TOWARDS A FORMAL MODEL OF KNOWLEDGE ACQUISITION VIA COOEPERATIVE DIALOGUE

Asma Moubaiddin
Department of Linguistics and Phonetics, Faculty of Arts, The university of Jordan, Amman, Jordan

Nadim Obeid
Department of Computer Information Systems, King Abdullah II School for Information Technology
The university of Jordan, Amman, Jordan

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Abstract: We aim, in this paper, to make a a first step towards developing a model of knowledge acquisition/learning via cooperative dialogue. A key idea in the model is the concept of integrating exchanged information, via dialogue, within an agent's theory. The process is nonmonotonic. Dialogue is a structured process and the structure is relative to what an agent knows about the world or a domain of discourse. We employ a nonmonotonic logic system, NML3, which formalizes some aspects of revisable reasoning, to capture an agent's knowledge and reasoning. We will present a formalization of some basic dialogue moves and the protocols of various types of dialogue. We will show how arguments, proofs, some dialogue moves and reasoning may be carried out within NML3.

1 INTRODUCTION

We aim, in this paper, to make a a first step towards developing a model of Knowledge Acquisition (KA)/learning via cooperative dialogue. A key idea in the model is the concept of integration; an agent learns a collection of propositions concerning some situation by integrating it within its knowledge about that situation. Agents may switch roles.

We assume that each of the participants in a dialogue has a certain well-define role, determined by the type of dialogue, the goal of that type of dialogue, and the rules for making moves in it. We shall, following (Frans, Van Emeren and Grootendorst, 1992; Walton, 1992; Walton and Krabbe, 1995), adopt a model of dialogue that is based on a commitment. Agents are computational entities that have knowledge and possess the ability to acquire and manipulate (modify, derive) through reasoning their knowledge.

We shall assume that the agents are cooperative, abide by the rationality rules, e.g. rules of relevance (cf. Grice 1975) and rational in the sense that they fulfil their commitments and obligations in a way that truthfully reflects their beliefs and intentions.

The types of dialogue we will be considering in this paper are: information-seeking, inquiry and persuasion. A dialogue is initiated through questioning. An answer to a question, about a particular situation, may confirm what the agent accepts/knows or it may somehow require a process of belief revision. This suggests that the process of incorporation of new information into an agent theory be modelled nonmonotonically. We employ for capturing an agent's knowledge and reasoning a three-valued based nonmonotonic logic, NML3, which formalizes some aspects of revisable reasoning and is amenable to implementation. Within NML3, we present a formalization of some basic dialogue moves and the rules of protocols of some types of dialogue. The rules of a protocol are nonmonotonic in the sense that the set of propositions to which an agent is committed and the validity of moves vary from one move to another. We will show how proofs, some dialogue moves and reasoning may be carried out within NML3.

We shall begin, in section 2, with a presentation of NML3 employed to capture an agent's knowledge and reasoning. In section 3 we present the types of dialogue and in section 4 we present a formalization of some dialogue moves, rules of protocols of some types of dialogue and the process

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of integration. We show in section 5 how proofs and reasoning are carried out in NML3. Section 6 is concerned with learning and dialogue.

2 REASONING WITH INCOMPETE INFORMATION

The agent's *partial* knowledge and reasoning capability are expressed in a non-monotonic Logic, NML3. The language L_{NML3} is that of Kleene's three-valued logic extended with the modal operator M (Epistemic Possibility). Staring with T (true), F (false) and a set of atoms: p, q, r, …, more complicated Well-Formed Formulae are formed via closure under ~ (negation), & (conjunction), V (disjunction) and → (implication). That is, if A and B are WFF, then so are ~A, A&B, AVB, A→B and MA.. In NML3, L is the dual of M, $LA \equiv {\sim}M{\sim}A$. (Obeid, 1996) defines a truth-functional implication ⊃ that behaves exactly like the material implication of classical logic, as follows:

$$A \supset B = M({\sim}A\&B) V {\sim}AVB.$$

Non-monotonic reasoning is represented via the *epistemic possibility operator* M. Using M, we may define the operators U (*undefined*), D (*defined*) and ¬ (*classical negation*) as follows:

$UA \equiv MA\&M{\sim}A$
$DA \equiv {\sim}UA$
$\neg A \equiv DA \;\&\; {\sim}A$

Formal Semantics

Definition 2.1 A model structure for L_{NML3} is $\boldsymbol{M} = \langle W, R, g\rangle$ where W is a non-empty set of information states, R is a binary relations on W and g is a truth assignment function for atomic WFF. R can be interpreted as *epistemic possible* extension between states. Given w, w_1 are members of W, we shall write w R w_1 to mean that the information state w_1 is an *epistemic possible* extension of the information state w.

We employ the notation $\boldsymbol{M},w \models_g A$ (resp. $\boldsymbol{M},w \dashv_g A$) to mean that A is accepted as true (resp. false) at w in $\boldsymbol{M}$ with respect to g and $\boldsymbol{M} \models_g A$ (resp. $\boldsymbol{M} \dashv_g A$) to mean that A is accepted as true (resp. false) at every w in $\boldsymbol{M}$ with respect to g. For convenience, reference to g will be omitted except when confusion may arise.

Definition 2.2 Let A, B be wffs then, the truth "$\models$" and the falsity "$\dashv$" notions are recursively defined as follows:

(i) $\boldsymbol{M},w \models T$
(ii) $\boldsymbol{M},w \models p$ iff $g(w,p) =$ true for atomic p
(iii) $\boldsymbol{M},w \models A\&B$ iff $\boldsymbol{M},w \models A$ and $\boldsymbol{M},w \models B$
(iv) $\boldsymbol{M},w \models {\sim}A$ iff $\boldsymbol{M},w \dashv A$
(v) $\boldsymbol{M},w \models MA$ iff $(\exists w_1 \in W)(wRw_1$ and $\boldsymbol{M},w_1 \not\models {\sim}A)$
(i') $\boldsymbol{M},w \dashv F$
(ii') $\boldsymbol{M},w \dashv p$ iff $g(w,p) =$ false for atomic p
(iii') $\boldsymbol{M},w \dashv A\&B$ iff $\boldsymbol{M},w \dashv A$ or $\boldsymbol{M},w \dashv B$
(iv') $\boldsymbol{M},w \dashv {\sim}A$ iff $\boldsymbol{M},w \models A$
(v') $\boldsymbol{M},w \dashv MA$ iff $(\forall w_1 \in W)($if wRw_1 then $\boldsymbol{M},w_1 \models {\sim}A)$

An Axiomatic System

NML3 is the smallest set of sentences of L_{NML3} which is closed under the following axiom schema and inference rules. We shall write $\vdash_{NML3}$ to mean that A is a theorem of NML3.

Axiom Schema

(a1) $A \supset (B \supset A\&B)$
(a2) $A \supset (B \rightarrow A)$
(a3) $A\&B \rightarrow A$ (a3') $A\&B \rightarrow B$
(a4) $(A \rightarrow B) \supset [(B \rightarrow C) \supset (A \rightarrow C)]$
(a5) ${\sim}{\sim}A \equiv A$ (i.e., ${\sim}{\sim}A \supset A$ and ${\sim}{\sim}A \supset A$)
(a6) ${\sim}(A\&B) \equiv ({\sim}A \; V \; {\sim}B)$
(a7) $A \rightarrow MA$

Inference Rules

Modus Ponens (MP) for ⊃ together with:
(R1) From ~AVB infer ~MAVB
(R2) From $A \supset B$ infer $MA \supset MB$
(R3) From the ability to infer ~A infer MA

NML3 is sound and complete. One of the advantages of NML is that defaults of Reiter's defaults logic (Reiter 1980) can be represented as sentences in the object language in the system. It can be shown that there is a one-to-one correspondence between extensions of a default theory and appropriate minimal information states which provide the semantic account (models) of the system NML3. For more details (cf Obeid, 2005).

3 DIALOGUE

Dialogue is an exchange of messages between two(or more) participants. Every dialogue has a goal and requires cooperation between the participants to fulfil its goal. This means that each participant has an commitment to work towards fulfilling its own goal and a commitment to cooperate with the other participant's attempt to realize their own goals.

(Walton and Krabbe, 1995) provides a typology of dialogue types between two agents. For each type of dialogue, they formulate an initial situation, a primary goal, and a set of rules. These constitute a model, representing the ideal way reasonable, cooperative agents participate in the type of dialogue in question. It is important to note that in the course of communication, there often occurs a shift from one type of dialogue to another. Dialogue embedding takes place when the embedded dialogue is functionally related to the first one. For instance, a persuasion dialogue may require an information-seeking sub-dialogue.

Information seeking (IS): In IS dialogue, one participant extracts information from another provided that it can be provided. An IS dialogue is initiated when a participant lacks some information. There may not be a need for proof in IS dialogue and it is not necessary to establish a collective belief.

Inquiry: The basic goal of *inquiry* is information growth so that an agreement could be reached about a conclusive answer of some question. The goal is reached by a incremental process of argumentation that employs established facts in order to prove conclusions beyond a reasonable doubt. In short, the aim is to acquire ***more reliable knowledge*** to the satisfaction of all involved. Inquiry is a cooperative type of dialogue and correct logic proofs are essential. It is the most relevant type of dialogue in collective decision making and learning. Inquiry may require persuasion and vice-versa.

Persuasion: The goal of *persuasion dialogue* is for one agent to persuade the other participant(s) of its point of view and the method employed is to prove the adopted thesis. The initial reason for starting a persuasion dialogue is a conflict of opinion between two or more agents and the collective goal is to resolve the issue. Argument here is based on the concessions of the other participant. Proofs can be of two kinds: (1) to infer a proposition from the other participant's concessions; and (2) by introducing new premises probably supported by evidence. Clearly, a process of knowledge update/belief revision takes place here.

4 DIALOGUE SYSTEM

A dialogue system is a formal model that aims to represent how a formal dialogue should proceed. It defines the rules of the dialogue.

The topic language, $L_{\mathbf{Topic}}$, is a logical language which consists of propositions that are the topics of the dialogue. $L_{\mathbf{Topic}}$ is associated with a logic Σ (in our case NML3) which determines the inference rules, the defeat relations between the arguments and defines the construction of proper arguments and dialogue moves. The choice of Σ (whether monotonic or nonmonotonic) has an impact on the entire dialogue system.

The communication language, L_{COM}, specifies the locutions which the participants are able to make in the dialogue. One of the most influential agent communication languages is KQML (Finin et al. 1994). Our proposed system uses a KQML-type of language. We will assume that every agent understands this language and that all agents have access to common argument ontology, so that the semantics of a message is the same for all agents.

4.1 Some Basic Dialogue Moves

A dialogue, D, is a sequence $M_1, \ldots, M_n$. A move is a quadruple as follows:

$M_i = \langle ID(M_i), PL(M_i), LOC(M_i), TARGET(M_i)\rangle$
where

(1) $ID(M_i)$, the identifier of M_i, is i (i.e., indicating that M_i is the i^{th} element of the sequence in the dialogue).
(2) $PL(M_i)$ is the player of the move.
(3) $LOC(M_i)$ is the locution of the move from L_{Topic}.
(4) $TARGET(M_i)$ is the target of the move.
If M_i is a reply to a message in M_j where $j < i$ then $TARGET(M_i) = M_j$.

Every dialogue system specifies its own set of locutions. There are, however, several basic types of communication primitives. Among these are:

Assert A: an agent g states A.

Retract A: this move is a countermove to Assert A. In NML3, Retract A by g does not commit g to Assert $\neg$A.

Accept A: An agent g accepts/concedes a proposition A given by another agent.

Reject A: a countermove to Accept A.
Reject A by g does not commit g to Accept $\neg$A.

Question A: An agent g questions/asks from another, g1, for information about A (e.g., whether A is derivable from its theory, i.e, whether $\Sigma(g_1) \vdash A$.

Chanllenge A: This move is made by one agent g for another g1, to explicitly state a proof (an argument supporting) for A.

4.2 Knowledge Update/Process of Integration

The way a dialogue affects an agent's knowledge or Knowledge Base (KB) depends on how the agent reacts to exchanged information.

Accepting a proposition A by an agent g1 entails that A is not inconsistent with its KB, $KB(g_1)$. We may distinguish the following cases:

(I) There is only one extension of $KB(g_1)$and either

(a) A is derivable from KB(g_1) using g_1's logic
or
(b) $\neg A$ is not derivable from KB(g_1).

(II) There are many extensions of KB(g_1) and A is derivable in one whereas $\neg A$ is derivable in another. Accepting A would be a commitment to the extension(s) of KB(g_1) where A holds.

Rejecting by g1 a proposition A asserted by g_1 may entail:

(a) $\neg A$ is derivable from KB(g_1)
or
(b2) neither A nor $\neg A$ is derivable from KB(g1).
A case of rejection without justification.

It is important to add that the issue of rejection and/or acceptance, by an agent, say g1, of propositions asserted by another agent, g2, is quite complicated by various rules such as (temporal) persistence, denying accepting previous assertions and citing contradictory support for a proposition and its negation.

4.3 Update Rules of Dialogue Moves

Let $COMIT_i(g)$ represent the commitment set of agent g at a move that has an identifier i. $COMIT_i(g)$ is a set of propositions from $L_{\mathbf{Topic}}$ which the agent g is committed to (e.g., prepared to hold on to) at that point in the dialogue. During the dialogue, propositions are added to and/or deleted from the commitment set.

Given such background, we give the update rules that specify how commitment stores are modified by the move (cf. Maudet and Evrard 1998).

Let j < i, M_j a move played by g1, and M is a move by g as a reply to M_j, then

(1) M = <i, g, Assert A, M_j>
$COMIT_i(g)=COMIT_{i-1}(g)\cup\{A\}$ and
$COMIT_i(g_1) = COMIT_{i-1}(g_1)$.

This step adds A to $COMIT_{i-1}(g)$ to result in $COMIT_i(g)$ and g can offer a proof of A.

(2) M = <i, g, Retract A, M_j>
$COMIT_i(g)=COMIT_{i-1}(g) - \{A\}$ and
$COMIT_i(g_1) = COMIT_{i-1}(g_1)$.

This step deletes A from $COMIT_{i-1}(g)$ to result in $COMIT_i(g)$, i.e., A is deleted from g's theory.

(3) M = <i, g, Accept A, M_j)
$COMIT_i(g) = COMIT_{i-1}(g) \cup \{A\}$ and
$COMIT_i(g_1) = COMIT_{i-1}(g_1)$.

Agent g accepts A from g_1. The impact of this step is that A will be added to $COMIT_{i-1}(g)$ to yield $COMIT_i(g)$ This can be possible if the locution of the message M_j is Assert A. The impact of this message will be an update of g's theory with A.

(4) M = <i, g, Reject A, M_j)
$COMIT_i(g) = COMIT_{i-1}(g) - \{A\}$ and
$COMIT_i(g_1) = COMIT_{i-1}(g_1)$.

Agent g rejects A from g_1. This can only be possible if the locution of the message M_j is Assert A. The impact of this message could either be no change to g's theory as it is in contradiction with A, in which case, $COMIT_i(g)=COMIT_{i-1}(g)-\{A\} = COMIT_{i-1}(g)$) or an update of g's theory by retracting A.

(5) M = <i, g, Question A, M_j)
This move does not alter either of $COMIT_i(g)$ or $COMIT_i(g_1)$. In this case g is asking from g1 for information about A (e.g., whether A is derivable from its theory, i.e, whether $\Sigma(g_1) \vdash A$.

(6) M = <i, g, Chanllenge A, M_j)
This move does not alter either of $COMIT_i(g)$ or $COMIT_i(g_1)$. In this move g is forcing g1, to explicitly state a proof (an argument supporting) A.

It is important to note that a participant in a dialogue must keep track of the conversational record between them and record what has been accepted, challenged or rejected.

4.4 Rules of Protocols of Different Types of Dialogue

Information-Seeking: If the information seeker is g and the other agent is g_1.

(1) g makes a *Question* move such as M_i = <i, g, Question A, M_l) where M_l is a move made earlier by g_1 and l > i.
(2) g_1 replies with the move M_k where the identifier is k and its target M_i, where k > I, as follows:
   (i) M_k = <k, g1, Assert A, M_i> or
   (ii) M_k = <k, g1, Assert $\neg A$, M_i> or
   (iii) M_k = <k, g1, Assert UA, M_i>.

UA means that for g_1 the truth value of A is undefined.

(3) g either accepts g_1 response using an *Assert* move or challenges it with a *Challenge* move. UA initiates an *inquiry* sub-dialogue between the agents or the information-seeking dialogue is terminated.
(4) g_1 replies to a *Challenge* move with a proof using a move M_r = <r, g1, Assert S, M_t> where S is a proof of A in $\Sigma(g_1)$.
(5) Go to step (3) for each sentence in S.

Inquiry. The following is an inquiry-protocol about a proposition A involving g and g_1.

(1) g seeks a support/proof for A. It begins with an *Assert* move that asserts B $\rightarrow$A or asserts B $\Rightarrow$

A, for some sentence B or a move that asserts UA.

(2) g_1 either accepts $B \rightarrow A$ or accepts $B \Rightarrow A$ using an *Accept* move or challenges either of $B \rightarrow A$ and $B \Rightarrow A$ as appropriate with a *Challenge* move.
(3) g replies to a challenge with *Assert* move that provide a proof P in $\Sigma(g)$ of the last proposition challenged by g_1.
(4) Go to step (2) for every proposition $C \in P$. That is, substitute C for $B \rightarrow A$ or $B \Rightarrow A$.
(5) g_1 seeks a support/proof for B, i.e., it replies with an *Assert* move that asserts $E \rightarrow B$ or asserts $E \Rightarrow B$, for some sentence E or a move that asserts UB.
(6) If $\text{COMIT}(g) \cup \text{COMIT}(g_1) \mid\!- A$ then the dialogue terminates successfully.
(7) The agents reverse roles and the appropriate agent seeks a support/proof for E (step 5).

Persuasion. The agent g is trying to persuade g_1 to accept A.

(1) g begins with a move that asserts A.
(2) g_1 replies with a move that
  (i) accepts A or
  (ii) asserts $\neg A$ or
  (iii) challenges A.
(3) two possibilities:
  (a) If the answer of g_1 in the previous step is (ii), then goto to step (2) with the roles of the agents reversed and $\neg A$ in place of A..
  (b) If the answer of g_1 in the previous step is (iii) (challenge), then
    (α) g should reply with a move that provide/asserts a proof P of A in $\Sigma(g)$
    (β) go to step (2) for every for every proposition $C \in P$.

5 ARGUMENTATION AND PROOF IN NML3

It is clear from Section 4 that arguments have an essential role to play in situations of conflict. They can be used by an agent to increase the degree of compatibility between its knowledge/beliefs and those of other agents; one agent can persuade another to adopt one or more propositions that it accepts by presenting proofs/support for those propositions (cf. Reed et al. 1997). In Artificial Intelligence (AI), It is used in different ways: (1) to structure knowledge where the aim is to determine how utterances form arguments and how arguments can be decomposed (cf. Toulmin, 1958); (2) to model dialectical reasoning and deal with argument construction (cf. Dung, 1995). It is important to present an argument in such a way so that it appeals to the other participant knowledge. It allows an agent to critically question the validity of information presented by another participant, explore multiple perspectives and/or get involved in belief revision processes.

5.1 Argumentation Framework

An Argumentation Framework (AF) system should capture and represent the constituents of arguments (e.g., the propositions which are taken into consideration). These may include facts, definition, rules, regulations, theories, assumptions and defaults. They can be represented as formulae or sets of formulae. It should also capture the interactions and reactions between arguments and constituents of arguments such as undercutting. Furthermore, some notion of preference over arguments may be needed in order to decide between conflicting arguments.

Definition 5.1.. Let Σ be a logical system. An argument in Σ is a triple $P = \langle S, A \rangle$ where
S is a set of Well-Formed Formulae (WFF) and A is a WFF of the language of Σ such that
(1) S is consistent
(2) $S \mid\!-_{\Sigma} A$ (A follows from S in Σ)
(3) S is minimal. No proper subset of S satisfies (1) and (2) exists.

An argument in a logical system Σ is simply a proof in Σ. S may need to be ordered. Thus, minimality in condition (3) may not necessarily be set-theoretic.

S is called the support of P and A is its conclusion. We shall use Support(P) (resp. Conc(P)) to denote that S is a support of P (resp. A is a conclusion of P).

If the logical system Σ contains defeasible implications/rules, then it would be worthwhile distinguishing between a defeasible argument and a non-defeasible/classical argument.

Definition 5.2 A defeasible argument is a proof $P = \langle S, A \rangle$ where S contains some defeasible implications. A non-defeasible/classical argument is a proof that does not contains any defeasible implication(s) or rely on any un-discharged assumptions.

It is important to note that in a defeasible/nonmonotonic theory, an agent could provide a argument for both a proposition and its negation, i.e., the theory of the agent may have multiple extension (cf. Reiter (1980)). Thus, the need for a notion of *undercutting*.

Definition 5.3 Let P1 and P2 be two argument in Σ. Then Undercut(P1, P2) iff ($\exists B \in$ Support(P2) such that B ≡ ¬Conc(P1) where " ≡" is the equivalence of classical logic.

P2 undercuts P1 if, and only if, P2 has a formula that is the negation of the conclusion of P1.

Propositions in agents theories may need to be ordered to reflect some preference between propositions needed to choose between conflicting arguments. Such order could reflect the degree of belief or truth in the proposition or some other measure of preference.

5.2 Proof Method For NML3

One of the essential features of the proof system is that it allows free and complete access to all stages of the proof process.

The proof method proceeds by the construction of a tableau (Beth, 1987). This is a tree-structure in which all the possible models allowed by the premises and negated conclusion are set out and examined for consistency. The construction of the tree is governed by rules for each logical connective in the language. These rules are closely related to the semantics of the language. A complete set of such rules for all truth-functional connectives is given in (Jeffrey, 1967).

The concept of refutation is considerably more straightforward in classical logic than it is in **NML3**. In the former case, to prove that a set of premises implies a conclusion A, it is sufficient to show that ~A cannot be true if the premises are. We have seen that in **NML3,** "A V ~A" is not a theorem. If we find no consistent models taking ~A as the negation of our conclusion, we will not have proven that A follows from our premises. We will have shown only that it might.

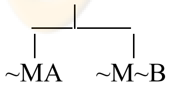
In **NML3** (cf. Obeid 2000)**,** we need to consider the following cases:

(1) A is true (resp. false) if we can find no consistent models for M~A (resp. MA)

(2) A is true (resp. false) or unknown if we can find no consistent models for ~MA (~M~A).

The tableau rules for the connectives & and V are the same as those for classical logic. The tableau rule is defined as follows: the negation of an atomic non-modalized formula A is ~MA and the negation of MA is simply ~MA.

The tableau rule for → can easily be shown to be of the form:



The rule

(R3) If we cannot infer ~A, infer MA

require special attention If there exists an open branch of a proof tree which includes a formula ~MA, or more than one, all including ~MA, then we might fire rule (R3) to try to infer nonmonotonically MA and thereby derive a contradiction and finish the proof. This is achieved by setting the target formula for proving that ~A is true against the original premise set, and running the proof process. If we fail to prove ~A is true, we may infer that it is consistent, and pass MA back to the parent proof.

It is our strategy that we only attempt to derive a proof nonmonotonically if we fail to close all the paths in a tree with the tableau rules. We are able to decide whenever we wish whether or not we can infer ~A, but it only makes sense to try when we know we need to. This means at present that we wait for the monotonic proof process to stop before looking for a way to apply the rule (R3).

If we fire (R3) thereby inferring a formula MA, we may close off any model in the proof including the formula ~MA. We may allow several applications of (R3) in one proof, thereby closing different branches of the proof in different ways.

6 DIALOGUE AND REASONING WITHIN NML3

In this section we give two examples that show how dialogue, together with the reasoning within the system NML3, is carried out. We shall not present formally the proofs in NML3 due to lack of space.

Example 6.1. Consider a case where we have two agents, g1 and g2, cooperate in a diagnostic task of a series of batteries. g1 is in charge of testing the voltage of the batteries and g2's task is to find out which battery is faulty.

Consider a battery which when operating normally has a voltage between 1.2 volts and 1.6 volts. We use Batt(B) to mean that B is a battery, Volt(B,V) to mean that the voltage of B is V and ok(V) to mean that $1.2 < V < 1.6$.

Suppose that we have Batt(B_1) and Batt(B_2) and g1 observed that "OBS=Volt(Series(B_1,B_2),1.45)". Then it cannot be the case that both B_1 and B_2 are working normally. To appreciate how subtle and intuitive the results are, we shall consider what g2 can infer in such a situation:

(i) should g2 infer that if one of the batteries is not working normally then the other is?

(ii) should g2 infer that if one of the batteries is working normally then the other is not?

It is a straightforward exercise to show that the answer to (i) is negative and the answer to (ii) is positive.

Example 6.2 Assume that we have two agents g1 and g2. g2 needs a lift in a car. It notices a car parked in front of John's house and decides to ask g1 the following query: ***can John drive?*** g1 knows that *john is skilled to drive* and *has a car*. Using classical logic, g1 should fail to drive that *John can drive* because it does not know whether *John has a driving licence*. Using NML3, g1 can give g2 the answer: *Yes.* To be more helpful, g1 may give the answer: *Yes, if John has a driving licence*. Such an answer can be reached because NML3 allows g1 to make the assumption that *John has a driving licence*(if there is no information to the contrary).

However, if g1 has learnt from another agent g3 that *John does not have a driving licence*, then g1 may give an answer: *No* or more informatively: *No,* because *John does not have a driving licence*.

7 RELATED WORK

Acquiring knowledge from a domain expert is considered to be one of the most important and difficult stage in developing a successful Knowledge Based System (KBS) (Smith, 1996). The process of KA, together with representation, is defined as being a means whereby information is extracted, structured and organized (Jeng, 1996). (Chan, 1995) proposes that there exists a need to avoid looking at KA process as an entire process but perceives it more like a series of identifiable phases: (1) knowledge elicitation (to obtain information from the expert), (2) knowledge analysis (to make sense of the data acquired in the former stage) and (3) knowledge representation.

In multi-agent communication languages, such as KQML (Finin et al. 1993) and COSY (Haddadi, 1996), the emphasis is at the level of individual messages, along with a relative neglect of overall task, knowledge modeling. The framework of the COMMONKADS methodology (Schreiber et al., 1994) provides a comprehensive conceptual modeling approach, ranging from organizational analysis to system design and implementation. However, it does not provide us with the formalism and the reasoning mechanism that allow us to *learn* from the message exchanged.

Most existing spoken dialogue systems focus on simple and constrained tasks. Some examples are found in (Pellom et al. 2001; Xu and Rudnicky 2000; Chu-Carroll 2000).

There has been other work on modelling dialogue for complex task domains such as the TRAINS system (Allen et al. 2001) and its successor, TRIPS (Blaylock et al. 2002). TRIPS is a distributed, agent-based cooperative dialogue system. Its components act asynchronously and communicate with each other by message passing.

Issues in supporting multi-modal interfaces have been addressed in (McGlashan 1996) which provides a combination of graphical and speech modalities. Work in (Traum et al. 2003) follows the framework of the TRINDI project (Larsson 2000) which aims to model multi-modal dialogue for multiple participant interaction.

An attempt in (Paek and Horvitz 2000) is made to build a probabilistic model (using Bayesian networks) of possible uncertainties at different levels of human-computer conversation. Thus the system would be able to identify actions that maximize the expected utility of achieving mutual understanding.

8 CONCLUDING REMARKS

In this paper, we have made a first step towards developing a model of KA/learning via cooperative dialogue. A key idea in the model is the concept of integrating exchanged information within an agent theory. Dialogue is a structured process and the structure is relative to what an agent knows about the world or a domain of discourse. We have employed a logic system **NML3** which formalizes some aspects of revisable reasoning. We have presented a formalization of some basic dialogue moves and the protocols of various types of dialogue. We have also given some indication as to how arguments, proofs, appropriate dialogue moves and reasoning may be carried out within NML3.

On the linguistic side, the question of how a collection of propositions is assigned as the semantic interpretation to a linguistic message is not trivial. Lexical and (to a lesser extent) structural ambiguity are sensitive to what an agent knows about the world, but "unfortunate" interpretations may still be consistent with respect to an agent's theory.

There is a general tendency to consider inconsistency, in agent's, say g, theory, to be a problem that concerns only g. However, in cooperative activities that involve more than one agent, it may be of interest to the other agents to know about, or minimally to be aware, of the way inconsistency or exchanged information is dealt with by g. This is because in such cases, one agent may regard another agent's knowledge as in some weak sense an extension of its own. Thus, there may be a need to define a notion of *compatibility* which is weaker and more permissive than localized logical consistency.

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