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Human Behavior Models for Game-Theoretic Agents: Case of Crowd Tipping

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ABSTRACT

This paper describes an effort to integrate human behavior models from a range of ability, stress, emotion, decision theoretic, and motivation literatures into a game-theoretic framework. Our goal is to create a common mathematical framework (CMF) and a simulation environment that allows one to research and explore alternative behavior models to add realism to software agents – e.g., human reaction times, constrained rationality, emotive states, and cultural influences. Our CMF is based on a dynamical, game-theoretic approach to evolution and equilibria in Markov chains representing states of the world that the agents can act upon. In these worlds the agents' utilities (payoffs) are derived by a deep model of cognitive appraisal of intention achievement including assessment of emotional activation/decay relative to concern ontologies, and subject to (integrated) stress and related constraints. We present the progress to date on the mathematical framework, and on an environment for editing the various elements of the cognitive appraiser, utility generators, concern ontologies, and Markov chains. We summarize a prototype of an example training game for counter-terrorism and crowd management. Future research needs are elaborated including validity issues and the gaps in the behavioral literatures that agent developers must struggle with.

1) INTRODUCTION

A common concern amongst agent developers is to increase the realism of the agents' behavior and cognition. People are known to anthropomorphize technologic items like cars, slot machines, computers, ATM machines, etc. A strategy is beginning to emerge of beating the competition by including greater degrees of personality, human modes of interactivity (voice synthesis for car navigation systems), and emotivity in personas embedded ubiquitously, for instance, via lip-synching and facially accurate expressions: e.g., see [1,2].

Similarly, in training, wargaming, and operations rehearsal simulators there is a growing realization that greater cognitive subtlety and behavioral sensitivity in the agents leads to both (1) a greater ability to explore alternative strategies and tactics when playing against them and (2) higher levels of skill attainment for the human trainees: e.g., see [3,4]. For this to happen, the tactics, performance, and behavior of agents must change as one alters an array of behavioral and cognitive variables. As a few examples, one would like agent behavior to realistically change as a function of: the culture they come from (vital for mission rehearsal against forces from different countries); their level of fatigue and stress over time and in different stiuations; and/or the group effectivity in, say, the loss of an opposing force's leader?

Closely related to the topic of emulating human behavior is that of "believability" of agents. The basic premise is that characters should appear to be alive, to think broadly, to react emotionally and with personality to appropriate circumstances. There is a growing graphics and animated agent literature on the believability topic (e.g., see [7,8]), and much of this work focuses on using great personality to mask the lack of deeper reasoning ability. However, in this paper we are less interested in the kinesthetics, media and broadly appealing personalities, than we are in the planning, judging, and choosing types of behavior -- the reacting and deliberating that goes on "under the hood". Finally, and perhaps most importantly the human behavior literature is fragmented and it is difficult for agent developers to find and integrate published models of deeper behavior. Our research involves developing an integrative framework for emulating human behavior in order to make use of published behavioral results to construct agent models.

We are not attempting basic research on how humans think but on how well exsisting models might work together in agent settings. That is, the framework presented here is intended for experiments on how to integrate and best exploit published behavioral models, so as to improve the realism of agent behaviors.

1.1) Definition of (Multi-)Agent Sytems

An intelligent agent is defined here as a software program that can sense and effect its environment, and use some degree of freedom in making lower level decisions that help it plan and carry out its higher level goals. Such an agent shouldbe adaptive as needed to accomplish its intentions. Often, an intelligent agent either uses a “mental states” concept or else one is attributed to it. This makes agents an interesting architecture for modeling human-like behavior and artificial lifeforms.

The agents described in this paper are able to (1) participate in a multi-stage, hierarchical, n-player game in which each agent observes and interacts with some limited subset of the n-1 other agents (human or artificial) via one or more communication modalities, (2) forms beliefs about those other agents’ action strategies (a_{mn} in A), and (3) uses those beliefs to predict nearby agent play in the current timeframe and by that guides its own actions in maximizing its utility (u) within this iteration of the game, $G = (A_{mn}, U_n, C_n)$. Here C_n is the class or type of agents in the game.

Von Neuman-Morgnstern game theory dictates that if each agent is attempting to maximize his utility under iterative play, then a Nash Equilibrium solution of the game’s payoff matrix is likely, though not guaranteed, to be uncovered [9]. The exceptions are that some games are cyclic and the agents can wind up never converging, while other games have multiple NE and its not clear a priori as to which of them the agents will settle on. Also, maximizing under local, iterative steps does not guarantee NE that are strict optima or pareto efficient. In fact in the Prisoner’s Dilemma game, the axioms of rationality dictate that players should settle on the coop-coop strategy, yet the NE lies at the reduced utility point of defect-defect.

In the games this article investigates, the players assign utility and perceived probability values dynamically as the game unfolds and in response to stress and emotional construals of the situation. Stress constrains the agents so they may not have the time to drive toward the utility maximum in any given step. Emotional construals on the other hand can redefine where the NE occur in the payoff table or they can redefine the entire game. That is, an emotive agent can recognize a meta-game and shift the play to a higher level of systemic interaction: e.g., see [10-12]. An example might be a terrorist who martyrs himself rather than be caught, and by that catalyzes his cause.

1.2) Role of Emotion and Concern Ontologies in Agent Behavior

“Emotive computing” is often taken to mean the linking of the agent state to facial and body expressions, vocal intonation, and humorous or quirky animation effects: e.g., see [2, 7-8]. However, recent theories identify emotions as vital to the decision-making process and to manage competing motivations [14]. According to these theories, integrating emotion models into our agents will yield not only better decision-makers, but also more realistic behavior by providing a deep model of utility. These agents will delicately balance, for example, threat elimination versus self-preservation, in much the same way it is believed that people do. These theories suggest that without adding emotional construal of events, the agents won’t know what to focus upon and what to ignore, and won’t know how to balance the set of next-step alternative actions against larger concerns, as in the case of Damasio’s pre-frontal cortex damaged patients who spend the entire day mired in highly logical decision analyses of banalities, even at the cost of their own self-interest and survival.

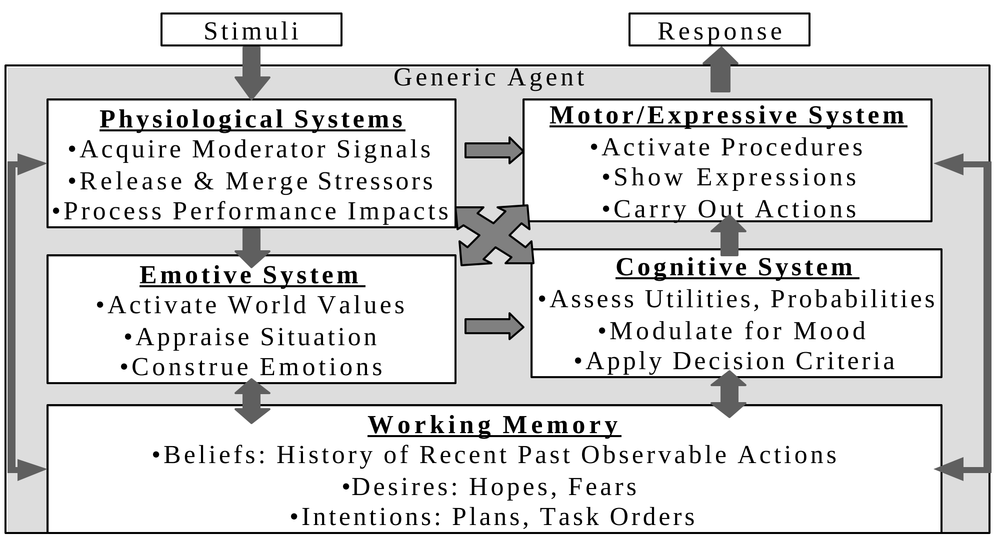
Important implementations of these ideas and theories were attempted in the “believable agents” movement such as [8, 13] which seek to improve the believability of characters’ behavior in fictional settings with the help of an emotion model. The OCC model is probably the most widely implemented of the emotion model [e.g., 15-17] and it explains the mechanisms by which events, actions, and objects in the world around us activate emotional construals. In both Oz [8] and the Affective Reasoner [13] projects, emotion was largely modeled as a reactive capability that helped characters to recognize situations and to reflect broad and believeable personality charateristics. Later versions of Oz include a behavior planner, but the link between emotion construals and behavioral choice is never well articulated in their published accounts. On the other hand, [18, 19], concretely extend the OCC model via the use of an event planner into a deeper deliberative reasoning mode where agents were able to construe the value of plans and plan elements (events that haven’t happened yet). In the current paper, we extend this still further so that agents can construe the value not only of plan elements (future events), but so they also can construe the impact of objects and behavior standards both on themselves and on those they like/dislike. We go beyond this too to the area of what is probably unconscious construals of stressors such as fatigue, time pressure, and physiological pressures. This means we attempt a fairly full implementation of the OCC model for reactions and deliberations of all types of events, actions, and objects.

This approach provides a generalizable solution to another issue in the OCC model. The OCC model indicates what emotions arise when events, actions, or objects in the world are construed, but not what causes those emotions or what actions an agent is likely to take as a result. There is no connection between emotion and world values, even though other theories suggest such a link [14, 16-17]. In contrast, concern or value ontologies are readily available in the open literature (e.g., the ten commandments or the Koran for a moral code, military doctrine for action guidance, etc.) and may readily be utilized to implement an agent of a given type in the framework we present here. We tie such concern ontologies in directly to the emotional processes of the agent, so that situation recognition as well as utilities for next actions are derived from emotions about ontologies and so that both reacting and deliberating (judging, planning, choosing, etc.) are affected by emotion.

2.0) Cognitive Architecture and Framework

The research described here is not to propose the best cognitive architecture or agent algorithms but to propose a reasonable framework within which the many contributions from the literature can be integrated, investigated, and extended as needed. That framework includes four somewhat arbitrarily separated subsystems plus a memory that form the stimulus-response capability of an agent as shown in Figure 2. There are a large number of similar frameworks in the literature:e.g. a useful comparison of 60 such models may be found in Crumley & Sherman [20]. The model we depict here shows an agent that receives stimuli and formulates responses that act as stimuli and/or limits for subsequent systems. The flow of processing in a purely reactive system would be counter-clockwise starting at the "stimuli" label, however, we are also interested in a deliberative system, one that can ponder its responses and run clockwise from the "cognitive system" to seek stimuli to support alternative response testing.

Figure 1 – Top Level of the Integrative Architecture for Researching Alternative Human Behavior Models for Generic Agents

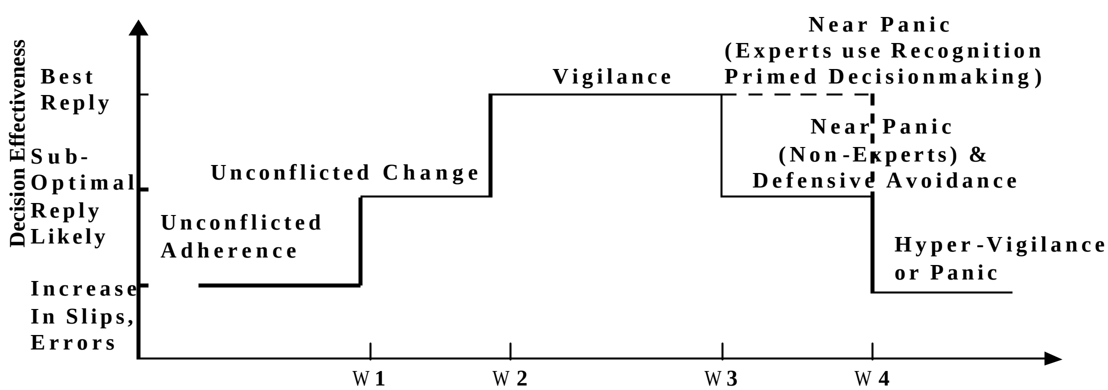


The agent model of interest to us is that of a modified Markov Decision Process (MDP). That is, the agent seeks to traverse a hierarchical and multi-stage Markov chain which is the set of nested games such as the one depicted partially in the case study (Sect. 3). In order for the agent to be aware of this chain one would need to place it into the agent's working memory as G(A,C), a set of possible goals and tasks that the agent might wish to work its way through as the game unfolds. More broadly, working memory should store and process beliefs, desires, and intentions. In keeping with the BDI agent model, the beliefs are those processed in the game theoretic sense of observing the world and of forming and remembering simple statistical models of the actions of those near us in the situation of interest. Desires are not well-defined in the BDI model, so here we define them as the future-focused affective states ofhope and fear as generated by the emotion system (Section 3.3). Intentions are the planned actions and sets of orders that the agent is seeking to carry out (a_{mn} in A).

2.1) Stress and the Physiological Subsystem

The physiological subsystem of Figure 1 initially reacts to a set of stimuli that are perceived from and/or experienced in the environment. This subsystem includes all sensory apparatus, but also grouped into here are a number of physical processes that may be thought of as reservoirs that can be depleted and replenished up to a capacity. At present we model eight physiological reservoirs or stressors, including: energy, sleep, nutrients, noise and light impacts, and other physical capacities: [21] provides more detail. For each of these there are a large number of stressors that moderate an agent's ability to perform up to capacity, and that in some cases send out alarms, for example when pain occurs or when other thresholds are exceeded (e.g., hunger, fatigue, panic, etc.). An important criterion for such a module is that it supports study of common questions about performance moderators: e.g., the easy addition or deletion of reservoirs of interest to a given study or training world (e.g., pain from virtual injuries, stress from proximity to land mines, etc.), individual differences in reacting to the same stressors, and/or how to model reservoir behaviors either linearly (our present approach) or non-linearly such as with bio-rhythms. Another vital criterion for such a module is that it should support studying alternative mechanisms for combining the many low level stressors and performance moderator functions into a single stress level. It is the overall stress that effects each of the other subsystems, and one would like a framework that shows how to compute an integrated level and then each of the subsequent modules need capabilities to reflect how their functioning is effected – emotions about stress, judgments under stress, and stressed motor/expressive acts.

Figure 2 - The Classic Performance Moderator Function is an Inverted-U



Use of all Avail.Info	Very Low	Medium	Complete	Low	Very Low
Time Avail. to Do Better	Very High	Adequate	Adequate	Insuf-ficient	None
Risks if don't change	None	Low or Medium	High	High	Very High

In particular, we model integrated stress or iSTRESS as a result of three prime determinants – (1) event stress (ES) which tracks agents' adverse and positive events, (2) time pressure (TP) which is a normalized ratio of available vs. required time for the tasks at hand, and (3) effective fatigue (EF) which integrates a normalized metric based on current level of many of the physiological reservoirs. Each of these is quantitatively derived and then emotionally filtered since a stoic will construe the same facts differently than a nervous type. The next section describes the emotional filtering. The quantitative factors that go into these modifiers are then summarized via the following where f{.} is currently a linear additivity model:

$$iSTRESS(t) = f\{ES(t), TP(t), EF(t)\} \qquad (1.0)$$

It is one thing to quantitatively derive an integrated metric called iSTRESS, but it is another to interpret its meaning and to translate that meaning into overall agent coping style. The approach we've adopted for accomplishing this translation is derived from [22] who provide what is probably the most widely sited taxonomy of decision strategies for coping under stress, time pressure, and risk. We interpret this taxonomy as the steps of the inverted U-curve of Figure 2 and define it below. The taxonomy includes a decisional balance sheet that indicates how stress, time pressure, and risk drive the decision maker from one coping strategy to another and we depict these items across the X-axis of Figure 2.

In particular, we use the framework without further elaboration here to label the cutoff points for the integrated stress, or the iSTRESS variable and to constrain the decision making since a given stress level dictates the agent's ability to collect and process both information and action alternatives ($a \in A$) when in a given state, s:

iSTRESS $\leq \Omega 1$ unconflicted adherence to current action, select $a_t = a_{t-1}$ (1.1)
$\leq \Omega 2$ unconflicted change to another a_t in mission plan or task orders
$\leq \Omega 3$ select $a_t \in A$ whichever is Best Reply (vigilance)
$\leq \Omega 4$ near panic, so pick any $a_t \in A$ (if highly experienced a_t = BR and this turns into Recognition Primed Decisionmaking as per Klein [24]. Also, defensive avoidance occurs at this level for non-experts where they ignore threatening factors)
$> \Omega 4$ panic, so a_t=run amok if safer, else cower prone at current spot (hyper-vigilance)

All but the third of these coping patterns are regarded by Janis & Mann[22] as "defective." The first two, while occasionally adaptive in routine or minor decisions, often lead to poor decision-making if a vital choice must be made. Similarly, the last two patterns may occasionally be adaptive but generally reduce the DM's chances of averting serious loss. The authors note, vigilance, although occasionally maladaptive if danger is imminent and a split-second response is required, generally leads to decisions of the best quality". Some authors have since refined these ideas as with Klein [24] who shows that experts work effectively in the "near panic" mode where they immediately recognize a best or near best alternative without vigilant scanning of other alternatives.

Unfortunately, Janis & Mann [22] do not provide either (1) precise threshold values (Ω_i) that indicate when decision makers trigger a change in coping style, or (2) any insight into how to integrate the many diverse stimuli, factors, or PMFs that determine stress and time pressure or risk. For these purposes, at present we use logic rules to combine these three factors. For example, such rules must account for facts such as a Very High value of anyone of the factors could push the agent to panic. However, panic is more likely if at least one factor is very high and another is high. Or alternatively, if one factor is very high and both of the others are moderately high, panic might also result. At the other end of the spectrum, as another example, all three factors must be very low to result in unconflicted adherence. These two rules are listed below, and similar ones exist for each of the other threshold cutoffs. At present we do not have empirical verification for these threshold levels, but this seems to work in the simulations attempted thus far..

		ES(t)	TP(t)	EF(t)
Panic (ISTRESS>= Ω5)	=	VERY HIGH +	HIGH or	
		VERY HIGH +	MEDIUM HIGH	+ MEDIUM HIGH
Unconflicted Adherence (ISTRESS<= Ω1)	=	VERY LOW +	VERY LOW	+ VERY LOW or ~0

The results of physiology and stress are thus a bounding on the parameters that guide the agent's decision or cognitive subsystem and that dictate the coping style it is able to select. These parameters and decision style constraints do not in themselves provide any guidance on how to construe the situation, on the sense-making that needs to go on. For that we turn to the emotion subsystem.

2.2) **Emotion Appraisal as a Deep Model of Utility**

In particular, the emotion subsystem recieves stimuli from the sensors as adjusted and moderated by the physiological system. It includes a long term associative or connectionist memory of its concern ontologies that are activated by the situational stimuli as well as any internally recalled stimuli. These stimuli and their impact on the concern ontologies act as releasers of alternative emotional construals and intensity levels. These emotional activations in turn provide the somatic markers that serve as situation recognition and that help us to recognize a problem that needs action, potential decisions to act on, and so on. In order to support research on alternative emotional construal theories this subsystem must include an easily alterable set of activation/decay equations and parameters for a variable number of emotions. Further, since construals are based on concern ontologies, this module must serve as a concerns ontology processor and editor. Simply by authoring alternative concern ontologies, one should be able to capture the behaviors of alternative "types" of people and organizations and how differently they would assess the same events, actions, and artifacts in the world. This requires the emotion module to derive the elements of utility and payoff that the cognitive system will use to access alternative actions.

In the next section we will examine how to combine multiple emotions into a utility estimate for a given state. For now we will only examine how our different emotions arise when confronted by a new state, s, of the world, or in reaction to thinking about being in that state. In general, we propose that any of a number of ξ diverse emotions could arise with intensity, I, and that this intensity would be somehow correlated to importance of one's values or concern set (C) and whether those concerns succeed or fail for the state in question. We express this as

$$I_x(s_k) = \sum_{j \in J_x} \sum_{c \in Cijkl} [W_{ijl}(c) * f1(r_j) * f2(O,N)] \qquad (2.0)$$

Where,

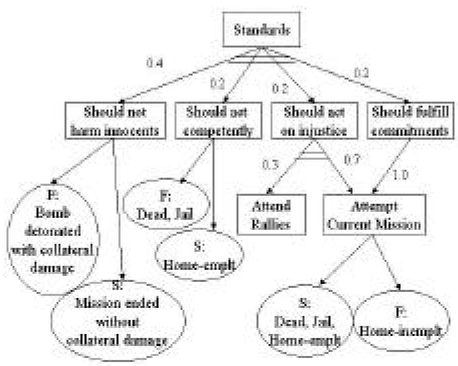
$I_\xi(s_k)$	=	Intensity of emotion, ξ, due to the kth state of the world
J_ξ	=	The set of all agents relevant to x . J_1 is the set consisting only of the self, and J_2 is the set consisting of everyone but the self, and J is the union of J_1 and J_2.
$W_{ij}(C_{ijkl})$	=	Weighted importance of the values of agent j that succeed and fail in one's ith concern set.
C_{ijkl}	=	A list of paths through the ith ontology of agent j triggered to condition l (0=success or 1=failure) by state k.
$f1(r_{jk})$	=	A function that captures the strength of positive and negative relationships one has with the j agents and objects that are effected or spared in state k
f2(O,N)	=	A function that captures temporal factors of the state and how to discount and merge one's emotions from the past, in the present, and for the future

This expression captures the major dimensions of concern in any emotional construal – values, relationships, and temporal aspects. For the sake of simplicity, we assume linear additivity of multiple arousals of the same emotion from the i=1,I different sets of values that the state may precipitate.

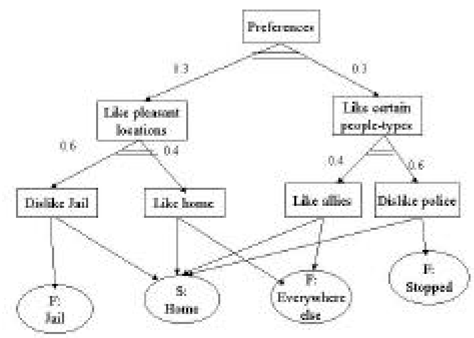
There are several emotion models from the psychology literature that can help to provide greater degrees of detail for such a model, particularly a class of models known as cognitive appraisal theories. These include the models mentioned earlier [15-17] that take as input a set of things that the agent is concerned about and how they were effected recently, and determine which emotions result. Most of them fit into the structure of equation 2.0 but they have different strengths to bring to bear. At present we have decided to pursue the OCC model [15] to see how it helps out. In the OCC model, there are 11 pairs of oppositely valenced emotions (ξ). One pair we use here as an example is pride-shame. Another pair we mentioned earlier was hope-fear for future events. One can experience both emotions of a given pair at the same time and if their intensities are equal, they cancel out from a utility perspective.

The OCC model assumes a decision making agent has 3 types of concern trees about the world: goals for action, standards that people should follow, and preferences for objects. Let us suppose as in Figures 3a & b that we have a terrorist agent who has two concern trees (let |C| = 2): one for standards (i=1) about how agents should act and one for preferences about objects or artifacts in the world (i=2). Of course any such agent would have many more concern trees and each might be more richly filled in, but these will suffice for the sake of the example. And in fact, the stopping rule on filling in concern trees for any agent is the limit of what behavior is needed from them in the scenario or micro-world in question. One can see from Figure 3 that concern trees bottom out in leaf nodes that can be tested against elements (events, actions, nearby objects, etc.) of the current state, k. Further, concern trees hold an agent's previously learned values or importance weights. Each link of a concern tree is labeled with a weight, w, and the sum of child weights always sums to 1.0 for the sake of convenience. The children can be either strictly or non-exclusively conjunctive or disjunctive.

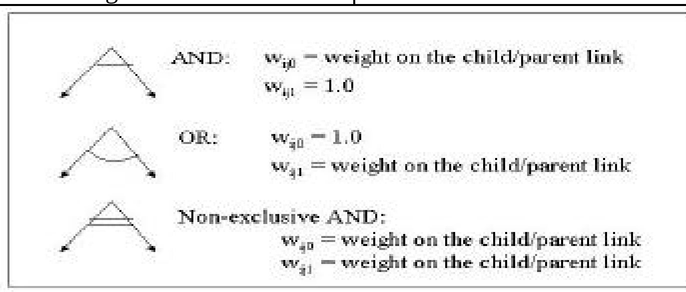
Figure 3 – Value Ontologies Showing Part of the Standards and Preferences of a Sample Terrorist



3a – Terrorist's Standards for Agent Behavior/Action



3b – Terrorist's Preferences for Artifacts or Objects



Thus far in our research we have derived the structure and weights on these trees manually as part of the process of building agents for a given micro-world, though one could in principle derive these trees via machine learning and knowledge discovery when interacting with a news event dataset about a given terrorist group. The way we use these trees in Equation 2.0 is as an evaluation function for Wi. That is, when a given state of the world causes a leaf node to fail or succeed, that leads to the wi being multiplied together up the branch of the tree from leaf node to root, and the overall Wi of that concern tree is computed. This may be expressed as:

$$W_{ijl}(c) = \sum_{appearance \ s(C_i)} \prod_{C_i=c}^{C_i=root} w_{ijl}(c_i, parent\ (c_i)) \qquad (2.1)$$

where,

ci	=	child concern or node
parent(ci)	=	parent node

As an example of Equation 2.1, consider how the use of the trees of Figure 3a&b result in the weighting on a strategy resulting in being dead. Upon the agent contemplating his death (k="dead"), no preferences (i=2) are caused to succeed or fail by being dead. Consequently, no prefernce-based emotions emotions would be generated from this agent's object preference ontology. However, k='dead' does effect the agent's standards tree and one standard (i = 1) directly succeeds and one fails. He feels pride at having attempted his mission (c="attempt current mission") for two reasons: he has fulfilled his commitment to the organization, and has attempted something to correct a perceived injustice.

$$C_{1,1,k,0} = \{\text{"attempt current mission"}\}$$

$$\begin{aligned}
W_{1,1,0}(\text{"attempt current mission"}) = \sum_{appearance\ s(c)} \prod_{c_i=c}^{c_i=root} w_{ijl}(ci,\ parent(c)) \\
&[w_{1,1,0}(\text{"attempt current mission"}, \text{"fulfill commitments"}) * \\
&w_{1,1,0}(\text{"fulfill commitments"}, \text{"standards"})] + \\
&[w_{1,1,0}(\text{"attempt current mission"}, \text{"act on injustice"}) * \\
&w_{1,1,0}(\text{"act on injustice"}, \text{"standards"})] \\
&= [0.7 * 0.2] + [1.0 * 0.2] \\
&= 0.14 + 0.2 \\
&= 0.34
\end{aligned}$$

r_{1c} is 1.0 by definition, as the cognitive unit with one's self is always perfect.Since we are only considering the feelings of one agent, J is the singleton set {1}.

$$\begin{aligned}
I_{pride}(\text{dead}) &= \sum_{j \in J} \sum_{c \in C_{1,1,1,k}} W_{1,j,0}(c) * r_{1c} \\
&= 0.34 * 1.0 \\
&= 0.34
\end{aligned}$$

However, his mission involved returning home safely, which is clearly thwarted by failing to survive. Consequently, he will feel shame at his incompetence as well:

$$C_{1,1,k,1} = \{\text{"act competently"}\}$$

$$\begin{aligned}
W_{1,1,1}(\text{"act competently"}) &= w_{1,1,1}(\text{"act competently"}, \text{"standards"}) \\
&= 0.2
\end{aligned}$$

$$\begin{aligned}
I_{shame}(\text{dead}) &= \sum_{j \in J} \sum_{c \in C_{1,1,k,1}} W_{2,1,1}(c) * r_{1c} \\
&= 0.2 * 1.0 \\
&= 0.2
\end{aligned}$$

On balance, in the current state, pride slightly outweighs shame at being a martyr. Whether an agent's decision subsystem would choose death, however, is also a function of its iSTRESS or Ω level and of its current goal tree construals, a topic we omitted from this example due to space considerations, though we illustrate a goal tree construal in Sec.3. Also omitted from this discussion are several other dimensions of the agent's reasoning in social situations, a few examples of which are: (1) construing relationships to others in the scenario that the agent likes, dislikes, etc.; (2) explicit modeling of partial knowledge of the emotions of those others to further guide his own actions; (3) assigning credit/blame to others for various actions and events; and (4) managing likelihood and temporal factors. The OCC model provides a number of inroads into how to handle these and we address them rather fully, along with a number of open research questions, in [21].

2.3) Game Theory and the Cognitive Susbsystem

The cognitive subsystem serves in our model as the point where the diverse emotions, stressors, memories, and other factors are all integrated into a decision for action (or inaction) to transition to a next state (or return to the same state) in the Markov decision process (MDP) sense. In essence, at each node of the Markov chain (and at each tick of the simulator's clock) each agent must be able to process the following information: the state name (or ID); the allowable transitions and what action might cause those state transitions (a_{nm} in A(iSTRESS)); current intentions as provided in a task list or plan and the intentions of their prior actions; expectations of what other agents are going to do in this state based on recent history and other memories/beliefs G(A, U, C); desires for actions based on the 11 pairs of emotional scales ($I_\xi(s_k)$ where $\xi = 1,22$); stress-based coping level (Ω_i where i = 1,5); and a mood, μ, that we discuss below. Using all this information as stimuli, the agent must select a decision style, Φ, also defined below, and process the stimuli to produce a best response (BR) that maximizes expected, discounted rewards or utilities in the current iteration of the game. The cognitive subsystem is thus governed by the following equation:

$$\text{BEST REPLY } (BR_t) = \Phi_{\mu,\, iSTRESS,\, \Omega}\{U_{mn}\,(s_t\,,\, a_{mnt}\,),\, p_{mn}\},\ \text{subject to } a_{mnt} \in \ A(iSTRESS) \qquad (3.3)$$

Where,

$\Phi_{\mu,\, iSTRESS,\, \Omega}\{.\}$	=	as defined below for the alternative values of μ, iSTRESS, and Ω
p_{mn}	=	perceived probability = $(1 - \Delta)\, e_m + \Delta_{m\tau}\, p_{m\tau}$
u_{mn}	=	(1-δ)x(U from equation 3.1)
Δ	=	memory coefficient (discounting the past)
τ	=	number periods to look back
e_m	=	$\begin{cases} 0 & \text{action m not situationally relevant} \\ 1.0 & \text{action m is situationally relevant} \end{cases}$
δ	=	expectation coefficient (discounting the future)
A(iSTRESS)	=	action set available after integrated stress appraisal (*see Section 2.1*)

We assume utilities for next states are released from the emotional activations. The previous section used the OCC model to help generate up to 11 pairs of emotions with intensities (I_ξ) for the current and/or next state of iterative play. Utility may be thought of as the simple summation of all positive and negative emotions for an action leading to a state. Since there will be 11 pairs of oppositely valenced emotions in the OCC model, we normalize the sum as follows so that utility varies between –1 and +1:

$$U = \sum_{\xi} I_\xi(s_k)/11 \qquad (3.1)$$

While one can argue against the idea of aggregating individual emotions, this summation is consistent with the somatic marker theory. One learns a single impression or feeling about each state and about actions that might bring about or avoid those states. The utility term, in turn, is derived dynamically during each iteration from an emotional construal of the utility of each action strategy relative to that agent's importance-weighted concern ontology minus the cost of carrying out that strategy. We further introduce a modifier on the emotional construal function – the first is a discount factor, δ, that more heavily weights game achievement the closer the agent is to the end of that stage of the game. Thus an agent might be conservative and construe survival as more important early in the game, yet be willing to make more daring maneuvers near the end point.

In terms of the perceived probabilities of Equation 3.0, at present we simply pre-specify these by hand. Eventually we hope to use these to introduce factors such as, for example, an agent who has discounted the vulnerability of himself and his comrades (prior probability of being hit) will consequently lower his estimated probability of losing the battle. Or a nervous soldier will tend to overestimate his probabilities of significant failures (risk averse on the prospect of a heavy loss), etc. This brings us to the earlier discussion about time pressure (TP) and how it effects decision making. At present all actions carry an ideal time to complete estimate (T_I) and the simulation generates an available time (T_A). We earlier mentioned the equation for TP is derived from these factors, but omitted the idea that as TP increases it directly impacts probability or P. Thus the less time we have to complete a task the less likely the task outcome will be successful.

It is useful to now turn to the discussion of the decision processing style function, $\Phi_{\mu,\ \mathrm{iSTRESS},\ \Omega}$. There is a large literature on decision style functions (e.g., among many others see [4, 9-10, 14, 20-24]), and the discussion here is merely to indicate that there is a rich set of possibilities that one can explore within the framework proposed here. We begin by indicating how the various components of iSTRESS (beyond just TP) and coping level (Ω) might impact upon an agent's choice of decision style. The rules for selecting a decision processing style are a matter for extended research, something beyond our current focus. Our goal here is only to show an illustrative set of rules that we are now working with and the idea of providing a mechanism for evaluating alternative rules that may exist in the literature such as in those references just mentioned. As do [22], we postulate that a balanced emotional construal of all values is something that happens only under vigilance at moderate stress levels. As event stress approaches very close to zero, one tends to do drop into unconflicted coping states and one does not invoke the emotional capabilities for situation recognition or for recognition primed decisionmaking [24]. At the other extreme, as event stress approaches some upper threshold, only the physiological concerns become significant and, once panic sets in, one tends to cower in place (if its safer) or run wildly away if not as in [8, 22]. Also, as do [25], we assume that being fatigued puts one in a state of wishing the world would slow down, and hence one tends to reduce the importance of values about higher level goals (ie, those above physiology and rest), and remote objects. We thus use the following as a guide to adjust the settings of all the equations presented in this paper.

Emotional Construal of Stress Components (impact of iSTRESS in $\Phi_{\mu,\ \mathrm{iSTRESS},\ \Omega}$)

Near Zero Event Stress:	use initial task plan and don't call emotion model (no situational construal) Ignore probabilities and apply criterion of optimism (maximax)
High Event Stress:	same as near panic (see below)
Fatigued (EF):	reduce all positive goal- and preference-based positive emotions (become timid). ignore probabilities and apply Wald's criterion of pessimism (maximin)
Time Pressure (TP):	primary impact is to reduce probabilities of success for an action as TP increases

Alternative Coping Strategies (impact of W on $\Phi_{\mu,\ \mathrm{iSTRESS},\ \Omega}$):

Vigilant:	use classical expected utility formulation (maximin)
Unconflicted:	same as Near Zero Event Stress (see above)
Denial:	ignore emotional construal (ignore situation). reduce probabilities of any dis-utile things down to zero (disbelief of negatives). base choice of action on minimum regret criterion
Near Panic – Expert:	same as vigilant
Near Panic – Non-Expert:	as in Equation 2.0, ignore situation and emotion, and randomly choose 1 of M actions available or base choice on minimum regret
Panic:	If feel safe at current location, then remain rooted Else, drop artifacts (e.g, weapon, tools, etc.) and run blindly away from threats

In the future, we hope to use mood to further guide the choice of decision criterion as described in [21].

2.4) Motor/Expressivity Subsystem

We complete the discussion of earlier Figure 1 by turning now to the motor/expresive subsytem. This module contains libraries of stored procedures that allow the agent to interact with the microworld and that allow it to display its motor and expressive outputs. Based on stimuli from all the other susbsystems, the motor subsystem recalls, activates, and adjusts the relevant stored procedures so it can perform the actions intended to reach the (best reply) next state. In attempting to carry out the actions the motor system seeks to carry out best reply actions and perform up to the limits that the physiologic system imposes and by expressing the emotions that currently dominate. To support this effort, those procedures include functions that allow them to portray alternative behaviors (e.g., fatigue leads to slower rate of movement across the screen). Also, the motor system serves as a stimuli to the other systems. For example crouching for a long period might cause fatigue, pain, emotive distress, and so on.

3.0) Case Study: Emergent Crowd Behaviors

We have attempted an initial, prototype implementation of our cognitive agent architecture to demonstrate how one might apply it to model the impact of alternative personas and motivations upon crowd behavior. This is not the final word on how to model crowd motivations and behavior, rather this is an attempt to illustrate the range and flexibility that the architecture supports. There are several diverging theories of how crowds turn into mobs, of how violence spreads in a community, and of how community opinion is polarized. One would ideally like to enable the modeling of any of these alternative theories and observe their impact upon a simulated community.

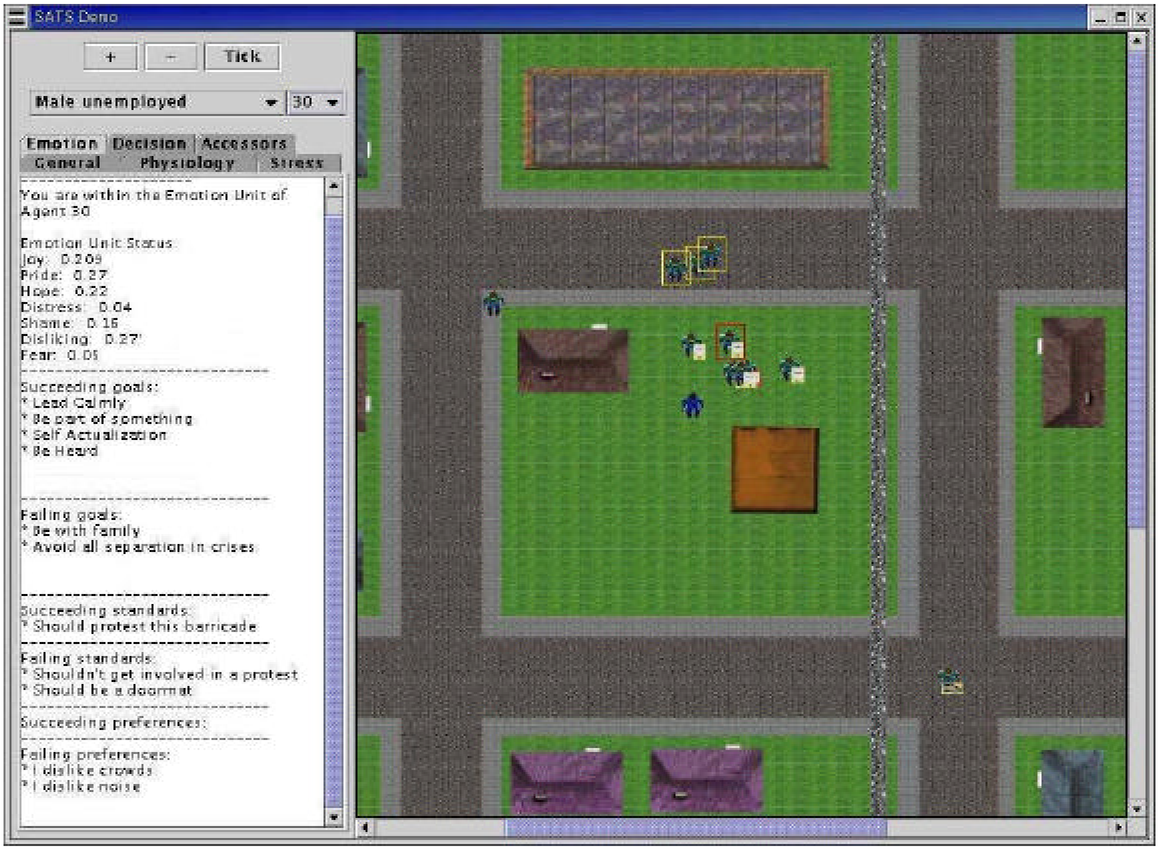
In particular, the scenario we constructed (see Figure 4) involves a microworld consisting of a poor population (Havenots) living in one half of a land and a wealthy population in the other half (Haves). A guerilla group has sprung up in the poor area. In the larger campaign, the guerilla group seeks to overthrow the established authority by conducting a number of missions to shift (meta-game) popular opinion of their supporters in their favor and to instill fear in the population of their enemy. Up to the point shown in Figure 4, they have successfully bombed several targets in the area of the Haves such that the Haves felt compelled to construct a barricade to close off access to their part of town (right side of Figure 4). It turns out that most of the jobs are in the area controlled and now barricaded by the Haves, so the Havenots organized a protest event at the checkpoint of the barricade. The guerilla group intends to send a provocateur to the protest. Figure 4 shows a small group at the outset of the protest, marching around in picket line formation in front of a security guard at the checkpoint.

So this scenario raises the prospect of researching the integration of (1) low level contributants to human behavior from a number of stressors (noise, light, crowd proximity, etc.), adrenal vs. fatigue factors, and other physiological factors, (2) emotion-guided decision-making at the individual level for the protestors as well as for the security force, (3) behavior emergence and social interactions of crowds, and (4) potential media impacts on the population at large. This simple scenario requires one to model terrorists, defenders, civilians, crowd dynamics, population opinion evolution, and so on.

To support viewing the internals of all these agents, on the left side of Figure 1 is a set of agent identifiers/pulldowns and window tabs. One of the pulldowns allows the user to select a type of agent such as terrorist, defender, or civilian (including up to five types of civilians such as unemployed male, employed male, female, etc). When this is selected, the agents in the microworld who fit that description are all highlighted. Another pulldown permits one to select a specific agent of that type (e.g. agent ID 30), and this agent is then further highlighted with a red box encasing them wherever they go in the microworld. For the selected agent, there are several tabbed windows also on the left side of Figure 1 – general, accessors, physiology, stress, emotion, and strategy – that allow one to inspect what that agent experiences, feels, and thinks about the microworld. Accessors are the agent's sensory capabilities and these include what the agent is able to see, hear, and feel as well as their memory. Physiology includes eight factors at present such as exertion, nutrition, damage (wounds), and so on. Stress in turn summarizes the accessors and physiology into the three integrated stressors as well as the overall ? level and allows one to view the agent's current fatigue level, event stress, and time pressure (if they are performing a task) as well as their overall ? or integrated stress level, from which one can tell if they are vigilant, panicked, etc. The emotion tab reveals up to 11 pairs of OCC emotions that the agent currently feels as well as the arousal levels of each of those sorted by goals, preferences and standards. We do not currently display the agent's feelings about each of the other types of agents in the microworld, but these do exist within the agent's "mind". Finally, the strategy tab displays the actions the agent has been thinking about and the utility he assigns to each alternative, as well as the action choices and any ongoing task or actions (a_{it}) stack the agent is attempting to process. Thus one could detect if an agent is attempting to carry out a planned set of tasks (e.g., attend the picket, march in the picket, and return home when it is over), has interrupted the plan with an opportunistic task (go on a rampage with the crowd), and/or has abandonned the intended task (e.g., escape area and return home). From these various tabs one can thus piece together the agent's beliefs, desires, and intentions of the moment.

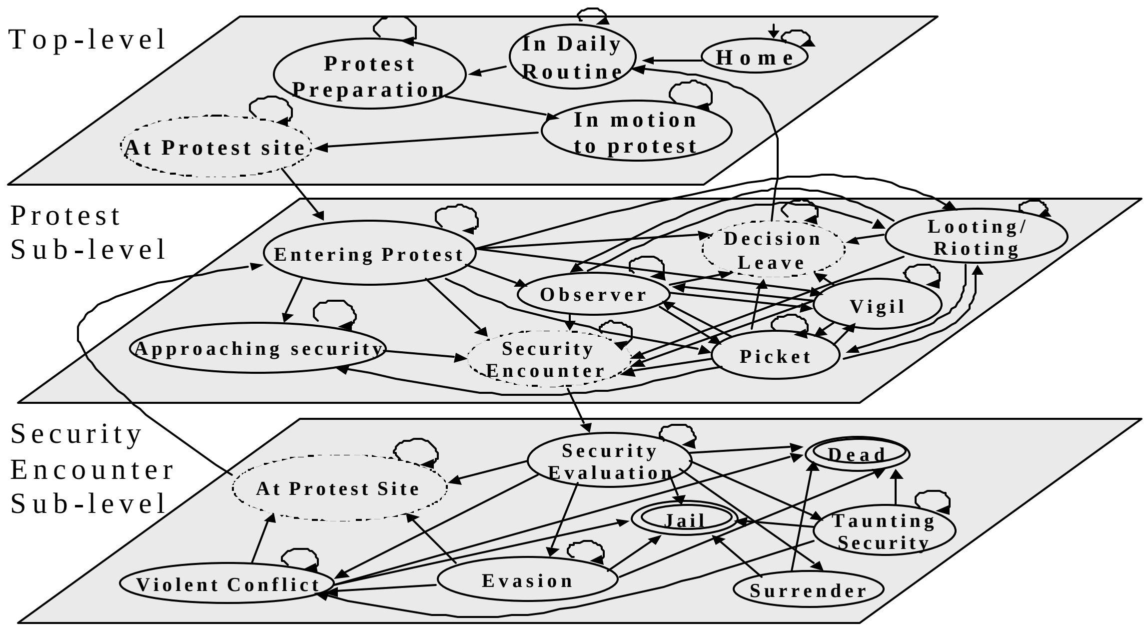
There are two basic modes of usage intended for the microworld – participant and analyst. At present the participant mode is unavailable, although we are developing the necessary realtime interfaces to support it. In participant mode, one realtime human player will be able to direct the policies and behavior of the defenders, acting as a leader of the security forces. This player would interact with the world in the effort to prevent, mitigate, or otherwise manage potential bombing incidents, crowd protest scenes, and other peacekeeping activities. At present, the role for human participants is via analyst mode in which they use the editors to try out their doctrines and policies and see if the scenario unfolds differently with different policies and doctrines in place for the security forces. Also, the viewing panels on the left of Figure 4 permit one to observe how alternative settings for all microworld participants work and interact.

Figure 4 – Screen Shot of the Protest Scene in the Land of the Havenots Showing Observers on the Road, Picketers Holding Placards, and a Sole Security Agent Facing the Crowd. Also, the Panel on the Left Shows the Detail of the Emotion Layer of One of the Unemployed Male Picketers



Let us examine a portion of the scenario in more detail so one can better see how analyst mode works and how the diverse agents determine their motives, and carry out their actions. The instigator agent sent by the guerilla group to the protest has a portion of his Markov chain that deals with attending protest events, alternative actions at the protest, encountering security, taunting them, and precipitating violent reactions from them as Figure 5 reveals. Using sources such as [2, 10, 11, 23] we have derived a representative concern ontology of a terrorist-provocateur and how he might be motivated to act in a non-violent protest scene. He has a concern ontology as shown in Figure 6 that includes strong weightings on his goals for belonging (to his terrorist cell), esteem from taking action (they tend to be young males who are action-prone), and self-actualization due to reaching for ideals of freedom. Each of these lower level goals are positively aroused by taking action against the security forces. Likewise his standards reveal a tendency to react strongly to anyone responsible for the barricading of his countrymen and denying them their freedoms. These are the elements that permit him to carry out the mission assigned to him of taunting the checkpoint guard and of attempting to provoke the guard into committing an act that will escalate the scene. By contrast, employed civilian males have the same Markov chain as instigators, but we model their concern ontology so they feel inhibited to either just observe the protest, or to avoid it altogether. This is due to the fact that they have a much higher weighting under their goals for avoiding security forces and by that for keeping their job. Also, they have standards for being obedient in front of authority.

Figure 5 – Portion of an Agent's Markov Chain Showing Some of the Hierarchy of Games He Can Engage in During Protest Scenes (G=G(A,C))



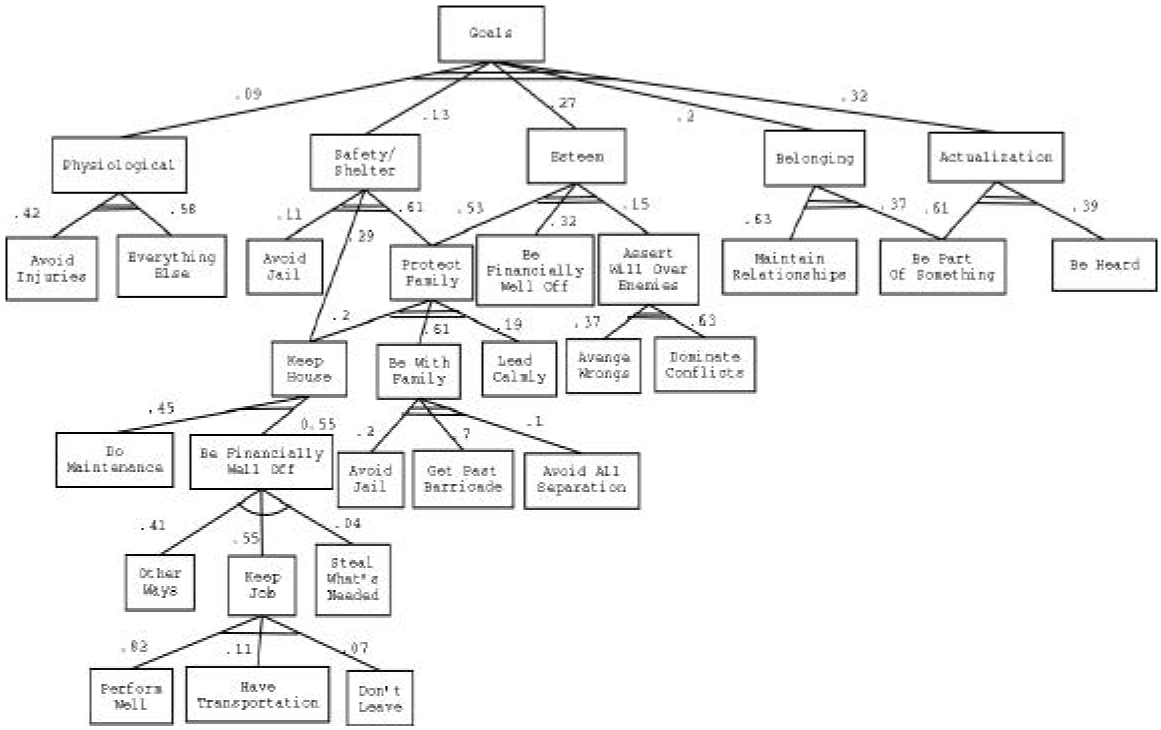
Social psychologists have studied factors that contribute to aggressive crowd behavior: e.g., see [5,6 among others]. There is not uniform agreement on the particulars, but in general the common factors that tend to contribute include: presence of weapons, authoritarian government, lining up behind a barricade, drawing lines between "us" and "you", dramatizing issues (e.g., in a speech) and making victims, large spatially concentrated crowds, and presence of television camera and crew.

Violent crowd behavior is fairly rare and generally requires a buildup of tensions over a series of perceived injustices along with poor performance by the agents of social control (ie., the police or security forces). Also, rioters do not tend to be criminals, but they do tend to be the "socially available" -- i.e., the unemployed, single, young males without children.

Our scenario includes a majority of these contributing factors. The bulk of attendees drawn to participate in the protest are the socially available (unemployed, young, single, childless males). This is because these attendees do not have the inhibitions in their concern ontology that exist for the female, employed male, and other members of the Havenot township. Their concern ontologies are closer to that of the terrorist instigator in terms of goals and standards, though they are untrained in handling security forces, have less idealism, and are more concerned about personal gain. They are therefore susceptible to crowd effects, and to a tipping event that sets them on a rampage including rioting and looting.

The tipping event occurs when the instigator is struck by the checkpoint guard (a neophyte in proper crowd dispersal tactics), an event that is observed by those near the front and communicated loudly. While it appears to obeservers of the microworld as a simple tipping event, this is really more of a chain of reactions atop a number of conducive conditions such as the presence of the barricade and security's weapons, the types of people at the protest, the naiveté of the security force and their inability to take any effective dispersal actions, the sudden creation of a new victim, the noise and exhortations to action. All these contribute to the intense emotional arousal of the crowd. Specifically, at the moment of realization that violence has erupted, the protesters must confront a number of issues. Primary among these is the fact that the protest has in all likelihood failed, leading to their hope for the barricade's removal dissolving into disappointment. They also must face the increasingly real possibility of becoming the target of violence themselves, leading to fear that can only be alleviated by leaving the protest. Depending on their resolve to see the barricade dismantled, for some there will still be enough hope to keep them involved in the protest, but for the majority this is not the case.

Figure 6 – Overview of the Goal Portion of the Concern Ontology of an Agent Provocateur



Yet where most find despair, others see opportunity. There are insufficient security forces present for the relative size and density of this crowd, a fact the young males notice. The erupting chaos provides a perfect diversion for those who would solve their financial problems with the unwilling help of local storeowners and with little fear of encountering police in the process. While many of these protesters are checked by the shame that such an act would cause, for some, particularly those whose standards have been suppressed by physiological arousal, the benefits are too tempting to ignore. And when the equilibrium of the event tips from picketing to rioting, the young unemployed males also target nearby stores and loot them for material items. Here they are addressing a variety of problems caused by their financial hardship, from having cash to pay the rent to having a new gadget to entertain them.

Finally, after a period of rioting it ends due to several things, not simply the arrival of a large security force. Before that, several factors take effect on the rioters including, the return of inhibitions over time due to baser emotions being fullfilled and standards resurfacing, the satisfaction of self-indulgence motives when looted items are obtained, and a growing sense of guilt and shame as they destroy Havenot property. So there are less rioters and looters on the scene by the time the security forces arrive. For all these reasons, the equilibrium is eventually restored to that of a resentful, though not openly violent populace in the Havenot township. We have not yet modeled the aftermath, the propagation of emotions across townspeople, or the media impacts of various groups messages and spin of the events for the sake of influencing the populace. But we do have the apparatus to propagate such message sets and let the townfolk process it, and we hope to add this later on.

4.0) Conclusions and Next Steps

To summarize, diverse communities are interested today in building realistic human-like behaviors into virtual personas. The animation and graphics approaches have lead to kinesthetically appealing and reactive agents. A few such investigators are now seeking to make them more behaviorally and cognitively realistic by reaching out to the artificial life, evolutionary computing and rational agent approaches. These approaches offer many benefits, but they need to be grounded in the behavioral literature if they are to be faithful to how humans actually behave and think. The behavioral literature, however, while vast, is ill-prepared for and cannot be directly encoded into models useful in agent architectures. This sets the stage for the goals and objectives of the current research.

A major challenge of this research, is the validity of the concern system ontologies and behavioral models we derive from the literature and try to integrate within our framework. As engineers, we are concerned with validity from several perspectives including the (1) data-groundedness of the models and ontologies we extract from the literature, (2) coherence of the agents' choices relative to theoretic predictions, and (3) correspondence of behavioral emergence and collectives with actual dynamics observed in the real world. In terms of data-groundedness, we conducted an extended review of the behavioral literature [21] and found a great many physiological studies that seem to be legitimately grounded and that possess model parameter significance from a statistical sense. However, these tend to be restricted to the performance moderator functions that feed into the individual reservoirs or components of the physiological subsystem. As soon as one tries to integrate across moderators and synthesize the iSTRESS (or even effective fatigue), one rapidly departs from grounded theories and enters into the realm of informed opinion. The problem only grows worse for the emotion subsystem, and for the cognitive layer if one hopes to incorporate behavioral decision theory, crowd models, and the like. And the informed opinions one encounters in the behavioral literature are not consistent. One must choose one's "experts" and opinion leaders. Its almost enough to make one forego deeper modeling, and to toss in with the 'believable agents' movement.

We have resisted that temptation believing that forward progress out of this groundedness swamp could be assisted by an integration framework, a roadmap or skeletal structure of what is needed and what is missing. We have tried to provide one such roadmap in this paper. This is not the penultimate roadmap or plan, rather it is at present a humble structure. We use simplifying assumptions and linearities throughout it. Our current bank of models within each subsystem are drawn from the literature, but we hope to revisit them and replace them piece by piece as time allows, and as new, better versions of the literature appear. We have striven initially for satisfying a workability test. That is, we set out to attempt to learn what we could gain by having viable models integrated across all 4 subsystems and across factors within each subsystem. In that regard, our efforts to date are successful. We now have an integrated fabric stitching together the models of varying groundedness and of different opinion leaders. We can rather easily plug in a new opinion leader's model and play it within our framework to study its impact, its properties, and its strengths and weaknesses. In this sense we think we have made progress over a hard-wired 'believable agent' set of behaviors, or at least we have stored-potential for progress.

In terms of the second validity concern, that of coherence, a colleague pointed out that we claim to be modeling differences in abilities, experience, culture, and so on, yet our ontologies are often created for a stereotyped agent (e.g., one ontology for all young, unemployed, Havenot males). Rather than a theory of individual differences, aren't we propagating a theory of central tendencies? In reality people have innumerable differences in goals, preferences and standards that will create nuances in construals that we can never hope to capture faithfully. The response to this criticism is in part that it's inaccurate, and in part that it's not relevant at present. Let me explain. What's inaccurate is that two agents with the identical concern ontology will in fact construe the world the same. Each agent experiences the virtual world through what they see and hear, and through what effort they have expended to date. A fatigued agent may operate at a different stress level than a rested one, and two agents at the same event may not see or encounter all the same facts. Also, we use a random number generator to perturb the weights slightly around the mean when each agent in a class is created. So a number of individual differences may, and in fact often do, emerge as "freebies" of the integrated framework. Further, in terms of relevance, for the type of training systems we are currently attempting to create, there is significant value in acquainting the trainee with a stereotyped crowd behavior, or a prototypically IRA vs. Hamas type of mission. The 'signatures' on these groups' missions do have a central tendency and that tendency varies from group to group. Subject to our available time and effort, however, we can program numerous ontologies to further distinguish individuals in these groups.

Finally, we offer no defense at present for our failure to have conducted correspondence tests. Its true that the agents may be observed to progress through various Ω levels (unconflicted adherence on the during daily routine, vigilant upon arriving at the protest, and panic during the looting) and the OCC model makes use of the noise reservoir, crowd proximity, and an array of goals, preferences, and standards to generate emotions that appear consistent with what crowds probably feel. However, we simply haven't matured this research to the point yet where we are able to recreate specific historical crowd events from the real world, and to see how well our models are able to simulate actual emergent behavior. That is, however, a vital next step for improving our models past simply being "believable" and for increasing trust in what is produced.

Despite this triumvirate of validity concerns, there have been some lessons learned to date:

- The literature is helpful for improving the realism of behavior models – There is a tendency in the engineering community to construct subsystem models unaided, believing no good could come from consulting the behavioral literature (e.g. see [3]).We have completed an indepth survey of the literature and have found a number of models that can be used as the basis of cognitive models for agent behavior. In fact the problem is less that there aren't any models, so much as the fact that there are too many and none of them are integrated. The bulk of the effort we undertook to date is to document those models, and to figure out how to integrate them into a common mathematical framework.

- There are benefits (and costs) of modeling stress-emotion-decision processing as an integrated topic – In attempting to create an integrated model, the benefits of this approach are that it is more realistic to try and deal with the interplay. Certainly these dimensions are connected in people, and the ability to address all of them in simulations opens up a large number of possibilities for improving agent behavior and for confronting trainees with more realistic scenes. These benefits are not cost-free, and it is expensive in terms of game developers' time to try and learn all these factors, and to adapt them so they fit the scenarios of interest. Perhaps more importantly, there is no single validated theory for integrating these elements, and the result may be appealing but ungrounded.

- Concern ontologies are vital but require ontological engineering– The approach we presented in this paper relies on a common mathematical framework (expected utility) to integrate many disparate models and theories so that agents can assess preferences and standards and determine next actions they find desirable subject to stress induced limitations and bias tendencies. However, to do this properly for any given simulation will also require extensive ontological engineering to flesh out the lower levels of the concern ontologies. Our current efforts are aimed at adding a set of tools for authoring, maintaining, and visualizing these ontologies.

- Emotion models are useful for utility and decision making not just for expressivity – A related contribution of this paper lies in the use of ontology-derived emotion not just for animation effect or for believable reactions, but also to help derive utilities dynamically. In standard decision theoretic models there is no basis for agents to compute their own utility functions. Instead these are derived by subject matter experts and inserted directly into the agents decisionmodule. In the approach postulated here, the subject matter experts would interact at a stage earlier, at the stage of helping to define the concern ontologies so that the agents can derive their own utility functions, values, and tradeoffs. This approach frees experts from having to infer utilities, and it places the debate more squarely on open literature accounts of value sets and concern ontologies.

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