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Foundations for Knowledge and Belief Management

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ABSTRACT

Three foundational principles are introduced: intelligent systems such as those that would pass the Turing test should display multi-agent or interactional intelligence; multi-agent systems should be based on conceptual structures common to all interacting agents, machine and human; and multi-agent systems should have an underlying interactional logic such as dialogue logic. In particular, a multi-agent rather than an orthodox analysis of the key concepts of knowledge and belief is discussed. The contrast that matters is the difference between the different questions and answers about the support for claims to know and claims to believe. A simple multi-agent system based on dialogue theory which provides for such a difference is set out.

KEYWORDS

Common Conceptual Structures, Dialogue Logic, ELIZA, Foundational Ideas, Knowledge and Belief, Knowledge and Belief Management, Multi-Agent Systems

INTRODUCTION

The *Veridicality Principle* (VP for short) is the one uncontested principle in epistemic logic:

(VP)$K_a p \supset p$ (where $K_a p \supset p$ is read as "*a* knows that *p* only if *p*.")

For example, an agent *a* knows that it's raining outside only if, as a matter of fact, it is raining outside. Contrapositively and equivalently, if it's not raining outside, then *a* does not know that it's raining outside. This gives the necessary condition for the truth of the proposition that *a knows* something, but not on sufficient conditions.

A quite different situation exists when turning to conditions for the truth of a proposition that *a* believes something. The analogous principle, the belief veridicality principle:

$B_a p \supset p$ (where $B_a p \supset p$ is read as "*a* believes that *p* only if *p*.").

definitely does not hold. An agent *a* may well believe that it's raining outside when, as a matter of fact, it is not. The agent has a belief, albeit a false belief. The VP distinguishes knowledge from belief in a sharp way in epistemic logic.

The VP gives expression to the common view that knowledge is somehow objective. Knowledge is not "just a matter of opinion." If someone says that they know it's raining outside and it's not, then the claim to know is false. Finding the sufficient condition for the truth of an assertion that someone

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knows is far more difficult. This is shown by the long, inconclusive and probably misleading debate about defining knowledge as justified true belief (JTB, for short).

The failure of a VP for belief gives expression to the common view that beliefs are subjective in a strong sense. A false belief is none the less a belief held by the person who avows it (lies, deception and insincerity are ignored for the moment). There can be false beliefs, that is, a belief remains a belief even when its content is false. But there cannot be "false knowledge". So, the contrast between knowledge and belief can be *partly* portrayed by saying that the VP holds for knowledge but does not hold for belief.

In what follows consideration is given to shifting the emphasis from the truth conditions *simpliciter* to conditions for *claiming to know* and *claiming to believe* . Consideration is given to what is involved when it is said that a particular claim is correct or mistaken. It is shown that that the conditions are exactly the same, so discussing claims to know or believe is the same as discussing knowing and believing *simpliciter.*

It will be argued that the contrasts which matter in implementing knowledge systems in which there is a difference between knowledge and belief are the contrasts between the different kinds of *questions* asked about knowledge and belief and the kinds of answers which are correct and incorrect. These are Austin's contrasts. Although they are usually posed in terms of *claims* to know and *claims* to believe, they are nonetheless just about knowing and believing *simpliciter*.

The second section of this paper presents the case for there being no important distinction between claiming to know or believe and simple statements of knowledge and belief. There is also a discussion of a point which lies somewhat deeper than the traditional contrast. This is concerns the notion that it is inconsistent for someone to believe both that a proposition is true and that they believe its negation. (Hintikka, 1962) This concern is so much the more obvious when considering a claim to believe.

The third section will consider the extent to which the implementation of any knowledge or belief system, or knowledge and belief system, has to be solipsistic.

In the fourth section an implementation is forwarded which is a system for both knowledge and belief, but where the distinction between knowledge and belief is Austinian. The distinction emphasises the difference between claiming to know and claiming to believe. The implications of this style of system for knowledge and belief revision will be discussed.

The concluding section will outline progress and further work.

CLAIMING TO KNOW AND CLAIMING TO BELIEVE

When some epistemic agent, say *a*, claims that they know that *p*, and *p* is false, then they have made a mistake because the content of the claim, $K_a p$, and the fact, $\sim p$, are together contrary to the VP.

The same is not the case for belief. When some epistemic agent, say *a* , claims that they believe that *p* and *p* is false, then they have not made a mistake. If the content of the claim, $B_a p$, and the facts, $\sim p$, are conjoined as $(B_a p \ \& \sim p)$, the conjunction is not contrary to any principle applicable to belief. They may well believe, but they have a false belief.

The focus here is on the contrast between correct and mistaken claims. The chief interest will not be on just whether it's true that someone claims to know or believe something. The interest is in whether it's true that someone correctly claims to know or believe, or whether it's not true that they correctly claim to know or believe. The notation C_a is introduced and used as an operator in formulas such as $C_a K_a p$. This is read as "*a* **correctly** claims to know that *p*." $C_a K_a p$ is abbreviated to $C_a Kp$, and similarly for belief. This is not to rule out $C_b K_a p$, read as "*b* **correctly** claims that *a* knows that *p*."

There are interesting relationships between correct claims and what is claimed. So:

KC. $C_a Kp \supset K_a p$

and by VP and transitivity of implication:

CVP. $C_aKp \supset p$

For belief:

BC. $C_aBp \supset B_ap$

but there is no analogue for CVP.

If someone does know something then their claim to know it will be correct. Similarly, if someone does believe something then their claim to believe it will be correct. Thus surprisingly:

CK. $K_ap \supset C_aKp$

and

CB. $B_ap \supset C_aBp$

This means that a correct claim to know something is equivalent to knowing it, and a correct claim to believe something is equivalent to believing it.

CK≡. $K_ap \equiv C_aKp$

and

CB≡. $B_ap \equiv C_aBp$

So there is no need for the claims notation and use can freely be made of both *claiming to know* and *know*, and similarly with belief. What the use of "claim" does do is to change the perspective from which to consider the role played by knowledge and belief statements or claims.

It will almost certainly be objected that someone can know something and never claim to know it, believe something and never claim to believe it. This objection is that CK≡ and CB≡ can only apply when all the knowledge and belief being considered is "out in the open".

CK and CB would hold for those situations in which all knowledge and belief is made explicit in terms of something like a conversational or dialogue context. In what follows only explicit assertions of knowledge and belief are considered. So, the equivalence of correctly claiming and truly knowing or believing can be sustained when all is explicit.

INTERNAL CONSISTENCY

In (Hintikka, 1962) there is a discussion of Moore's problem. The problem is presented as the claim "that the paradoxical sentence *p* but I do not believe that *p*. (8) is not self-contradictory." (p 64) Hintikka goes on to assert that "most people would probably admit that there is something *logically* very queer about (8)." (p 65) Hintikka is almost certainly correct in his common sense assertion. The real problem here can be brought into sharp focus as follows. Say it's agreed that one of the main features of belief is that, from a person's correct claim that they believe that p , it does not follow that p . Say it's also agreed that if a person claims to believe that *not p* , then they will not claim to believe that p if they wish to be consistent. But, there is no inconsistency in a person's claiming to believe

that *not p* while *p* is true. It also follows that there is no inconsistency in a person's not claiming to believe that *p* while *p* is true.

But if this is true of all persons, why is (8) logically inconsistent? Hintikka argues in detail and at some length that the problem is that:

$$B_a p \ \& \sim B_a p$$

is the real source of the problem, not just:

$$p \ \& \sim B_a p$$

The latter is what (8) appears to be, but the first person "I" is the giveaway. If the person who asserts (8) is *a*, then there is an inconsistency. But if the person who asserts (8) is someone other than *a* then there is no problem. This becomes an issue of observer or commentator inconsistency or consistency. There is no observer inconsistency in (8).

In other words, when a person asserts something, as is indicated in (8) by "I", they have normally to be taken as claiming to believe it. So (8) is equivalent to:

$$C_a B p \ \& \sim B_a p \tag{9}$$

which entails:

$$B_a p \ \& \sim B_a p \tag{10}$$

The problem with (8) is the straight forward problem of internal consistency, and (10) cannot be accepted.

Now, consider what this reasonable view means for someone's claiming to agree with the VP. For that person, say *a* , at least:

$$C_a B \ (K_a p \supset p) \tag{11}$$

or maybe even, given Hintikka's **S4** logic for knowledge, that:

$$C_a K \ (K_a p \supset p) \tag{12}$$

If knowledge entails belief, then a knowledge claim will include a belief claim. The former is included in the latter. The emphasis is on the "If". Austin's account is quite contrary to the JTB, definition of knowledge, and would not accept the idea that knowledge entails belief.

It may be argued that there is a first person case and that this makes for a difference. But, the principle has a first person instance. When someone agrees with it they are agreeing that "I know that *p* only if *p* ." In terms of claims this becomes "My claim to know that *p* is correct only if *p* ."

This will be:

$$C_a B \ (C_a K \ p \supset p) \tag{13}$$

or:

$$C_a K \ (C_a K \ p \supset p) \tag{14}$$

(14) entails (15), and (15) entails (16), and (16) entails (17):

$$B_a (C_a K p \supset p) \tag{15}$$

$$K_a (C_a K p \supset p) \tag{16}$$

$$(C_a K p \supset p) \tag{17}$$

The interesting question then becomes, how does a person check out their knowledge claims in the light of the VP? Any claim they make about their own knowledge's being checked out will fall, at best, inside their own knowledge claims.

In practice, when the VP is applied it reduces to the same sort of internal consistency principle that applies to belief. This means that in practice, the VP is not as important as it might at first seem.

SOLIPSISM

There is an insight embedded in autoepistemic logic which is simply the same thing from another perspective:

$$p \supset \mathrm{L}p \tag{18}$$

where Lp means that *It is believed that p* . No information is left outside the scope of some epistemic operator. Epistemic agents are caught within their own knowledge and belief. There is a saying that no-one believes anything which is false. That is, no-one claims to believe anything which they believe to be false. Although this is sometimes claimed to lead to a paradox (Schlesinger, 1985), the import for us is that even though VP does not hold for belief, once an agent discovers that *not p*, even if they have once believed that p , they will revise their beliefs or attempt to cope with a patently inconsistent belief set. In a kind of operational sense, VP does hold for belief. But the revision of belief does not lead to the repudiation of the former belief avowal. It is conceptually acceptable for an agent to say, "I used to believe that p , but now I believe that *not p* ."

The difference with knowledge is that if an agent revises their knowledge set they will have to repudiate their former knowledge claims as mistaken. It is not conceptually acceptable for an epistemic agent to say, "I used to know that p , but now I know that *not p*." The conceptually correct thing is to say something such as, "I now know that *not p* , and although I used to *claim* (*thought, believed*) that I knew that p , I was mistaken. I did not *know* that p ." Knowledge revision has retrospective consequences, belief revision does not.

The VP should be seen, not as a principle which can be objectively applied, but as a principle to do with the revelation of mistaken knowledge claims. Later knowledge reveals the former mistakes, if there are any.

In the general area of belief revision the main concern is for the present belief set of the believer. Their past beliefs, or their belief history is often ignored. The classical belief revision theory (Gardenfors, 1988), often called the AGM theory (Alchourron, Gärdenfors and Makinson, 1985), has no real concern for belief history. In AGM theory there are three important changes to belief sets. When beliefs are added to a set there is *expansion* . When beliefs are abandoned there is *contraction* . When a belief set is contracted by removing a belief and then expanded by adding the negation of what was removed, there is *revision* . There are well known problems to do with the disregarding of belief history in the context of revision. These problems have to do particularly with the contraction

of belief sets. It turns out that there are good reasons for keeping track of the history of belief sets and of reasons for expanding and contracting them.

But these problems do not concern judgements about what was believed in the past. If someone believed at time t_1 that p , and at time t_2 revised their beliefs by withdrawing p and adding *not* p , then there is no retrospective revision of the belief set at time t_1.

Yet, if knowledge were to be included in our considerations, and a knowledge revision system were to be set up, then knowledge and belief history would have to be looked at seriously. Since there are other reasons for keeping some account of belief history, advantage might well be taken of the situation to give some depth to any knowledge revision system.

THE DIFFERENCES

The differences between knowledge and belief claims, according to Austin, have to do as much with promises and questions as with the VP. Austin argues that the difference between knowledge and belief claims is to be found in three areas. The first concerns VP, in as much as knowledge claims can be mistaken. The second distinction concerns what Austin claims to be the *promissory* nature of knowledge. A claim to know, he says, is when "*I give others my word: I give others my authority for saying* that '*S* is *P*'." (p 67, 1961) But when one claims to believe, or even to be certain but not to know, then one is not prepared to enter that unqualified promissory note. The claim to believe is the claim of caution. The caution can arise from uncertainty, or from something else. This has to do with being cautious, and protecting oneself from criticism. "I did not say I knew, I only said that I believed it."

The third distinction concerns the difference between the *questions* which can be put to those who claim to *know* and those which can be put to those who claim to *believe* . If someone claims to know that p , it can be asked, "*How* do you know that p ?" But if someone claims to believe that p , it can be asked, "*Why* do you believe that p ?" The former question implies that if a knowledge claim is correct then the claimant should be able to give an account which guarantees the agent asking the question that if they follow the method set out in the answer then they will also come to know what the knowledge claimant knows. Acceptable responses to "*How* do you know that p ?" are determined by a range of issues to do with the knowledge domain, the community of experts, and the status of the claimant. If the correct type of response is not given, then the claim to know is called into doubt. The response that someone 'just knows' might not be logically unsatisfactory, but it does call the claim to knowledge into question.

In answer to the question, " *Why* do you believe that p ?", it is usual in academia for the believer to give reasons which support the belief. But other accounts might be given including explanations, historical accounts of the believer's experience, and psychological accounts. These are all legitimate responses, and do not call the claim to believe into question.

When consideration is given to the implementation of these contrasts and distinctions in a knowledge and belief system, it becomes clear that there are at least four design principles to be observed (cf. Girle , 1990). There may be others which need to be observed because of considerations to do with revision. These formal belief revision matters are not considered here.

The first principle arises not from any contrast between knowledge and belief generated by VP, but simply from the needs for both knowledge and belief to be as internally consistent as seems reasonable. There is a considerable literature on non-trivial inconsistent systems. But, apart from the interesting logical property of para-consistency, the focus here is on coping with inconsistency by revision.

Austin's second distinction means that a system has to distinguish, in principle, at least two kinds of information. An easy way to do this is to place all information under one or other of the two epistemic operators *knows that* and *believes that* . In this way there is no difficulty in keeping track of information qualified by caution and the inferences that are drawn from such information.

Given what has been said about the retrospective effects of knowledge revision, any system will have to keep, in principle, some track of the history of the machine's knowledge and belief. One way of doing this is to be found in the area of implemented dialogue logic. Dialogue logic provides a means for showing the way in which a system's knowledge and belief develops, grows, and is revised. In particular, there would be principles to govern the knowledge and belief store in the system so that retrospective revisions could be made consequential upon present revisions.

It has been argued elsewhere (Girle, 1993) that dialogue logic can deal with the history lacking deficiency of classical belief revision theory. The facility for dealing with the history of belief is easily extended to knowledge revision. Set out below is a relatively simple system of dialogue logic. (cf. Walton, 1984; Walton and Krabbe, 1995)

Any machine system for knowledge and belief, which took Austin's third distinction seriously, would have to have explanatory and reason giving modules to go with knowledge and belief representation. There would have to be, as it were, a way of dealing with How questions and a a way of dealing with *Why* questions. Once again, dialogue logic provides what is needed.

The principles are that there should be:

- some regulation of consistency
- two categories of epistemic content
- retrospective revision for knowledge claims.
- facility to answer two kinds of questions

DIALOGUE SYSTEMS

Dialogicians have created and discussed several dialogue systems at a formal level. (Barth and Martens, 1982; Girle, 1996; Hamblin, 1970; Mackenzie 1979 and 1984, Walton and Krabbe, 1995) Despite some differences between these dialogue systems, most of the systems discussed by these authors have several things in common. In particular, there are two main elements:

The two main elements in dialogue-logic are: first a *sequence of locution events*, and second, a *commitment store* for each participant in the sequence. There is a set of rules to govern each of these elements. Dialogue-logic also has syntactic stipulations concerning the types of locutions with which the logic will deal. The syntactic list contains the sorts of locutions which are to be found in real discourse: statements, responses of various sorts, questions of various kinds, and withdrawals. Some logics also include commands. (Girle, 1996) Although commands are important for answering *How* questions, details are beyond the scope of this paper. They will be dealt with in another more summary way

There are *Interaction Rules* which set out the proper sequence in which the locutions should be used in order to sustain the dialogue. For example, a question of the form "Why do you believe that p ?" must be followed by the reasons from which one is to draw the conclusion that p . Such stipulations make the system a prescriptive dialogue game ("game" in the serious sense of "game theory"). These rules also make the dialogue into a joint activity. Breach of the rules indicates a failure in the joint activity.

There is also a set of *Commitment Store Rules*. The commitment store is added to and subtracted from according to which statements, questions, commands, answers and withdrawals are used by participants during the dialogue. The content of a commitment store is subject to rules. A participant's commitment store does not have to be logically consistent. Its logical consistency becomes an issue only if the other participants in the dialogue detect *prima face* logical inconsistency and demand that the inconsistency be resolved.

It was established earlier that in an explicit conversational context there is an equivalence of claiming to know and knowing, claiming to believe and believing. In the dialogue logic set out below there will be overly explicit treatment of knowledge and belief, and free movement backwards and

forwards between claiming and knowing or believing. The notation will not include any symbols for correctly claiming, because it is taken that the contextual equivalence will be enough.

THE SYSTEM KB-DL

The rules for a dialogue-logic, **KB-DL**, based on the system **BQD** are forwarded. (Mackenzie, 1979, 1984). For **KB-DL** there are just two participants, *X* and *Y* . There are eight sorts of locutions allowed: *statements of four kinds, withdrawals, tf-questions, two sorts of challenges,* and *resolution demands*. All the material related to Predicate Logic in **BDL** is omitted.

In what follows it is assumed that any unqualified statement of *p* by a participant *X* means $K_X p$. This assumption is based on the common assumption built into the standard sequence:

X: *p*
Y: How do you know?

The onus is on the participants to make explicit any reservations they have which qualify their statements as belief statements. *Att* will be used as a place holder for either *K* or B . It is useful to use $Att_E\ p$ where *E* is for either *X* or *Y*.

- The *categorical statements* are statements such as *p*, ~*p*, (*p and q*), (*p or q*), (*If p then q*), $Att_E\ p$, Att_E (*p and q*), Att_E (*p or q*), and Att_E (*If p then q*).
- The *reactive statements* are *grounds*: *Because* $Att_E\ p$, denials Att_E *not p*, and *statements of not knowing* or *non-belief*: *not* $Att_E\ p$, *statements describing how*: *By p*.
- The *logical statements* are *immediate consequence conditionals* such as: *If p, and p implies q, then q* and: *If* $Att_E\ p$ *and* B_E (*If p then q*) , then $B_E\ q$
- The *withdrawl* of *p* is of the form *I withdraw p* or *not* $Att_E\ p$.
- The *tf-questions* are of the form *Is it the case that p?*
- A *belief challenge* is of the form *Why* $B_E\ p$? an open question.
- A *knowledge challenge* is of the form *How* $K_E\ p$? an open question.
- The *resolution demands* are of the form *Resolve whether* $Att_E\ p$. Resolution demands are a particular kind of command.

The rules of **KB-DL** are set out with comments on their dialogical significance and operation. There are eight **Commitment Store Rules** :

(C1) *Statements*: After any statement *p* , unless the preceding event was a challenge, *p* goes into both *X's* and *Y's* commitment stores, except that if a statement by *X* is of the form $K_X\ q$ then *q* also goes into both commitment stores and $K_Y q$ goes into *Y's* store instead of $K_X\ q$.

(It is assumed that everyone agrees with statements unless and until they deny them or withdraw them. If one agrees with the other's knowledge statement then they also know. This exception reflects the principle that if *Y* accepts that *X* knows, then *Y* also knows.)

(C2) *Belief Defences*: After the statement of reasons by *X* , *Because* $Att_X\ p$, when the preceding event was a belief challenge by *Y* , *Why* $B_X\ q$? , both $Att_X\ p$ and Att_X (*If p then q*) goes into *X's* commitment store, and both $Att_Y\ p$ and Att_Y (*If p then q*) go into *Y's* commitment store, and (*If p then q*) is the *reasoning conditional* connecting the reasons to what they support.

(If someone gives a reason for believing that q , then the reason and its assumed connection goes into the commitment stores of all participants.)

(C3) *Knowledge Defences*: After the account of how X came to know q , *By* p, when the preceding event was a knowledge challenge by Y , *How* $K_X q$?, both $K_X p$ and *If* K_X (*If* p *then* q) goes into *X's* commitment store, and both $K_Y p$ and *If* K_Y (*If* p *then* q) and go into *Y's* commitment store, and p and q and (*If* p *then* q) go into both stores. (*If* p *then* q) is the *reasoning conditional*.

(If someone gives an account of how they came to know q , then that account and its assumed guarantee of knowledge goes into the commitment stores of all participants.)

(C4) *Withdrawals*: After the withdrawal of p or a statement of ignorance (not knowing) or not believing p or a denial of p , the statement p is not included in the speaker's commitment store if it's there.

(C5) *Belief Challenges*: After the challenge of $B_X q$ by Y , the challenge Why $B_X p$? goes into the *Y's* commitment store, and the statement $B_X p$ goes into the *X's* commitment store, and $B_Y p$ is removed from *Y's* store if it is in *Y's* store.

(Although it might seem strange to put $B_X p$ into the *X's* commitment store, X can withdraw it or deny it (see (v) (a) below and C4 above). This signifies the questioner's commitment to finding an answer. Also, if $B_Y p$ is in *Y's* commitment store the challenge should not have been issued unless Y is going to abandon $B_Y p$.)

(C6) *Knowledge Challenges*: After the challenge of $K_X p$ by Y , the challenge *How* $K_X p$? goes into *Y's* commitment store, and the statement $K_X p$ goes into *X's* commitment store if not there, and $K_Y p$ and p are removed from *Y's* store if they are in *Y's* store.

(The same strictures apply here as in the previous rule.)

It is important to look more closely at Rule C4 . This Rule is the Rule most relevant to belief revision. As it stands, (C4) is a simple Withdrawal Rule. In the normal course of events the following sort of situation is allowed. Say someone withdraws q but also has p and ($p \supset q$) still in their commitment store, then it is up to the other agent in the dialogue to detect and ask for a resolution of this "hanging conditional". Rule (vii) below deals with this situation by means of a resolution demand.

There are nine **Interaction Rules**:

1. *Repstat*: No statement may occur if it is in the commitment stores of both participants.

(This rule prevents vain repetition and helps prevent begging the question. It does not accord with everyday speech where people tend to repeat statements up to at least three times in any debate or discussion. But there is a sense in which this paper is dealing with ideal agents.)

2. *Imcon*: A conditional whose consequent is an immediate consequence of its antecedent must not be withdrawn.
3. *LogChall*: An immediate consequence conditional must not be withdrawn.

(These rules, (ii) and (iii) , prevent the withdrawal or challenge of logical principles.)

4. *TF-Quest*: After *Is it the case that* $Att_H P$? the next event must be either

a. an affirming statement that $Att_S p$, or
b. a statement that *not* $Att_S p$, or
c. a withdrawal of $Att_S p$, or
d. a statement of ignorance or non-belief *not* $Att_S p$.

(This rule must be read in conjunction with C1 and C4.

A *tf-question* is formed from a proposition, *p*, by a query operation, say ¿ , to give ¿*p*. The forms of answer, (a) to (d), are fairly obvious. Strict formality is not needed for (iv), given some restrictions. Note: this system does not allow a *tf-question* to be answered by either a question or a command. This limitation can only be addressed by a general logic of questions, a matter beyond the scope of this paper and most literature.)

5. *Bel.Chall*: After *Why* $B_E p$? the next event must be either

a. a withdrawal or denial of $B_E p$, or
b. the resolution demand of an immediate consequence conditional whose consequent is $B_E p$ and whose antecedent is a conjunction of the statements to which the challenger is committed, or
c. a statement of grounds *acceptable* to the challenger.

Mackenzie's definition of what an *acceptable* statement of grounds is:

A statement of grounds, *Because p* , is *acceptable* to participant *X* iff either *p* is not under challenge by *X* , or if *p* is under challenge by *X* then there is a set of statements to each of which *X* is committed and to none of which is *X* committed to challenge, and *p* is an immediate *modus ponens* consequence of the set.

This definition is discussed at length in (Mackenzie,1984).

(When the challenge to a belief is issued, see C5 , the person challenged can either (a) deny any claim to *p* , or (b) throw the challenge back to the challenger by pointing out that the challenger is committed to *p* , or (c) give a reason acceptable to the challenger.

The range of acceptable answers is strictly limited in this system. The limitation is imposed partly because predicate logic has been set aside for the moment, and a *Why* question requires predicate logic for a general analysis of its nature. Also, questions cannot be answered with either a question or a command in this system.)

6. *Know.Chall*: After *How* $K_S p$? the next event must be either

a. a withdrawal or denial of $K_S p$ and of *p* by *S*, or
b. the resolution demand of an immediate consequence conditional whose consequent is $K_S p$ and whose antecedent is a conjunction of the statements to which the challenger is committed, or
c. a statement by *S By q* .

(When the challenge is issued to a knowledge claim, see C6 , the person challenged can either (a) deny any claim to know that *p* , or (b) throw the challenge back to the challenger by pointing out that the challenger knows that *p* , or (c) give an account of how *p* came to be known *By q*. The restriction on the options for answering *How* questions arise for the same reasons given above for answering *Why* questions.)

7. *Resolve*: The resolution demand of *Resolve whether p* can occur only if either

a. *p* is a statement or conjunction of statements which is immediately inconsistent and which its hearer claims to know or believe, or
b. *p* is of the form *If q then r* and *q* is a conjunction of statements all of which its hearer claims to know or believe, and *r* is an immediate consequence of *q* , and the previous event was either *I withdraw r* or *Why* $B_E r$? or *How* $K_E r$?

(The rule opens the way for keeping commitment stores consistent, and for dealing with what were described above as "hanging conditionals.")

8. *Resolution*: After *Resolve whether p* the next event must be either

a. the withdrawal of one of the conjuncts of *p* , or
b. the withdrawal of one of the conjuncts of the antecedent of *p* , or
c. the consequent of *p* .

In the table below there is an example sequence in which there are two participants, *X* and *Y*. *X+A* will be used for *A* is added to *X's* commitment store if not already there, and *X−A* for *A* is taken out of *X's* commitment store if it is already there:

This table shows how the system applies to a dialogue about *X*'s knowing that *p*. It may well be said that it is complex. But the analysis provided by the changes in the Commitment Stores show that the simple sequence of three locutions does have a complex changing context. This context is generated purely out of the sequence, and does not take any social context into account. Incorporating a wider context is well beyond the scope of this paper.

Table 1.

Agent	Location	*X's* Store	*Y's* Store	Rule
X:	$K_X p$*;*	*X+* $K_X p$ and *p;*	*Y+* $K_Y p$ and *p*	(C1)
(Then comes the *knowledge challenge* as in (vi))				
Y:	*How* $K_X p$?;		*Y+ How* $K_X p$*?*	(C6)
X:	+ $K_X p$ and *p;*		*Y−* $K_Y p$ and *p*	
X:	*By q;*	*X: +By q;*	*Y: +By q*	(C3)
X:	+ K_X(*If q then p*);		*Y:* + K_X(*If q then p*)	
X:	+ $K_X p$ and *p;*		*Y:* + $K_Y p$ and *p*	
X:	+ *p, q,* (*If q then p*);		*Y:* + *p, q,* (*If q then p*)	

IMPLEMENTATION AND FURTHER WORK

As can be seen from the example above, a key point of this system is that the interactive nature of knowledge and belief management creates a context which can be seen as a rapidly changing complex data base. A machine would need such a complex data base in order to interact intelligently with people

Further work is required on the logic of questions. **BQD** and the derivative system **KB-DL** above have a very contingent approach to questioning. This contingent approach reflects the absence of a satisfactory general logic of questions. Work is in progress on this matter with a focus on question-answer pairs (Hiz, 1978; Goody, 1978).

Work has already begun on the implementation of dialogue logic in which the machine is seen as one of the agents in a dialogue. There are problems to do with the strategies which automatic systems should adopt in dialogue. At one extreme the systems can be highly sceptical and aggressive, at the other they can be passive and credulous (Stewart-Zerba, 1993).

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