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Heterogeneous BDI Agents I: Bold Agents

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Abstract

One of the most interesting issues that arises in agents based on the BDI (belief-desire-intention) formalism is capturing notions of realism, that is constraints that describe possible interrelationships between the three attitudes. Three such sets of constraints have been considered in the literature: *strong realism*, *realism* and *weak realism*. In this paper we propose notions of realism for heterogeneous BDI agents and in particular we explore what we call bold agents. We interpret bold BDI agents as agents that are willing to take risks, and thus adopt intentions even though they may not believe in all respective accessible worlds that these are achievable.

Keywords: Intelligent Agents, BDI Models, Agent Theories

Introduction

Agents are obviously highly complicated systems and formal theories that describe and explain their behaviour are of interest to the agent community. We consider agent theories as specifications, and we are mainly concerned with building a useful and expressive theory capable of capturing agents with a sufficient degree of rationality. In particular we opt for developing formalisms that capture relationships between the various elements of an agent's cognitive state.

The classical BDI paradigm of Rao and Georgeff (Rao and Georgeff 1991), (Rao and Georgeff 1998) describes agents as having three propositional attitudes: beliefs, desires and intentions. One of the most interesting issues that arises is defining notions of realism, that is constraints that describe possible interrelations between beliefs, desires and intentions. One way to describe these constraints is in terms of relations between the sets of accessible worlds. Three such sets of constraints known as *strong realism*, *realism* and *weak realism*, Figure 1, have been explored. We regard these three notions as the first step towards conceptualising heterogeneous agents, that is agents that may have a different cognitive model which may render them more suitable for some applications than others. This paper touches upon some of the issues on the relationships between the intentional notions. In particular, motivated by the work of Rao and Georgeff and by their remark that other useful BDI systems can be constructed, we propose notions of realism for capturing bold agents in the BDI framework. The paper is organised as follows. In the next section we present the classical BDI paradigm. Next we discuss our motivation and basic ideas behind heterogeneous agents and the concept of a bold agent. The four subsequent sections discuss four notions of realism formalising bold agents along with their properties. Due to space limitations lemmas and theorems are stated without proof. A summary and a brief discussion of our findings is then provided and the paper ends with the conclusions and a pointer to future work.

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The BDI Framework

Motivated by the need to express an agent's cognitive state in terms of both information attitudes and pro-attitudes and influenced by Bratman's philosophical work on intentions (Bratman 1987), Rao and Georgeff developed the BDI framework (Rao and Georgeff 1991), (Rao and Georgeff 1998). The BDI framework is a theoretical formalism in which an agent's information state is described in terms of beliefs, its motivational state in terms of desires (or goals), and its deliberation state in terms of intentions.

The logical language is a first order language which apart from the usual connectives, and quantifiers also includes three modal operators Bel_i, Des_i, $Intend_i$ for expressing beliefs, desires and intentions respectively. Thus, the formula $Bel_i(\phi)$ means that agent i believes proposition ϕ. In addition the framework uses a branching temporal component based on CTL logic (Computational Tree Logic), in which the belief-, intention-, and desire-accessible worlds are themselves branching time structures. Due to lack of space we will not present the temporal part of the BDI framework but its details can be found in (Rao and Georgeff 1991) and (Rao and Georgeff 1998).

The semantics of the BDI framework is based on the notion of possible worlds. The basic concept behind possible worlds is that besides the true state of affairs, the real world, there are other possible states of affairs or worlds relative to an agent. Thus there is a set W of accessible worlds which are connected with accessibility or possibility relations. An accessibility relation indicates the possible worlds relevant to an agent's perspective. Thus, $\mathcal{B}_i$ is the accessibility relation for belief for agent i, and similarly for $\mathcal{D}_i$ and $\mathcal{I}_i$. An interpretation for the logical language $\mathcal{L}$ is a tuple $M = < W, \mathcal{U}, \pi, \mathcal{B}, \mathcal{D}, \mathcal{I} >$ where W is a set of possible worlds, $\mathcal{U}$ is the universe of discourse, and π determines the truth values of the atomic formulas of the language. $\mathcal{B}, \mathcal{D}$, and $\mathcal{I}$, map the agents' current situation to their belief-, desire- and intention-accessible situations respectively. The semantics for the intentional notions is therefore as follows:

$M, w \models Bel_i(\phi)$ iff $\forall$ w' such that $\mathcal{B}_i(w, w')$, $M, w' \models \phi$
$M, w \models Des_i(\phi)$ iff $\forall$ w' such that $\mathcal{D}_i(w, w')$, $M, w' \models \phi$
$M, w \models Intend_i(\phi)$ iff$\forall w'$ such that $\mathcal{I}_i(w, w')$, $M, w' \models \phi$

The first clause states that a formula ϕ is believed in a world w if and only if it is true in all its belief-accessible ($\mathcal{B}_i$) worlds. By imposing restrictions on the accessibility relations we can capture certain axioms. Thus, $\mathcal{B}_i$ is taken to be serial, transitive and symmetric, and $\mathcal{D}_i$ and $\mathcal{I}_i$ are serial. The basic BDI axiomatisation is as follows:

Belief

$Bel_i(\phi) \wedge Bel_i(\phi \Rightarrow \psi) \Rightarrow Bel_i(\psi)$ (Distribution Axiom)
$Bel_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$ (D axiom, seriality)
$Bel_i(\phi) \Rightarrow Bel_i(Bel_i(\phi))$ (S4 axiom, transitivity)
$\neg Bel_i(\phi) \Rightarrow Bel_i(\neg Bel_i(\phi))$ (S5 axiom, symmetry)
if $\vdash \phi$ then $\vdash Bel_i(\phi)$ (Necessitation Rule)

Desires

$Des_i(\phi) \wedge Des_i(\phi \Rightarrow \psi) \Rightarrow Des_i(\psi)$
$Des_i(\phi) \Rightarrow \neg Des_i(\neg\phi)$
if $\vdash \phi$ then $\vdash Des_i(\phi)$

Intentions

$Intend_i(\phi) \wedge Intend_i(\phi \Rightarrow \psi) \Rightarrow Intend_i(\psi)$
$Intend_i(\phi) \Rightarrow \neg Intend_i(\neg\phi)$
if $\vdash \phi$ then $\vdash Intend_i(\phi)$

The Distribution axiom and the Necessitation rule are inherent of the possible worlds approach and they hold regardless of any restrictions that we may impose on the accessibility relations. Thus the agents are logically omniscient (Fagin et al. 1995) regarding their beliefs, desires and intentions. Before proceeding a note needs to be made. Since the temporal component has not been presented some of the schemas that will be introduced such as $Intend(\phi) \Rightarrow Bel(\phi)$ may appear unintuitive. This schema should be read as: if an agent intends ϕ then it believes it to be possible or achievable some time in the future.

Notions of Realism

It is reasonable to assume that an agent's beliefs affect its desires and intentions as well as the course of actions that it is going to take in order to achieve them. One way of defining relations between the three attitudes is by imposing conditions on the set relations of the belief, desire, and intention-accessible worlds. These constraints are called notions of realism and the interesting and meaningful ones can be characterised semantically and captured axiomatically. Rao and Georgeff have considered three such notions which suggest ways in which the propositional attitudes could be related to each other yielding different types of agents.

In the first notion of realism called *strong realism* the set of belief accessible worlds is a subset of the desire-accessible worlds, and the set of desire accessible worlds is a subset of the intention accessible worlds, as is illustrated in Figure 1(i). Set containment corresponds to logical implication and thus the relationships between sets of accessible worlds entail the following axioms:

$Intend_i(\phi) \Rightarrow Des_i(\phi)$
$Des_i(\phi) \Rightarrow Bel_i(\phi)$

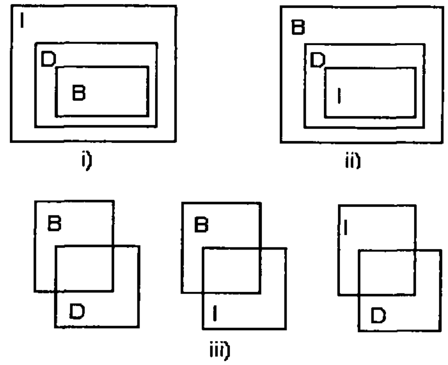

Figure 1: i) Strong Realism, ii) Realism iii) Weak Realism

Lemma 1 *The connection axioms for strong realism are sound in all models that satisfy the semantic conditions:*
(i) $\forall w \forall w'$ $\mathcal{D}_i(w, w') \Rightarrow \mathcal{I}_i(w, w')$
(ii) $\forall w \forall w'$ $\mathcal{B}_i(w, w') \Rightarrow \mathcal{D}_i(w, w')$

Thus, S-BDI (S-: *Strong realism*) comprises of the BDI logic and the axioms for *strong realism*. According to *strong realism* the agent is very cautious, and only intends and desires propositions that believes to be achievable, Figure 1(i).

In *realism* the set of intention accessible worlds is a subset of the desire-accessible worlds, and the set of desire-accessible worlds is a subset of the belief-accessible worlds. These relations are depicted in Figure 1(ii). The *realism* axioms that ensue from the set relations are the following:

$Bel_i(\phi) \Rightarrow Des_i(\phi)$
$Des_i(\phi) \Rightarrow Intend_i(\phi)$

Lemma 2 *The connection axioms for realism are sound in all models that satisfy the semantic conditions:*
(i) $\forall w \forall w'$ $\mathcal{D}_i(w, w') \Rightarrow \mathcal{B}_i(w, w')$
(ii) $\forall w \forall w'$ $\mathcal{I}_i(w, w') \Rightarrow \mathcal{D}_i(w, w')$

The R-BDI logic (R-:*Realism*) consists of the basic BDI axiomatisation and the *realism* axioms. An agent based on the *realism* constraints is an enthusiastic agent and believes that it can achieve its desires and intentions, Figure 1(ii). *Realism* was employed by Cohen and Levesque (Cohen and Levesque 1990) in their theory of intentions.

Finally, in *weak realism*, the intersection of intention- and desire-, intention- and belief-, and belief- and desire-accessible worlds is not the empty set as is shown in Figure 1(iii). The axiom schemas for *weak realism* are as follows:

$Intend_i(\phi) \Rightarrow \neg Des_i(\neg\phi)$
$Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$

Lemma 3 *The connection axioms for weak realism are sound in all models that satisfy the semantic conditions.*
(i) $\forall w \exists w'$ *such that* $\mathcal{I}_i(w, w') \wedge \mathcal{D}_i(w, w')$
(ii) $\forall w \exists w'$ *such that* $\mathcal{I}_i(w, w') \wedge \mathcal{B}_i(w, w')$
(iii) $\forall w \exists w'$ *such that* $\mathcal{D}_i(w, w') \wedge \mathcal{B}_i(w, w')$

A1	I-B Inconsistency	$\vdash Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
A2	I-B Incompleteness	$\not\vdash Intend_i(\phi) \Rightarrow Bel_i(\phi)$
A3	I-D Incompleteness	$\not\vdash Intend_i(\phi) \Rightarrow Des_i(\phi)$
A4	I-D Inconsistency	$\vdash Intend_i(\phi) \Rightarrow \neg Des_i(\neg\phi)$
A5	B-D Incompleteness	$\not\vdash Bel_i(\phi) \Rightarrow Des_i(\phi)$
A6	B-I Incompleteness	$\not\vdash Bel_i(\phi) \Rightarrow Intend_i(\phi)$
A7	D-B Inconsistency	$\vdash Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
A8	D-I Incompleteness	$\not\vdash Des_i(\phi) \Rightarrow Intend_i(\phi)$
A9	D-B Incompleteness	$\not\vdash Des_i(\phi) \Rightarrow Bel_i(\phi)$

Table 1: Asymmetry Thesis Principles.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
S-	T	F	F	T	T	T	T	T	F
R-	T	T	T	T	F	F	T	F	T
W-	T	T	T	T	T	T	T	T	T

Table 2: Asymmetry Thesis in classical BDI Systems.

As in the previous two notions of realism, the enhanced systems will be distinguished by the letter W- in front of their name. The agent described by the *weak realism* constraints is a more balanced agent than the other two types.

Asymmetry thesis and Consequential Closure

Bratman (Bratman 1987) and Rao and Georgeff (Rao and Georgeff 1998), discussed several conditions that should be taken into account in a logical formalism if we are to say that an agent is acting rationally. These conditions are also known as the asymmetry thesis or the incompleteness and the inconsistency principles, and they hold pairwise between desires, beliefs, and intentions. They are listed in Table 1. According to Rao and Georgeff, the three inconsistency principles (A1,A4,A7) are expressed as axioms, the rest of the principles are expressed as formulas that should not be valid. We will explain the first two and similar comments can be made for the rest of them. In Intention-Belief Inconsistency if an agent intends to do something it should not believe it to be impossible. In Intention-Belief Incompleteness an agent can have the intention to do an act but not necessarily believe that it will do it. In Table 2 the fulfillment of these properties in the classical BDI logics under the constraints of *strong realism, realism* and *weak realism* are repeated from (Rao and Georgeff 1998).

Apart from the asymmetry thesis, the principles of consequential closure (CC) state additional properties that should be satisfied by an agent's beliefs, desires and intentions. For instance, it is required that an agent that intends ϕ_1 and believes that $(\phi_1 \Rightarrow \phi_2)$ need not intend ϕ_2. Thus, an agent that intends to go to the dentist and believes that a visit to the dentist implies pain, it does not necessarily intend to suffer pain. Similarly, if an agent intends ϕ_1 and desires $\phi_1 \Rightarrow \phi_2$, it need not intend ϕ_2 and finally, if an agent desires ϕ_1 and believes $\phi_1 \Rightarrow \phi_2$, it may not necessarily desire ϕ_2. These intuitions are captured by the following formulas:

CC1. $Intend_i(\phi_1) \wedge Bel_i(\phi_1 \Rightarrow \phi_2) \wedge \neg Intend_i(\phi_2)$
CC2. $Intend_i(\phi_1) \wedge Des_i(\phi_1 \Rightarrow \phi_2) \wedge \neg Intend_i(\phi_2)$
CC3. $Des_i(\phi_1) \wedge Bel_i(\phi_1 \Rightarrow \phi_2) \wedge \neg Des_i(\phi_2)$

The satisfiability of these formulas depends upon the additional realism constraints, thus:

Proposition 4 *(Rao and Georgeff 1998, pp 332):*
a) The CC principles are satisfiable in S-BDI.
b) The CC principles are not satisfiable in R-BDI.
c) The CC principles are satisfiable in W-BDI.

Motivation

It is reasonable to suggest that different domains of applications for agents have different requirements, which need to be reflected in the conceptualisation, design, and implementation of the agents. For instance, an agent that has to deal in the stock exchange market should have a different reasoning model from an agent that acts as an air-traffic controller. The stock exchange agent needs to be able to engage in transactions that involve some risk, whereas an air-traffic controller agent needs to be strictly a cautious agent and avoid decisions that involve uncertainty and risk. Thus, the need for heterogeneous agents stems from the fact that the cognitive model of the agent may have to vary depending on the requirements of a particular application. In the level of agent theories and in particular in the BDI paradigm this need is addressed by adopting different realism constraints. Three such constraints have been considered: *strong realism, realism* and *weak realism.* In this paper we are interested in finding suitable constraints for characterising agents that are willing to take risks, such as the stock exchange agent in the example above. We will refer to such agents as "bold" agents. We interpret bold agents in the BDI framework as agents that may intend a proposition if they do not at least believe it to be unachievable. Therefore, a bold agent may adopt an intention even if it does not believe in all its belief-accessible worlds that it is achievable.

The notion of *realism* adopted by Rao and Georgeff characterises an enthusiastic agent. It is therefore plausible for the agent to adopt an intention even though it may not believe in all belief-accessible worlds that it is achievable. However, according to the *realism* constraints whenever the agent believes something in all worlds, then it will intend it as well (CC1). Thus, although agents are enthusiastic, they are not bold in our sense. In *realism* none of the consequential closure principles is satisfied. Hence, if the agent believes that by bombing a weapons factory it will kill the children in the nearby school, and intends to bomb the factory, it will intend to kill the children as well. *Weak realism* captures bold agents and overcomes the problems of *realism.* Our aim has been to thoroughly investigate the space of possibilities between *realism* and *weak realism* constraints in order to capture bold agents.

On the opposite end of bold agents stand circumspect agents. Circumspect agents are not willing to take any risks and they will only adopt intentions if they believe in all accessible worlds that they are achievable. However, we will not be concerned with circumspect agents here; future work will address such issues. In the subsequent sections we will present four notions of realism for capturing bold agents that seem to have interesting properties.

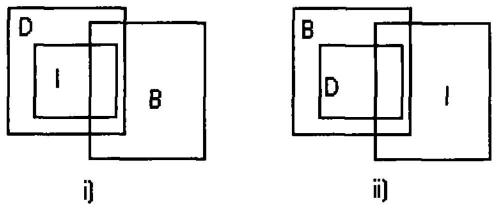

Figure 2: Set Relationships: i) R1-BDI, ii) R2-BDI

R1-BDI Realism

We begin our investigation into possible notions of realism for conceptualising bold agents by considering a set of constraints based on the traditional notion of *realism* with a modification. In R1-BDI realism the agent intends its desires and can adopt intentions even though it may not believe that they are achievable in all possible worlds. Hence, in terms of set relations, the set of intention-accessible worlds is a subset of the desire-accessible worlds and the intersection of belief- and intention-accessible worlds is not the empty set, as depicted in Figure 2 (i).

These set relationships yield the following axioms:
$Des_i(\phi) \Rightarrow Intend_i(\phi)$
$Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$

Lemma 5. *The axioms for R1-BDI realism are sound in all models that satisfy the following semantic conditions:*
(i) $\forall w \forall w'\ \mathcal{I}_i(w, w') \Rightarrow \mathcal{D}_i(w, w')$
(ii) $\forall w \exists w'\ \mathcal{B}_i(w, w') \wedge \mathcal{I}_i(w, w')$

The respective system called R1-BDI comprises of the basic BDI axiomatisation and the axioms for R1-BDI realism. The following are derivable:
$Intend_i(\phi) \Rightarrow Des_i(\phi)$
$Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
Furthermore, we can impose the following axioms providing further relationships between beliefs, desires and intentions:
BI. $Intend_i(\phi) \Rightarrow Bel_i(Intend_i(\phi))$
BD. $Des_i(\phi) \Rightarrow Bel_i(Des_i(\phi))$

Lemma 6. *The above axioms are sound in all models that satisfy the following semantic conditions respectively:*
BI.$\forall w, w', w''\ \mathcal{B}_i(w, w') \wedge \mathcal{I}_i(w', w'') \Rightarrow \mathcal{I}_i(w, w'')$
BD.$\forall w, w', w''\ \mathcal{B}_i(w, w') \wedge \mathcal{D}_i(w', w'') \Rightarrow \mathcal{D}_i(w, w'')$

Adopting the BD semantic condition in R1-BDI systems yields the following formula being a theorem:
$Des_i(\phi) \Rightarrow Bel_i(Intend_i(\phi))$

The satisfaction of the Asymmetry Thesis and the Consequential Closure principles for R1-BDI as well as the remaining notions of realism is given in Tables 3 and 4.

R2-BDI Realism

In R2-BDI realism if the agent believes a proposition it will have a desire towards that proposition, but its desires and beliefs are loosely coupled with its intentions. Thus the agent can adopt intentions, even though it may not believe them in all possible worlds to be achievable and it can also adopt an intention even though it may not desire that proposition in all possible worlds. As shown in Figure 2(ii), the set of desire-accessible worlds is a subset of the belief-accessible worlds, and the intersection of desire- and intention-accessible worlds is not the empty set. These set restrictions yield the following axioms:
$Des_i(\phi) \Rightarrow \neg Intend_i(\neg\phi)$
$Bel_i(\phi) \Rightarrow Des_i(\phi)$

Lemma 7. The axioms for R2-BDI realism are sound in all models that satisfy the following semantic conditions:
$\forall w \exists w'\ \mathcal{D}_i(w, w') \wedge \mathcal{I}_i(w, w')$
$\forall w \forall w'\ \mathcal{D}_i(w, w') \Rightarrow \mathcal{B}_i(w, w')$

The respective system is called R2-BDI system. The following are theorems in this system:
$Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$

We can also add the axioms *IB* and *DB* to capture further interrelationships between the three notions (Lemma 6).

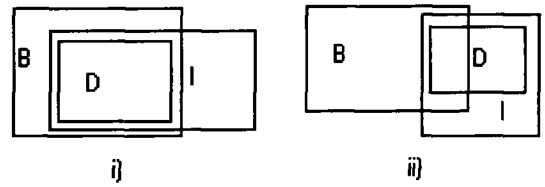

Figure 3: Set Relationships: i) R3-BDI, ii) R4-BDI

R3-BDI Realism

The R3-BDI notion of realism is based on the same intuitions as R2-BDI realism, namely that the agent can form an intention even though it may not have complete information that it is achievable in all possible worlds. The difference is located in the way intentions are related to desires. Thus, the set of desire-accessible worlds is a subset of the belief-accessible worlds, the set of desire accessible worlds is a subset of the intention-accessible worlds as well, and the intersection of the belief- and intention-accessible worlds is not the empty set as is depicted in Figure 3(i). These intuitions are captured by the following axioms:
$Intend_i(\phi) \Rightarrow Des_i(\phi)$
$Bel_i(\phi) \Rightarrow Des_i(\phi)$

Lemma 8. The axioms for R3-BDI realism are sound in all models that satisfy the following semantic conditions:
$\forall w \forall w'\ \mathcal{D}_i(w, w') \Rightarrow \mathcal{I}_i(w, w')$
$\forall w \forall w'\ \mathcal{D}_i(w, w') \Rightarrow \mathcal{B}_i(w, w')$

The respective R3-BDI system comprises of the basic BDI axiomatisation and the axioms for R3-BDI realism. The following are theorems:
$Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Intend_i(\neg\phi)$
As in the previous two notions of realism for bold agents we impose additional semantic constraints (Lemma 6) in order to capture the following principles:
$Intend_i(\phi) \Rightarrow Bel_i(Intend_i(\phi))$
$Des_i(\phi) \Rightarrow Bel_i(Des_i(\phi))$

Furthermore adopting the semantic condition BI yields the following being a theorem in R3-BDI system:
$Intend_i(\phi) \Rightarrow Bel_i(Des_i(\phi))$

R4-BDI Realism

In R4-BDI realism the set of intention-accessible worlds of an agent is a subset of the desire-accessible worlds, and the intersection of desire- and belief-accessible worlds is not the empty set, Figure 3(ii). The axioms capturing these relations of R4-BDI realism are as follows:
$Bel_i(\phi) \Rightarrow \neg Des_i(\neg\phi)$
$Intend_i(\phi) \Rightarrow Des_i(\phi)$

Lemma 9. The axioms for R4-BDI realism are sound in all models that satisfy the following semantic conditions:
$\forall w \exists w' \ \mathcal{D}_i(w, w') \wedge \mathcal{B}_i(w, w')$
$\forall w \forall w' \ \mathcal{D}_i(w, w') \Rightarrow \mathcal{I}_i(w, w')$

An agent based on R4-BDI realism is characterised as being bold, and if it intends a proposition it will have a desire towards that proposition, but it will not necessarily desire all its beliefs. The respective derived system is called R4-BDI. The following are theorems in this system:
$Intend_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Bel_i(\neg\phi)$
$Des_i(\phi) \Rightarrow \neg Intend_i(\neg\phi)$

Axioms providing further relationships between the three notions can be included in R4-BDI by imposing additional semantic conditions (Lemma 2). In particular adopting *BI* as an axiom in R4-BDI system entails the following theorem:
$Intend_i(\phi) \Rightarrow Bel_i(Des_i(\phi))$

All Consequential Closure principles are satisfiable in R4-BDI realism (Table 4). The satisfaction of the Asymmetry Thesis is provided in Table 3.

Comparison and Conclusions

The research presented in this paper has been driven by the need to formalise heterogeneous agents and in particular bold agents in the classical BDI paradigm. Bold agents are interpreted in the BDI framework as agents that are willing to adopt intentions even though they may not believe in all their belief-accessible worlds that their intentions are achievable. The paper in particular discussed four different types of realism constraints for bold agents. The properties of agents based upon these notions of realism were presented. In the scope of this research and in the effort to investigate all the available options between the notions of *realism* and *weak realism* 8 additional possible notions of realism were uncovered. Due to lack of space we only described those available options that seem to yield the most reasonable properties for agents.

One way of evaluating these different notions of realism and the respective systems, is by checking the asymmetry thesis and the consequential closure principles. Tables 3 and 4 summarise the asymmetry thesis and consequential closure properties for this category of agents. Checking these two tables and comparing them with Table 2 and Proposition 4 we see that all four systems proposed for bold agents yield nicer features than *realism*. In R1-, R2- and R3-BDI realism only one of the consequential closure principles is not satisfied, whereas in R4-BDI realism all of them are satisfied. Furthermore, although in the notion of *realism* three of the asymmetry thesis principles are not fulfilled, in R3-BDI two of them are not, whereas in R1-,R2- and R4-BDI only one is not fulfilled. So our specifications for BDI bold agents come closer to the desiderata laid down by Bratman, and Rao and Georgeff. Of course this is with the exception of *weak realism* where the asymmetry thesis and all the consequential closure principles are satisfied. To sum up, the alternative notions for bold agents seem to satisfy some of our intuitions about the relations between the intentional notions and offer nice features and properties that seem to come closer to the desiderata for rational reasoning agents than the classical notion of *realism*.

	A1	A2	A3	A4	A5	A6	A7	A8	A9
R1	T	T	T	T	T	T	T	F	T
R2	T	T	T	T	F	T	T	T	T
R3	T	T	F	T	F	T	T	T	T
R4	T	T	F	T	T	T	T	T	T

Table 3: Asymmetry Thesis in Systems for Bold Agents

	C1	C2	C3
R1	T	F	T
R2	T	T	F
R3	T	T	F
R4	T	T	T

Table 4: Consequential Closure in Systems for Bold Agents

The notions of realism presented here have only been examined with respect to the relationships between the three sets of accessible worlds. Space did not allow us to present the temporal component of BDI logics as well as present the properties of these notions of realism for bold agents with respect to the structure of possible worlds. Furthermore, extensions of the work presented here involve research under way investigating possible frameworks for capturing circumspect (cautious) agents. An extended version of this paper will cover all the aforementioned issues.

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