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A preliminary model of participation for small groups

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Abstract We present a small-group model that moderates agent behavior using several factors to illustrate the influence of social reflexivity on individual behavior. To motivate this work, we review a validated simulation of the Battle of Medenine. Individuals in the battle performed with greater variance than the simulation predicted, suggesting that individual differences are important. Using a light-weight simulation, we implement one means of representing these differences inspired in part by Grossman's (On Killing: The Psychological Cost of Learning to Kill in War and Society. Little, Brown and Company, New York, 1995) participation formula. This work contributes to a general theory of social reflexivity by offering a theory of participation as a social phenomenon, independent of explicit agent knowledge. We demonstrate that our preliminary version of the participation model generates individual differences that in turn have a meaningful impact on group performance. Specifically, our results suggest that a group member's location with respect to other group members and observers can be an important exogenous source of individual differences.

Keywords Social aspects of cognition · Participation · Reflexivity · Individual differences · Cognitive architecture

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Introduction

How do individual variation and social distance influence group performance? How do groups influence individual performance? Over the past decade, interest has grown in these questions as virtual worlds and synthetic agents have become more prevalent. Simulations offer a way to model and predict large-scale emergent properties (Axelrod 2003), while agents provide a means for controlling variance and predicting the effects of embodiment on social systems (e.g., Norling and Ritter 2004; Silverman 2004; Taylor et al. 2006).

Researchers have focused on representing contextual differences by manipulating the agent's perception and by making rule knowledge situationally dependent. And yet, few social effects have been incorporated into agent models. There are some counter examples, see, for instance, work by Carley and Newell (1994), Gratch and Marsella (2004), Silverman (2004), and Yen et al. (2001).

In this paper, we describe a theory of participation, an organizational theory operating at the small-group level, and present an implementation of the theory. In our theory, we represent individual outcomes as instances of participation and hesitation. By participation, we refer to incidences of particular and recognizable acts by an agent, while defining hesitations as incidences of non-action or resistance by an agent. The theory uses a notion of social reflexivity to predict the impact that social factors such as *group size* or *distance between teammates* have on individual behavior and thus group performance. This work begins to address the challenges implicit to modeling individual differences and social activity by implementing a theory of group effects based on exogenous and endogenous variables.

We acknowledge that models without social effects or individual differences are appropriate where: (a) individuals are similar; (b) decisions are frequent and routine; and (c) there are no known social effects. These approaches' limitations become evident, however, when modeling social interactions such as classroom management (Jussim and Harber 2005) or combat situations (Grossman 1995). We start with a situation where individual differences in participation were important, the Battle of Medenine.

Ironside and the Battle of Medenine: a case study

Ironside was a two-sided, closed, stochastic, ground-combat simulation developed at the Royal Military College of Science in the UK (Harrison et al. 1999). Ironside was a battle group simulator that modeled operational doctrine and behavior, including the effect of terrain. Ironside integrated a representative command and reporting structure with realistic platform representations. Users could construct command hierarchies for platoon to division-sized elements with corresponding entity-level weapon platforms. Ironside enabled individual entities to identify and engage targets within a rich simulation environment.

We begin with Ironside for three reasons. First, while Ironside was developed in the 1990's, its emphasis on entity-level activity remains relevant and instructive. Second, the validation and verification study for Ironside is detailed, well documented, and persuasive. The validation study's outcomes provide a compelling case for accounting for low-level group interaction and individual differences because it was unable to fully replicate the historical record, despite representing doctrine, terrain, and equipment.

Poncelin de Raucourt (1997) studied Ironside's ability to replicate the Battle of Medenine (March 6, 1943). He found that Ironside's software and engineering supported its designers' intent. Nevertheless, Ironside generated outcomes that were reliably different from the historical record for the anti-tank gun emplacements. Although many characteristics were similar, the battle's duration, the entities' engagement range, and the individual distribution of casualties per battery were inconsistent with the historical record.

Poncelin de Raucourt's analysis suggests that Ironside's terrain modeling, its lack of a decision-making task model, and its inability to predict the effect of either individual differences or low-level group interactions all significantly impaired its ability to match the historic record. Like the battle of Decauville (October, 1918) and the liberation of Holtzwihr (January, 1945), the outcome at Medenine was disproportionately influenced by the actions of a few soldiers, in this case Sergeants Andrews and Vincent (Faulkner 2008; Rowland 2006; St. John 1994). The distribution of fire in Ironside was normally distributed; however, the distribution of fire was not normally distributed in the historical record. The terrain favored eight of the fourteen positions. Nevertheless, the distribution in the historic record suggests that more than terrain effects influenced the outcome. In his analysis, Poncelin de Raucourt (1997) argued that individual differences and variability across units (heroic or degraded behavior) explained this discrepancy. This hypothesis is strongly supported by autobiographical accounts, noting that the morale of several units was low due to recent fierce fighting.

We believe that theories of individual differences, particularly in respect to participation, would begin to explain and predict the causes for this variation in behavior. In the next section, we draw from work in social psychology and sociology to define more clearly what such a theory would entail.

An organizational theory of participation

In this section, we describe seven major factors that can influence participation before offering a preliminary formula that we have implemented in a small demonstration simulation. For the purpose of this discussion, we model individual agents in a tank simulation based upon a moderated form of Newell's (1990) decision cycle: Perceive → Decide → Act, similar to Boyd's (1987) *O*bservation, *O*rientation, *D*ecision, and *A*ction (OODA) Loop.

Theoretical premises

Our theory of participation rests on three general premises. First, human social networks are complex systems that moderate individual behavior. Second, our awareness of ourselves and of others is a defining characteristic of human cognition. Third, changes to social networks lead to changes in the agent's state that manifest themselves in divergent outcomes.

A theory of participation is a theory of action. The first premise (social networks moderate behavior) defines the context of that action, specifically of collaborative activity. Consequently, we must identify and account for the constraints present in social networks, in this case small groups. We attempt to model these constraints by using an agent-based approach in a light-weight simulation.

A theory of participation is a theory of social cognition. The second premise posits that modeling the mutual awareness of agents, as well as modeling perception and memory, is necessary for any working theory of participation of this sort (e.g., Carley 1986, 1991). This form of awareness is an intrinsic and important aspect of human cognition, and one mediated by both individual and collective goals (Frank 1944; Milgram 1963).

Finally, a theory of participation is a theory of change. The third premise asserts that changes in the social network precipitate changes in the agent's state that give rise to divergent outcomes. The system's interconnected nature engenders two effects. First, individual differences in performance become more important as the nodes (agents) become interconnected through more edges (relationships) (Carley 2002). This requires organizations to compensate and control variation in routine operations through standard operating procedures (SOPs, e.g., filing time-sheets every week) and techniques, tactics, and procedures (TTPs, e.g., administering first-aid). Further, analysts must account for individual variation (e.g., the presence of leaders such as Sergeants Andrews or Vincent) when predicting unit performance. Second, the unit's configuration and composition directly impacts its performance because these factors influence the ability of leaders and groups to structure behavior.

The challenge of reflexivity

Modeling activity and change in a social system entails a concept of reflexivity (Simon 1954). We define reflexivity as the property of a phenomenon where both the cause and the effect of the phenomenon can mutually affect each other. Reflexivity enables us to establish consequential relationships both with other human beings and with symbolic actors such as the state, the community, or our family (Giddens 1978; Goffman 1974; Rock 1979). Historically, reflexivity has been problematic for the social sciences. Modeling reflexivity is difficult in activities where it is ambiguous what influences are operating, especially because human beings often rationalize their activity as acts of free will when there are clear indications to the contrary (Frank 1944). Popper (1957) followed by Nagel (1961) questioned the feasibility of predicting social phenomena because making predictions can change realized outcomes.

The literature describing observer effects provides examples of socially moderated behavior. Rosenthal's and Jacobson's 1968–1992 study (Rosenthal 1994) found that the greater expectation placed on a target group the better the group performed on average. Milgram (1963) demonstrated the influence of authority figures, particularly in instances where the choices confronting the participants seem mutually exclusive (e.g., choosing to shock or not shock). Milgram found that verbal promptings from an authority figure were sufficient to goad most participants into administering (apparently) fatal shocks.

Even in instances of participation and hesitation where the choices appear mutually exclusive, these "choices"[1] generally result from complicated context dependent sets of interaction whose consequences condition future choices. This conditioning of future choices tends to produce structures of replicating activities (Collins 1981; Fine 1991). The relationships humans have with these structures serve to enable or constrain human agency (Giddens 1991; Tskeris and Katrivesis 2008). Furthermore, we can conceive of hesitations as arising from departures from these structures, instances where these guiding regularities are either inapplicable or inoperable (Duncan 1968).

Taking up these issues, Simon (1954) demonstrated that making correct predictions of social behavior is theoretically possible. To predict social behavior would, however, require knowledge of the shape of the reaction function. A reaction function for reflexivity is the degree to which reflexivity influences behavior within a specific task domain, public voting in Simon's case. One reason agent-based approaches have been successful is because these approaches have typically focused on contexts where reflexivity has little or no influence on behavior, for instance, in modeling checklist procedures.

We find in our review a tendency to focus on factors that contribute to change. This tendency seems connected not only to the epistemological challenges associated with model building but also with the human tendency to focus on points of unpredictability and irregularity while ignoring other chains of action that satisfy basic threshold conditions (March and Simon 1958). Consequently, there is far less work examining the cumulative effects of hesitation or inaction on a social system. And yet, when we examine participation, these hesitations appear to have a significant effect on organizational outcomes (e.g., Snook 2000).

Borrowing from Lewin (1947), we describe social change using two broad categories: on one hand, *actual change* or *lack of change;* and on the other, *resistance to change*. Comparing social systems to physical ones, Lewin further argues that groups have unique properties distinct from the properties of subgroups that in turn differ from the properties of individuals. Modeling change both within and across organizational levels, and how changes that occur at one level influence the others remains a challenge. Nested within these broad questions are further questions such as how to capture change, what changes are significant, and what factors contribute to changes at any given level.

In regards to these questions (capturing change, determining significance, and identifying catalysts of change), our earlier discussion regarding Ironside and agent-based approaches offers some guidance. Simulations offer us a way to model and predict large-scale emergent properties arising from local interactions (Axelrod 2003). They provide a dynamic means of modeling change.

In the case of Ironside, it may have been partly its inability to replicate these local interactions (the influence of leaders on their subordinates) that decreased its fidelity.

[1]Describing these interactions as "choices" is problematic, especially when describing instances of hesitation that are not the result of a conscious decision-making process. Though participants may themselves describe these interactions as choices, the term implies a degree of intentionality that is often inferred subsequent to the event (Collins 2008).

Furthermore, Poncelin de Raucourt (1997) pointed to small-groups as a crucial unit of analysis. Variance at the group and individual level had a disproportionate impact on the outcome of the battle of Medenine. Yet, without the warning of impending attack passed down from the Allies intelligence services, the local leader's actions are unlikely to have had the same effect—illustrating the interconnectivity of organizational levels. Nevertheless, modeling the decisions of local leaders seems a fruitful and necessary task for developing predicative models of larger organizations.

Using Lewin's categories, we examine factors that influence the probability and degree of change within a given system, specifically at the individual and small-group level. Agent-based approaches, particularly cognitive architectures, offer persuasive theories regarding human memory and perception (Newell 1990). They provide three powerful ways to model variation: first, by varying the individual cognitive capacities of agents; second, by varying agent knowledge; and third, by varying individual and group goals. Cognitive architectures, therefore, are a powerful tool for modeling the emergence of social behavior because they provide three principled approaches for capturing individual variance. The ability to introduce and control individual variation within a system affords agent-based approaches a greater likelihood of identifying and isolating significant interactions that either facilitate or hamper change in real-world systems.

And yet, agent-based approaches have historically lacked systematic explanations describing changes in behavior caused by changes in an agent's social context. We next present the seven factors used in our theory to define the social context of small groups and teams.

Factors that influence participation in a social system

Our theory models how situational factors translate into changes in an actor's operational context, specifically the impact of organizational factors on individual behavior that in turn influences organizational outcomes. We describe these factors (summarized in Table 1) and the relationships between them in more detail. We first discuss the influence of group characteristics such as size and composition. We then analyze the effect that intra-group relationships have upon behavior, both in terms of relative distances and authority. Finally, we examine how goals mediate behavior.

Group size

We first examine how group size effects group dynamics. Group size seems to influence the communication effectiveness between group members (Cartwright 1968; Hare 1952), the group's tendency towards hierarchy (Bales et al. 1951), and the relationship dynamics existing within and between groups (Bales and Borgatta 1955; Shalit 1988). Shifts in group size correspond with shifts in behavior; dyads are different than triads or larger groups (Latane and Darely 1970, Freedman 1974). Benenson et al. (2001) confirmed these findings, though they found some gender effects. These differences in behavior between dyads and larger groups seem to correspond to the sense of mutual dependence and anonymity shared by the group (Bales and Borgatta 1955; Slater 1958). Dyad members eschew confrontational language and tend

Table 1 Seven factors that influence performance by defining an agent's social context

Factor	Brief definition
Group size	The number of members in the group
Group composition	An abstraction of the number of unique qualities possessed by members of the group. We define it as the number of unique agent types present in the group
Social distance	The perceived distance between the goals and motivations of any two actors
Spatial distance	The physical distance between any two actors
Mutual support and surveillance	Mechanisms for maintaining shared norms and coherence by minimizing the expression of the diverse characteristics of group members
Presence or absence of legitimate authority figures	The actor's perception of their leader's authority and legitimacy
Task attractiveness	The alignment of the leader's task with the actor's internal motivations

to be more responsive to avoid their partner's withdrawal (Slater 1958). In larger groups, the presence of third parties affords greater anonymity and diffuses group tension, allowing for greater competition both between and among groups (Benenson et al. 2001; Collins 2008). In addition, group diffusion can distance group members from the consequences of collective acts (Grossman 1995) as well as from needy bystanders (Latane and Darely 1970).

So, individuals in groups behave differently than individuals on their own. Group size increases the social distance between both group members and other groups, making hostile action more likely but collective action more difficult.

Group composition

Group composition and shifts in composition also play an important role in defining a group's social context. By shifts in composition, we mean changes in personnel as opposed to changes in distributions or capabilities. There is significant evidence suggesting that differences among group members negatively affect group performance (Byrne 1971; McGrath 1984; Newcomb 1961). This literature generally ascribes the level of group performance as a function of the organization's level of social integration, or the degree to which group members are psychologically linked or attracted toward interacting with one another in pursuit of common objectives (O'Reilly et al. 1989). Social integration constitutes a goal-driven process arising out of the daily interactions of team members, and mediated by the length of contact between members and their respective organizational roles.

Heterogeneity and social integration are different but related. When describing heterogeneity in reference to social integration, D.A. Harrison et al. (1998) distinguish between surface and deep-level diversity. Surface-level diversity refers to differences in members' overt phenological characteristics. These characteristics are thus usually immutable, almost immediately observable, and measurable (Jackson et al. 1995). In contrast, deep-level diversity describes differences among the members' attitudes, beliefs, values, and skills. These differences are generally more subject to construal and thus are more mutable over time (Milliken and Martins 1996). Though there is ample evidence that group members make initial assessments of one another based upon stereotypes (Allport 1954; Amir 1969; Berger et al. 1980; Byrne 1971), there is evidence that these initial assessments give way when deeper-level knowledge is obtained (Stangor et al. 1992; Turner 1987).

Furthermore, studies suggest that group performance and cohesiveness more strongly correlate with similarities in attitudes and values than with phenological characteristics (Terborg et al. 1976; Turban and Jones 1988). Also, negative outcomes associated with surface-level diversity decrease as a group remains together (Milliken and Martins 1996). These findings highlight the importance of organizational continuity to organizational functioning. With large turnovers in personnel come periods of organizational acclimation, and consequently a drop in overall group functioning as members acquire new deep knowledge about one another (Carley 1992).

In summary, groups that are (a) more cohesive, (b) who have worked together longer, and (c) who share more values, will perform better and be more likely to achieve their collective goals. Additionally, tightly knit groups are better able to support members who must routinely engage in harmful acts towards outsiders.

Social and psychological distance

Social distance is related to the concept of social integration discussed above. Park (1924) defines social distance as "the grades and degrees of understanding and intimacy which characterize pre-social and social relations generally." Revising Bogardus's social distance scale (1933), Westie and Westie (1956) introduced a social distance pyramid that measured the effects of caste, class, and race. In more recent work (Perloff 1993; Eveland et al. 1999), social distance refers to a continuum stretching from an in-group bias (just like me) to an out-group bias (not at all like me). Developments in network theory also suggest that social distance is a function of the ties between group members (Ethington 1997; Wetherell et al. 1994). Nevertheless, we retain a concept of social distance similar to that of Perloff (1993) to model culture's influence on the development of out-group biases. Other work (Ginges and Eyal 2009) distinguishes social distance from psychological distance, arguing that individual and group interactions are fundamentally different. Based on our readings, we believe that this distinction is a question of modality; we focus on the social distance modality, where group identity is primary.

So, smaller social distances allow group members to better receive and provide support, making participation in the group's activities more likely. Conversely, larger social distances increase the likelihood of group members to act against their own group members or other groups.

Spatial relationships

The metaphorical use of space implied in social distance also seems to possess a spatial correlate. Spatial distances as encountered in daily life mediate the formation of familiarity (Ethington 1997). Notions of familiarity in turn act reciprocally to help produce communities of practice (Bourdieu 1980; Williams 1973). In other words, space fundamentally defines our sense of the familiar, influencing our perceptions of community and otherness. Furthermore, distortions to our perception of space also distort both our sense of accountability and attachment to others (Grossman 1995).

So, spatial relationships influence participation. Local activities, where group members are in close proximity, encourage participation. Alternatively, increasing the distance between group members tends to discourage participation in acts against perceived outsiders.

Mutual support and mutual surveillance

Thus far, we have described how the properties of a group (number and heterogeneity) and the distance between group members moderate behavior. We now examine how role-based relationships between group members influence behavior. We distinguish between subordinate-subordinate (peer) and subordinate-superior relationships. The literature supports this distinction (D.A. Harrison et al. 1998; Terborg et al. 1976; Turban and Jones 1988), and we believe that shifts in either relationship lead to significant and divergent outcomes in team performance (Grossman 1995). We first discuss subordinate-subordinate relationships, highlighting both the social support they provide as well as the normative control they exact.

Groups provide their members several benefits. Group norms provide groups a sense of identity and belongingness, offer guidelines for ambiguous situations, structure chaotic situations, and help their members predict the actions of others (Chekroun and Brauer 2002; Cialdini et al. 1990; Smith and Mackie 1995). Furthermore, social support can moderate the effects of stress, buffering their members from negative events (Caplan 1974; Cobb 1976; Epley 1974). Sandler and Lakey (1982) found that group support benefited individuals differently based on the coping mechanisms exhibited in an event's aftermath, making the relationship between social support and stress reduction complex.

Social support and conversely social sanction arise out of a system seeking but never achieving equilibrium (Festinger 1954; Festinger and Thibaut 1951). Considering the benefits (coherence, narratives) group norms provide their members, the impulse to protect those norms, and thus for uniformity, seems natural. Chekroun and Brauer (2002) note that in settings where deviation is clearly attributable to individuals—members offer larger and more rapid responses to sanction deviant acts. Liska (1997) and Festinger (1954) found, contrary to expectations, that larger deviances are typically first met with attempts to mediate actor behavior rather than expulsion. The pressure for uniformity, furthermore, appears to be even greater when group membership holds increased relevance and value (Festinger 1954). The existence of a discrepancy in a group leads group members to try to reconcile the discrepancy. As the discrepancies narrow, the pressure for uniformity appears to increase. Simultaneously, however, the impulse to individuate oneself and, for many people, to increase one's relative status ensures a constant state of comparative surveillance, particularly for groups operating in risky situations for prolonged periods (Dinter 1985).

So, this factor reinforces and helps explain the spatial factor. Groups that are close, physically or socially, buffer their members from exigencies while also ensuring the keeping of group norms and the meeting of group goals. If viewed through the lens of appraisal theory (Festinger 1954; Lazarus and Folkman 1984; Selye 1956) group support provides a resource to encourage participation by making tasks appear challenging rather than threatening.

Presence or absence of legitimate authority

Milgram's (1963) obedience studies provide further evidence of reflexivity's significance, specifically in regards to power relationships and symbolic actors. By symbolic actors, we mean patterns of repetitive associations in relation to particular physical objects, places, or people that influence behavior (e.g., Congress and Capital Hill, or the presidency and the White House). We can see in Milgram's study the concept of symbolic authority at work. The power wielded by the experimenter in Milgram's study was not physically coercive or economic but rather symbolic. Milgram comments on this, noting that the goal and the premises influenced the participants to acquiesce to the experimenter's demands (Milgram 1963, p. 377). In the Milgram study and later obedience studies (e.g., Athens 1980; Haney et al. 1973; Katz 1988), belief in the symbolic actor's legitimacy and power resulted in granting that actor actual power over the participant.

When we examine Frank's (1944) work on resistance and passivity, we can find interesting trends regarding compliance to authority figures including: (a) participants will tend to balk early, or not at all; (b) contracts are important, as they impose a sense of obligation; (c) cooperation is more dependent on the contract's terms than on the task's characteristics; (d) perceptions of relative authority (i.e., from more senior leaders) tend to limit the capabilities of subordinate leaders to affect participation; and (e) rules are impersonal and induce conformity, where defying rules requires personal investiture and risk.

The more authority a legitimate leader exerts, the more group members will feel compelled to participate. When authority is weak or perceived as less legitimate, group members will participate in the group's activities less.

Goal attractiveness

Frank's (1944) and Milgram's (1963) studies highlight the importance of legitimate goals in relation to obedience. In addition, people frequently indicate in interviews and surveys that goals were a motivating factor in their behavior (Collins 1981; Frank 1944). Goals seem to motivate human beings to act, although they may serve to justify rather than motivate the behavior in question. Representing social goals poses a challenge because they emerge at the interface between cognitive and social activity. In this paper, we do not attempt to describe goal emergence but rather how existing goals influence behavior.

So, legitimate goals tend to make group members more compliant. Illegitimate goals, over time, are pursued less and erode the ability of leaders to influence their subordinates.

Other factors influencing participation

There are other individual and social factors that influence an actor's likelihood to participate. We do not include them yet in our approach. These may include time of day, practice at the task, and trust. With this approach, however, factors like these can be included at a later time. We acknowledge that there are further factors to be included in the future.

The theory's mathematical formulation in three equations

We summarize our review in (1), (2), and (3). These equations were inspired by Grossman's (1995, p. 341) informal equation,[2] and are an initial step towards formalizing our concept of participation. In (1), we describe total distance (d) as the square root of the sum of squares along the social and spatial dimensions for a given relationship, x. We use Euclidean distances because we intend to model differences across multiple dimensions. In our formula, we use d for distance to friends, leaders, or observers. We use the term observer to distinguish between the influence of in-group and out-group ties on participation; observers are individuals who influence us but with whom we are unfamiliar or have little in common. Depending on the organizational context, we can construe observers as enemies, but they can also be bystanders requiring assistance (Latane and Darely 1970).

A candidate distance equation in two dimensions.

$$d_x = \sqrt{(social_x)^2 + (spatial_x)^2} \tag{1}$$

From the distance measures in (1), we then create a probability of immediate aggressive action against an observer using a logit-transform function (2). We chose to use a logit-transform function because it has proven useful in discrete-choice models (McFadden 1980). Relationships in our equation are role-based. In this equation, we assume that participants acting as 'friends', 'leaders', or 'observers' are significant. When representing these relationships in (2), the equation uses the optimal or lowest distances to friend and leader while using the distance to an action's intended recipient as the observer distance. The quantity p_a is the calculated probability of taking an aggressive action towards the observer.

A candidate equation for determining the probability of taking an aggressive action.[3]

$$p_a = \frac{1}{1 + (\frac{1}{t_d} * e^{\frac{g_{\text{composition}} * ((d_{\text{friend}} * \sqrt{g_{\text{size}}}) + \frac{d_{\text{leader}}}{t_a + k})}{g_{\text{size}} * d_{\text{observer}} * (c+k)}})} \tag{2}$$

[2]Grossman's (1995) equation is a function of functions. The top-level function is *Probability of Personal Kill* = (*demands of authority*) × (*group absolution*) × (*total distance from victim*) × (*target attractiveness of victim*) × (*aggressive predisposition of the killer*).

[3]Note that the relationship between p_a and the distance calculations of (2) is an inverse relationship. As the distance terms increase, the probability of participating in a harmful act decreases.

The constant t_d represents the task domain's effect on task participation. Group (g) has two significant factors, composition ($g_{\text{composition}}$) and size (g_{size}). We define a group's composition ($g_{\text{composition}}$) as the set size that can be extracted from that group (i.e., the number of unique 'types', as opposed to the number of individuals). The formula implies that leaders are less able to influence their followers as the group's heterogeneity increases because the social distance between group members also increases. In addition, mutual support and surveillance, although not explicitly represented by variables, are modeled through the interaction of g_{size} and d_{friend}, as g_{size} increases the perceived distance between friends increases resulting in a drop in mutual support and surveillance.

The task's attractiveness (t_a) can be scored from 0 to infinity—larger values mean that the task is more in accordance with the actor's internal motivations (i.e., goals). We can think of the mediation of d_{leader} by t_a as a function that specifies to what extent a task distances a group's leader from subordinates. A highly attractive task can compensate for a marginal leader while a repugnant group goal can impair a leader's effectiveness. The constant term, k, is a very small value (akin to terms used in smoothing) used to set a maximum bound on both the effect of d_{leader} and of c.

Finally, we represent an individual's predisposition towards hostile or helpful action as c, which will vary across individuals and represents the agent's personal circumstances. Predisposition ranges from 0 to 1, with a distributional-mean closer to 0 (because people generally find it difficult to harm others). We recognize that this part of our theory remains underdeveloped; however as we note later, adequately addressing the effect of individual differences may entail integrating some form of our theory into a cognitive architecture, a step beyond our current implementation.

An example from our implementation environment may be helpful. Let us assume that all agents in the team are the same 'type', so $g_{\text{composition}}$ is 1. The team has 4 members, so g_{size} is 4. A particular agent's teammates are nearby ($d_{\text{friend}} = 10$ m) as is their team leader ($d_{\text{leader}} = 20$ m). The agent's closest observer (d_{observer}) is 100 meters away, and for this example is treated as an enemy. The agent is not particularly predisposed to harmful action, so $c = 0.2$. We assume that the task is in line with the agent's current goals so t_a is 1 (because t_a and c are not near 0, k can be ignored). After exploring the function, we set t_d to 0.1. With these assumptions, the probability of hesitating is .15 (p_a is .85). If the same agent is isolated, where friends are far away ($d_{\text{friend}} = 100$ m, $d_{\text{leader}} = 150$ m) and the target is close ($d_{\text{observer}} = 50$ m), it is almost certain the agent will hesitate; the probability of hesitating is .9984 ($p_a = .0016$). We should note that hesitating agents are frequently given the opportunity to participate again—eventually even the agent in the second scenario would most likely fire (the cumulative probability of hesitating over 100 time intervals is .85, and over 1000 time intervals is .20).

In (3), we assume that actions are positive or negative in intention. A 'neutral' action would constitute ignoring the observer, and would thus be a form of non-action. A hesitation differs from a non-action in that hesitations occur when the agent is committed to performing an act (because of explicit rule knowledge) but fails to perform it. We assert that taking an immediate beneficial action (p_b) towards an observer has the inverse probability of taking an aggressive action. Although we believe that this may provide explanation of other reflexive phenomena, such as the Bystander Effect (Latane and Darely 1970), this part of our theory will be a subject for future work.

A candidate equation for determining the probability of taking beneficial actions towards an observer.

$$p_b = 1 - p_h \tag{3}$$

Implementation of a simple participation model

We have implemented our participation model in a simulation to test it. The model moderates behavior at the small-group level; it is a theory that describes participants making tactical as opposed to strategic decisions. Though there is evidence that these processes influence overall organizational performance (Carley 2002; Grossman 1995), we do not claim that these processes are replicated at every organizational level or apply to other types of tasks. We first describe the implementation, and follow that with a discussion of the model's organizational domain and how that domain informed our implementation choices.

A modular implementation approach

Figure 1 is a concept diagram describing our implemented (preliminary) participation model in dTank (Morgan et al. 2005). Agents are represented as triangles while the arrows between agents represent their physical distance in the environment. In the figure, the agent is central and essentially unchanged. A thin "participation module" surrounds the agent, influencing behavior based on the presence and absence of other actors, such as leaders (L), friendly actors (F), and observers (O). The environment generates state changes that the agents respond to, which in turn generates subsequent

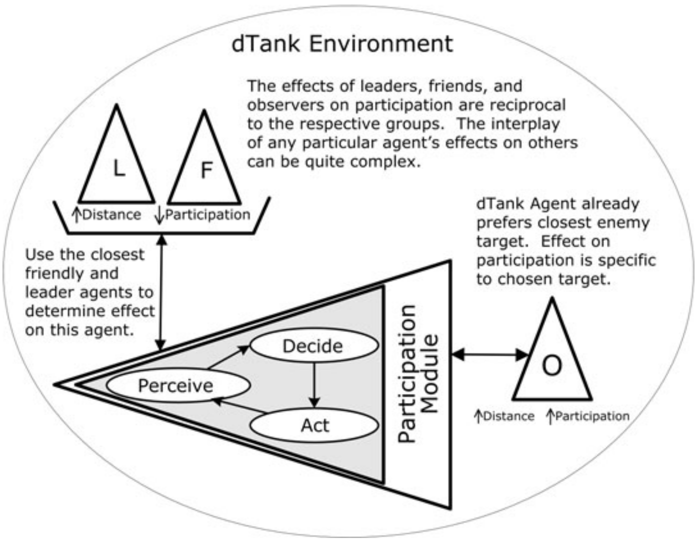

Fig. 1 Concept diagram of a preliminary implemented model of participation for taking harmful actions

state changes. The agents' actions arise out of their perception of the environment and reflect human processing and sensory limitations.

Generally, cognitive architectures treat perception and decision making as independent of social influences. Agents perceive the environment and act in accordance to a goal hierarchy. In most cases, the proximity of other agents has no influence on agent behavior unless their presence or absence impacts the agent's ability to achieve its goals. Figure 1 shows an explicit representation of the dynamics influencing whether an agent participates or not in an activity. In Fig. 1, the arrows leading to and away from the participation module illustrate the influence that others have upon decision-making. The model itself represents inter and intra-group awareness and the management of that awareness (Collins 2008; Grossman 1995) within a structured environment, in this case a military team.

Implementation domain: Small military teams

In our daily lives, culture influences the likelihood that we will or will not participate, as well as how we express that choice. The expression of choice in many domains can be hard to discern and is moderated by culture. Because of this difficulty, we have chosen to model participation in a combat environment, where organizational influences are apparent and reactions are predictable because human responses to tension and fear are relatively generalizable (Collins 2008).

Human beings react to fear in three general ways: running, blustering, and fighting. Out of the three, fighting is generally the alternative of last resort, and for most human beings requires intra-group support to do routinely (Collins 2008; Grossman 1995). Accordingly, successful military organizations structure their organizational environments to ensure unit lethality by managing their member's intra and inter-group awareness (Collins 2008; Grossman 1995).

Organizations encourage participation through the use of mutual support and surveillance mechanisms, such as: compartmentalizing decision making, instilling group accountability, and instituting a chain of command. Successful organizations moderate individual behavior in two ways: first by distorting the agents' sensory data, and second by ensuring close contact between group members and leaders. The organization's ability to moderate behavior in this simple model is limited by distance and size. We will develop these points in reference to Fig. 2.

Figure 2 depicts a simple squad configuration consisting of two infantry fire teams. In this example, the squad leader is coordinating an attack with the second team leader via radio. The boxes designate two visual groups (operational units that tend to remain in visual range) that in turn represent two organizational environments.

For this and all subsequent examples, the combatants have equivalent levels of training, conditioning, and intra-group support. In both environments, all team members are in visual range of one another, meaning the ability to engage in deviant behaviors is limited. For this example, intentionally misaiming is considered deviant. In addition to this sense of accountability, team members also benefit from a sense of group absolution. The responsibility for killing is shared by the group; and the group's intersecting fields of fire creates ambiguity, providing group members some plausible deniability (Grossman 1995). The double-headed arrows indicate that all group members share this mutual sense of accountability and anonymity.

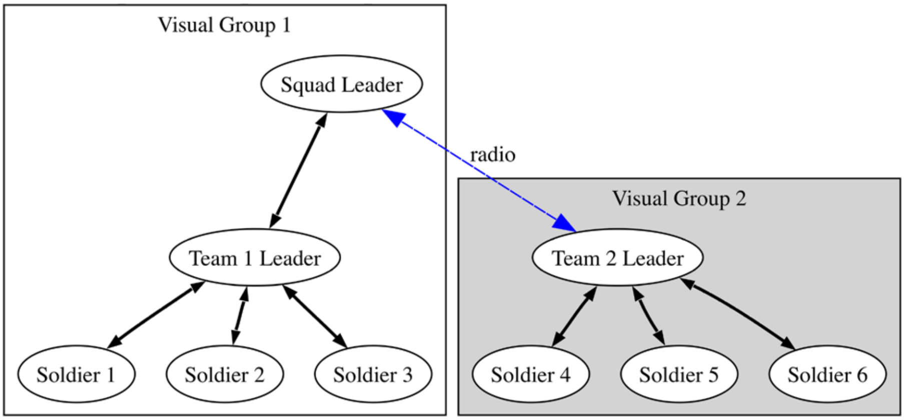

Fig. 2 Sparse network of squad interaction

Each environment also possesses a definitive leader whose presence further limits the set of acceptable choices and reinforces the group's sense of absolution (Grossman 1995; Milgram 1963). The environments do differ in respect to their composition. Visual group 1 includes not only its team leader but also the squad leader while group two only possesses a team leader. Although team leaders may differ in their ability to compensate for distance, we do not yet model this.

We can, however, model the increased load that the physical distance has placed on the system. This distance limits the ability of both group leaders and members to ensure group accountability or provide absolution. Thus, in the model, there is an inverse relationship between intra-group distance and unit lethality.

For example, communications between the two teams can cease entirely. If, for example, the radio is destroyed, the probability of deviant behavior would increase throughout the whole system. Neither the squad nor the second team leader would have to respond to the other, meaning one less person to regulate behavior. Visual group 1, however, would be more likely to participate because the squad leader and team leader remain accountable to each other and the squad. Even when communication mediums are available, ambiguity introduced by the communication of uncertainty or contradictory orders can impede mission performance. Therefore, in the model, communications are beneficial only to the extent that they alleviate uncertainty.

Where increasing the distance between group members decreases unit lethality by mitigating the group's ability to moderate behavior, increasing the distance to the observer (within the technological limits of the unit) raises unit lethality. Again, knowledge of an observer is fundamental to the model. Increased distance facilitates participation by anonymizing the enemy, thus increasing their attractiveness.

Demonstration

To test our theory, we have implemented the model in a light-weight simulation. We recorded several aspects of the simulated entities' behavior to see how our model of participation (shown in (4)) could change performance. Equation (4) represents an initial step towards a more ideal equation noted above, but excludes factors that do not change in this simulation, such as task-attractiveness and group composition. Equation (4) converts representations of distance and group size ($d_{\text{friend}}, d_{\text{leader}}, d_{\text{observer}}$ and g_{size}) into a probability of participating in an immediate aggressive act, p_a. The constant c represents the agent's predisposition to participate. For moderated agents, c was set to .2. We chose this value based on exploration of the mathematical function independent of the simulation.

Function implemented in the participation module.[4]

$$p_a = \frac{1}{1 + (\frac{1}{t_d} * e^{\frac{1*((d_{\text{friend}} * \sqrt{g_{\text{size}}}) + \frac{d_{\text{leader}}}{1+k})}{g_{\text{size}} * d_{\text{observer}} * (c+k)}})} \tag{4}$$

To visualize the interplay of some of (4)'s key mechanics, we show in Fig. 3 a response surface for two potential conditions in our simulation. Both response surfaces show the change in probability of taking an aggressive action (p_a) as distance to the closest friend (d_{friend}) and the distance to the targeted enemy (d_{observer}) change.

These plots show several interesting effects. The probabilities (p_a) are generally higher in the team plot (right) than in the dyad plot (left), showing that p_a is greater in a larger group. In both plots, d_{observer} has a greater effect on the probability than d_{friend}. The relationship between d_{observer} and p_a changes as g_{size} and d_{friend} change. In some cases, d_{observer} has a nearly linear relationship with p_a (e.g., far from friend, dyad), where at other times the relationship between d_{observer} and p_a acts more like a threshold, for instance, at 200 m there is little difference in p_a (e.g., in team, with close friend). Even in the most extreme situation (i.e., close to friend, far from enemy), p_a is not 1; this does not mean, however, that agents in these situations will not fire, merely that it is possible they will hesitate before firing.

To explore this function, we performed a small experiment, applying the function to moderate behavior in a lightweight simulation. For this experiment, we consider three hypotheses. First, based on our previous work, we expect that inhibiting shooting should result in agents firing fewer shots in the moderated condition. Second, based on Fig. 3, we expect the results to exhibit a more evident "success to the successful" dynamic in the moderated condition—where initial casualties cause further degradation of performance, causing yet more casualties for the losing force. We define casualties as entity destruction, where the asset is no longer able to participate in the battle. We define "winning" as having fewer losses. Third, we expect fewer casualties in the moderated condition (regardless of force) because the hesitation penalty inhibits performance.

Method

The participation probability's effect on behavior was tested by applying it to an 8 vs 8 battle in a slightly modified version of dTank 4.5 (Morgan et al. 2005). The

[4] As in (2), the relationship between p and the friend and leader distance calculations in this equation is an inverse one. As these distances increase, the probability of participation decreases.

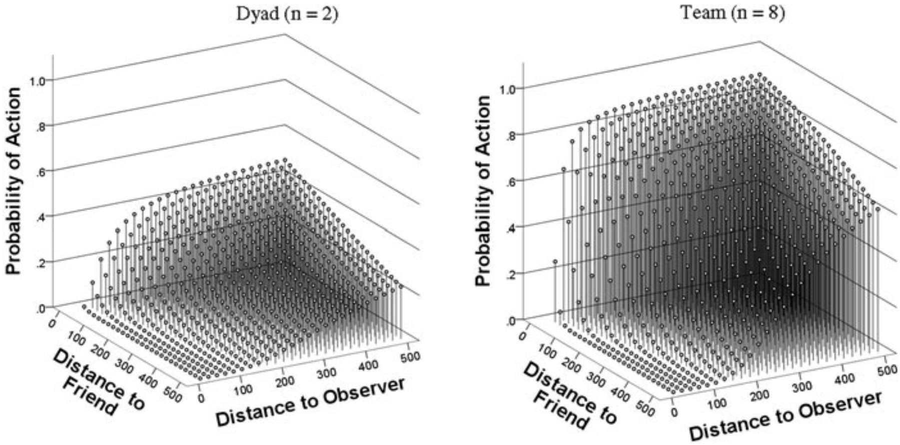

Fig. 3 Response surface for the implemented equation showing the effect on p_a as d_{friend} and d_{observer} (d_{enemy}) change for two conditions (where g_{size} equals 2 and 8). Other values remain constant

agents were modifications of simple Java agents included in the dTank simulation (SmartCommanders). These agents attack when they see an opponent and otherwise wander until an opponent is found. In every simulated battle, all agents were either moderated (using (4)), or unmoderated. All other variables were held constant. Board positions were alternated to avoid position effects.

The teams were started on a 1 km by 1 km board. Battles were allowed to last up to 2000 simulated seconds. The map size ensured the agents began the battle out of visual range of the opposing force, precluding the possibility of instantaneous attacks and allowing the agents to potentially isolate themselves. The trial length allowed for the possibility of multiple survivors. The simulation was run 200 times per condition.

We used (4) to calculate a participation value passed to each moderated agent each time the agent targeted an opponent. The calculating function had access to the number of active friends, the number of visible enemies, their distances, and the agent's distance to their team leader. If the calculated participation value was greater than a uniformly distributed random number, the agent participated (i.e., fired at the opponent). Otherwise, it hesitated. This hesitation lasted for 3 seconds. After this period of hesitation, the agent, assuming an applicable target was in range, had another opportunity to participate. Each time the agent's participation score fell below a randomly generated number, it would hesitate again. This cycle would persist throughout the life of the agent.

Results

We first conducted a surface validation of the participation module by examining a trace (Fig. 4) displaying shifts in the participation probabilities of one battle. The thickest line represents the average participation value for the Red team; the lightest line represents the average participation value for the Blue team while the thinnest line displays shifts in the participation probability of a single agent (Agent Blue3). We see in each trace that shifts in the agents' participation probability correspond not

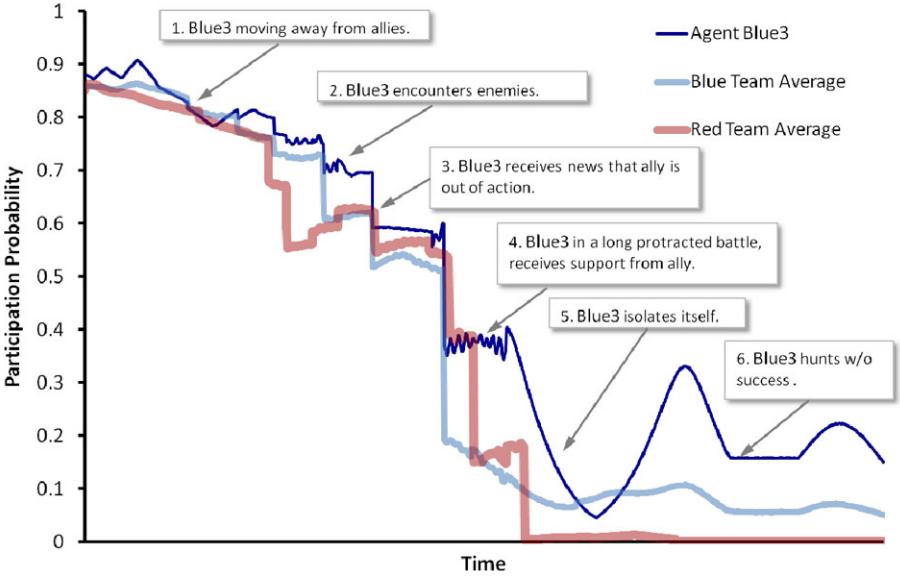

Fig. 4 Trace of agent's participation values in an 8 × 8 battle

only to changes in the spatial distance between opponents and friends but also to the loss of friends and leaders, resulting in cumulative decrease in the agents' probability to participate over time. Figure 4 confirmed, for us, that the participation module worked as expected.

When we examine the traces of Agent Blue3 and the Red team, we can see both effects. At point 1, Agent Blue3 is moving slowly away from its colleagues. In the trace, gradual changes in the trace's slope illustrate the effect of movement on the agent's participation probability. The rapid oscillation of Agent Blue3's participation probability at point 2 indicates a skirmish. These oscillations correspond to the agent's rapid change in position as it maneuvers to engage its target; these in turn slightly affect the agent's participation probability. At point 3, the sharp drop in Agent Blue3's participation probability indicates that it has learned of an ally's loss. Because the probability of participating is based on the agent's knowledge, the simulation does capture to some extent the effect of incomplete information upon participation, in that latencies between the events and the agent's perception of the event can occur. Points 4, 5, and 6 are further examples of these three effects. Finally, the steep and sustained drop in the Red team's average participation probability indicates the loss of a team leader.

Our theory proposes three alternative hypotheses: (1) moderated tanks will fire fewer shots; (2) moderated tanks will win by a larger margin, exhibiting a success to the successful dynamic; and (3) fewer moderated tanks will be destroyed in each battle. Because of our hypotheses, we removed instances where the two forces had equal casualties. This occurred evenly across both conditions approximately 7% of the time.

Table 2 shows that the participation model influenced performance. The moderated agents fired less, displayed a more evident success to the successful dynamic, and

Table 2 Experimental results for three tested variables, over 200 runs per condition

Variable	Unmoderated (Std)	Moderated (Std)	T-test (adjusted df) of means	T-test on variance
Shots fired	190.0 (28.6)	138.2 (31.7)	11.0 (369), $p < .005$	1.29, $p > .05$
Winning side casualties	3.8 (1.2)	2.3 (1.5)	10.0 (351.3), $p < .005$	3.53, $p < .05$
Total casualties	10.4 (1.4)	8.7 (1.6)	16.5 (369), $p < .005$	2.14, $p < .05$

sustained fewer casualties. In addition, the moderation increased differences between individuals as shown by the increase in the standard deviations of all three measures.

For all three hypotheses, the differences in means across conditions were reliably different (shown in Table 2). In these measures, moderation also *increased variation*. To test the reliability of these changes, we used a modified t-test as suggested by Howell (1987, pp. 176–177), df is approximately the same as a t-test. The variance between moderated and unmoderated measures was reliably different for the winning side casualties and for total casualties, but not for shots fired.

Discussion and conclusion

We presented the case that individual differences related to participation are important, and when missing, can impair a simulation's fidelity. We started by reviewing a validation study of the Battle of Medenine. This study showed that individual performance varied more than would be expected even when the impact of terrain was considered, and that this effect heightened the differences between the simulated and historical outcomes. We believe that participation in a group action is a *reflexive* phenomenon, one where the effects and causes can be hard to distinguish. We presented the challenges associated with modeling and predicting reflexive phenomena. Without the ability to predict phenomena, we cannot provide a useful simulation of that phenomena's emergence. Simon (1954) argued, however, that it is possible to predict reflexive phenomenon if the reaction function of that phenomenon could be delineated.

Subscribing to Simon's theory, we identified seven factors that influence participation as noted in Table 1: group size, group composition, social distance, spatial distance, mutual support and surveillance, the presence or absence of legitimate leaders, and task attractiveness. We summarized the review's findings in three equations.

Outlined in our review and shown in our equations, we make several predictions regarding the interaction of these factors on the probability of participating in harmful acts towards an observer. This study illustrates the impact of three effects: (a) greater distance to friends and leaders inhibits harmful actions; (b) the closer the target, the more difficult it is to perform a harmful acts; and (c) as group size increases, harmful acts become easier to perform although group size also increases distance to friends and leaders. We also posit, but do not attempt to prove, that the probability of engaging in a beneficial act is the inverse of engaging in an aggressive act toward the same observer.

We implemented these equations into a light-weight agent simulation. In our simulation, actors were either moderated or unmoderated. All other conditions were held constant, although force positions were alternated within the condition blocks to avoid terrain effects. In the moderated condition, all actors were moderated; the converse is true of the unmoderated condition. As expected, we found that: (a) fewer shots were fired in the moderated condition; (b) the winning force suffered fewer losses in the moderated condition; and (c) total casualties were lower in the moderated condition.

With these results, we have shown that a participation module can be used to show individual variation in the performance even of simple agents in a battle domain. We have considered alternative possibilities including changing the task, domain, and architecture. We believe all of these to be potentially fruitful lines of inquiry.

Spatial location as a source of exogenous individual differences

The results suggest that the location of agents with respect to each other can lead to meaningful individual differences between agents. That is, the likelihood of participating in a task changes based upon the agent's physical relationship to other agents. The effect of the agent's physical location in a given situation appears to provide a useful exogenous source of variation, a source of individual differences that arises outside of the agent, but may appear to arise from the agent itself. The agent's natural inclinations may influence its spatial placement, reflecting the agent's self-perceptions regarding its relationships to others (but this effect was not included in our agents).

Further, the agent's ability to maintain accurate representations of the world depends upon its capacity to perceive, make sense of, and remember spatial data. The variation in the agents' capacities to perform these tasks (spatial perception, comprehension, and memory) presents another source of individual differences as noted by Downs and Stea (1973). A cognitive architecture may allow capturing these differences by modeling an agent's ability to obtain and maintain this spatial information based on resources and tasks. For instance, we sometimes forget our friends and family when we are busy.

Limitations and future work

The placement of participation in a separate 'thin' module does entail tradeoffs. This separation makes it possible to integrate this module across a range of agent architectures. Further, this allows simple agents to show reflexive variation without explicit agent knowledge. This externality does, however, have costs. It is impossible for this component to interact with other core mechanisms of the chosen modeling paradigm at the architectural level. Though it is possible to add explicit connections or agent knowledge to consider the outputs of the participation module, this is not ideal. For example, connecting a participation module to an episodic memory system would be powerful, where the agent considers its past priors and evaluates the potential for hesitating or participating in the future state of interest, incorporating this probability into its cost functions. We believe that human actors tend to avoid situations where they hesitate (or 'choke').

It is, nevertheless, an open question as to whether modeling reflexive phenomena is consistent with the intentions and approaches of knowledge-level architectures, or if this type of modeling should occur outside of these architectures. We believe that it is possible, in a single architecture, to model individuals and their variation (e.g., Lovett et al. 2000; Norling and Ritter 2004). Architectures that have multiple levels such as symbolic and sub-symbolic levels may be more amenable to this approach because reflexivity can impact symbol perception (March and Simon 1958).

The use of the participation score in our demonstration suggests further reasons to explore this line of research. As implemented, our model is based on discrete moments. Participation, however, appears to entail a sense of momentum, and that sense seems rooted in the consequential nature of past instances of participation and hesitation. As an interim step, we are considering using the variable k to represent the cumulative effect of past instances of participation and hesitation. Nevertheless, it may require integrating a theory of participation into a cognitive architecture to fully capture the consequential nature of these events on individual performance. This approach would afford us the ability to explore how differences in knowledge, perception, and stress can mutually inform the theory and influence performance (e.g., Duric et al. 2002; Ritter and Norling 2006; Ritter et al. 2007), and allow us to better capture more complex and contextually dependent sequences of interaction.

The implemented equation does not include all the social factors influencing participation noted in our review, and the review does not yet include all the factors noted in Grossman (1995) or all the pertinent social psychology dynamics. For instance, our current model does not include all the individual differences that arise from the individuals themselves—for example, we do not represent the 1–3% of individuals who seem to require no social support to participate in combat environments (Grossman 1995), but could in future work incorporate a wider distribution of predisposition values for (c).

We also do not fully capture the social dimension of group size (g_{size}) or the full effect of social distance independent of spatial distance. The literature on small groups (Collins 2008; Festinger and Thibaut 1951; Ginges and Eyal 2009) notes that as g_{size} increases anonymity among group members also increases, resulting in an increase in the social distance between friends. The relative impact of adding members of a group on the likelihood of participating, however, diminishes with every member added. Thus, as currently implemented, the effect of g_{size} is always stronger in the denominator than the numerator, meaning that as g_{size} increases the increase in p_a is monotonic. The literature, however, suggests a point where the marginal increase of g_{size} on d_{friend} would offset the effect of g_{size} on p_a, making organized actions against observers more difficult (Collins 2008) as size increases. We do not yet capture this group optimum. We believe modeling this optimum would require further work defining social distance within (1).

Finally, we are interested in investigating not only the model's performance across a wider range of tasks (beneficial as opposed to harmful) but also whether it can predict behavior in a wider range of environments (structured as opposed to unstructured). As we noted in our theory section, we can view some instances of hesitation as departures from routine, instances where the agent's structured interactions are for some reason inoperable. We could, therefore, view hesitations as signifying gaps in the agent's working competencies, and potentially as opportunities to learn. When viewed in conjunction with "scripts" or "narratives", hesitations not only indicate opportunities to learn new scripts but also represent consequential moments of indecision that can disrupt the agent's understanding of itself and its environment. There remains much work to be done to include the effects of social aspects of cognition on behavior in theories realized as cognitive architectures.

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