# BUILDING A COMPUTATIONAL LABORATORY FOR THE STUDY OF TEAM BEHAVIOUR IN PRODUCT DEVELOPMENT

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**Abstract:** As the result of the first phase of building a computational laboratory which is aimed to enable detail study of the emergent team properties and team behaviour in product development, this paper focuses on the design of a computational representation of a member of product development team. Since team members are often faced with the necessity to adjust to changes in their environment, the emphasis was put on modelling of human adaptive capacity. Specifically, the paper brings together the theoretical findings on mechanisms individuals use when faced with disruptions and introduces the architecture of an adaptable agent that can be used for studying adaptation of product development team. Building on the findings from psychology, sociology and cognitive science, the proposed agents are defined as cognitive, situated, affective and social. The proposed computational workbench is aimed to augment understanding of team processes prior, and in response to adaptation triggers in the context of product development projects, and should enable anticipation of possible pitfalls, enhance the development of design methodologies and tools, and provide guidelines for design education.

## 1 INTRODUCTION

The importance of teams in product development is well recognised (Edmondson and Nembhard, 2009), but due to difficulty, time requirements and cost of conducting studies on teams, there are still many unknowns, and further research is needed to gain a deeper understanding of team behaviour and processes. Teamwork studies can be facilitated by the use of computer simulations as they allow flexibility in the choice of input parameters, enable process control, provide means for "what-if" experiments, and enable repetition, expansion, and modification of experiments, and simulation of long-term scenarios. In other words, implementation of simulation models can be seen as a *computational laboratory for research on product development teams*, which provides means for carrying out different experiments with a flexibility unattainable in the real world setting.

Since product development teams are subject to constant change due to internal and external circumstances, team's capability to change (i.e. adaptability) and processes occurring during the adaptation are of particular interest to researchers focusing on the product development. Namely, product development teams have to adjust to changes in market trends, respond to new customer's requirements and adapt to changing technologies or resources constraints. Further, team members are affected by perturbations within organisation structure, as well as within the team itself. For example, team boundaries are often fluid, membership in product development teams is often temporary and project based (Edmondson and Nembhard, 2009) and teams are required to accommodate new members or substitute for the ones that have left. The team's flexibility and ability to cope with unanticipated environmental circumstances is essential for a successful project completion. Thus, a simulation tool which would enable exploration of team adjustments to a wide variety of circumstances could prove to be especially valuable. One way to achieve such flexibility is by equipping modelled team members with the ability to learn and change their behaviour based on experience, their understanding of the situation, and cooperation and interaction with others. Such implementation will enable the study of team adaptation and team adaptability as the consequence of interactions between adaptive individuals, i.e. as a team property emerging from local, self-directed, autonomous changes of individual agents, rather than a consequence of predefined, global rules.

To get reliable and relevant results, assumptions implemented in the desired computational laboratory must rest on existing theoretical and empirical-based grounds. Therefore, as the first phase of computational laboratory development, this paper focuses on the formulation of a computational representation of an individual team member with attention given to modelling of human adaptive capacity based on the research-based understanding of human cognition and behaviour. In the following phases of this study, obtained architecture will be implemented as a workbench for simulating team adaptation, tested and verified by comparison with empirical data, and refined based on the findings.

This paper is structured as follows. In Section 2 findings from the team adaptation research are reviewed, and existing computational models of product development teams are compared based on their capability to simulate various aspects of team adaptation. Next, team and individual characteristics and processes relevant for adaptation simulation are identified, and the architecture of a computational model built on this theoretical foundation is presented. Further, the architecture of an adaptive agent is developed. In Section 4, research capabilities gained by using such a workbench are explicated. The paper concludes with a discussion of limitations and directions for future work.

# 2 BACKGROUND AND RELATED WORK

## 2.1 General studies on team adaptation

Adaptation is defined as a deviation in team processes (from the standard procedure) in response to disruptions and changes in environment or situational demands. It is a process that leads to a functional outcome for an entire team and manifests in modifications of team structure, capacities, affection, motivation, and/or behavioural or cognitive goal-directed actions. (Maynard et al., 2015; Burke et al., 2006, Kozlowski et al., 2015).

Triggers for adaptation range from change in team membership, necessity of overcoming social and cultural differences, formal organisational or team restructuring, change in availability of resources, detection of unfamiliar or ill-defined problems, introduction of new resources, alternation of requirements or restrictions, and change in priorities and (sub-) goal's importance, to adjusting to novel time restrictions or difficult physical conditions (Pulakos et al., 2000). Each of these listed disruptions may require a different response from team members.

Team members' adaptive performance is influenced by their previous experience and personality traits, along with their understanding of the team goal, their level of goal commitment, and their goal-orientation. For example, LePine (2003, 2005) found that teams whose members scored high in cognitive ability, achievement and openness to experience, and low on dependability were the most successful in adapting to unforeseen change. Further, when the set team goal is difficult to achieve, teams whose members are focused on achieving high performance rather than learning-oriented are found to be especially unlikely to adapt. Thus, team adaptation is a process shaped by a composition of team member's characteristics and results from member's joint effort to coordinate their actions to reach their goal and achieve the desired level of performance. While there is a growing body of literature on team processes occurring during adaptation of teams in general (see Maynard et al., 2015, for review of related work), product development research has seldom focused on team processes and team states occurring during adaptation..

## 2.2 Team adaptation in product development process

Several studies have explored manners in which management can foster adaptation of the project team through encouraging idea sharing, using frequent milestones, building a multifunctional team, ensuring goal clarity, and putting an emphasis on the development of adaptive designs (e.g. Eisenhardt and Tabrizi, 1995). Susman et al. (2003) have explored how introduction or change of collaborative technologies affects team's behaviour. Authors argue that technology adaptation is successful if it resolves misalignments that occur between technology, the task, and the social structure during the appropriation process. While exploring how new product development teams adapt to electronic communication media, Kock et al. (2006) have found evidence supporting compensatory adaptation theory according to which team members compensate for obstacles, in this case for shortcomings of communication over electronic media. In their recent study, McComb et al. (2015) have studied how teams of undergraduate students adapt to changes in design requirements and found differences in problem-solving processes of high and low performing teams.

In addition to studies of adaptation, attention was also given to team characteristics and processes closely related to adaptation. Dayan and Basarir (2009) have explored the extent to which group members deal with group's objectives, strategies and processes, and adapt to current and anticipated endogenous or environmental circumstances. Akgun et al. (2006) have studied unlearning, a sub-process of team learning defined as a change in team member's beliefs and design routines. Research revealed that unpredictable events cause the effect of team crisis and anxiety under which team members tend to revise their previous beliefs. By proper assessment of current state and unlearning obsolete or inapplicable routines, team members can promote adaptation as they can incorporate new knowledge effectively and, in turn, improve chances of new product success.

From the literature review, it can be concluded that team-level adaptation has only started to receive attention in product development research field leaving many knowledge gaps. Filling these gaps is especially important as product development teams are considered vital for organisational effectiveness, and adaptability is particularly important due to dynamics and complexity of development project.

## 2.3 Computational models of the teamwork in product development

Team adaptation is influenced by behaviour and cognition of each team member (Burke et al., 2006). Thus, when building a computational model of team adaptation, techniques that enable detailed modelling of individuals are of interest. The technique that is particularly suitable for modelling cognitively rich, heterogeneous, adaptive and autonomous individuals is agent-based modelling, which enables capturing of emergent phenomenon such as the adaptation of a team.

However, most of the agent-based models of teamwork in product development focus on modelling of approximate workflow to provide an estimation of team performance in terms of time, cost and quality; e.g. VDT (Yin and Levitt, 1996) and Crowder et al. (2012). Agents, as implemented in some of these models, possess characteristics that correspond to dimensions of adaptive performance (defined by Pulakos et al., 2000) like learning or dealing with uncertainties, but their actions are based on preprogramed, unchangeable responses to sensed data, thus restraining the possibility of studying adaptation as an emerging process.

In some models, however, agents can learn and choose their actions, which are necessary conditions for studies of adaptation. For example, agents in Construct (Schreiber and Carley, 2013), Gero and Kannengiesser's (2004), and Singh and Gero's (2007) models are social and cognitive, possess dynamic mental models, and are driven by their perceptions and expectations. This is important since, as detailed in following sections, a review of work in psychology, cognitive science and sociology domains revealed that four aspects of human behaviour are important for the study of adaptation: situatedness, cognition, affect, and socialness. In other words, humans are affected by their interactions and emotions, aware of the situation, and able to learn and decide on their actions. Accordingly, to model human behaviour, agents representing designers have to be social, cognitive, affective and situated. Of existing models, only Singh and Gero's model (2007) was found to include all of the listed characteristics. Construct (Schreiber and Carley, 2013), Gero and Kannengiesser's (2004), and Singh and Gero's (2007) models can be used to study the effect of turnover on information sharing, team expertise, and social structure. However, none of the listed models has explored the influence of task-based change, such as design requirements change, on team behaviour.

An overview of adaptive performance dimensions addressed by each of these models is presented in Table 1. Models not addressing any of the adaptive performance dimensions were omitted from this table.

*Table 1. An overview of existing agent-based models of product development teams*

| **Reference and model name** | **Purpose** | **Adaptive performance dimensions addressed** | **Situatedness Cognition Affect Socialness** |
|---|---|---|---|
| Gero and Kannengiesser model (2004) | Simulation of expertise of temporary design teams | Learning, interpersonal adaptability | Situatedness, cognition, socialness |
| Singh and Gero model (2007) | Modelling of temporary design teams | Learning, interpersonal adaptability | Situatedness, cognition, affect, socialness |
| TEAKS (Martinez-Miranda and Pavon, 2011) | Selection of best team configuration based on personality traits and emotions of team members | Dealing with stress, interpersonal adaptability | Affect, socialness |

| | | | |
|---|---|---|---|
| Construct (Schreiber and Carley, 2013) | Evolution of communication, knowledge and belief networks | Interpersonal adaptability, cultural adaptability, learning | Cognition, socialness |
| Crowder et al. model (2012) | Examination of team performance sensitivity | Learning | Affect, socialness |
| Dehkordi et al. model (2012) | Study of project overload impact on innovation | Dealing with stress, creativity | Affect, socialness |
| Sosa and Gero model (2012) | Examination of the group influence on brainstorming | Creativity, learning | Cognition, socialness |
| Singh et al. model (2013) | Study of the role of social learning in task coordination | Learning, interpersonal adaptability | Cognition, socialness |
| CISAT model (McComb et al., 2015) | Capturing human problem-solving trends | Learning | Cognition |

# 3 COMPUTATIONAL WORKBENCH FOR SIMULATING TEAM ADAPTATION

## 3.1 Team-level view of adaptation process

Adaptation starts with a trigger. If FBS view of the team (Gero and Kannengiesser, 2007) is adopted, triggers can be classified as those affecting team function, i.e. what team aims to do or deliver, team behaviour, i.e. what team members are doing to achieve their goal, or team structure, i.e. what team consist of. As a response to the trigger, the team engages in "adaptive cycle" consisting of four process-oriented phases: situation assessment, plan formulation, plan execution and team learning (Burke et al., 2006), leading to the desired improvement in team performance. Building on the taxonomy of team processes developed by Marks et al. (2000), phases can be classified as action phase (consisting of coordination, monitoring and back-up processes), or transition phase (consisting of mission analysis, goal specification and planning). Team situation awareness, psychological safety and shared mental models, play a crucial role as they serve as input, mediators, and output of each of previously mentioned phase (Maynard et al., 2015).

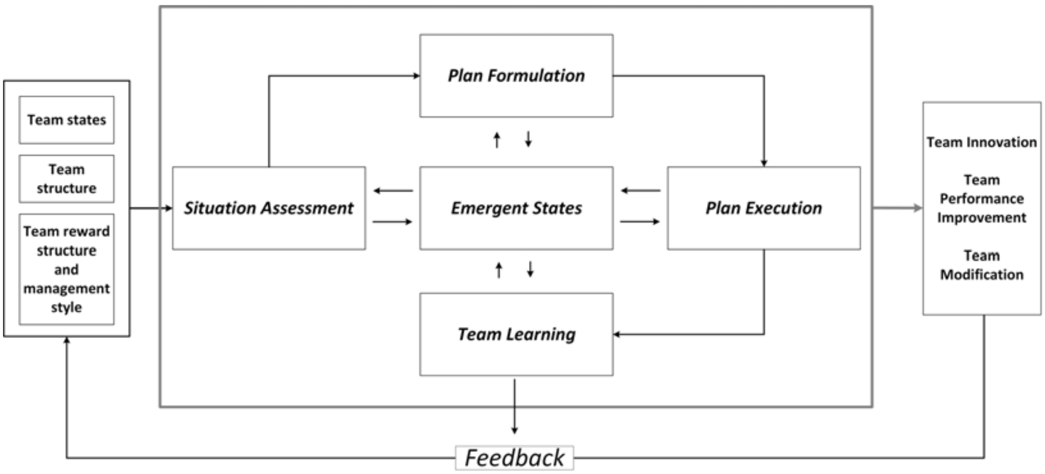


*Figure 1. Model of team adaptation (after Burke et al., 2006)*

Adaptation process takes as the input current team states like team mental models and climate (Burke et al., 2006), team management style and reward structure (Maynard et al., 2015; Burke et al., 2006), team structure and composition (DeRue et al., 2008), task features, and access to resources (Burke et al., 2006). Adaptation results in performance improvement, team learning, team innovation and/or team modifications (Burke et al., 2006), as is shown in Figure 1.

## 3.2 Individual-level view of adaptation process

The complex behaviour observed at a team level is necessarily a consequence of joint actions and characteristics of individual team members. The literature review revealed team adaptation is influenced by characteristics of individual team members such as cognitive ability, dependability, openness to experience and membership achievement (LePine, 2003), their attitude towards goals (LePine, 2005) and team (Burke et al., 2006), emotional stability, self-efficacy (Schmitt and Chan, 2014), and individual adaptive performance (Burke et al., 2006).

As previously described by Gero and Kannengiesser (2004), individual's actions are based on their interpretation of their observed environment. These actions are driven by push and pull processes where production of the internal representation of the environment is "pushed" by the environment, and its interpretation is affected ("pulled") by individual's experiences and existing concepts. If, however, a discrepancy from existing concepts is encountered, one attempts to rationalise and resolve it in the adaptation process. Consequently, adaptation is influenced by team member's previous experiences and mental models (George and Jones, 2001).

When individual team members are faced with discrepancies relevant to their goals and objectives, inability to rationalise them triggers an emotional reaction which, in turn, triggers a process of (re)interpreting the discrepancy. Thus, emotions, emotional stability and self-efficacy are seen as the main drivers for individual's adaptation (George and Jones, 2001, Schmitt and Chan, 2014).

Apart from their emotions, individual's decisions are influenced by their interactions with other team members which create a social context for individual's sensemaking process (George and Jones, 2001). Team members keep a record of each other's knowledge, maintain their mutual trust, create expectations on each other's behaviour and performance, and communicate to align their understanding of the situation, plans, strategies and goals.

Ployhart and Bliese (2006) presented the Individual Adaptability Theory according to which the adaptation process of an individual develops in cycles of four phases. Situation perception and appraisal is the first of four major individual adaptability process steps. During this process, an individual determines whether the situation is stressful or challenging. Based on an understanding of contextual factors, previous experiences, motivation, abilities and personal traits, an individual chooses a strategy and creates expectations of action outcomes. Strategy selection is followed by a phase where individuals regulate their behaviour in a manner consistent with their goals, try to cope with stress, and create the change in the situation. Finally, individuals acquire knowledge about the situation and determine the quality of their adaptation.

## 3.3 Agent-based model of adaptation process in product development

Building on the theory presented in preceding subsections, a computational model of the simulation workbench to study team adaptation was developed using the agent-based modelling paradigm. In the proposed model, each team member is represented by a design agent and characterised by its objectives, traits, behaviours, and mental models. An agent can interact with other agents (or with the whole team) directly, through communication, or indirectly, through observation. Interactions help agents to learn about each other and guide their understanding of the team and its objective. Further, an agent works on the design task and uses available resources, i.e. interacts with them. Finally, an agent interacts with itself through reflection on its previous actions, evaluation and construction of novel concepts. The proposed agent architecture for studying adaptation processes is illustrated in Figure 2.

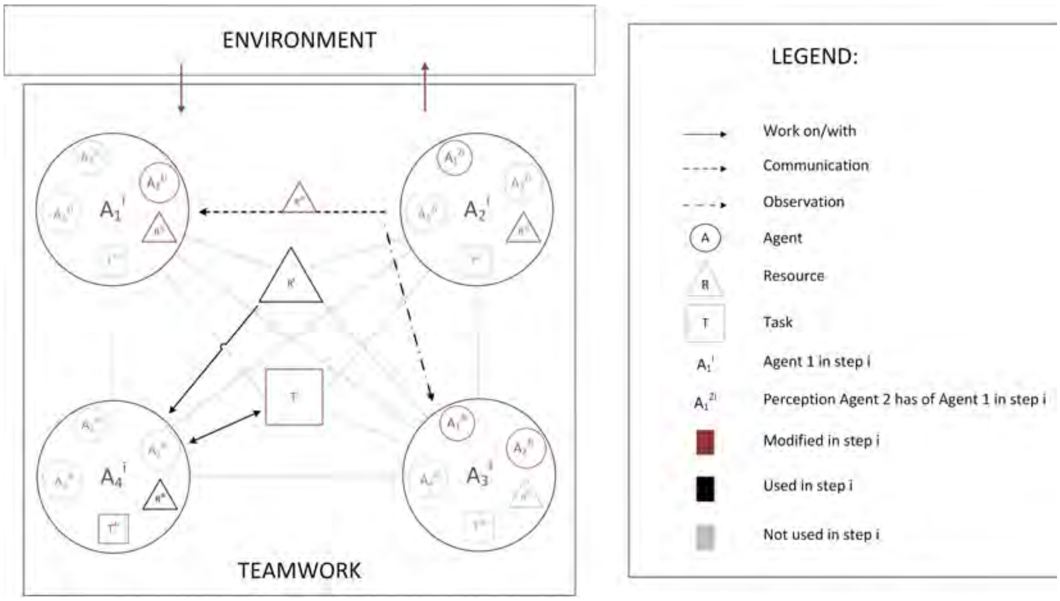


*Figure 2. Architecture of the agent-based model for studying adaptive team behaviour*

A team consist of two or more design agents working on a given design task while using a resource(s) (Kozlowski et al., 2015). Each agent, represented by a circle, possesses a perception of the current situation, i.e. about itself, other agents, tasks, resources and relations between these elements. The perceptions are dynamic and are influenced by interactions and evolution of agent's experience over time. Team affects and is affected by the environment. When triggers arise (from the environment, or within the team), they influence task, resource, agents, or relations between them. Depending on the attention and perception, agents may not immediately realise a trigger has appeared.

Drawing on the models constituting situated, cognitive design agents (e.g. Thomas and Gero, 2015) and building on the situation awareness (Endsley, 1995) and adaptation theories presented in Sections 3.1 and 3.2, the design agent's cognitive architecture is presented in Figure 3.

Agents can be performance or learning oriented, which plays a part in the evaluation of their potential strategies (LePine 2005). Performance-oriented agents are more likely to be affected by team performance drops and choose their actions based on their likelihood of goal-achievement. Learning-oriented agents tend to focus on the creation of new strategies suitable for the perceived situation. Agents also vary in the level of their orientation to the team (Burke et al., 2006). Highly team-oriented agents often share their ideas, are more likely to compromise when a conflict is encountered and are willing to help and support others.

Agent's *cognitive ability* and *personality traits* influence agents in that, for example, cognitive ability facilitates the in-depth activation of agent's memory and formation of generalisations and rules based on previous experiences. Personality traits like dependability and openness to experience influence an agent's emotional reactions to new situations, indirectly influencing an agent's decisions and actions. Agent's cognitive ability and personality traits do not significantly change over shorter periods of time (Ployhart and Bliese, 2006), and thus are modelled as static. However, other elements of agent's architecture change at every simulation step. The fundamental part of agent's cognitive architecture, which guides agent's behaviour (and, consequently, agent's adaptation) is agent's *memory* system consisting of agent's interpretations of encountered situations, i.e. past experiences.

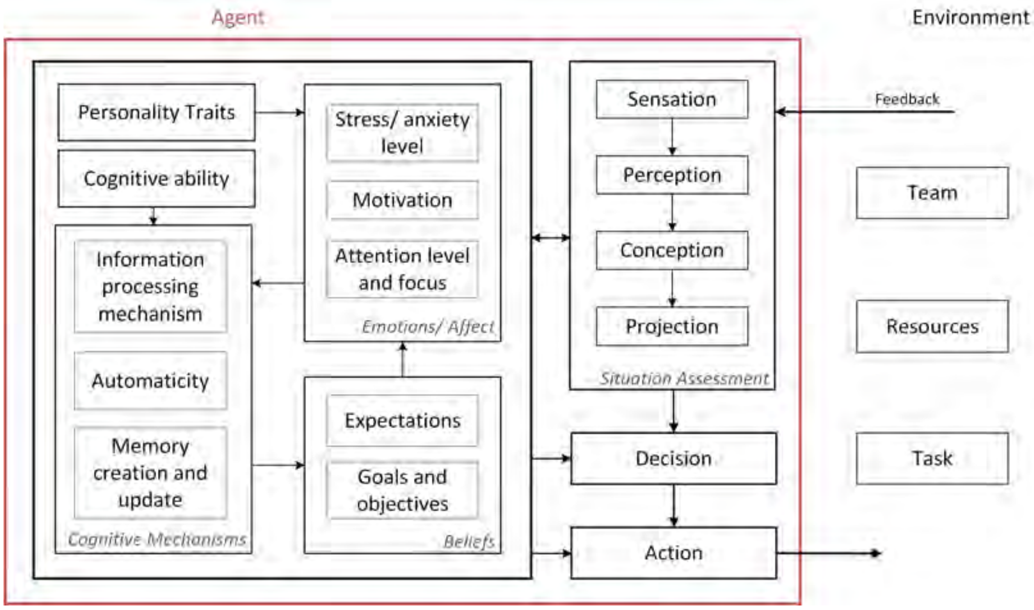


*Figure 3. Agent's cognitive architecture*

Building on a notion of constructive memory (Gero, 1999), an agent's memory system changes with new experiences. Each new experience, consisting of the assessed *situation*, the chosen *action* and received *feedback*, is stored in memory and can be accessed, used and updated in subsequent situations. New memories influence and are influenced by previous experiences. New memory's impact on existing constructs is dependent on its perceived importance, i.e. the level of emotional arousal it has caused. Agents are capable of generalising and classifying their memories and, therefore, creating rules and forming concepts. Further, they may create new memories by combining existing ones, and they use newly formed rules to evaluate previous experiences. Thus, their memory evolves over time with memories losing or gaining importance, and obtaining new meaning.

Drawing on their memory, and influenced by their *emotional state*, agents form *expectations* and may modify their *goals and objectives*. At every simulation step, an agent *senses* part of the environment, thus obtaining data about tasks, resources, and/or team and assigns meaning to it (through processes of *perception* and *conception*), based on its current mental models. Derived interpretations do not necessarily resemble reality as they are influenced by agent's expectations (formed based on previous experiences). If the interpreted situation matches the agent's expectations, no emotional trigger will be activated, and the agent will follow its routine. If, however, the expectations are not met, depending on perceived importance of the current situation, the difference from expectations, and agent's characteristics, an emotional reaction will be triggered, and the agent will revise its mental models.

An agent will activate its memory and, if none of the current concepts matches the perceived situation, the agent will learn and try to create new concepts through memorising new data, deriving new hypotheses and validating them through subsequent experiences. Emotions are, thus, signalling the need for change (and adaptation) as they arise when a discrepancy between important concepts and reality is encountered. But emotions also guide agent's actions as individuals tend to perform actions which result in positive impact on one's emotions. Thus, agents learn which actions lead to positive emotional change and tend to perform them more often. Sometimes, however, agent's act irrationally. For example, if the situation is perceived as highly stressful, an agent can act impulsively (without extensive evaluation) or even randomly.

Agents' memories, thus, are continuously updated through simulation course and include task, team and resource features, perceived goals and objectives, actions they have performed, as well as how successful these actions were, and their experiences with others. Agents also keep track of each other's knowledge, responsibilities and their mutual relation. Through formal and informal communication, and observation, agents may build mutual trust and learn about each other's information needs and capabilities, which can be later used to provide or request help. When working together, they exchange ideas and try to align their perceptions. If insufficient information about other agents is available, the agent will be guided by their experiences which are recognised as similar.

## 4 RESEARCH CAPABILITIES

The primary goal of the desired simulator is to provide a means for simulation of team-level behaviour observed in the real world. To provide the possibility of exploration of the causes of the team-level phenomenon's occurrence, the insights from various theories are integrated in the agent's architecture. If the agent's behaviour is consistent with multiple theories, it increases the confidence in the reliability of the model as a tool for setting the hypothesis which can direct the future empirical research and guide the intuition of the researchers (Carley, 2009). Another advantage of presented agent's architecture is applicability as the agent's architecture and processes presented are equally applicable to the studies of adaptation to changes in the tasks, team or resources. Since the agents as designed are affected by their traits, memories, emotions, and their relationship with others, their behaviour will not be necessarily predictable. Thus, research experiments with a workbench consisting of such agents has the potential to reveal emergent patterns of team behaviour.

A computational workbench consisting of agents whose architecture is presented in Figure 3 enables the modelling and simulation of a team consisting of agents with different personal traits, cognitive ability, and/or experience and examination of their influence on the team behaviour and task performance. Further, researchers can study whether and how team processes differ when the task requires slight modification of existing team member's concepts, from the case where obtaining solution asks for a drastic change of mental models. In another example, by simulating a sequence of similar tasks, the workbench can be used to track how routines are formed within a team. Upon introducing change, either in task requirements or team structure, a researcher may observe how team member's mental models reshape, how new strategies are created, or how social structures are formed. The workbench can be used to explore: to what extend does a shared mental model help teams when performing a task and in which cases does shared mental model hinder adaptation (for example, in case of fixation or groupthink); how does knowledge become grounded and what is its impact when change is required; what is the effect of formal restructuring on informal social structures; how does perception about each other help team members when task requirements change; what is the effect of newcomers on the team social structure and under which conditions may newcomers influence team member's mental models, and consequently, promote adaptation and innovation; how does an individual’s adaptability level impact adaptation of the whole team (for example, if influential team member does not change his/her mental models); and what is the effect of downsizing on team behaviour and performance.

Such an agent-based model offers a unique means for detailed, controlled studies of teams over time. The model allows a researcher to expose the team to a sequence of similar adaptation triggers and to examine how team's response changes over time. Similarly, one may build two distinct teams and simulate how a transfer of a team member from one team to another influences each of them. Moreover, one may simulate the team member's return to his/her original team and compare the team behaviour with the one the team would display if team member never left.

All of these examples illustrate the potential of agent-based model implemented as a workbench in studying how phenomenon unfold bottom-up across levels and time, which is particularly suitable for studying team processes and behaviour in product development.

## 5 DISCUSSION AND CONCLUSIONS

Design teams are often faced with different challenges to which they have to successfully respond to maintain their desired performance. The aim of this paper was to bring together the mechanisms individuals use when faced with disruptions and to develop a computational representation that will provide a system for studying team behaviour with a particular focus on adaptability in product development projects. Building on the findings from psychology, sociology and cognitive science, the proposed agents are defined as cognitive, situated, affective and social. They are aware of, and affected by, both, technical and social components of the design task, and are, thus, capable of dealing with a task- and team-based disruptions. They are capable of responding to unpredictable and uncertain situations, of learning, dealing with stress, dealing with emergencies and crisis, and responding to interpersonal adaptation dimensions. As opposed to many of the existing computational models of product development teams, adaptation along these dimensions arises from the agent's cognition and situation perception, rather than being guided by explicitly modelled rules. Additional dimensions of interest for design team research are creativity and cultural adaptation, which will be addressed in future by adapting the agent's architecture. Further improvements may also include modelling of different roles within the team - in particular, a team leader whose decisions have a direct impact on team structure, team climate and motivation, goal clarity, reward system, plan formulation and project execution.

Every computational model, including the presented workbench, includes approximations and may not display exact behaviour observed in the real world. However, once the workbench is implemented, the model will be verified through extensive testing, and the team-level behaviour obtained will be validated by comparing the displayed behaviour with the theoretically-based predictions, and empirical data collected through a series of experiments designed to test several aspects of the model. Insights obtained by comparison with the empirical data will be used to refine the model, and finally, will lead to experimentation with the workbench. The wide applicability of proposed agent's architecture suggests that once validated, workbench can serve as a test-bet for various new ideas, thus aiding the decision-making, suggesting potentially valuable experiments, and creating new hypotheses (Carley, 2009).

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