From Inter-Agent Interaction to Multiagent Social Networks

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Abstract. This paper examines the major issues and modes of interactions between a small number of agents, outlines the extension of these concepts to inter-groups, and points to promising directions of research that are useful in modeling dynamic organizations of agents.

Keywords: Agents, Social networks, Self-adaptive software

1 Introduction

Social elements of interaction have received considerable attention in multiagency [Jennings and Campos 1997, Castelfranchi 1998]. This research formalizes such notions as norms, roles, autonomy, delegation, control, trust, power, preference, and responsibility. It mostly focuses on an agent-centric viewpoint and suggests how individual agents relate to one another. Dynamic groups of agents like coalitions and teams follow well-known policies over these elements. Organized groups of agents such as organizations may in addition have rules over such policies that govern agent and group interaction. Beyond direct attitudes between two agents, in groups of agents, there are also derived or indirect effects that are very pow-

erful influencers of the individuals in the group. To capture the relationships among agents, mathematical models of graphs or networks are commonly applied. In general, in such models, the nodes represent agents and the arcs represent relationships.

In this paper we will review salient features of social attitudes, both in direct form and as derived or implied. We limit our interest to social models where relationships are among agents. We believe examining scaling issues of social networks on inter-group interactions is an important research effort that has been mostly addressed in isolated cases. We will outline directions for theories that synthesize them into unified models.

The idea of networks is pervasive in many disciplines. There are a few that are beyond our scope. First, intra-agent models have been modeled as in action selection networks [Maes, 1991]. Second, networks of bids as in contract net [Smith, 1980], communication as in [Xiang, 1996], negotiation as in [Banerjee, et al, 2001], nodes are propositions instead of agents. Third, the study of human social networks and organizations has been a long-standing effort [Katz and Lazarsfeld, 1955, Scott, 1991, Garton, et al. 1999]. The aim in social networks analysis is seeking to understand the ties among individuals and from that suggest some properties about connectivity of the whole group or each individual [Garton, et al. 1999]. Gathering survey data or automated means is used to perform this research in sociology. The human issues are interesting and relevant, and by and large in our study of multiagent systems we share the aim of understanding and improving interactions in agent

networks. The difference in approach in multiagent systems is to understand and embody intentional notions taken for granted in humans.

In recent years management sciences are also developing computational models of organizations and even consider agents [Carley, 1995]. The aim here is at a meso-level where “they seek to explain and predict macro-level behavior, such as overall organizational performance, from micro-level actions, such as the interaction among agents, each of which are ‘cognitively’ limited” [Prietula, et al. 1999]. The research we describe generally fits under the rubric of computational organizations, but has a decidedly micro-level orientation.

Let’s outline salient relationships among a group of agents. Figure 1 shows that an agent as a member of a group is influenced by a set of group values. These values are terminal goals that the group shares and each agent may help set forth. The values are things like rationality principles of a society [Nozik 1993; Tuomela 2000]. The group contains a set of roles that agents handle. There are complex relationships among roles, norms, and goals that an agent weighs the alternatives to settle on a consistent set at any moment. Agents use the relationships for collective predictability of behaviors of its agent members. The group of agents might share a plan that is the result of complex trio-relations. The Figure is deliberately simple to avoid confusion. The reality is much more complex and many of the relationships shown are part of research activities but our aim is to set the stage to discuss issues at a high level.

Figure 1. Inter-agent Relationship Ontology

A motivational element between two agents, such as power or autonomy can be understood in terms of a relationship of one agent toward the other. This can be the basis of networks of such relationships; e.g., social power networks [Castelfranchi, et al. 1992], and trust networks [Abadi, et al 1999]. Figure 2 shows a set of motivational and deliberative elements that can be networked. In an organization there is usually a policy for setting up such networks. Generically, when we say a sortie as an Air Force operation, specific rules of command and control over networks are implied. Organizational agents are assigned or join groups that obey rules of such networks. Agents, however, may defect from one group to another when their internal preferences do not match the network requirements.

There have been suggestions for using networks for coordination among agents, for example in the supply chain domain [Barbeceanu 1997] and collaboration at the team level [Yen, et al. 2001]. However, there are no general frameworks that extend the networks to organizations nor is there a theory that specifies the relationships among the networks. Such a general theory can be used to monitor and forecast potential problems in organizations and it can also be used for design or proactive measures. In the next section we will outline these relationships.

Figure 2. Inter-group Relationship Ontology

2 Outline of known selected networks

2.1 Trust networks

[Marsh 1992, 1994] is one the earliest works on trust in multiagency. Marsh clearly defines trust as a function of (a) a basic trust attitude toward another agent, and (b) the value of the object of trust. More recent theories of trust in multiagency are found in [Castelfranchi, Falcone 2000]. However, Trust and security are mostly explored in mobile agents research. We summarize the models presented in [Swarup and Fábrega, 1999]. Agents (called keys) are represented as nodes of a graph. Statements are also nodes of such a graph. One type of directed edge is between two agents (A → B) and it represents that A trusts B. Another type of directed edge is between an agent and a statement (A → P), and it represents that agent A states P. In a network of agents and statements, specific policies can be defined. For example a policy that insists on two independent corroborating trust paths per statement can be used to identify all agents that accept a given statement. The number of false positive and negative statements in the trust graph can be used in ratios of these numbers over the number of statements to compare policies.

2.2 Responsibility and delegation networks

Agents are represented as nodes of a graph. One type of labeled directed edge is between two agents (A $\tau\rightarrow$ B), and it represents that A delegates τ to B or conversely B is responsible to A with respect to τ. This is the approach taken in the CAST project [Yen, et al. 2001]. Yen and colleagues consider the delegation relationships to be non-reflexive, anti-symmetric, and transitive. The transitive property can be used to establish implied relationships.

2.3 Individual dependence networks and power networks

In social dependence network defined in [Sickman, Conte, Demazeau, Castelfranchi, 1997], two types of dependence are resources and action. In this work, dependence is in terms of one agent depending on another agent and it is called individual dependence. A different conception is presented in [Mylopoulos, et al 1990]. The objects of dependencies between two agents here are one of the following types: goal, task, resource, and softgoal. Using these types of dependencies, they define several types of organizational structures [Chung, et al 2000]. They claim that these patterns can be used to model interactions commonplace in organizations. For instance, *structure-in-5* is a network of 5 types of agents shown to be applicable in mobile robot control software.

Power is a highly related notion and at times it is treated in the one network. In a group with a plan with many actions (i.e., steps), an agent i is *dependent* on another agent j if and only if an action (i.e., a plan step) of agent j is beneficial for agent i while agent i is not in a position to carry it out, and the action is as good as any agent j would otherwise select. Conversely, in this scenario, agent j has *power* over agent i. There are versions of this given in [Castelfranchi, Miceli, and Cesta, 1992, David, Sichman, and Coelho, 1999, Brainov, 1999].

2.4 Role networks

[Prasad, et al 1996] presents techniques for learning organizational roles. They describe a distributed search problem and how agents need to learn to choose the most appropriate roles. Networks of roles are more clearly seen in role-based access control. Role hierarchy

and role grouping are useful for selecting subsequent roles [Moffett and Lupu, 1999, Na and Cheon, 2000].

2.5 Preference networks

In a labeled directed graph, nodes are agents and an arc between agents i and j is agent i's attitude toward agent j [Barinov and Sandholm, 1999]. The attitudes are represented by the differential utilitarian importance an agent places on the agent's utilities. If this degree is positive the agent is benevolent, if it is negative the agent is malevolent, and if this degree is zero the agent is self-interested. Attitudes are propagated by multiplying the degrees on the arcs. For example, if i's attitude toward j is represented by the degree α, and j's attitude toward k is β, then agent i's attitude toward agent k is $\alpha * \beta$. He then goes on to define the main relationship in a coalition as a set of balanced benevolent relationships.

2.6 Autonomy and potential delegation networks

Autonomy can be considered as a potential for *choices* or *permissions*. When an agent considers the potential for delegation toward another agent, a relationship for potential delegation exists. When an agent considers the potential for sharing toward another agent, a relationship for potential cooperation exists. The author is proposing a network of such relationships [Hexmoor, 2001]. In addition to binary relationships between two agents, the reciprocal autonomy relationships among agents can be characterized as joint autonomy [Beavers and Hexmoor, 2001].

3 Social structures and properties

Many social structures rely on a pattern over social attitudes. For instance, in a trust network, we might expect each assertion to have at least two chains of trust support. We can examine the valid assertions that fit this condition or find subset of agents who trust in a given assertion.

A more complex example is coalitions that require a balance of benevolence relationships. Unbalance exists whenever two agents have a non-reciprocal preference stance toward one another.

Teams require individuals to have reciprocating (or joint) awareness, autonomy, and cooperation. A team functions best when there are adequate and reciprocal levels of these social attitudes. An automated system might detect deficiencies in these levels in team members and suggest remedies for improved teamwork.

Interesting graph-based results over referral social networks are reported in [Yu, et al, 2000]. For instance, they experimented with varying levels of expertise and sociality in agents and found that the quality of the network had an inverse relationship with the density of the network.

4 Research Directions

Much remains to be explored. Chief among these are the concerns about the relationships among networks of sociality under norms, roles, autonomy, delegation, control, trust, power, preference, and responsibility.

4.1. Relationships among networks. There are some hints of relationships in the literature among social notions. Relating the relationships among social notions is in its infancy. Relatively little is written about the relationship among closely related common notions such as control, power, trust, and autonomy. Conceptualizations of these notions should relate them to more basic notions such as belief, desire, and intention. Comprehensive studies of the relationships are needed both as ontological studies as well as logic-based representations. A few of these relationships can be best explored in a formal framework called the correspondence theory [Lomuscio, 1999, Wooldridge, 2000]. Yet other work is closer to social psychology [Miceli and Castelfranchi, 2000].

4.2 Self-adaptive software. When attitudes such as autonomy belong to a whole group, in addition to group members sharing these attitudes the attitudes can exist beyond a single agent. This suggests construction of a Virtual Agent (VA) that possesses such group attitudes and can interact with its counterparts. Such agents are different than middle agents of multiagency, primarily since their life-times are limited by the group attitude. VA can be very useful in (a) fault-tolerance in case one of the agents is disabled, and (b) forming larger units of agents. These and other types of self-adaptation are explored in a series of recent conference [Laddaga, 2001]. Traditional adaptation techniques in machine learning or con-

trol theory are in regards to specific reference parameters and do not scale well. Methodologies are needed to explore adaptation such that mission objectives are preserved.

4.3. Multiagent software engineering. There is recent work in modeling agents and extending software engineering methods to account for multiagency [DeLoach, 1999; DeLoach & M. Wood 2000]. More work is needed to extend the work to account for design and maintenance of social networks of agents. By and large, social notions have dynamic values and change over time. A related area is properties of coherent and harmonious interaction and validation. To this date, no techniques exist that provide analysis of interaction among social agents and methods for assuring a desired pattern of interaction.

4.4. Empirical validation. The role of software agents in application domains such as defense, business, and knowledge management are clearly useful. But to date little has been done to empirically validate the extent of this benefit with quantified values of social relationships. [Ferrán-Urdaneta 1999] presents hypotheses about the usefulness of a few different structures. Simulations will be useful for gathering effectiveness of agent interactions in a social network as shown in [Yu, et al 2000]. Research is needed to develop quantification of social notions and how they change over time. For instance, an individual gains power by merely standing in a line to wait for service but as the line grows, the individual near the service rendering end of the line experience more power relative to the individuals farther away. In this simple example, power appears to be proportional to the position in line.

5 Conclusion

We discussed social attitudes between two agents, and reviewed how they can be extended to larger units of interacting agents that form social networks of agents. This work is similar to computational models of organizations, but is limited in scope to exploration of the social intentional notions of norms, roles, autonomy, delegation, control, trust, power, preference, and responsibility. We have outlined some work in this area and outlined some useful research directions.

Acknowledgements

This work is supported by US AFOSR grant F49620-00-1-0302.

References

1. M. Abadi, A. Banerjee, N. Heintze, and J.G. Riecke. 1999. A Core Calculus of Dependency. In Proceedings of the 26th Annual **ACM SIGPLANSIGACT** Symposium on Principles of Programming Languages, pages 147-160, San Antonio, Texas.
2. B. Banerjee, A. Biswas, M. Mundhe, S. Debnath, S. Sen, 2001. Using Bayesian Networks to Model Agent Relationships, In the Special Issue of the **Applied Artificial Intelligence Journal** on Deception, Fraud and Trust in Agent Societies.
3. M. Barbuceanu, and M. Fox, 1997. Integrating Communicative Action, Conversations and Decision Theory to Coordinate Agents, Proceedings of the First International Conference on Autonomous Agents, **Agents 97**, Marina Del Rey, ACM.

4. G. Beavers and H. Hexmoor, 2001. Teams of Agents, In Proceedings of the **IEEE Systems, Man, and Cybernetics Conference**.

5. S. Brainov and H. Hexmoor, 2001. Quantifying Relative Autonomy in Multiagent Interaction, In IJCAI-01 Workshop, Autonomy, Delegation, and Control.

6. S. Brainov, T. Sandholm, 1999. Power, Dependence and Stability in Multiagent Plans. AAAI/IAAI 1999: 11-16.

7. K. M. Carley, 1995. Computational and Mathematical Organization Theory: Perspectives and Directions, **Journal of Computational and Mathematical Organizational Theory**, Vol. 1, No. 1

8. C. Castelfranchi, R. Falcone 2000. Trust and Control: A Dialectic Link, Applied Artificial Intelligence journal, Special Issue on **Trust in Agents** Part1, Castelfranchi C., Falcone R.,Firozabadi B., Tan Y. (Editors), Taylor and Francis 14 (8), 2000.

9. C. Castelfranchi, 1998. Modeling social action for AI agents. **Artificial Intelligence**, 103: 157-182.

10. C. Castelfranchi, M. Miceli, A. Cesta, 1992. Dependence relations among autonomous agents. In Proceedings of **MAAMAW'92**, Elsevier Science Publishers B. V., Amsterdam, pages 215-227, 1992.

11. L. Chung, B. A. Nixon, E. Yu, J. Mylopoulos (editors). 2000. Non-Functional Requirements in Software Engineering, Kluwer.

12. S. A. DeLoach. 1999. Multiagent Systems Engineering: a Methodology and Language for Designing Agent Systems. In Proceedings of **Agent Oriented Information Systems '99 (AOIS'99)**, pp. 45-57. Seattle WA.

13. S. A. DeLoach & M. Wood. 2000. Developing Multiagent Systems with agentTool. The Seventh International Workshop on **Agent Theories, Architectures, and Languages (ATAL-2000).** Boston, MA.

14. C. Ferrán-Urdaneta, 1999. Teams or Communities? Organizational structures for knowledge management. In Proceedings of the **ACM Computer Personnel Research (SIGCPR'99),** New Orleans, Louisiana.

15. L. Garton, C. Haythornthwaite, and B. Wellman, 1999. Studying On-line Social Networks, In **Doing Internet Research**, Edited by Steve Jones: Sage pub.

16. D. Nuno, J. Sichman, and C. Helder, 1999. **Extending Social Reasoning to Cope with Multiple Partner Coalitions** In: Francisco Garijo and Magnus Boman, editors, Multi-Agent Systems Engineering - Proceedings of MAAMAW'99 (Modelling Autonomous Agents in a Multi-Agent World), LNAI1647, Springer Verlag, pages 175-187, June 30-July 2.

17. H. Hexmoor, 2000a. A Cognitive Model of Situated Autonomy, In Proceedings of **PRICAI-2000** Workshop on Teams with Adjustable Autonomy, Australia.

18. H. Hexmoor, 2000b. Case Studies of Autonomy, In proceedings of **FLAIRS 2000**, J. Etherege and B. Manaris (eds), p. 246- 249, Orlando, FL.

19. H. Hexmoor, 2001. Stages of Autonomy Determination, Submitted to IEEE Transactions of Man, Machine, Cybernetics.

20. N. R. Jennings and J. R. Campos, 1997. Towards a Social Level Characterisation of Socially Responsible Agents, in: **IEE Proceedings on Software Engineering**, 144 (1), 1997, 11-25.

21. E. Katz and P. F. Lazarsfeld, editors. 1955.Personal Influence: The Part Played by People in the Flow of Mass Communications. Free Press, Glencoe, IL.

22. R. Laddaga, 2001.

http://www.doll.com/iwsas2000.html and http://www.mit.bme.hu/events/iwsas2001/

24. C. Lomuscio. 1999. Information Sharing among Ideal Agents. Ph.D. Thesis. School of Computer Science, University of Birmingham.

25. S. Marsh 1992. and Reliance in Multi-Agent Systems: A Preliminary Report. In: **MAAMAW'92**, 4th European Workshop on Modeling Autonomous Agents in a Multi-Agent World, Rome.

26. S. Marsh 1994. Formalizing Trust as a Computational Concept. Ph.D Thesis, University of Stirling, April 1994.

27. P. Maes. 1991. The agent network architecture (ANA). **SIGART Bulletin**.

28. M. Miceli and C. Castelfranchi, 2000. The Role of Evaluation in Cognition and Social Interaction In: K. Dautenhahn (ed.), Human Cognition and Social Agent Technology **(pp. 225-261). Amsterdam: John Benjamins.**

29. J. Moffett and E. Lupu, 1999. The Uses of Role Hierarchies in Access Control. In 4th ACM Workshop on **Role Based Access Control (RBAC).** 1999, George Mason University, Fairfax, VA.

30. J. Mylopoulos, A. Borgida, M. Jarke, and M. Koubarakis. Telos: Representing knowledge about information systems. In **ACM Trans. on Information Systems**. vol. 8(4), 1990.

31. R. Nozik, 1993. **The Nature of Rationality**, Princeton Press.

32. M.V.N. Prasad, V.R. Lesser, and S.E. Lander. 1996. Learning organizational roles in a heterogeneous multi-agent system. In Adaptation, Coevolution and Learning in Multi-agent Systems: Papers from the 1996 AAAI Spring Symposium, pages 72--77, Menlo Park,CA, March 1996. AAAI Press. AAAI Technical Report SS-96-01.

33. M. Prietula, K. Carley, and L. Gasser, 1999. Introduction: A Computational Approach to Organizations and Organizing, In M. Prietula, K. Carley, and L. Gasser, editors, Simulating Organizations: Computational Models of Institutions and Groups. AAAI Press/MIT Press.

34. S.Y. Na and S.H. Cheon, 2000. Role delegation in role-based access control Proceedings of the fifth ACM workshop on **Role Based Access Control (RBAC)**, 2000, Berlin Germany.

35. J. Scott, 1991. Social Network Analysis: A Handbook. London: Sage Publications.

36. J. Sickman, R. Conte, Y. Demazeau, C. Castelfranchi. *A **social** reasoning mechanism based on **dependence** networks In: EUROPEAN CONFERENCE ON ARTIFICIAL INTELLIGENCE* (ECAI), 11, Amsterdam, Netherlands, 1994. Proceedings. p. 173-177.

37. V. Swarup, J.T. Fábrega, 1999. Trust: Benefits, Models, and Mechanisms. *Secure Internet Programming*, 3-18, Jan Vitek and Chistian Jensen (Eds), Springer Verlag.

38. Reid Smith, 1980. The contract net protocol: High-level communication and control in distributed problem solver, **IEEE Transactions on Computing**, Vol. C-29 1980, pp. 1104-1113.

39. R. Tuomela, 2000**. Cooperation: A Philosophical Study, Philosophical Studies Series,** Kluwer Academic Publishers.

40. Y. Xiang. 1996. A probabilistic framework for multi-agent distributed interpretation and optimization of communication. **Artificial Intelligence,** Vol.87, No.1-2, pp 295-342.

41. J. Yen, J. Yin, M. Miller, D. Xu, R. Volz, and T. Ioerger, 2001. CAST: Collaborative agents for silumating teamwork. In **IJCAI-2001**.

42. B. Yu, M. Venkatraman, and M.P. Singh, 2000. The MARS Adaptive Social Network for Information Access: Architecture and Experimental Results, In **Applied Artificial Intelligence**.

43. M. Wooldridge, 2000. **Reasoning about Rational Agents**, The MIT Press.