COMPUTATIONAL MODELING OF TEMPORARY DESIGN TEAMS

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Abstract. This paper presents a framework for a computational model of temporary design teams (TDTs). The framework is based on the situated Function-Behaviour-Structure (FBS) ontology, which is used to describe the different aspects of a TDT. This paper demonstrates how TDTs can be represented and reasoned about in terms of the FBS variables. A situated social agent's architecture is introduced. At the agent level the social attributes that are considered include agent's motivation, threshold point, attitude and beliefs. This agent is built on the idea of constructive memory. Constructive memory gives the situated agent the ability to adapt to the changing environment, which in this case is the team structure, team goals, and the other agents. This allows the framework to be used for studying the social aspects of changing team structures and team composition, which are characteristic of TDTs and the changing work culture that are facilitated by improved communication and IT tools. This research aims to lay the computational foundation for a means of studying temporary design team behaviour.

1. Introduction

Design is usually a team activity involving experts from different domains. This makes designing in a team different to designing as an individual. Since part of the knowledge and understanding of the goals and solutions is generated as the design progresses compatibility and constant interaction among the team members is essential for design development. This interaction and group dynamics are influenced by factors like organizational structure, interpersonal relationships, dependencies, and communication media. These factors change as design teams are increasingly becoming project-based, and hence temporary. In such teams members may come from different organizations, with different experiences and different social backgrounds, and it is possible that their ability to adapt to the changing team structure and work culture would be different. A framework representing TDTs must include the factors influencing team behaviour. The literature on group and collective behaviour in different domains such as organizational behaviour, sociology, psychology, and cognition suggest that these factors are interrelated and are a function of experience and time. The behaviour of the group and the individual not only changes the environment but is also influenced by the changing environmental conditions.

The framework presented in this paper includes some of these factors that may vary with team type, and aims to lay a foundation for studying team behaviour resulting from this increasing shift towards TDTs. The development of computational implementations where such frameworks as this can be modelled and simulated allows experimentation and evaluation of the framework, which in a real world environment may not be feasible. Since both design as well as the team are dynamic and influenced by experience and current environmental state, we adopt an agent-based situated stance (Gero 2003) in developing the framework. Team members are modelled as computational agents.

Three important aspects of a TDT that the framework models and that may vary with the team type are: team structure, social characteristics of agents, and the tools. Some typical variations along these are listed here:

1. Team structure: a) rigid or flexible with respect to organizational structure; b) closed or open in terms of team boundary.
2. Team composition: a) distribution of agents based on social characteristics such as attitude, motivation, and threshold point. Here, threshold point is the limit beyond which an agent's behaviour changes under the influence of some quantifiable external factors; b) varied experience across team types and existing social networks: agents from same parent team but re-grouped; agents from two or more parent teams in a collaborative project; and agents in a marketplace with no parent affiliation.
3. Use of various tools by the team that include: a) skill complementing tools that improve work quality and efficiency; b) information and communication tools that facilitate knowledge acquisition and communication.

The types of tools used by the team may influence different social factors like social network and trust relationships, and hence the group dynamics and social interaction within the team. Some evidence of this is provided in the literature (Nijstad 2003, Carley 1995, Schreiber and Carley 2004, 2003).

2. Related works

Team work and team building is a social process (Toye et al 1994, Cross and Clayburn Cross 1995) that develops over time (Tuckman 1965) as members gain experience working with each other. A team has its value only when members provide feedback and support to each other. Behavioural characteristics of high-performance teams include a high level of interaction with other team members (Dougherty 1992). As suggested by Klimoski and Mohammed (1994) and Cannon-Bowers et al (1993) members need to know about the interacting player's expertise, knowledge and competency. The amount of interaction and coordination depends on factors like intra-team communication, interpersonal relationships, and task dependency.

2.1. OTHER COMPUTATIONAL MODELS

Computational models relating to teams and organizations include VDT (Kunz et al 1998), ORGAHEAD (Carley and Svoboda 1996), and TAC Air Soar (Tambe et al 1997) that are significantly different in their objectives. The work on VDT (Kunz et al 1998) is focused on identifying the influence of organizational structure and information processing tools on team performance, assessed mainly from the perspective of project management. VDT involves modelling the processing time, work flow, and tool usage and does not include the social characteristics of the team members. ORGAHEAD (Carley and Svoboda 1996) is focused at developing theories relating to organizational design and organizational learning. ORGAHEAD's design is modular involving building blocks for task assignment, organizational structure (hierarchy or flat), communication tools, and so on. Unlike VDT, agents in ORGAHEAD can learn new skills, while agents in both VDT and ORGAHEAD do not communicate informally. TAC Air Soar (Tambe et al 1997) is focused at developing simulation environments and tools for facilitating real-time task coordination involving both human and artificial agents. Though the focus of the models is different, each of these models emphasizes the importance of coordination and communication for effective teamwork.

The proposed model incorporates social attributes in agents such that their effect on coordination and communication within the team can be studied, which in missing in these models.

3. Theoretical framework

The TDT model is built on the situated FBS framework developed by Gero and Kannengiesser (2002). Based on Gero and Kannengiesser (2004, 2006), the situated FBS framework is used for describing both the task and the team. The various aspects of a TDT are described using the FBS ontology.

The elements of a TDT are:

1. Agents
2. Organizational structure: a) formal- hierarchy, flat, core-periphery; b) informal- social network, social groups. Agents may form social groups based on neighbourhood, task similarity, beliefs, and so on (Laubacher and Malone 1997).
3. Infrastructure: a) information and communication tools such as knowledge sources like books, internet, and online databases, and communication media like email and telephone; b) skill complementary tools: this includes visual representation aids like graphic and CAD tools, basic analytical and editing aids like calculators, and organizers for memory aid like digital calendars.

   Other tools include process enhancing tools like copiers and scanners and advanced analytical and simulation tools. Some tools may fall under different categories with varying degree of conformity.
4. Formal structure: norms and conventions, bylaws, and policies. These correspond to the organizational structure, and may have different implications on the TDT behaviour. For example, if the team's policy promotes access and interaction for team members to their peer groups

outside the team it can be tested whether the team cohesion is different to that in a closed team that inhibits external interaction.

Behaviours corresponding to TDT structures:

1. Agent's behaviour, in terms of their competence (derived from expertise), willingness (derived from motivation), confidence (derived from attitude state), and persistence (derived from threshold point).
2. Behaviours corresponding to different organizational structure are: a) formal and legal structure: rigid or flexible (in terms of interaction); open or close (boundary conditions that determine if agents can interact with non-team members); b) informal structure: homogeneous or heterogeneous; closed or open (team boundary).
3. Behaviours corresponding to tools that form the infrastructure are: a) IT and communication tools: reach (one to one or one to many), accessibility (synchronous or asynchronous), dependence; b) skill complementary tools: efficiency, scaling (facilitate or constraint).

3.1. AGENT MODEL

Each agent has limited reasoning abilities. Agent's actions, behaviour and learning are governed by their experience and interactions. They are built on principles of situated cognition (Clancey 1997, Gero 2003) and constructive memory (Bartlett 1932, Schacter et al 1988, Gero 2003).

3.2. AGENT ARCHITECTURE

Agent's action is a response to the sensed data (as perceived by the agent) and depends on its experience, attitude, and threshold point, which determine agent's behaviour that can either be reflective, reactive or reflexive (Maher and Gero 2002). The behaviour type influences the inference process and hence the agents actions, Figure 1.

Agents' attitude is itself influenced by its motivation, while whether it reaches its threshold point at any given time or not depends on its recent experiences. Agents' threshold point has two different effects: a) agent's behaviour in group decision making, where its decision may be influenced by majority decision; b) agent's persistence with respect to multiple failures in the recent past. An agent's motivation relates to its bias for social networking. These biases are based on beliefs or expertise, and using these agents may seek homogeneity or diversity.

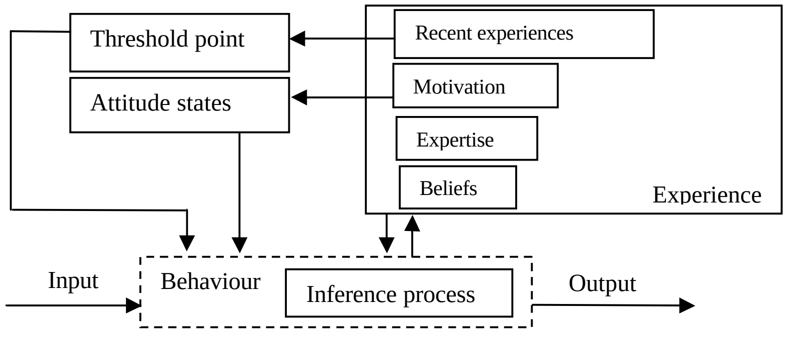

Figure 1. Architecture for a typical TDT social agent.

3.3. KNOWLEDGE REPRESENTATION AND MENTAL MODELS

Each agent constructs a mental model of other agents, Figure 2, which allows it to keep track of others' capabilities, knowledge and expertise. This helps maintaining the group capabilities. This is similar to the idea of transactive memory (Wegner 1986) and facilitates social cognition and social behaviour of the agents.

Agents develop mental models of groups and teams the same way as they build mental models of individual agents. Generalization is the process of hypothesizing expected FBS variables of an agent, for which observed data may not be sufficient, Figure 2. This allows agents to use their past experience with other agents to form expected mental model of an agent that it may not have enough information about.

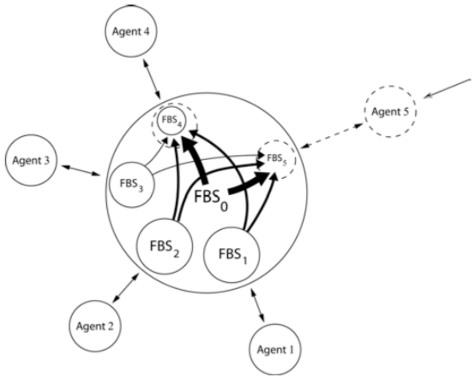

Figure 2. Agents build new and update old FBS models of other agents, besides generalizing based on others mental models (Gero and Kannengiesser 2004). Size of the circles represents how developed the FBS model of corresponding agent is. Further developed models contribute more to the generalisation, as denoted by arrow thickness.

3.4. AGENT'S ACTIONS

An agent can have one to one interactions with itself, another agent, a social group or with the team itself. As agents interact they update mental models of others based on the interpretation of others' actions, Figure 3. When this interaction is mediated through technological tools some actions are either facilitated or constrained by the tool, and their expertise in using those tools. Such factors may influence the social dynamics of the team.

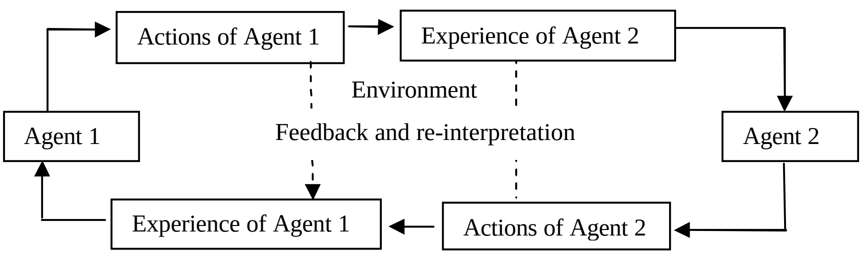

Figure 3. One agent's actions become sense data for other agents.

The influence of transactive memory in a team promotes existence of two types of data that Schreiber and Carley (2003) refer to as task data (possessed by the agent) and referential data (accessed by the agent from other sources). Referential data can come from other agents, tools, databases and other knowledge sources accessible to the team members. Confidence or trust in the referential data may vary depending on the source. For example, a technical report will generally be considered more trustworthy than a webpage.

3.5. REPRESENTING TDT

Only some of the agents in a given population are part of the TDT at any given time. This means that agents may have non-team members in their informal and social networks. This is shown in Figure 4.

A team can be formed out of an agent population (either by selection, competition or collaboration). Each TDT formed, will have its own organizational structure, infrastructure and regulations. Team 1 does not provide its member's connectivity to outside agents (either because of technical or physical limitations or regulations), while Team 2 allows its members to connect with and consult others outside the team. In such a scenario, a member who has been part of both the teams (agent shown as shaded circle in Figure 4) may perform better in the later case because there it has more options to obtain referential data and support.

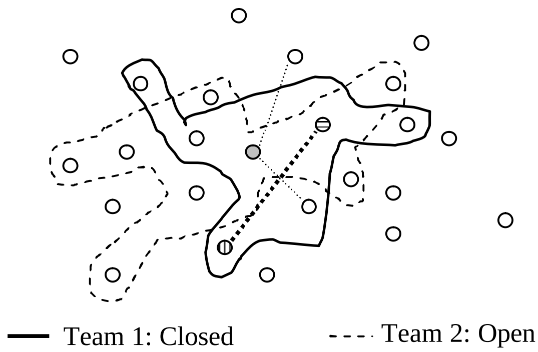

Figure 4. TDT as part of a larger agent population. The two bounded areas show two different TDTs formed at different times, and circles represent agents.

The TDT approach helps agents to build new contacts, meet new agents, who may then go on to be part of the agent's network. In Figure 4 the two agents (hatched fill) interact as part of being the members of Team 1. This interaction allows agents to know about each others expertise and know-how, which they can benefit from even after the team ceases to exist. For example, the hatched fill agent from Team 2 can contact the other hatched fill agent for information and support. The motivation for maintaining or developing a network between two agents may be different.

4. Research approach

A framework of TDT has been developed based on FBS ontololgy and includes social attributes in agents. Structures of an entity have a casual effect on its behaviour. An FBS representation facilitates identification of the structures that typically change across different TDTs and agents. These structures are the control parameters for the experiments. There are parameters at agent level as well as team level. By varying the agent level parameters like agents social characteristics we can study the emergent team behaviour resulting from interaction among the agents. By varying team parameters like team infrastructure we can study the influence of the other environmental conditions in a team that influence social behaviour within TDTs. By varying multiple parameters at the same time we can also study whether superposition of such parameters is applicable or not.

4.1. EXPERIMENT DESIGN

The experiments have been designed to study the emergent social behaviour in a TDT with situated agents. For example, we can compare the social network of two agents starting with the same experience and network but with different motivations. Similarly, in another experiment we can compare the networking patterns and intra-team cohesion between open and closed TDTs with the same agents.

To establish the benefits of using situated agents for studying social behaviour in TDTs we will compare results from these experiments with results from similar experiments with TDTs with non-situated agents.

5. Conclusion

The framework demonstrates how a temporary design team can be represented in terms of the Function-Behaviour-Structure ontology of an agent and how it represents other members of the team. The main structures in a team are the agents, organizational structure, team infrastructure, and legal structure. Variations in these structures result in different team behaviours. It is suggested that in the case of temporary design teams the structures in the team are likely to vary across the different team types. The situated social agents may vary in their social characteristics namely attitude, motivation, threshold point and beliefs. Similarly, organization structure and associated norms and policies may either be rigid or flexible with respect to intra team interaction, closed or open to participation and involvement of non-team members. Technological tools include IT and communication tools, and skill complementary tools, and teams may vary in their tool availability and usage, which may influence the team behaviour. The framework lays a foundation for building a computational model of temporary design teams, which will be used to conduct experiments to study the influence of team composition, organizational structure, and tool usage on team behaviour.

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References

Bartlett, FC: 1932 (reprint 1964), *Remembering, A Study in Experimental and Social Psychology*, Cambridge University Press, Cambridge.

Carley, K: 1995, Communication technologies and their effect on cultural homogeneity, consensus, and the diffusion of new ideas, *Sociological Perspectives* **38** (4): 547-571.

Carley, KM and Svoboda, DM: 1996, Modeling organizational adaptation as a simulated annealing process, *Sociological Method and Research* **25** (1): 138-168.

Cannon-Bowers, JA, Salas, E and Converse, S: 1993, Shared mental models in expert team decision making *in* Castellan, J Jr. (ed.), *Current issues in individual and group decision making*, Hillsdale, NJ, Erlbaum, pp 221-246.

Clancey, WJ: 1997, *Situated Cognition, On Human Knowledge and Computer Representations*, Cambridge University Press, Cambridge, pp.1-75.

Cross, N and Clayburn Cross, A: 1995, Observations of teamwork and social processes in design, *Design Studies* **16**: 143-170.

Gero, JS and Kannengiesser, U: 2002, The situated function-behavior-structure framework, *in* JS Gero (ed.), *Artificial Intelligence in Design'02*, Kluwer, Dordrecht; pp. 89-104.

Gero, JS: 2003, Situated computing: A new paradigm for design computing, *in* S Hayman (ed), *Proceedings of the 37th ANZAScA*, University of Sydney, pp. 315-323.

Gero, JS and Kannengiesser, U: 2004, Team expertise from individual expertise (through social interactions in computational agents), *in* Cross, N and Edmonds, E (eds), *Expertise in Design*, University of Technology Sydney, Sydney, pp. 311-322.

Gero, JS and Kannengiesser, U: 2006, An ontology of situated teams, URL: http://www.arch.usyd.edu.au/%7Ejohn/publications/2006/06GeroKannengiesserTeams.pdf, accessed on 20/05/06.

Klimoski, R, and Mohammed, S: 1994, Team mental model: Construct or metaphor? *Journal of Management* **20**: 403-437.

Kunz, JC, Levitt, RE and Jin, Y: 1998, The virtual design team, a computational model of project organizations, *Communications of the Association for Computing Machinery* **41** (11): 84-92.

Laubacher and Malone: 1997, Flexible work arrangements and 21st century worker's guilds, Initiative on Inventing the Organizations of the 21st Century, Working Paper #004, http://ccs.mit.edu/21C/21CWP004.html, Accessed on 26/06/06.

Maher, ML and Gero, JS: 2002, Agent models of 3D virtual worlds, *ACADIA 2002 Thresholds*, California State Polytechnic University, Pomona, pp 127-138.

Nijstad, BA, Stroebe, W and Lodewijkx, HFM: 2003, Production blocking and idea generation, does blocking interfere with cognitive processes? *Journal of Experimental Social Psychology* **39**: 531-548.

Schacter, DL, Norman, KA and Koutstaal W: 1998, The cognitive neuroscience of constructive memory, *Annual Review of Psychology* **49**: 289-318.

Schreiber, C and Carley, KM: 2004, Going beyond the data: Empirical validation leading to grounded theory. *Computational and Mathematical Organization Theory*, 10(**2**): 155-164.

Schreiber, and Carley, K: 2003, The impact of databases on knowledge transfer, simulation providing theory, *NAACSOS Conference Proceedings*, Pittsburgh, PA.

Tambe, M: 1997, Agent architectures for flexible, practical teamwork, *in Proceeding of the AAAI American Association of Artificial Intelligence*, Providence, Rhode Island, AAAI Press, 22-28.

Toye, G, Cutkosky, M, Leifer, L, Tenenbaum, M, & Glicksman, J: 1994, SHARE, A methodology and environment for collaborative product development, *International Journal of Intelligent and Cooperative Information Systems* **3** (2): 129-153.

Tuckman, B: 1965, Developmental sequence in small groups. *Psychological Bulletin* **63**: 384-399.

Wegner, DM: 1986, Transactive memory, a contemporary analysis of the group mind, *in* Mullen, B and Goethals, GR (eds), *Theories of Group Behavior*, New York, Springer-Verlag, pp. 185-205.