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Formal Conversations for the Contract Net Protocol

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Abstract. In this paper we present a fairly complex example of how the social model for agent conversations based on social commitments we have developed in the past formally supports the implementation of conversations for the Contract Net Protocol.

1 Introduction

In open environments such as the Internet agents from heterogeneous sources could exist and interact to accomplish joint activities. The common denominator for agents in these settings is not how they are built but how they *converse*. Furthermore, for conversations to be coherent, agents need the ability to understand messages (through *message semantics*) and their sequencing in time (through *compositional semantics*) [1].

In the landscape of current agent communication languages, most approaches specify messages as *speech acts* defined in terms of private states (such as beliefs and intentions), and whose sequencing is governed by conversation protocols. It has been argued that speech acts should be specified as a function of public events rather than private states [3;6;7;9], and that conversation policies should be favored over protocols to enable versatile and context-sensitive conversations [5].

To that end, we have specified a unified social model for conversations based on social commitments [4] in which speech act semantics is an emergent product of identity, conversational use, and expected accomplishments, and where conversational composition is guided by conversation policies.

In this paper we elaborate further on the application of our model to support conversations in the Contract Net Protocol.

The structure of this paper is as follows. In Section 2 we briefly describe the main elements and concepts in our social model for agent conversations. In Section 3, we describe in detail how our model supports the implementation of Contract Net Protocol conversations. Finally, in Section 4 we conclude this paper with an overview of future avenues of research.

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2 A Social Model For Agent Conversations

In this section, we briefly describe the basic definitions in our model, which we have specified using the Z formal notation [2]. In general, we see our model as being applied to guide the joint activities of autonomous agents whose interactions are primarily communicational.

We use illocutionary points, i.e., the publicly intended perlocutionary effects, as the basic compositional elements of speech acts. This view allows us to describe the meaning of a speech act as the emergent property of its enclosed illocutionary points.

As shown below, we define speech acts as structures composed of an illocutionary force and a set of illocutionary points.

SPEECH_ACT

force: ILLOCUTIONARY_FORCE;
points: $\mathbb{P}$ ILLOCUTIONARY_POINT;

We also specify that a speech act is a kind of action (where physical acts are other type of actions that could be included in this definition).

ACTION ::= SpeechAct ⟪SPEECH_ACT⟫

In addition, we specify that an utterance is an event that takes place at a certain moment in time, and which involves a speech act that is communicated from a speaker to an addressee.

EVENT $\widehat{=}$ [time:TIME; action: ACTION]
UTTERANCE $\widehat{=}$ [EVENT; speaker:AGENT; addressee:AGENT; speechAct:SPEECH_ACT |
(action $\in$ ran SpeechAct) $\wedge$ (speechAct = SpeechAct~ action)]

We define a social commitment as a structure where there is a debtor committed to an action relative to a creditor on whose behalf this action is done. Based on this definition, we then specify that a shared social commitment is a structure comprising a commitment being shared among agents.

Note that having speech acts been declared as actions allows us to have social commitments entailing a speech act.

SOCIAL_COMMITMENT

debtor, creditor: AGENT;
action: ACTION;

SHARED_SOCIAL_COMMITMENT

SOCIAL_COMMITMENT;
among: $\mathbb{P}$ AGENT;

among $\neq \emptyset$

To denote that social commitments can be adopted or discharged we define the type OPERATION, which is defined in terms of a social commitment.

OPERATION ::= Add ⟪SOCIAL_COMMITMENT⟫ | Delete ⟪SOCIAL_COMMITMENT⟫

Succinctly, we conceptualize an agent in our model as an entity that maintains a set of shared social commitments and a history of the utterances it has witnessed. Agents autonomously decide whether other agents can affect their set of shared social commitments. This is supported by a negotiation process based on the utterance and sequencing of speech acts, as described next.

AGENT

commitments: ℙ SHARED_SOCIAL_COMMITMENT;
utterances: ℙ UTTERANCE;

We define a basic protocol for the negotiation of social commitments, which we call the *Protocol for Proposals* (PFP). This protocol starts with a proposal from a sender to a receiver to concurrently adopt or discharge a social commitment. Either the receiver replies with an acceptance, rejection, or counteroffer, or the sender issues a withdrawal or counteroffer[2]. All utterances except a counteroffer terminate an instance of the protocol. A counteroffer is deemed as a proposal in the sense that its utterance is followed by any of the reply speech acts (but with speaker-addressee roles inverted if the original addressee is the speaker of the utterance). In theory, a counteroffer can follow another counteroffer *ad infinitum*; in practice, the number of successive counteroffers might be limited by the reasoning, competence, or endurance of interacting agents. Finally, it is expected that when an acceptance is issued both speaker and addressee will simultaneously apply the proposed commitments to their record of shared social commitments.

To model the PFP, we define five basic illocutionary points: PROPOSE, ACCEPT, REJECT, COUNTER, and INFORM. We define them as illocutionary points as follows:

ILLOCUTIONARY_POINT ::= Propose ⟪PROPOSE⟫ | Accept ⟪ACCEPT⟫ | Reject ⟪REJECT⟫ | Counter ⟪COUNTER⟫ | Inform ⟪INFORM⟫

As shown in the definitions below, PROPOSE specifies the operation on commitment being proposed, and a time interval in which a reply is expected (we informally call this time the *window of interaction*). ACCEPT indicates the operation on commitment being accepted, and REJECT the operation on commitment being rejected. COUNTER is defined in terms of REJECT and PROPOSE, where the former indicates the commitment previously proposed and now being rejected, and the latter presents the new proposed commitment along with a new window of interaction. Finally, INFORM is specified as containing certain information being informed.

PROPOSE

proposing: OPERATION;
replyBy: TIME;

ACCEPT

accepting: OPERATION;

REJECT

rejecting: OPERATION;

COUNTER

REJECT;
PROPOSE;

INFORM

informing: INFORMATION;

We specify three conversation policies that entail the adoption and discharge of commitments when the illocutionary points in the PFP are uttered. These policies are formally specified in terms of shared social commitments (see [4] for details). Informally, we describe them as follows:

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[2] It is also possible that the addressee goes silent. In such cases, the elapsing of the expected reply time indicates to the speaker (or any observer) that the addressee either intentionally forfeited his obligation to reply or was unable to communicate as expected.

POLICY 1: For each PROPOSE or COUNTER illocutionary point in a just uttered speech act, add as a shared commitment between speaker and addressee that the addressee (the debtor) will do for the speaker (the creditor) a speech act (the action) containing an ACCEPT, REJECT or COUNTER illocutionary point with the same operation on commitment as that of the just uttered PROPOSE.

POLICY 2: For each ACCEPT, REJECT, or COUNTER illocutionary point in a just uttered speech act from speaker to addressee, such that there is a past utterance from addressee to speaker in which there is a PROPOSE or COUNTER illocutionary point with the same operation on commitment as that of the just uttered ACCEPT, REJECT, or COUNTER, and where the PROPOSE or COUNTER indicated a reply time that hasn't elapsed yet, then delete the shared commitment between speaker and addressee that the speaker (the debtor) is to do for the addressee (the creditor) a speech act (the action) containing an ACCEPT, REJECT or COUNTER with the same operation on commitment as that of the just uttered ACCEPT, REJECT, or COUNTER.

POLICY 3: For each ACCEPT illocutionary point in a just uttered speech act from speaker to addressee, such that there is a past utterance from addressee to speaker in which there is a PROPOSE or COUNTER with the same operation on commitment as that of the just uttered ACCEPT, and where the PROPOSE or COUNTER indicated the reply time that hasn't elapsed yet, then perform the operation on commitment that was proposed and is now accepted.

We define eight utterance definitions in terms of the relations between the speaker and addressee of an utterance, the creditor and debtor of a social commitment within such utterance, and the type of operation being applied to this social commitment.

The first four descriptions, which are based on PROPOSE, are: Request, Offer, Release, and Discharge. Informally, a Request is a proposal to adopt a social commitment for action in which the speaker is the creditor and the addressee is the debtor; an Offer is a proposal to adopt a commitment in which the speaker is the debtor and the addressee is the creditor; a Release is a proposal to discharge a commitment in which the speaker is the creditor and the addressee the debtor, and finally, a Discharge is a proposal to discharge a commitment in which the speaker is the debtor and the addressee the creditor.

The remaining four descriptions, which are based on ACCEPT, are: Accept, Grant, Comply, and Approve (which are the acceptance counterparts for Request, Offer, Release, and Discharge, respectively). Informally, an Accept is an acceptance to adopt a social commitment for action in which the speaker is the debtor and the addressee is the creditor of the commitment; a Grant is an acceptance to adopt a commitment in which the speaker is the creditor and the addressee the debtor; a Comply is an acceptance to discharge a commitment in which the speaker is the debtor and the addressee the creditor; and finally, an Approve is an acceptance to discharge a commitment in which the speaker is the creditor and the addressee the debtor.

3 Example: The Contract Net Protocol

In the dynamics of our model, agents will join societies where the description of activities is specified in terms of roles, sequencing of communicational actions, and the description of actions and their results.

Currently our model only accounts for the expected sequencing of communicative actions and roles in an activity. We acknowledge though the importance of action definitions, but their study will not be pursued here.

In this section, we present the application of our model to guide the evolution of a conversation in the Contract Net protocol (CNP) [8], which is a task allocation mechanism for requesting bids for a task and awarding its performance to the most suitable bidder. This protocol can be described as unfolding in five steps:

1. *Request for bids*: A manager requests a bidder to submit a bid.
2. *Submission of bids*: The bidder prepares a bid and submits it to the manager for evaluation.
3. *Awarding of contracts*: The manager evaluates the bid, which could (or not) be awarded as a contract to the bidder.
4. *Acceptance of contracts*: If awarded, the bidder is requested to accept (or decline) the execution of the contract.
5. *Submission of results*: The bidder submits the results of executing the contract.

We define three actions for this protocol: DoBid, EvaluateBid, and DoContract. We specify these as part of our the definition of action:

[DO_BID, EVALUATE_BID, DO_CONTRACT]
ACTION ::= SpeechAct ⟪SPEECH_ACT⟫ | DoBid ⟪DO_BID⟫ | EvaluateBid ⟪EVALUATE_BID⟫
| DoContract ⟪DO_CONTRACT⟫

As previously mentioned we will not elaborate on the specification of these action definitions, and we only informally describe them as follows:

- DO_BID: described as "to produce a bid."
- EVALUATE_BID: described as "to assess the adequacy of a bid as a possible contract."
- DO_CONTRACT: described as "to perform a contract."

Under social models of agency, autonomous agents join normative societies through the adoption of roles defining their expected abilities and behavior. In the case of the CNP, we define the roles Manager and Bidder as follows:

MANAGER == AGENT
BIDDER == AGENT
ROLE ::= Manager ⟪MANAGER⟫ | Bidder ⟪BIDDER⟫

In the case of the interaction of purely communicational agents, all information that is shared is integrally passed among parties since there are no default settings through which results could be mutually accessed. In such circumstances, agents in a CNP conversation need to communicate three pieces of information: 1) the initial conditions to produce a bid (provided in the *Request for bids*); 2) the bid itself (in the *Submission of bids*); and 3) the results obtained from executing an awarded contract (in the *Submission of results*). We define these data as follows:

[CONDITIONS, BID, RESULTS]
INFORMATION ::= Conditions ⟪CONDITIONS⟫ | Bid ⟪BID⟫ | Results ⟪RESULTS⟫

As in the case of actions, we do not detail the definition of these data, but we acknowledge that complete implementations will include their concrete definitions as guidelines to justify the accomplishment of tasks (for example).

We define ten utterance names for the CNP (as with previous utterance definitions,

that an utterance is equated to a name only implies that the utterance contains at least those illocutionary points given in the definition). These utterances are: RequestForBids, AcceptToBid, SubmitBid, AcceptSubmission, AwardContract, AcceptAwarding, RejectBid, AcceptRejection, SubmitResults, and ApproveResults.

Figure 1 shows these utterances as well as the illocutionary points they contain (shown in the shaded box next to the utterance). The utterance RequestForBids, for example, contains two illocutionary points: 1) a proposal to adopt a commitment in which the addressee (the debtor) is to do a bid for the speaker (the creditor), and 2) an inform containing the conditions over which the bid is to be produced. On the same lines, an AcceptToBid is an utterance in which the speaker accepts to adopt a commitment in which he is to do a bid for the addressee.

The remaining utterances are briefly described as follows:

- SubmitBid: utterance in which the speaker 1) proposes to the addressee the mutual discharge of the commitment that he (the speaker) does a bid for the addressee, 2) proposes to the addressee the mutual adoption of the commitment that she (the addressee) evaluates a bid, and 3) informs the addressee of a bid.
- AcceptSubmission: utterance in which the speaker accepts both the mutual discharge of the commitment that the addressee is to produce a bid, and the mutual adoption of the commitment that she evaluates the bid.
- AwardContract: utterance in which the speaker proposes 1) the mutual discharge of the commitment that she evaluates the bid, and 2) the mutual adoption of the commitment that the addressee commits to carry out the bid he proposed.
- AcceptAwarding: utterance in which the speaker accepts 1) the mutual discharge that the addressee evaluates the bid, and 2) the mutual adoption of the commitment that the speaker does the previously proposed bid and now awarded contract.
- RejectBid: utterance in which the speaker proposes the mutual discharge of the commitment that she evaluates the bid.
- AcceptRejection: utterance in which the speaker accepts the mutual discharge of the commitment that the addressee evaluates a bid.
- SubmitResults: utterance in which the speaker 1) proposes the mutual discharge of the commitment that he does the awarded contract, and 2) informs the addressee of the obtained results of doing the contract.
- ApproveResults: utterance in which the speaker accepts the mutual discharge of the commitment that the addressee does an awarded contract.

We define six conversation policies to describe the expected adoption and discharge of conversational commitments that advance the state of CNP conversations.

The first policy, which we identify here as Policy 4 (Figure 2), indicates that the acceptance to a proposal for adopting the action DoBid causes the adoption of the shared commitment that the accepting agent will utter a speech act in which he proposes to discharge the commitment that he performs such action. This is, that an agent accepts to commit to do the action DoBid causes the adoption of another commitment in which he proposes to discharge that he does the action. Although this commitment could also be included in the proposing speech act RequestForBids, its definition as a policy in the public description of the CNP allows agents to know before hand how the interactions in this activity are expected to evolve.

Policy 5 (not shown) indicates that once the creditor agent has accepted the proposal to discharge the action DoBid, there is the automatic discharge of the shared

commitment that the debtor has to propose discharging the commitment to do such action.

Policies 6 and 7, and policies 8 and 9 (not shown) follow the same pattern of adoption and discharge of commitments that propose the discharge of commitments for the actions EvaluateBid and DoContract, respectively.

These policies, used in conjunction to those in the PFP, enable the coherent evolution of CNP conversations, as illustrated in Figure 1.

Note that the diagram in this figure is an oversimplification of the possible conversations that are supported in our model. For simplicity and clarity of the example, we are only showing the sequence of proposals and acceptances that could occur using the PFP. This is the case, for example, of the utterance RequestForBids (a proposal from agent A) which is shown to be followed solely by an AcceptToBid (an acceptance from agent B). As mandated by the

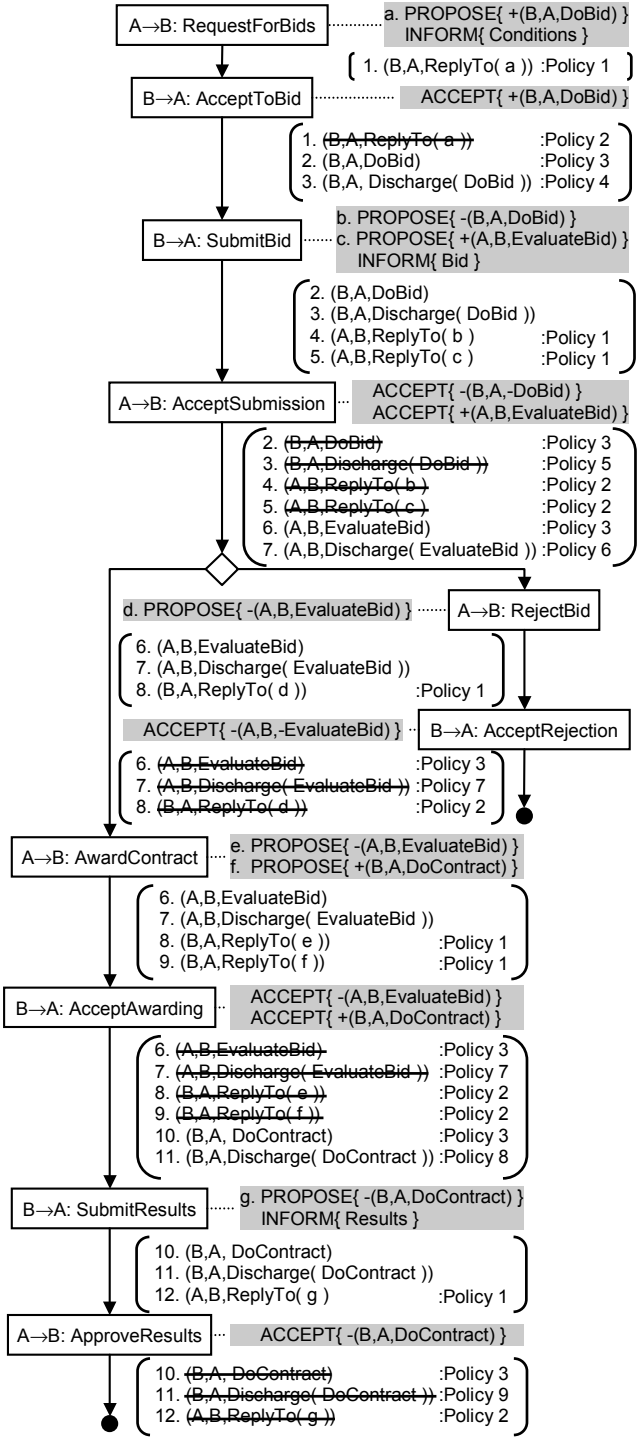

Fig. 1. Example utterances, sequencing, and state of social commitments for CNP conversations.

PFP, this proposal can also be followed by a rejection or counter from agent B, or a rejection or counter from agent A.

To illustrate the accumulation and discharge of shared commitments during this conversation example, we will track the evolution of the state of shared social commitments between agents A and B at all points in the conversation (this is shown in the round-bracketed areas located between the shadowed boxes in the figure). For the sake of the clarity of this example, the initial state of shared commitments is empty.

The conversation starts when agent A utters to agent B a RequestForBids speech act. As shown in the first bracketed area (from top to bottom), this utterance causes the application of Policy 1 (uttering a proposal causes the shared conversational commitment that this proposal will be replied) resulting in the addition of shared commitment number 1 to the state of shared social commitments.

Next is an utterance from agent B to agent A in which the former accepts committing to do the action DoBid. This acceptance triggers the following policies: Policy 2 (the reply to a proposal discharges the commitment to reply), which deletes commitment number 1; Policy 3 (the acceptance of a proposal causes the shared uptake of the proposed commitment, in this case that agent B will do a bid for agent A), which adds commitment number 2; and, Policy 4 (accepting to perform the action DoBid causes the shared commitment that the agent doing this action will propose the discharge of the commitment to do the action), which causes the adoption of shared commitment number 3.

This last utterance (AcceptToBid) indicates that the initial proposal (RequestForBids) has been accepted, thus signaling the termination of one instance of the PFP. At this point, two instances of the PFP could follow: 1) agent B can propose the discharge of the commitment that he produces a bid—presumably because he has produced one, or because he is polite enough to communicate that he will not produce one; or 2) agent A can propose to release agent B of this commitment[3]. From these options we only show the case in which agent B proposes the discharge of the commitment to do a bid given that he is submitting one (as defined in SubmitBid). In addition, this utterance proposes that the bid is evaluated for adequacy as a possible contract.

As shown, the uttering of a SubmitBid causes the application of Policy 1 (uttering a proposal causes the shared conversational commitment that it will be replied) twice, one per proposal in the utterance, resulting in the adoption of shared commitments 4 and 5 (indicating that the proposals in the utterance will be replied).

This is followed by the utterance of AcceptSubmission, which triggers the following policies: Policy 3 (the acceptance of a proposal causes the shared uptake of the proposed commitment), which results in the discharge of commitment number 2 and the adoption of commitment number 6; Policy 5 (the acceptance of a proposal to discharge the action DoBid causes the discharge of the commitment to propose the discharge of the commitment to do this action), which discharges commitment number 3; Policy 2 (the reply to a proposal discharges the commitment to reply), which discharges commitments number 4 and 5; and Policy 6 (accepting to perform

[3] We are yet to explore the effects that liability and compensation may exert in such circumstances, e.g., when an agent discharges a commitment without a reasonable justification (making her liable for breaking a commitment), or when an agent is released from a commitment (entailing a compensation for the efforts incurred).

the action EvaluateBid causes the shared commitment that the agent doing this action will propose the discharge of the commitment to do the action), which causes the adoption of shared commitment number 7.

The pair of utterances SubmitBid and AcceptSubmission realizes another instance of the PFP. Again, two instances of the PFP could follow at this point: 1) agent A can propose to discharge the commitment that she evaluates the bid—because she has reached a decision, or because she will not reach one at all; or 2) agent B can propose to release agent A of her commitment to evaluate his bid, e.g., if he decides to withdraw his bid. The diagram shows the two cases in which agent A proposes to discharge the commitment that she evaluates the bid given that she is awarding the

POLICY_4

```
Δ AGENT
utterance?: UTTERANCE;
set: ℙ SHARED_SOCIAL_COMMITMENT;
manager, bidder: AGENT;
doBid: ACTION;
_____________________________________________________
utterance?.time = now;
#set = #(getallRequestForBidsforallAcceptToBid( utterances, utterance? ));
doBid ∈ ran ContractNet_DoBid;

∃ role:ROLE | role ∈ ran Manager
• manager = Manager~ role ∧ manager = utterance?.addressee;
∃ role:ROLE | role ∈ ran Bidder
• bidder = Bidder~ role ∧  bidder = utterance?.speaker;

∀ accept:ACCEPT
 | accept ∈ getACCEPTpoints utterance?.speechAct ∧
  (∃ c:SOCIAL_COMMITMENT
     | c.debtor = bidder ∧ c.creditor = manager ∧ c.action = doBid
    • c = Add~ accept.accepting) ∧
  (#{propose:PROPOSE |  (∀ u:UTTERANCE
                              | u ∈ utterances ∧ u.time < now ∧
                                u.speaker = manager ∧ u.addressee = bidder
                              • propose ∈ getPROPOSEpoints u.speechAct ∧
                                propose.proposing = accept.accepting ∧
                                propose.replyBy > now)} > 0)
• ∃ sc:SHARED_SOCIAL_COMMITMENT; action:ACTION; s:SPEECH_ACT; p:PROPOSE;
     c:SOCIAL_COMMITMENT
    | sc.among = {manager, bidder} ∧  sc.debtor = bidder ∧ sc.creditor = manager ∧
      action ∈ ran SpeechAct ∧ action = sc.action ∧ s = SpeechAct~ action ∧
      p ∈ getPROPOSEpoints s ∧
      c.debtor = bidder ∧  c.creditor = manager ∧  c.action = doBid ∧ c = Delete~ p.proposing)
    • sc ∈ set;

commitments' = commitments ∪ set
_____________________________________________________
```

Fig. 2. Accepting to do the action DoBid commits to propose its discharge.

contract or rejecting the bid (as defined by AwardContract and RejectBid, respectively).

Uttering the latter (rejecting the proposed bid) causes the application of Policy 1 (uttering a proposal causes the shared conversational commitment that it will be replied), resulting in the adoption of commitment number 8. Accepting this rejection (through AcceptRejection) causes the application of policies 3, 7 and 2, which discharge the commitments 6, 7 and 8, respectively. At this point, all shared conversational commitments have been deleted, signaling the termination of the conversation.

As shown in the figure, this same pattern of proposals and acceptances develop for the execution of the contract (AwardContract and AcceptAwarding), and the submission of results (SubmitResults and ApproveResults).

4 Conclusions

In this paper we presented an implementation of the Contract Net Protocol for purely communicational agents based on our model of agent conversations and social commitments. With this example, we seek to demonstrate that our model can account rich and dynamic conversations

Currently we are working on an experimental engine that agents can use to support our model for conversations in an environment where agents could be engaged in multiple simultaneous conversations. Additionally, we are in the process of defining a set of theorems to prove the correctness of the theory in which our model is based.

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