example, $a \mathfrak{R}_I p$, $a \wedge (p \vee q) \mathfrak{R}_I (a \vee b) \wedge p$.

With that indifference relation, we can create classes of indifferent formulas. In particular, we have $max_{\mathfrak{R}_S} \mathcal{R}_a^Q$, i.e. relevant formulas preferred by $\mathfrak{R}_S$.

For example, if $\mathcal{R}_a^Q = \{a, a \vee p, (a \vee r) \wedge p, r \vee s, a \wedge p, p, a \wedge (t \vee s)\}$, then $max_{\mathfrak{R}_S} \mathcal{R}_a^Q = \{a, p, r \vee s, a \wedge p, a \wedge (t \vee s)\}$. We can see that there are still elements that we had removed with cubes such as $a \wedge p$. Thus, we have to use a preorder on the obtained set. We extend to general formulas the preorder used for cubes.

Definition 7. *Let φ_1 and φ_2 two formulas of a set $\mathscr{E}$. $\geq$ is a relation on $\mathscr{E} \times \mathscr{E}$ defined by: $\varphi_1 \geq \varphi_2$ iff $\vdash \varphi_2 \rightarrow \varphi_1$*

[5] We remind that an implicant of φ is a conjunction of literals and that an implicant α of φ is prime iff it ceases to be an implicant upon the deletion of any of his literals.

Proposition 15. $\geq$ *is a preorder.*

What interests us here is the set $max_{\geq} max_{\mathfrak{R}_S} \mathcal{R}_a^Q$ that we will note $\mathfrak{R}m_a^Q$.

For example, if we take back $\mathcal{R}_a^Q = \{a, a \vee p, (a \vee r) \wedge p, r \vee s, a \wedge p, p, a \wedge (t \vee s)\}$, we have $\mathfrak{R}m_a^Q = \{a, p, r \vee s\}$.

We write $Rm_a^Q \varphi$ instead of "$R_a^Q \varphi$ and $\varphi \in \mathfrak{R}m_a^Q$". $Rm_a^Q \varphi$ is read φ *is maximal relevant for* a *concerning* Q.

This algorithm generalizes the two previous cases : for clauses, the set of most relevant information obtained by this algorithm is the set of most relevant information with the preorder $\leq_{Cl}$. Likewise, for cubes, the set of most relevant information obtained by this algorithm is the set of most relevant information with the preorder $\leq_{Cu}$.

The problem with maximal relevance defined this way is that we do not, for the moment, have a semantic characterization of formulas obtained with this algorithm. Moreover, contrary to cubes and clauses, we do not have a stratification of relevant information but we get only the set of most relevant formulas.

4 Multi-agent case

Let us now extend the previous definition to several agents. Let a and b be two agents of $\mathcal{A}$ and φ a formula. Let's suppose that a has an information need modelled by request Q. From relevance definition, we get:

$$B_b R_a^Q \varphi \leftrightarrow B_b(I_a BifQ) \wedge B_b \varphi \wedge B_b(B_a(\varphi \to Q) \otimes B_a(\varphi \to \neg Q))$$

That means that agent b believes that φ is relevant for a concerning Q iff b believes that a has an information need Q, b believes that φ is true and b believes that a, from his own beliefs and from φ, can deduce Q or (exclusive) deduce $\neg Q$. Thus, b can believe that an information is relevant for another agent a concerning Q, only if b knows about a's information needs.

Moreover, it can happen that b thinks that an information is relevant for a concerning an information need while it is not. This happens when b's beliefs are wrong i.e when b believes that a has an information need and a does not have this information need, or when b believes that φ is true and φ is not, or when b believes that a, from his beliefs and from φ, can deduce Q or (exclusive) deduce $\neg Q$ and a does not have enough knowledge.

5 Information need generalized

Information need considered until now was a *wants to know if* Q *or if* $\neg Q$. This information need can be extended in the following way a *wants to know if* q_1 *or if* q_2*, ... or if* q_n , q_i being requests and being mutually exclusives to each other.

Let $\mathcal{Q}$ be the set of alternative answers to information need. We suppose that $\mathcal{Q}$ is finite and countable and that all formulas q_i of $\mathcal{Q}$ are mutually exclusives to each other. We can model the information need the following way :

$$I_a Bif_a \mathcal{Q} \Leftrightarrow I_a(B_a q_1 \otimes B_a q_2 \otimes ... \otimes B_a q_n)$$

For example, information need for a to know if the result of an exam is $good$, $average$ or bad is $I_a Bif_a \mathcal{Q}$, with $\mathcal{Q} = \{good, average, bad\}$.

Thus, we can extend relevance the following way :

Definition 8. *Let $\mathcal{Q}$ be a set of n requests exclusive to each other.*

$$R_a^{\mathcal{Q}} \varphi \equiv I_a Bif_a \mathcal{Q} \wedge (B_a(\varphi \to q_1) \otimes B_a(\varphi \to q_2) \otimes ... \otimes B_a(\varphi \to q_n)) \wedge \varphi$$

$R_a^{\mathcal{Q}} \varphi$ is read φ is relevant concerning $\mathcal{Q}$ for a.

Let's take our exam example. We will note ex_1 and ex_2 the two literals representing the facts that exercises number 1 and 2 have been succeed. Let a's set of beliefs be : $\{ex_1 \wedge ex_2 \to good, ex_1 \otimes ex_2 \to average, \neg ex_1 \wedge \neg ex_2 \to bad\}$, i.e. the exam is good if exercises 1 and 2 have been succeed, the exam is average if only one of the two exercises has been succeed and the exam is bad if no exercise has been succeed. In that case, $R_a^{\mathcal{Q}}(ex_1 \wedge ex_2), R_a^{\mathcal{Q}}(ex_1 \otimes ex_2), R_a^{\mathcal{Q}}(\neg ex_1 \wedge \neg ex_2)$.

Properties We have the same properties than before.

Proposition 16.

$$R_a^{\mathcal{Q}} \varphi \to \neg B_a \neg \varphi$$

Proposition 17.

$$R_a^{\mathcal{Q}} \varphi \to \neg B_a \varphi$$

Proposition 18.

$$R_a^{\mathcal{Q}} \varphi \to ((Bel_a * \varphi) \to q_1) \otimes ... \otimes ((Bel_a * \varphi) \to q_n)$$

Proposition 19.

$$(q_1 \otimes ... \otimes q_n) \wedge I_a Bif_a \mathcal{Q} \to R_a^{\mathcal{Q}} q_1 \otimes ... \otimes R_a^{\mathcal{Q}} q_n$$

The hypothesis $q_1 \otimes ... \otimes q_n$ is necessary to make sure than at least one request q_i is true. Without that, relevance is impossible.

6 Conclusion

The main contribution of this paper is a definition of agent-oriented relevance. In the framework of BDI models, we defined a new modal operator that represents the fact that a piece of information is relevant for an agent concerning an information need. We have shown how this definition can be applied in the multi-agent case. However, formulas which are considered as relevant are too many. So, we have given a method selecting the most relevant ones.

There are several extensions to this work.

First, event if it is done in the case of clauses or cubes, giving a semantic characterization of the most relevant information remains to be done for general formulas. Studying the properties of these formulas will be possible only when this is done.

Secondly, in the case of multiple choice requests, it would be interesting to define degrees of relevance. Thus, a piece of information would be partially relevant if it would allow to eliminate some requests among all possible requests of multiple choice.

Dealing with first order logic and open requests also remains to be done.

Finally, it would be very interesting to address other needs than information need as well as or to deal with more complicated requests. For example, an agent may have a *verification need* that means he needs to verify that his beliefs are true. In this case, relevant information are the ones reinforcing or contradicting his beliefs. Symmetrically, an the agent may have a *need for completion* that means that he wants to be aware of any information which are true (or any information in a given domain).

References

1. Herzig A. and Longin D. A logic of intention with cooperation principles and with assertive speech acts as communication primitives . In C. Castelfranchi and W. L. Johnson, editors, *Proc. 1st Int. Joint Conf. on Autonomous Agent and Multi-Agent System (AAMAS 2002) , Bologna*, pages 920–927. ACM Press, 2002.
2. Alchourrón C., Gärdenfors P., and Makinson D. On the logic of theory change: partial meet contraction and revision functions. In *Journal of Symbolic Logic*, volume 50, pages 510–530, 1985.
3. Voishvillo E.K. Philosophical-methodological aspects of relevant logic. In *Bulletin of Section of Logic*, volume 18/4, pages 146–151, 1989.
4. Chellas B. F. Modal logic: An introduction. Cambridge, MA, 1980. Cambridge University Press.
5. Crestani F. and Lalmas M. Logic and uncertainty in information retrieval. pages 179–206, 2001.
6. Enderton H.B. In *A Mathematical Introduction to Logic*. Academic Press, 1972.
7. Chevallet J.P. Modélisation logique pour la recherche d'information. pages 105–138. Hermes, 2004.
8. Floridi L. Understanding epistemic relevance. *Erkenntniss*, 2007.
9. Lalmas M. and van Rijsbergen C.J. A model of information retrieval system based on situation theory and dempster-shafer theory of evidence. In *Proceedings of the 1st Workshop on Incompleteness and Uncertainty in Information Systems*, pages 62–67, 1993.
10. Wooldridge M. In *Reasoning about rational agents*, Cambridge, Massachusetts, 2000. The MIT Press.
11. Borlund P. The Concept of Relevance in IR. *Journal of the American Society for Information Science and Technology*, 54(10):913–925, 2003.
12. Tagawa T. and Cheng J. Deontic relevant logic: A strong relevant logic approach to removing paradoxes from deontic logic. In *PRICAI '02: Proceedings of the 7th Pacific Rim International Conference on Artificial Intelligence*, pages 39–48, London, UK, 2002. Springer-Verlag.
13. Wilson T.D. Models in information behaviour research. In *Journal of Documentation*, volume 55(3), pages 249–270, 1999.