MODELING SOCIALITY IN THE BDI FRAMEWORK

PIETRO PANZARASA, TIMOTHY J. NORMAN, NICHOLAS R. JENNINGS

Dept. Electronic Engineering, Queen Mary and Westfield College, University of London, London E1 4NS, UK. {P.Panzarasa, T.J.Norman, N.R.Jennings}@qmw.ac.uk

Abstract. We present a conceptual model for how the social nature of agents impacts upon their individual mental states. Roles and social relationships provide an abstraction upon which we develop the notion of *social mental shaping*.

1   Introduction

Belief-Desire-Intention (BDI) architectures for deliberative agents are based on the physical symbol system assumption that agents maintain and reason about internal representations of their world [2]. However, while such architectures conceptualise individual intentionality and behaviour, they say nothing about the social aspects of agents being situated in a multi-agent system. The main reason for this limitation is that mental attitudes are taken to be *internal* to a particular agent (or team) and are modeled as a relation between the agent (or a team) and a proposition. The purpose of this paper is, therefore, to extend BDI models in order to investigate the problem of how the social nature of agents can impact upon their individual mental state. Particularly, we shall address the following questions: (i) how is an agent's mental state influenced by the social context in which it is situated? (ii) what is the relationship between the mental states of interacting agents? and (iii) what are the conceptual mechanisms that enable these relationships to be effected?

The remainder of the paper is organised as follows. Section 2 informally introduces the notion of *social mental shaping*. Section 3 formalises this notion. Finally, Section 4 introduces a number of key types of social exchange.

2   Social Mental Shaping

The mental states of BDI agents are usually viewed as constituted only by *internally motivated* mental attitudes. However, this traditional image is threatened whenever we take into account the social nature of agents. Particularly, we claim that the adoption of attitudes can be driven either by *social roles* or by *social relationships.*

We use the term *social context* to refer to a *pattern of interrelated roles*. A role is here conceived as *a system of prescribed mental attitudes*, rather than a system of prescribed behaviour. Roles provide agents with much of the information and many of the goals and other attitudes that drive their behaviour. Roles tell them how to reason about the problems and decisions they face: where to look for appropriate

goals, informational resources, and value premises, how to achieve goals, and how to react to changes in information, goals, and value premises.

On the other hand, there are a number of ways in which social relationships can drive an agent's behaviour by influencing its mental state. Among others, we have:

? *Authority*. An agent's mental state may be changed by another agent when the latter has the power to guide the behaviour of the former.

? *Helping disposition*. An agent may be influenced to adopt another agent's attitude simply because it intends to contribute to the welfare of the latter.

? *Trust*. An agent may be influenced by an acquaintance to adopt a mental attitude merely on the strength of its confidence in that agent.

? *Persuasion.* An agent may be influenced to adopt another agent's mental attitude through a process of argumentation.

Thus both roles and relationships offer mental attitudes that the agent can adopt to complement or merely to change its individual mental state. This suggests a view of the agent as a kind of *associative* entity, engaged in an iterated series of social actions and interactions aimed at *completing* its mental state. The complex interplay between the agent and its social context turns out to be a process in which roles and social relationships may complement and augment bare individual mental attitudes. We propose to call this completing process *social mental shaping*.

3   Formalising Social Mental Shaping

This section introduces the formal framework within which we can explore the process of social mental shaping in more detail. We work broadly within the logical model introduced by Cavedon and Sonenberg [1]. However, we extend their framework in two directions. Firstly, in our model, roles can provide agents not only with goals but also with beliefs, desires, and intentions. Secondly, as opposed to [1], mental attitudes are provided not only by roles but also by social relationships.

We start by assuming a non-empty set of agents, D_{Ag}, with a_1, a_2, …, a_n denoting individual agents. Each agent will typically be required to perform several tasks, and will have to make decisions about how to achieve them.

3.1   Mental Attitudes

Our analysis is based on a fairly standard BDI framework as found, for instance, in [2]. Agents' mental attitudes are characterised by using the notions of beliefs, goals, desires, and intentions, as represented by the modalities: *BEL(a, f)*, *DES(a, f)*, *GOAL(a, f)*, and *INT(a, f)*. For simplicity, *Att(a, f)* means that agent *a* has a mental attitude *Att* towards *f* (either a belief or a desire or a goal or an intention).

An agent's belief set includes beliefs concerning the world and beliefs concerning mental attitudes of other agents. This belief set may be incomplete. An agent's desires are the primary motivators of action. However, an agent may have

conflicting and even unrealisable desires. Goals can be described as a consistent subset of the set of desires. Since a goal is conceived of as a candidate for being moved up to intention-status, any goal should be believed by the agent to be achievable. Finally, an agent's intention represents a goal that it is committed to achieving.

3.2   Roles and Social Relationships

As with agents, our language allows quantification over roles, relationship types, and relationship instances:

? D_{Roles} is a non-empty set of roles that an agent may undertake, with r_1, r_2, …, r_n denoting individual roles. We introduce the predicate *In* with two parameters, agents and roles: *In(a, r)* asserts that agent *a* is in role *r*.

? $D_{RelTypes}$ is a non-empty set of social relationship types. Here a relationship type represents a relationship between a pair of roles: $D_{RelType}$ $\check{I}$ $\{(r_i, r_j):r_i, r_j\hat{I} D_{Roles}\}$.

? D_{Relns} is a non-empty set of relationship instances, that is, instantiations of relationship types. To indicate that two agents a_i, a_j are in a social relationship, we write $rn_{i,j}$.

3.3   Roles and Social Mental Shaping

We now express the influence of *roles* on an agent's mental state, outside of any particular social relationship. To this end, we introducing the modal operator *Infl*:

$$\forall a_i, \forall r_i \ Infl \ (Att \ (a_i, \textbf{f}), \ r_i) \ \text{iff} \ In \ (a_i, r_i) \ \acute{E} \ Att \ (a_i, \textbf{f})$$

The meaning of *Infl(Att(a, f), r)* is that if *a* takes on the role *r*, then it will adopt the attitude *Att* towards *f*. We therefore have the social mental shaping rule (schema) that asserts that if role *r* can influence agent *a*'s mental state with respect to a mental attitude *Att*, and if *a* takes on *r*, then *a* will adopt *Att*:

$$\forall a_i, \ \forall r_i \ (Infl(Att(a_i, \textbf{f}), r_i) \ \grave{U} \ In(a_i, r_i)) \ \acute{E} \ Att(a_i, \textbf{f})$$

3.4   Social Cognitive Relationships

We now want to present a formal framework to show how an agent's mental state can be influenced by its being within a *social relationship* with another agent. This kind of social mental shaping is captured by the following axiom:

$$\forall a_i, a_j \ \forall rn_{i,j} \ Infl \ (Att \ (a_i, \textbf{f}), \ rn_{i,j,}) \ \text{iff} \ (BEL \ (a_i, Att(a_j, \textbf{f})) \supset Att(a_i, \textbf{f}))$$

Crudely, if an agent a_i, which is in a social relationship with another agent a_j, believes that a_j has a mental attitude *Att*, and simply for this reason it changes its

mental state by adopting *Att*, then we can say that a_i is influenced by its being situated within a social relationship with a_j.

Next, we define the concept of *social cognitive relationship*. Two agents a_i, a_j are in a social cognitive relationship iff: (i) they are in a social relationship, and (ii) *at least* one of the two agents will adopt a mental attitude simply because it believes that the other holds that attitude. Formally, we say that agents a_i, a_j are in a social cognitive relationship, $cogn(a_i, a_j)$, iff:

$$\mathbf{S} \; rn_{i,j} \; Infl(Att(a_i, \mathbf{f}), rn_{i,j}) \; \mathbf{Ú} \; Infl(Att(a_j, \mathbf{f}), rn_{i,j}).$$

3.5   Social Cognitive Structures

Before we can define social cognitive structures, we need to formalise the notions of social context and social structure. A social context is a set of interrelated roles.

Definition. A subset S of social relationship types, $S \; \tilde{\mathbf{I}} \; D_{RelTypes}$, is a *social context* iff S is non-empty and weakly connected.

A social structure is a set of relations between agents. These relations are instantiations of relations between roles in a social context.

Definition. A *social structure* is a sextuple *(Ag, R, Rel, T, m, l)* where:
? $Ag = \{a_1, a_2, ...a_n\}$ is a set of agents where, $a_1, a_2, ...a_n \; \hat{\mathbf{I}} \; D_{Ag}$;
? $R = \{r_1, r_2,..., r_n\}$ is a set of social roles, where, $r_1, r_2, ...r_n \; \hat{\mathbf{I}} \; D_{Roles}$;
? $Rel = \{(a_i, a_j)$ s.t. $a_i, a_j \hat{\mathbf{I}} \; Ag\}$ is a set of binary relations; *Rel* is non-empty and weakly connected;
? $T = \{(r_i, r_j)$ s. t. $r_i, r_j \; \hat{\mathbf{I}} \; R\}$ is a set of social relationship types;
?   *m: Ag ® R* labels each agent in *Ag* with a role in *R*;
?   *l: Rel ® T* labels each arc in *Rel* with a social relationship type in *T*.

Not all social structures are also cognitive. For a social structure to be cognitive, agents must be connected to one another via social cognitive relations.

Definition. A social structure *(Ag, R, Rel, T, m, l)* is a *social cognitive structure* iff *Rel* is a set of binary social cognitive relationships: $Rel = \{cogn(a_i, a_j)$ s.t. $a_i, a_j \hat{\mathbf{I}} \; Ag\}$.

4   Forms of Social Cognitive Relationships

To illustrate the power and flexibility of the concept of social mental shaping, we examine a number of fundamental forms of social cognitive relationships.

Imitation. Imitation is a form of social mental shaping grounded on desires. Since, and as long as, a_i is in a social relationship with a_j and believes that a_j has a desire to

f, a_i adopts this desire. More formally, we have: $\forall a_i, a_j, \forall rn_{i,j}$ $Imit$ $(Att$ $(a_i, f), rn_{i,j})$ $^{\circ}$ BEL $(a_i, DES$ $(a_j, f))$ $\acute{E}$ $DES(a_i, f)$.

Adoption. We call adoption that form of social mental shaping that refers to goals. Formally, we have: $\forall a_i, a_j, \forall rn_{i,j}$ $Adopt(Att$ $(a_i, f), rn_{i,j})$ $^{\circ}$ $BEL(a_i, GOAL(a_j, f))$ $\acute{E}$ $GOAL(a_i, f)$. According to this definition, an agent will adopt a goal because it believes that another agent has that goal. The agent thus completes its own mental state by *extending* it so as to include the other agent's goal.

Adhesion. By adhesion we mean that form of social mental shaping that is grounded on intention. An agent may intend to achieve a state of the world simply because it believes that another agent intends to do so: $\forall a_i, a_j, \forall rn_{i,j}$ $Adhes(Att(a_i, f), rn_{i,j})$ $^{\circ}$ BEL $(a_i, INT(a_j, f))$ $\acute{E}$ $INT(a_i, f)$.

Exploitation. It is often the case that an agent can easily lean on the information possessed by another agent to get the job done. In such cases, the agent extends its own mental state so as to include the other agent's beliefs. Such a mental extension is based on the agent's belief that the other agent has a belief. We refer to such a form of social mental shaping as exploitation. Formally, we have: $\forall a_i, a_j, \forall rn_{i,j}$ $Expl(Att(a_i, f), rn_{i,j})$ $^{\circ}$ BEL $(a_i, BEL(a_j, f))$ $\acute{E}$ $BEL(a_i, f)$.

5 Conclusions and Future Work

This paper describes our preliminary investigations into the impact that sociality has on an agent's mental state, and how it can be formalised within a BDI framework. Our notion of social mental shaping captures the impact that both roles and social relationships have on an agent's mental state.

Future work involves the investigation of *why* and *when* social mental shaping arises. Further attention also needs to be paid to how social mental shaping develops over time. Finally, we intend to address the problem of inconsistency both among socially adopted attitudes and between these and internally motivated ones.

References

1. L. Cavedon and L. Sonenberg. On social commitment, roles and preferred goals. In *Proceedings of the Third International Conference on Multi-Agent Systems*, pages 80-86, 1998.
2. A. S. Rao and M. P. Georgeff. Modeling agents within a BDI architecture. In R. Fikes and E. Sandewall, editors, *Proc. of the 2nd International Conference on Principles of Knowledge Representation and Reasoning (KR '91)*, pages 473-484, Cambridge, MA, April 1991. Morgan Kaufmann.