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## **Corporate Agents**

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# Corporate Agents

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## Abstract

The logic of belief and intention in situations with multiple agents is increasingly well understood, but current formal approaches appear to face problems in applications where the number of agents greatly exceeds two. We provide an informal development of *Corporate Agents*, an intensional approximation of individual and group states which treats groups symmetrically with autonomous agents. *Corporate Charters*, constraints derived from typical patterns of information flow, replace detailed reasoning about the propagation of attitudes in most contexts.

The approximation to an ideal logical formulation is not tight, but the model appears to function well in information-poor environments and fails in ways related to characteristic human errors. It may therefore be particularly appropriate to application in the area of natural language discourse.

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### Abstract

The topic of belief and intention in situations with multiple agents is increasingly well understood, but current formal approaches appear to face problems in applications where the number of agents grows. This article provides an informal development of Corporate Agents, a formal approximation of individual and group states, which treats groups symmetrically with autonomous agents. Corporate Agents are motivated by typical patterns of information flow, which is then reasoning about the propagation of attitudes in multi-agent systems.

The approximation to an ideal logical formalism is not tight, but the model appears to function well in information-rich environments and fails in ways related to characteristic human errors. It may therefore be particularly appropriate to application in the area of formal

language theories.

# 1 Introduction

This work is motivated by problems in natural language discourse. A system for natural language discourse acts as a single agent in a multiagent environment, and as such, it must possess a practical method of tracking other agents' beliefs, goals and intentions. We construe these other agents broadly to include groups and perhaps abstract agencies as well as individuals.

This paper considers the problems of *implementing* an agent and describes that agent's mechanism for processing its beliefs about the mental states of others. Focus on the individual agent, rather than on group interaction as such, sets certain priorities. First is the consideration of fully *situated* (one might say, mildly solipsistic) formalisms. An agent is faced with a Cartesian shortfall of access to objective reality; thus, while it can layer acceptance and preference strategies on its basic mechanism for belief, no notion of knowledge with *truth* as a condition can be entertained. Likewise, we do not require a generalisation across all agents including the self to acquire the same status for the agent as its normal working beliefs. The second consequence of this focus is that practical processing strategies become more important than philosophers' and logicians' sound and complete systems. This paper provides practical approximations to the ideal solutions of these problems; the results will be judged in terms of performance rather than competence. Typical human failures in problem solving are, in this light, a valuable source of data about corners that might be cut in representation or implementation.

In subsequent sections we describe our notion of *corporate agents*, the structures that we employ to represent the other agents in an environment; and the *charters* that integrate these with default-reasoning mechanisms; we then provide examples of their behaviour.

## 2 Corporate Agents

Mathematically, the most natural approach to representing attitudes in a multiagent context is to represent groups just as sets of individuals, and common beliefs as the maximal consistent sets of beliefs of individual members. Models of coöperation and communication often rely on introspection over shared beliefs, as in this two-agent definition of *mutual belief*:

$$MB_{\{x,y\}P} \triangleq B_{xP} \wedge B_{yP} \wedge B_x B_{yP} \wedge B_y B_{xP} \wedge B_x B_y B_{xP} \wedge \dots \quad (1)$$



where  $B_x p$  says that agent  $x$  believes proposition  $p$ . The modal operator **MB** captures the notion of full, bilateral, symmetric and introspective belief of the proposition  $p$ . Generalizing this to the multiagent case gives

$$MB_{GP} \triangleq \bigwedge_{\bar{x} \in G^+} B_{\bar{x}} p \quad (2)$$

where  $B_{(x_0, x_1, \dots, x_n)} \triangleq B_{x_0} B_{x_1} \dots B_{x_n} p$ .

In considering the beliefs of a particular agent  $x$ , and given the common assumption that  $B_x p \Leftrightarrow B_x B_x p$ , we obtain the ‘one-sided’ version (given here for a two-agent group),

$$BMB_{x, \{x, y\}} p \triangleq B_x p \wedge B_x B_y p \wedge B_x B_y B_x p \wedge \dots \quad (3)$$

or in general,

$$BMB_{x, GP} \triangleq \bigwedge_{\substack{\bar{y} \in G^+, y_0 \neq x, \\ y_i \neq y_{i-1}, 0 < i < |\bar{y}|}} B_x B_{\bar{y}} p \quad (4)$$

Previous work has focussed on the mechanics of representing [11] and generating [1, 9] these states.

This theoretical ideal suffers from a number of practical drawbacks. Most obviously, the infinite conjunctions (or formal substitute) may prove inconvenient for certain reasoning mechanisms. Less avoidably for multiagent systems, even the low-order terms proliferate rapidly with number of agents. This is a serious impediment to representation of belief spaces as persistent data structures. Finally, this formulation of mutual belief (and indeed the powerset notion of group) becomes harder to apply when all the agents involved are not rigidly designated and known *a priori*. These problems seem ultimately soluble, but the solutions may not be computationally attractive.

A more ‘commonsense’ strategy is to attribute mental states directly to groups as a whole. The notion of *Corporate Agent* is a sharpening of this fundamental intuition. For us, an agent may be *any* entity that makes changes in the world known to our subject, whether or not it has a distinct physical manifestation. In particular, we call our agents ‘corporate’ because we admit groups directly as agents<sup>1</sup>. Although in reality only individuals can have beliefs or make inferences, the model is more practical in disregarding

<sup>1</sup>Depending on the application, we would also admit such abstract agencies as ‘folks,’ or ‘fate,’ or ones below the level of an individual, such as various sides of a personality [10].

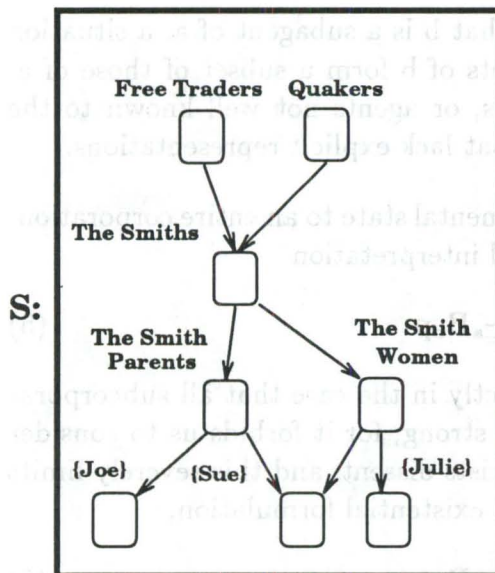


Figure 1: Simple Corporate Agents

this nicety. It retains only enough information about interactions between members of the corporation to allow successful interaction with it. However, the representations of these internal relationships distinguish corporate agents from uninterpreted groups, for two corporations with distinct patterns of communication might still be built from the same set of individuals. We refer to these records as *corporate charters*; they are described below.

Briefly stated, corporate agents form a directed acyclic graph of subsumption relations as does the powerset model. The principal differences are that there may be distinct corporations with the same members, and that calculation often proceeds without reference to intermediate sets.

Figure 1 represents the dag of corporate agents existing *in the beliefs of some computational agent S*. This is essential in examples involving interactions between agents, where one must distinguish beliefs contemplated by the researcher and those of a particular participant. The system does not model itself at all in this diagram; the reflexive case will be discussed later.

The arrows in this diagram represent subagent relationships. There are three individuals, which appear as singleton sets; one, the singleton Sue, is a subagent of both the Smith Parents and the Smith Women. All three singletons are subsidiary to the Smiths, whether explicitly or transitively. We



will use the notation  $b \sqsubseteq a$  to indicate that  $b$  is a subagent of  $a$ , a situation that can only arise if the singleton agents of  $b$  form a subset of those of  $a$ . Note that large groups like the Quakers, or agents not well known to the system may have additional members that lack explicit representations.

Consider now the ascription of some mental state to an entire corporation. One candidate definition is the universal interpretation

$$B_a p \Leftrightarrow \forall b \sqsubseteq a B_b p \quad (5)$$

in which a corporation holds that  $p$  exactly in the case that all subcorporations hold it. This formulation is overly strong, for it forbids us to consider as corporations groups in which there exists dissent; and this severely limits the utility of the model. Conversely, the existential formulation,

$$B_a p \Leftrightarrow \exists b \sqsubseteq a B_b p \quad (6)$$

is far too weak, and does not admit the anomalous but useful case of a corporation which manifests beliefs held by *none* of its members.

Rather than committing to one or the other of the above extremes, we adopt a promiscuous approximation, subject to two restrictions: that the automatic propagation of information along corporate lines occurs only by default; and that even when otherwise consistent, it never occurs unless explicitly licensed by the corporate charter. Ignoring the charter conditions for the moment, we now have the two rules:<sup>2</sup>

$$a \sqsubseteq b \vdash B_a p \rightarrow B_b p \quad (\sqsubseteq B)$$

$$a \sqsupseteq b \vdash B_a p \rightarrow B_b p \quad (\sqsupseteq B)$$

Assuming, now, the initial conditions on the left of figure 2,  $S$  can compute the structure on the right. Each initially attributed belief is based on prior information; and unlike the powerset model, corporate agency does not require the system to posit an agent subsuming just Joe and Julie, if it does not find such a grouping relevant. The proposition  $r$  simply propagates downward.  $\neg q$  propagates upward from Sue and Joe to The Smith Parents. Recalling the properties of default inference, we see that  $p$  cannot propagate

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<sup>2</sup>In the reflexive case, the first of these rules could have the effect of surpressing concrete action, and so must be inhibited. This point is taken up below.

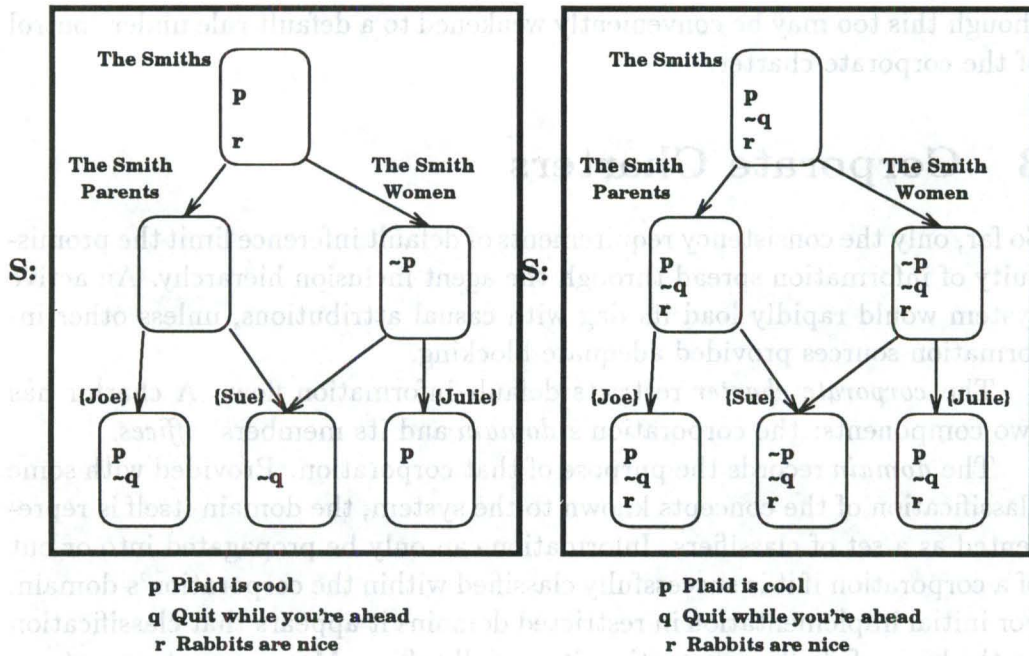


Figure 2: Default Belief Attribution

upward from Julie, being blocked by a prior belief attributed to the Smith Women. However, it does propagate to The Smith Parents either coming up from Joe or down from The Smiths. Finally, Sue is depicted as having inherited  $\sim p$  from The Smith Women. This inference will occur in some default logics if The Smith Women attains higher salience than The Smith Parents, but as such will depend on the system's focus of attention, an issue that is beyond the scope of the current paper.

These collapsed compound agents prove to be much more convenient in practise than stricter and more formal models. By using mechanisms similar to the above for the ascription of goals, intentions and other attitudes we can typically sidestep the need for fully represented mutual belief. In the case that they are still needed, however, the ramifications of classical mutual belief are still available via the direct generalisation to corporate agents of the axiom of introspection,

$$a \sqsubseteq b \vdash B_b p \Rightarrow B_a B_b p \quad (B+)$$



though this too may be conveniently weakened to a default rule under control of the corporate charter.

### 3 Corporate Charters

So far, only the consistency requirements of default inference limit the promiscuity of information spread through the agent inclusion hierarchy. An active system would rapidly load its dag with casual attributions, unless other information sources provided adequate blocking.

The *corporate charter* restricts default information flow. A charter has two components: the corporation's *domain* and its members' *offices*.

The *domain* records the purpose of that corporation. Provided with some classification of the concepts known to the system, the domain itself is represented as a set of classifiers. Information can only be propagated into or out of a corporation if it is successfully classified within the corporation's domain. For initial implementation in restricted domains it appears that classification on the basis of shallow syntactic criteria will suffice. More competent systems might use deeper reasoning or information retrieval technology.

The *office* of an agent similarly records its purpose or rôle with respect to the given corporation. The different propagation patterns of different corporate sub-concerns can be modelled by making the corresponding subagents' offices further constrain belief transfer. Thus, we give each office a separate domain, and make the effective domain for attitude transfer the *intersection* of the applicable corporate and office domains. Some offices, such as membership in a civic group, are bland and uniform, while other coöperative undertakings have highly specialized and asymmetric offices. To simplify the representation of such specialisation, we will assume that offices are themselves classified in a hierarchy, rooted in the most general office, 'member.'

The corporate charter, in the form of the domain and the offices of the corporate agent, effectively encodes summary domain knowledge about the *purpose* and *organisation* of the corporation and consequently the anticipated kinds of information flow. It abstracts completely away from the mechanisms by which this is accomplished, and indeed from the direction of flow. This is important because in the absence of a model of the mechanisms involved, we can be concerned only with the *correlations* between the attitudes of different agents—what they might agree to.

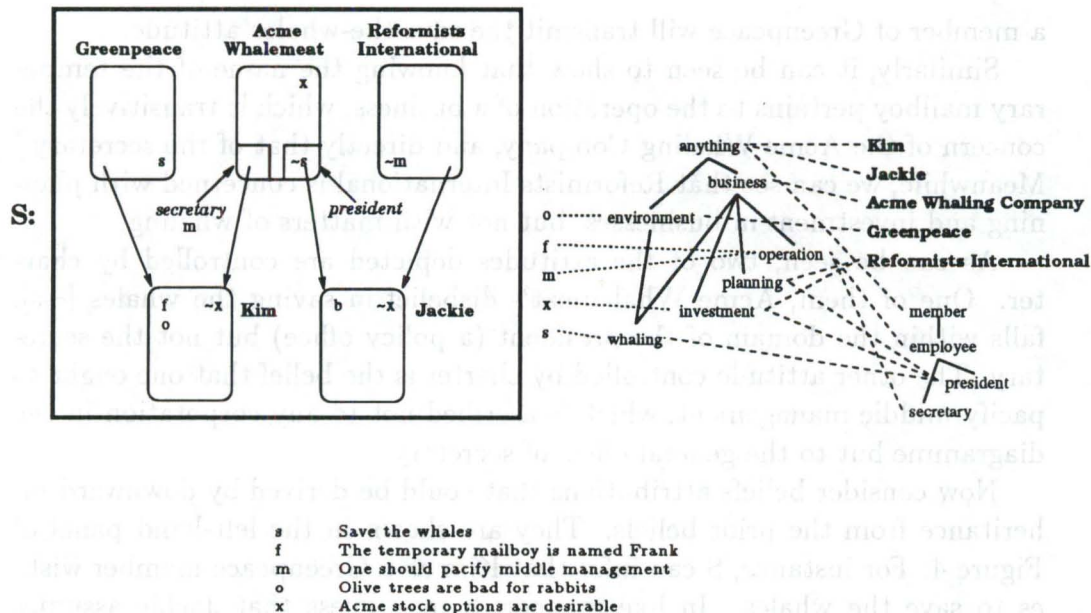


Figure 3: The Acme Whalemeat Scenario

## 4 An Example

In the situation depicted in figure 3, system S believes that Kim is a member of Greenpeace, and is also (perhaps somewhat uncomfortably) employed as a secretary in the Acme Whalemeat Company. S also believes that Jackie, the company president, is a member of Reformists International, an organisation of high-powered business executives set on streamlining their corner of the economy in time for the Millennium.

The left panel of the figure shows those attitudes which S has prior reason to attribute to the different corporations in the figure. According to S, Greenpeace wants to save the whales [s], while Jackie and Kim independently reject the notion of investing in the company that pays them [ $\sim x$ ].

The right panel depicts the corresponding portion of the classification scheme. To see which corporations and which rôles will transmit a given attitude, we need to trace upwards in the classification hierarchy. The goal "save the whales" [s] classifies under 'whaling'; moving upwards, we can see that this is dominated *both* by 'environment,' which falls within the domain of the Greenpeace agent, and by 'anything,' in the purview of the most general office, 'member.' Thus we would predict that the particular office of



a member of Greenpeace will transmit the save-the-whales attitude.

Similarly, it can be seen to show that knowing the name of the temporary mailboy pertains to the operation of a business, which is transitively the concern of the Acme Whaling Company, and directly that of the secretary.<sup>3</sup> Meanwhile, we can see that Reformists International is concerned with planning and investment in businesses, but not with matters of whaling.

As can be seen, two of the attitudes depicted are controlled by charter. One of them, Acme Whalemeat's disbelief in saving the whales [ $\sim s$ ], falls within the domain of the president (a policy office) but not the secretary. The other attitude controlled by charter is the belief that one ought to pacify middle management, which is ascribed not to any corporation in the diagramme but to the general office of secretary.

Now consider beliefs attributions that could be derived by downward inheritance from the prior beliefs. They are shown in the left-hand panel of Figure 4. For instance, S can infer that Kim as a Greenpeace member wishes to save the whales. In like manner, S may guess that Jackie assumes Reformists International's delight in raising the ire of middle management. S also can infer that the individual agents inherit those beliefs dictated by their chartered offices in Acme Whalemeat. Kim pacifies middle management, while Jackie does not, as a corporate officer, save the whales. This partitioning of areas of concern can be seen in the classification of concerns in the right-hand panel of figure 3.

The belief that Acme stock options are desirable is not inherited by our models of either Kim or Jackie, since each independently is already known to believe the contrary. This is a case where an attitude is attributed despite the fact that the system knows of no singleton agent having that attitude. It is therefore not an 'aggregate' opinion, but is worth maintaining nonetheless.

Consider now how attitudes propagate upwards. The right-hand panel of figure 4 presents a number of straightforward inferences: since Kim personally knows the name of the temporary mailboy [f], it is inferred that Acme Whalemeat corporately is aware of this fact; similarly Reformists International may become aware of the undesirability of Acme stock [ $\sim x$ ]. More surprisingly, we find the view [o] that olive trees are bad for rabbits ascribed to Greenpeace; this follows because it is a view of Kim's that falls soundly

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<sup>3</sup>We here ignore the fact that offices are determined relative to their corporation, since in the absence of multiple businesses in the example, there is no ensuing ambiguity.



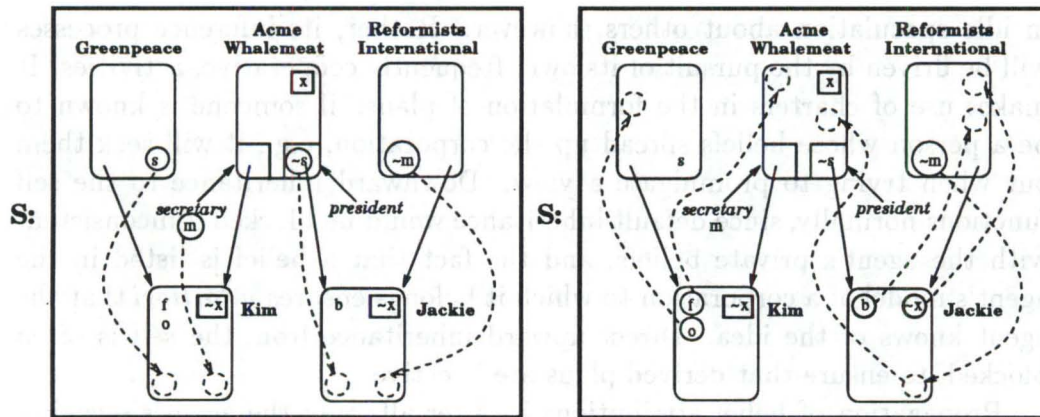


Figure 4: Derived Acme Attitude Ascriptions

within the domain of Greenpeace's environmentalist charter.

One further upward propagation takes place: the belief  $[\sim m]$  in stirring up middle management that our model of Jackie acquired from the Reformists is passed back up to Acme Whalemeat. This iterable V-shaped pattern of propagation is that which, if unconstrained, would eventually smear beliefs across most of the agents in existence. Given charters, this is comparatively rare; here it is licensed only because it is within both the charter of Reformists International and the office of president of Acme.

Default reasoning ensures that disbelief in the desirability of Acme stock options  $[\sim x]$  does not pollute our notion of Acme itself: its optimism is (perhaps rightly) incurable by the mechanisms presented here.

It is the patterns of *non*-propagation that are the most interesting. No beliefs  $[o]$  about the ecological interactions of bunnies and olives are imputed to the Acme Whalemeat Company via Kim, since olive growing and bunny-culture fall outside of its domain; and similarly, Greenpeace is not inferred to have any knowledge of the name of the mailboy  $[f]$ . Thus charters constrain default propagation of beliefs along corporate lines.

## 5 Discussion

We have seen how charters place general constraints on the default propagation of corporate belief attributions. An agent will not normally be engaged

in idle speculation about others, however. Rather, its inference processes will be driven by the pursuit of its own, frequently coöperative, activities. It makes use of charters in the formulation of plans: if someone is known to be a person whose beliefs spread up the corporation, e.g., it will seek them out when trying to promulgate a view. Downward inheritance to the self functions normally, since default inheritance would be blocked if inconsistent with the agent's private beliefs, and the fact that a belief is listed in the agent's model of a corporation to which it belongs ensures *a fortiori* that the agent knows of the idea. Direct upward inheritance from the self is often blocked, to ensure that derived plans are effective.

Propagation of belief attributions is, after all, only the agent's oversimplified model of processes grounded in real communication mediated by real, physical agents. To participate, the agent must also have communicative capabilities. At its disposal is an array of explicit communicative actions, each having a corporate belief state as a consequence [3]. Communicative actions are invoked to fulfill goals involving shared belief.

The work reported in this paper is being implemented within project DISCO, a multi-agent natural language discourse system under development at the German Artificial Intelligence Research Centre, the DFKI. The knowledge representation platform is Rhet[7], an advanced horné-clause theorem prover, developed at the University of Rochester. Its first application domain will be appointment scheduling, which involves such offices as professional, management and clerical staff, and software appointment scheduling agents; and domains such as scheduling, room reservation and meeting topics.

Rhet includes a mechanism for belief propagation, which allows for trees (not dags) of nested belief spaces, and one global mutual belief space from which the others inherit. It does not allow for mutual beliefs of subgroups or other explicit group belief mechanisms, and has not to our knowledge been used for applications involving more than two agents. Its followon, Shocker[6], supports a dag structure.

The system of [11] addresses the beliefs that an individual agent has about others, and is also implemented. Several other discourse projects [2, 4, 5, 8] have some representation of an individual's beliefs about another individual, but in general, systems capable of handling several agents seem lacking.



## 6 Conclusion

Relative to a full logical treatment of groups and mutual beliefs, *Corporate Agents* exhibit redundancy between assumed attitude propagation and underlying physical mechanisms, undue homogeneity in modelled attitudes of less carefully modelled subagents, and a tendency for ascriptions to depend on salience. They support a number of anomalous states in which the group attitudes diverge from those of *all* members, and allow the ascription of goals, beliefs and intentions to groups that have no members at all.

Though imprecise, they provide an efficient model for approximate attitude ascription in an environment where many agents interact with different rôles and objectives. By ascribing attitudes directly to groups they provide for simpler and more uniform representations than would otherwise be possible, while reducing both the total number of belief spaces and the number of distinct groups that must be considered during inference. Furthermore, the anticipated failure modes should be comprehensible, perhaps even familiar, to human interlocutors.

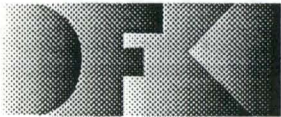
These structures permit us to focus on those groups and communicative mechanisms that are cognitively salient, and thus provide a useful substrate for a number of problems in the implementation of autonomous agents.

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