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# Ad-hoc online teams as complex systems: agents that cater for team interaction rules

R. A. Kildare

*School of Computing, University of Tasmania*
*Launceston, Tasmania, Australia*
Email: Robert.Kildare@utas.edu.au

**Abstract**

This paper justifies the treatment of ad-hoc online teams as complex systems. Scenarios exist where collaborative asynchronous processes are necessary to solve a particular problem. These processes are both task related and team related. They have been one focus of Computer Supported Collaborative Learning (CSCL), Computer Supported Collaborative Work (CSCW), and socio-psychological investigations into team behaviours and outcomes. Difficulties with the predictability of teams arise because they are complex systems. Software support for enabling teams to establish rules can allow for emergence and also capture expertise (patterns) in a given context. This software can act as an educational tool through the active participation of team members and the application of their rules.

## 1. Introduction

This paper considers leaderless, ad-hoc online teams as an example of a complex system and proposes the creation of a software moderator to support these teams.

Online collaboration between individuals, in order to complete a specific task or to solve a specific problem, is becoming a common occurrence. It often tends to be between professionals who are considered independent. Examples include a number of supervisors combining to oversee a postgraduate student, medical, nursing and paramedical practitioners collaborating for community or client needs and the remote development of software by experts. Consider also students at all educational levels, involved in collaborative learning activities, both formally and informally, with and without instructors or intelligent support, and with varying degrees of face-to-face contact. These ad-hoc, asynchronous, online collaborations take advantage of being able to overcome time zone and scheduling problems.

The software moderator, it is hypothesised, will provide support for the team by enabling the team to create, use and review rules for team interaction, thus educating the users about the nature of effective team interactions as well as supporting the actual operation of the team itself.

Software support is readily available for business teams. Computer support for collaborative learning has also been an expanding field. Both of these areas have focused predominantly on task or goal support and not on supporting team processes. In the case of the often transient, asynchronous, ad-hoc teams addressed by this paper, support for the well-being of the team is arguably more important than providing clever tools for the task. Major risks, including freeloading and domination, threaten team existence. Having team members learn about team processes can be considered an end in itself, particularly for those about to enter a world of loosely coupled cyber-collaboration.

In order to understand how to support these loosely coupled teams and evaluate the effectiveness of the support, understanding of team behaviour is necessary. Substantial literature exists on organisations as complex systems (Marion and Bacon, 2000, Ng, 2003) and a significant history of research exists on emergent co-operation (Schweitzer et al., 2002). The literature implies that teams should be considered complex systems and team processes considered as emergent patterns. Much team theory can be reinterpreted in terms of the characteristics of complex systems. The lack of predictability of a complex system must somehow be accommodated by the software.

The transient nature of these teams and the variety of contexts in which they occur suggest that expertise in running the teams will be rare. It is perhaps possible to provide a software agent to aggregate interaction rules developed by multiple previous teams, prioritise the rule set and provide suggestions to a particular team as to which rules work best in their situation.

Before expanding on these arguments and introducing architecture for the moderator and expert agents, a definitional issue must be addressed. Do the ad-hoc collaborations for which the software is designed constitute teams? Both traditional team studies and more recent cross–system analysis (comparing definitions from the fields of insect behaviour, robotics theory and human team studies) concur.

> *A team is two or more individuals with specific (although not fixed) role assignments who must perform specific tasks and must interact or coordinate to achieve a common goal or outcome. The efforts of the team must amount to more than the sum of their parts.*
>
> *(Anderson and Franks, 2004, Baker and Salas, 1997)*

The collaborations targeted by this paper fulfil this definition's requirements of size, role assignment and specific purpose. If there is any advantage in terms of efficiency, in overcoming lack of ability, improving fault tolerance, or if it is cheaper to use a team of single taskers than pay for a multitasking individual, then the efforts of the team amount to more than the sum of their parts.(Anderson and Franks, 2004). It will be difficult to find a group that does not provide any of these benefits.

The following sections describe team research from a socio-psychological perspective and view the team as a complex and thus unpredictable complex system. The software available for supporting online teams is described, providing a context in which to view a software design for the support of unpredictable team interaction policies.

## 2. Features of Teams and Team Performance

Team behaviour has been studied for some time with a view to understanding processes and outcomes. The edited book Brannick, et al, provides a comprehensive summary of the literature, the main branches of study and methods of evaluation (Brannick et al., 1997). Time, Interaction and Performance (TIP) theory attempts to explain group behaviour in the real world rather than a laboratory setting (McGrath, 1991). TIP theory is often cited and has been used recently in computerised team support work by Reimann (2003).

Teams can be classified into types according to the degree of interdependence required of its members (Anderson and Franks, 2004, Tesluck et al., 1997).

Teams have modes of operation between which they will switch non-sequentially. TIP theory identifies these phases as inception (or goal choice), problem solving (technical or means choices), resolution of conflict (policy choice) and execution (goal attainment). McGrath argues that these four modes can be seen in the three basic functions of the group – production, maintaining group well-being and providing member support (McGrath, 1991).

Team processes are regarded as being either task related or team related or both task and team related. Typical team processes include monitoring progress, backing up team members, and giving personal feedback. These are processes that satisfy needs and wants of the group as an entity. Task specific processes might be editing a common file or building a model. These processes are dictated by the nature of the task. Building a model for another team member would be a process belonging to both team and task sets (Baker and Salas, 1997).

When evaluating performance outcomes, research usually focuses on task outcomes. These include how well the concept was learnt, the problem solved, how efficiently the task was performed or what subtasks could be performed better. However, team outcomes such as shared models of team interactions, and an understanding of the team's well being do exist (Baker and Salas, 1997, MacMillan et al., 2002, Reimann, 2003). They tend not to get the same attention as outcomes which can be construed as commodities.

Time is an issue as teams mature. Members learn as they interact, becoming more efficient and altering communications both qualitatively and quantitatively (Brannick and Prince, 1997).

Toquam identifies four sources of variability that provide control problems when evaluating team performances:

- Member Characteristics – features of the individuals such as dexterity and cognitive skills
- Team Characteristics – features unique to the team such as cohesion, homogeneity, length of shared history and communications structures)
- Task Characteristics – features related to the problem to be solved, such as difficulty and complexity
- External Conditions Imposed on the Team

(Toquam et al., 1997)

# 3. Teams as Complex Systems

While teams themselves have been seen as the consequence of complex behaviour – life forms dependent on their neighbours - the processes within teams receive most attention from disciplines outside the complex systems field. Many of the features mentioned above can be reinterpreted in terms of complex systems.

Concepts of co-evolution have been part of complexity studies since the early days of its inception, with simulations such as Conway's Game of Life and Brian Arthur's analyses of trading partners. Issues of co-operation as found in the Prisoner's Dilemma problem have also come under much scrutiny. (Waldrop, 1992) More recently attempts to model the nature of symbiosis, competition and the predator-prey relationship have been undertaken (Lopez-Ruiz and Fournier-Prunaret, 2004) and an interesting 5-person team spatial simulation of the Prisoners' Dilemma has been created. (Schweitzer et al., 2002) A team of two or more, shares similarities with a symbiotic arrangement between species – with granularity closer to a mini-ecosystem as the numbers of the team grow. As with a trading bloc, or a symbiotic relationship, there has to be some payoff for the participants. Sufficient payoff causes a phase of instability. If the feedback is not too large, new patterns emerge. Trading partners, while they don't necessarily multiply, do change the patterns of resource use and productivity in response to positive feedback. Old forms of productive behaviour are destroyed and new patterns emerge (such as new employment, infrastructure and resource usage patterns). These incorporate a variety of different relations with the trading partner(s). Trade agreements formalise the relationships between the parties. Throughout the process of emergence, at the edge of chaos, there is uncertainty as to what patterns will emerge or whether the old patterns will dissolve altogether into chaos. Similarly the processes between and within team members are potentially volatile and unpredictable. The software proposed is intended to implement team interaction rules that are analogous to trade agreements and as such needs to accommodate unpredictability.

Toquam found that team performance could not be linearly predicted when changing task characteristics.(Toquam et al., 1997) Choosing any of the other major internal variables as predictor is likely to have the same effect. One would expect that changes in team characteristics, such as a new member arriving would influence individual members in different ways. This would have a non-linear effect on team performance. Considering team maturity will further complicate the relationship.

The third internal variable identified by Toquam is the characteristic set of the individual team member. What goes on in the mind of the individual mediates changes to both task and team characteristics before being translated into team performance. McCrone summarises the current state of understanding of neurology, memory and learning. Neurones are seen as a highly complex system of weighted pathways and interconnections which are activated, refreshed and reorganised according to the experiences of the individual. Included in this summary are findings that suggest mechanisms for why memories change and how learning occurs. What goes in and what comes out of an individual member as a result cannot be predicted, as the human CPU changes with input. (McCrone, 2003)

Externally, the team is part of a complex system of coarser granularity. A change of communication medium for the team (change of available resource), or a team member winning the lottery (change of feedback regime) can readily impact on team performance, but the effect is not predictable.

Teams possess the characteristics of non-linearity and unpredictability that typify complex systems. Teams also move through phases that vary with the feedback that they receive. While this paper does not seek to quantify feedback levels to strengthen the view that teams are complex systems, it is possible to identify the feedback from a sociological perspective.

McGrath defines the well-being function as "activities that have to do with development and maintenance of the group as a system; hence they reflect relations among group members." He defines the member support function as "the ways in which the individual is embedded within the group; hence they reflect relations between individual members and the group" (McGrath, 1991). His analytical framework (see Table 1.) breaks down as they are mutually dependent. The "embedding" of the individual is dependent upon the well-being of the group and the group is dependent upon the relations between individuals. The point at which McGrath's two functions cease to be mutually exclusive is when the group is dealing with policy and conflict resolution – assertions of power and allocations of "payoff". The understanding of the patterns of this system lies outside the boundaries of McGrath's analysis and are likely, ultimately, to be evolutionary.

McGrath proposes four phases or "modes" (see Table 1.).The first and last modes can be considered as phases of stability – the former, setting up the group, can be regarded as the outcome of some external complex system. The final mode is the mature state of the group where little change occurs to processes. It will produce output that is of value to the external system that enabled the team to form.

*Table 1. McGrath's analytical framework for team performance. (McGrath 1991)*

| **MODES** | **FUNCTIONS** | | |
|---|---|---|---|
| | **Production** | **Well-Being** | **Member Support** |
| Mode I. Inception | Production Demand/ Opportunity | Interaction Demand/ Opportunity | Inclusion Demand/Opportunity |
| Mode II. Problem Solving | Technical Problem Solving | Role Network Definition | Position/ Status Attainments |
| Mode III. Conflict Resolution | Policy Conflict Resolution | Power/ Payoff Distribution | Contribution/ Payoff relationships |
| Mode IV. Execution | Performance | Interaction | Participation |

Two modes are identified which encapsulate the active formation of both the team and the task processes - the "problem solving mode" and the "conflict resolution mode". Teams continually switch between these modes. McGrath identifies the functions that the team performs for both the team and the members when in this state of process building. McGrath's framework is in harmony with the Group Closure theory of Max Weber and uses similar terms: "power/payoff distribution", "position/status attainment", "contribution/payoff relationship". Weber explained the motives for nations, communities, groups and associations to form as the desire for wealth, power and status (Abukuma, 2003, Andreski, 1964).Wealth and status need to be treated carefully as they can include learning (acquiring knowledge which may or may not be a tradable commodity) and honour (self esteem that may or may not be public esteem). The phase of generating emergent processes (two of McGrath's "modes") is specifically to permit the acquisition and distribution of feedback in terms of wealth, power and status.

Sufficient feedback is needed to launch a team from inception into performance. If too much of the feedback is available to the members from other external sources, the team would disintegrate because there is no longer any symbiotic advantage. McGrath's "policy" structures constrain competitive behaviours such as dominance and freeloading. These behaviours are considered to be intimately related to the co-operative forces studied in the Prisoner's Dilemma and its application to public policy. (Ostrom, 1990) The software proposed in this paper is intended to capture these constraining structures as symbolic rules.

Research into teams has found difficulty in finding variables that reliably predict team performance. Teams can also be considered to have phases where emergent processes are triggered by feedback from the environment. If teams are complex systems, it is hypothesised that structures for managing team behaviour will emerge that are intended to manage the distribution of rewards, power and status and that given the complexity of their origins; these structures will vary from team to team and context to context.

# 4. Software Support for Online Teams

While software support for the problem solving or task-based processes of online teams is becoming more commonplace, there is little support for the team focussed processes. A quick search for 'groupware' will provide many sources of schedulers, chat and video conference channels, Gantt charts and project managers (PHPROJEKT, 2004). Emerging from the discipline of CSCW, some work has been done by Group Systems.com in creating "Active Methods" for business teams. These are templates of processes that the team must follow for a specific business activity. The team leader is supposed to choose the active method and will be able to create an active method if necessary (GroupSystems, 2004). There are a number of reasons why this software will not suit the ad-hoc online team scenario. Firstly the software is specific to business processes and insufficiently general to cater for the variety of ad-hoc teams that emerge in a non-corporate environment. Secondly, the participants in these ad-hoc teams are loosely coupled – more like Weber's associations than "closed" business teams. Leadership may emerge, but is likely to be transient and distributed. "Active Methods" are not designed to accommodate emergence, instead relying on the experts in corporate online team work (as designers and team leaders) to efficiently define the patterns to be used. They can, however, be used in both synchronous and asynchronous scenarios. Finally, the 'Cognito' package will not operate in a dialup environment.

The CSCL discipline has a number of contributions to make – particularly in the realm of teaching the task. The COLLIDE research team has considerable infrastructure for supporting distributed collaborative learning. One tool for facilitating task processes is COOL MODES a modelling tool that allows the team to build a shared directed graph with labelled edges (Pinkwart and Herrmann, 2003). This can be used for describing knowledge, task structures, activity flow charts and so on. While face-to-face, synchronous teams have shared mental models, sharing online requires that these models be concrete. Another form of collaborative support is the use of intelligent agents to fulfil various functions for individuals in a team.(Cao and Greer, 2003, Shimoda et al., 1999) Support for team processes rather than task processes are not so easy to find. Reimann provided motivation monitoring and member contribution behaviours as feedback. This graphical "interaction history" provided well-being support for the team, without constraining the way in which the information could be used. He also included a "design history" which charted the task-based problem-solving history of the team. The experiment was applied in an educational scenario and both forms of feedback were found to have a positive effect on the group's production and well-being functions (referring to McGrath's TIP theory group "functions"). Better solutions and more task contributions were accompanied by enhanced motivation for the task and positive attitudes towards the curriculum (Reimann, 2003).

While software support for teams need not be specifically for educational purposes, the learning implications of mirroring should not be overlooked. The experts in business team processes exist and can teach fellow team members by example. In the more loosely coupled, ad-hoc scenarios there is no expert. There is no leader or moderator to deal with potential conflicts. There is no clear policy that will suit the shifting set of individuals and the shifting set of tasks in a shifting environment. Shared mental models of team policies need to be formalised in an online situation. Software needs to be able to gather and record team rules.

Ostrom's work in social dilemma theory is instructive. It begins with the prisoner's dilemma and extends to analysing successful social systems that maximise returns on common assets. Dilemmas in the implementation of policy stem very much from institutions that apply simplistic models to complex systems. Those approaches to policy that have been successful were allowed to emerge over time and were generated by the group of individuals that must co-operate to share in the "payoff" without destroying the resource.

> *"Instead of presuming that the individuals sharing a commons are inevitably caught in a trap from which they cannot escape, I argue that the capacity for individuals to extricate themselves from various types of dilemma situations varies from situation to situation." (Ostrom, 1990)*

Ostrom found that the most successful communities required a system to monitor and sanction members' behaviour, but carried out by the members themselves rather than an external body. The democratic ability to set and review interaction rules is important to the well-being of the team.

While "governing a commons" is several orders of magnitude beyond creating and sharing the assets of an ad-hoc online group, the notion of emergence is the same. Policy must be allowed to emerge as it is not predictable. This implies that policy is not fixed - that it can be reviewed and changed. The process of discovery through the mirroring and editing (of policy rules) is a commonly accepted educational practice based on constructivist learning theory used in much educational software (Jermann et al., 2001) including the work of Reimann. Software that can gather rules from team members, implement the rules and permit revision will not only support the team by taking on the role of leader in an emergent situation, but will also act as an educational tool.

Multiple teams working in the same context may derive common rules, and certainly some rules that work better than others. Creating a separate module or agent that monitors the rule sets of the teams' moderators will produce an expert in policy rules for a particular context. The advantage of having such a set is that it can be used as a starting point for new teams. They can still change their rule set, but will not have to reinvent the wheel.

# 5. Hypotheses

If teams are complex systems, it is hypothesised that policy rules for managing team processes will emerge and that, given the complexity of their origins, these structures will vary from team to team and context to context. It is further hypothesised that if the members of the team are permitted to create and modify these structures, active learning about team dynamics will take place. Finally, it may be possible to create a software agent with expertise in the team processes appropriate for a given context.

# 6. Architecture for Team Moderator Agents

An architecture is now proposed for a programmable moderator that will capture emergent rules of team interaction, implement the rules and permit their change. It will provide an expert capable of evaluating and informing the rules of each moderator.

Central to the capturing of emergent rules is the limitation of emergence set by the computational environment. Just what rules can be created will depend upon what the system can perceive. One cannot make a rule about lateness if time is not monitored, for example. The more data that is monitored the greater the potential for rule variety – and the greater the chance of confusion for the participants. In keeping with the behaviour of complex systems, it is anticipated that an expert set of rules will emerge from the system, given sufficient time and incentive for the participants.

## *6.1. Rule format*

This design will use the If Conditions Then Consequences symbolic rule format of traditional expert systems primarily because the rules will need to be created by and intelligible to people. The software provides the underlying structures, while the participants are free to express their meaning by choosing language to represent these structures. The system will be concerned with the truth and falsehood of attribute values and operations performed on these. The users will be concerned with the implications for the well-being of themselves and the team. Degrees of punctuality can be rewarded or punished, lateness of some tasks may be tolerated and others not. The user interface is crucial for successful rule creation and will need to be carefully designed to minimise confusion.

In keeping with the principles of genetic mutation and evolution, rules should be able to be selected by participants as conditions for new rules. Derived rules will allow changes to large chunks of meaning without having to start from the primordial soup each time. The fitness of rules will be up to the team to decide – as they will have the power to delete or modify those that perform unsatisfactorily. This applies particularly to a rule that fires frequently – it can be catching a circumstance in the team that is intended or it may simply be a poorly constructed rule. Further generalisation of fitness will be carried out by the context expert agent.

To allow for the fact that rules need to be re-evaluated there needs to be some process for deciding whether a rule has correctly captured the circumstance for which it was designed. Because this is a key part of the learning process that the moderator is intended to encourage, forcing serious and conscious thought about each rule will help the user to construct their knowledge. The Multiple Classification Ripple Down Rules (MCRDR) approach (Kang et al., 1995) asks “Does this particular rule fit your circumstances? If not why not?” The user is expected to introduce an attribute (a condition) that the rule does not cover, or identify an attribute that does not need to be covered. The system responds by choosing the best alternative from the selection of the rules at its disposal. When alternatives are exhausted a new rule can be created.

A tool for collaboration is described in association with the moderator and evaluator agents (Figure 1). The features of the tool are important architecturally in that they will provide the data from which rules can be created.

## *6.2. Client*

The client in this architecture provides access to written communications between team members. The member’s identifier and the date are stored, as is the recipient. Communication templates are provided according to the type of communication chosen, allowing simplified content element analysis. This avoids the problems associated with raw text semantic analysis. Having the user describe the type of communication may be sufficient for initial attempts at setting up rules. (Reimann, 2003)

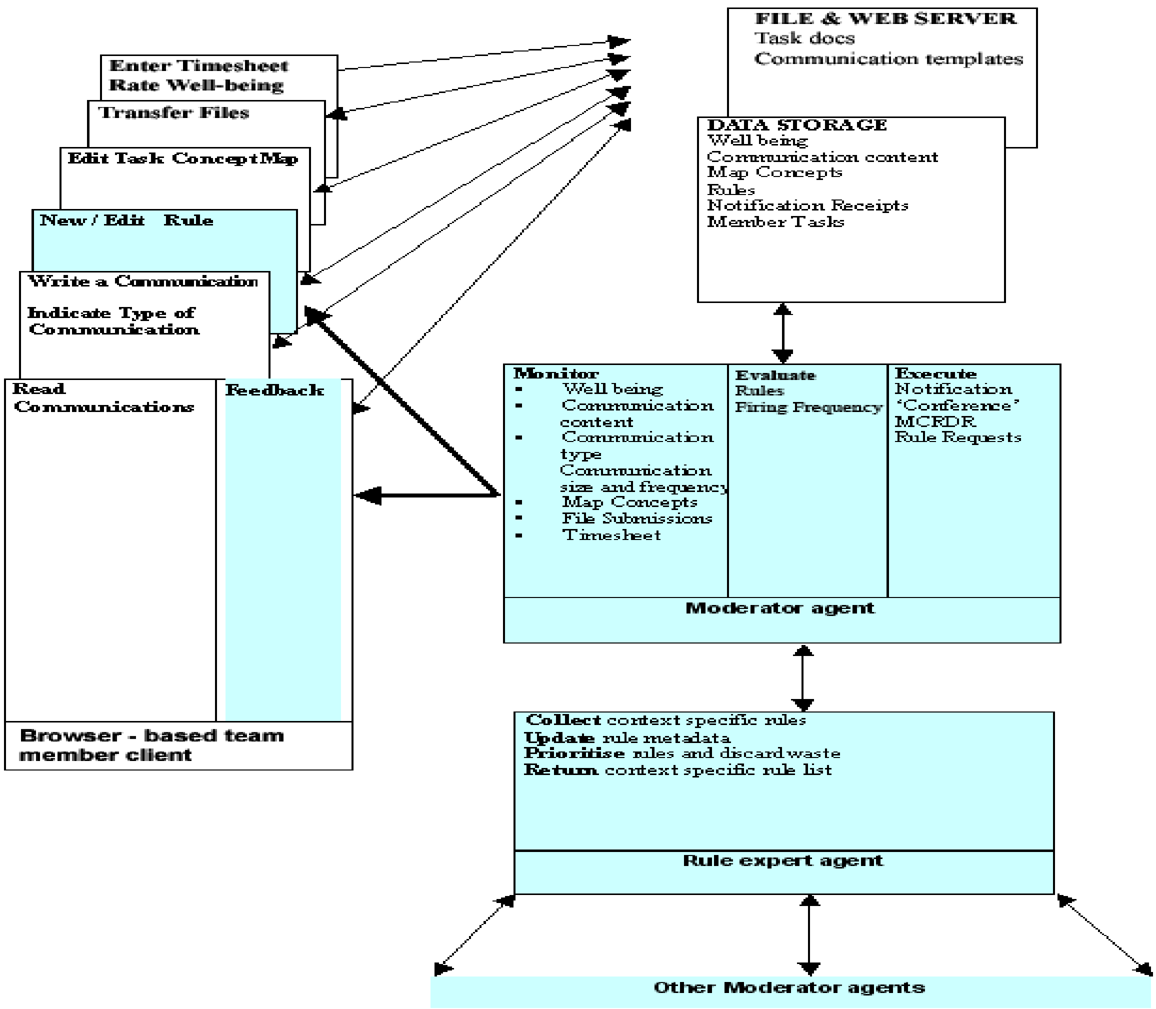


*Figure 1. Architecture for task-based, asynchronous collaboration including moderator and rule expert agents. Arrows indicate directed message passing.*

Following the work of the COLLIDE researchers, the ability to create and edit directed edge-labelled graphs is included. User and timestamp attributes for each node and edge could be used to create rules. A Gantt chart may also be a useful collective representation of the timetabling of subtasks.

File transfer facilities are suggested so that electronic team resources and outputs can be collected. Version control will create issues for consideration. User and timestamp logs can be searched and thus rules based on down and upload can be created.

A timesheet is envisaged as useful, at least for experimental purposes. The ongoing motivation survey feedback used by Reimann can also be implemented as part of the support for team well-being.

The rule creation interface will provide a drop-down list of primitives and operations for creating the array of attribute-value pairs that make up the conditions of a rule. Established rules can be used as derived conditions – having possible values of true or false. The team's rule set should be displayed with an indication of firing frequency. Consequences of firing will appear in the main view of the client.

The team's moderator agent will be able to access the storage facilities and return feedback to the main view of the client, updated at the time of client login. The moderator will also feed both current rules and expert suggestions back to the rule creation interface.

### *6.3. Data storage*

Given that there is no need to store procedures, and that current relational databases can save records and views of attribute values securely, an account for each team can be created in a standard RDBMS and accessed by the team member's client and the team's moderator agent. The agent can evaluate the rule base independently of client interaction and update the database where necessary.

### *6.4. Moderator Agent*

The moderator agent will be required to read database values whenever there is a change. The rule set used by the group will specify which values to read. If a rule fires. this needs to be noted. A frequency field for the rule in the database is incremented. The consequence of that rule must then be executed, involving feedback to the client.

In addition to executing rule consequences, the moderator may be requested to edit the rule set. This will involve the option of invoking an MCRDR process. The user will be asked to review the rules that exist and specify a new rule if necessary. Lastly the moderator must be able to satisfy a request by the expert agent for the rule data and should be able to accept a list of suggested rules in return.

### *6.5. Expert agent*

The expert agent will request rules from moderator agents operating in a given context when notified of a change to that moderator's rule set. From the collection of rules it will identify similarities between rules and attempt to data mine for those rules that are most likely to be useful. The rules can be prioritised by adding weighting metadata in the classification process and the ordered expert set returned to the moderator.

## 7. Conclusion

Understanding leaderless ad-hoc online teams to be complex systems informs the design of software intended to support their collaboration. Performance of these teams is unpredictable. Policy rules are necessary to manage the acquisition and distribution of feedback. A moderator has been proposed to facilitate the democratic creation of policy rules for the team as a means of stabilising a loosely coupled entity.

Will the moderator be a useful learning tool for immature teams? Before and after studies evaluating individual understanding of team processes would use traditional pre-test / post-test methodology in combination with qualitative survey. Increases in team maturity are likely to be reflected in reduced need for communications (Kraiger and Wenzel, 1997). This could be confirmed. The question of whether team maturity correlates with individual learning could also be explored.

Will this software support for leaderless teams assist in optimizing task performance? Task experts can evaluate the efficiency (value / time) performance of teams with and without the software support.

Is it legitimate to consider ad-hoc online teams as complex systems? Examination of patterns of change of rule sets for each team will inform understanding of whether ad-hoc online teams behave as complex systems. Further information can be gained by examining the diversity of expert rule sets when the software is used in different contexts.

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## References

Abukuma, M. (2003) Weberian Sociology of Religion. Max Weber's Texts: Sociology of Community, http://www.ne.jp/asahi/moriyuki/abukuma/weber/society/soci_comm/index.htm

Anderson, C. and Franks, N. R. (2004) Teamwork in Animals, Robots and Humans, Advances in the Study of Behaviour, 33**,** pp 1-48.

Andreski, S. (1964) Method and Substantive Theory in Max Weber, British Journal of Sociology, 1**,** 1-18.

Baker, D. P. and Salas, E. (1997) Principles for Measuring Teamwork: A Summary Look Toward the Future. in Team Performance Assessment and Measurement: Theory, Methods and Applications, (Eds) Brannick, M. T., Salas, E. and Prince, C.(Eds), Lawrence Ehrlbaum Associates, New Jersey, pp. 331-355.

Brannick, M. T. and Prince, C. (1997) Overview of Team Performance Measurement in Team Performance Assessment and Measurement: Theory, Methods and Applications, (Eds) Brannick, M. T., Salas, E. and Prince, C.(Eds), Lawrence Ehrlbaum Associates, New Jersey, pp. 3-16.

Brannick, M. T., Salas, E. and Prince, C. (Eds.) (1997) *Team Performance Assessment and Measurement: Methods and Applications,* Lawrence Ehrlbaum Associates, New Jersey.

Cao, Y. and Greer, J. (2003) Agent Programmability in a Multi-Agent Learning Environment, Artificial Intelligence in Education, (Eds) Hoppe, U., Verdejo, F. and Kay, J.(Eds), IOS Press, Sydney

GroupSystems (2004) Cognito Teamwork ActiveMethod, http://www.groupsystems.com/products/teamwork.htm

Jermann, P., Soller, A., Muehlenbrock, M. and Monés, A. M. (2001) From Mirroring to Guiding: A Review of State of the Art Technology for Supporting Collaborative Learning,Maastricht The Netherlands

Kang, B., Compton, P. and Preston, P. (1995) Multiple Classification Ripple Down Rules: Evaluation and Possibilities, Proceedings of the 9th AAAI-Sponsored Banff Knowledge Acquisition for Knowledge-Based Systems Workshop, (Eds) Gaines, B. and Musen, M.(Eds), Banff, Canada

Kraiger, K. and Wenzel, L. H. (1997) Conceptual Development and Empirical Evaluation of Measures of Shared Mental Models as Indicators of Team Effectiveness. in Team Performance Assessment and Measurement: Theory, Methods and Applications, (Eds) Brannick, M. T., Salas, E. and Prince, C.(Eds), Lawrence Ehrlbaum Associates, New Jersey, pp. 63-84.

Lopez-Ruiz, R. and Fournier-Prunaret, D. (2004) Three Logistic Models for the Two-Species Interactions: Symbiosis, Predator-Prey and Competition, Los Alamos Reprint Archives, Non-Linear Sciences, http://xxx.lanl.gov/PS_cache/nlin/pdf/0406/0406020.pdf

MacMillan, J., Paley, M. J., Entin, E. B. and Entin, E. E. (2002) Questionnaires for Distributed Assessment of Team Mutual Awareness in Handbook of Human Factors and Ergonomics Methods., (Eds) Stanton, N., Eduardo, S., Hendrick, H. W., Hedge, A. and Brookhuis, K.(Eds), Taylor & Francis Group.

Marion, R. and Bacon, J. (2000) Organizational Extinction and Complex Systems, Emergence, 1**,** 71-96.

McCrone, J. (2003) Not So Total Recall In *New Scientist*, Vol. 178, 3rd May 2003, pp. 26-29.

McGrath, J. E. (1991) Time Interaction and Performance (TIP). A Theory of Groups., Small Group Research, 22**,** pp147-174.

Ng, D. (2003) Social Structure of Organisational Change and Performance, Emergence, 5**,** 99-119.

Ostrom, E. (1990) *Governing the Commons. The evolution of institutions for collective action,* Cambridge University Press, New York.

PHPROJEKT (2004) PHProjekt **-** and open source groupware suite, http://www.phprojekt.com/

Pinkwart, N. and Herrmann, K. (2003) Checking Conditions for Graph Based Collaborative Modeling Systems, Supplementary Proceedings AIED2003, (Eds) Aleven, V., Hoppe, U., Kay, J., Mizogucci, R., Pain, H., Verdejo, F. and Yacef, K.(Eds), SIT, Sydney Australia

Reimann, P. (2003) How to Support Groups in Learning:More Than Problem Solving., Supplementary Proceedings, (Eds) Aleven, V., Hoppe, U., Kay, J., Mizogucci, R., Pain, H., Verdejo, F. and Yacef, K.(Eds), University of Sydney, Sydney Australia

Schweitzer, F., Behera, L. and Mühlenbein, H. (2002) Evolutiion of Cooperation in a Spatial Prisoner's Dilemma, Advances in Complex Systems, 5**,** 269-299.

Shimoda, T. A., White, B. Y. and Frederiksen, J. R. (1999) Acquiring and Transferring Intellectual Skills With Modifiable Software Advisors in a Virtual Inquiry Support Environment,Institute of Electrical and Electronics Engineers, Hawaii

Tesluck, P., Mathieu, J. E. and et al (1997) Task and Aggregation Issues in the Analysis and Assessment of Team Performance in Team Performance Assessment and Measurement: Theory, Methods and Applications, (Eds) Brannick, M. T., Salas, E. and Prince, C.(Eds), Lawrence Ehrlbaum Associates, New Jersey, pp. 197-224.

Toquam, J. L., Fujita, Y., Macaulay, J. L., Westra, C. D. and Murphy, S. E. (1997) Assessment of Nuclear Power Plant Crew Performance Variability in Team Performance Assessment and Measurement: Theory, Methods and Applications, (Eds) Brannick, M. T., Salas, E. and Prince, C.(Eds), Lawrence Ehrlbaum Associates, New Jersey, pp. 253-287.

Waldrop, M. M. (1992) *Complexity. The Emerging Science at the Edge of Order and Chaos.,* Simon and Schuster, New York.