Social Network Influences on Strategic Choices

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Abstract

The decision space of international conflict is not confined merely to resource acquisition, expected payoff optimization, or political negotiation. There is a recognized social aspect involved in conflict of multiple (>2) parties; however it is traditionally neglected as either insignificant or analytically intransigent. On the other hand, there exists a substantial literature on these social aspects - belief and trust formation and social influence - in social network theory, but it decouples these beliefs and influences from decisions and actions. This paper attempts to resolve the deficiency in traditional conflict models by applying social network methods to multi-agent conflict situations. Specifically, methods of network representation and derivative relationships, and methods of belief and belief propagation through social networks are discussed. Based on these methods, a method for predicting agents' decisions in conflict scenarios is developed. Finally, a method of simulation using the Complex Organizational Reasoning Simulation (CORES) is presented.

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1. Introduction

Conflict is, by definition, a social interaction - either 'diplomacy carried on by other means' *a la* Clausewitz, or as a facet of a more complex interaction. This social interaction is not merely an accident of the juxtaposition and interaction of the participants in the conflict but a determinant of the actors' participation in and perception of the conflict. Granted this, this paper describes a model of decision making in conflict situations that explicitly models the interactions between allied, interacting, and conflicting parties. This problem is of specific relevance to both current events and the current academic literature on conflict decision making. The decision space of conflicts is not confined merely to resource acquisition, expected payoff optimization, or political negotiation; areas covered extensively in various academic fields. The social aspects involved in conflict of multiple parties are traditionally neglected as either insignificant or analytically intransigent. As low intensity or insurgent conflicts become more widespread, the need for a model of conflict that takes into account the social aspects of conflicts becomes more pressing.

In order to avoid a confusion of terms, a more precise definition of 'the social aspects of conflict' is in order. Ultimately, the 'social aspects' referred to in this paper refer to those facets of the conflict amenable to analysis with the methods of social network theory and organization theory. This concerns primarily actors' perceptions of other actors - influence, hostility, affinity; generally, phenomena describing relationships between actors. This also includes measurements of phenomena which are not strictly socially defined (*e.g.*, power) but which are affected by an entity's social relationships.

1.1 *Purposes of the model:* This paper seeks to develop a model of conflict scenarios in which the parties to the conflict interact socially. Specific phenomena defined and quantified in the scope of the model include:

1.1.1 Meta-matrix representation of conflict scenarios: A prerequisite for the use of many analytic techniques developed for social networks is a robust matrix-oriented method of describing conflict situations. A computationally tractable and readily scalable method of modeling (relatively) large numbers of entities is presented.

1.1.2 To describe a framework for conflicts in which the goals of parties to the conflict are not necessarily mutually exclusive; in which parties can act cooperatively or antagonistically. Incumbent upon this is a definition of goals in which the goals of conflicting parties can be correspondent and payoffs can be shared between actors.

1.1.3 To describe a model of social interaction in which actors' beliefs affect the actions they take; and the results of these actions and influential actors' beliefs affects the propagation of beliefs within the social network. For these purposes, 'beliefs' is taken to mean preferences regarding certain actions, hostility towards other actors, and social influence between actors (heretofore referred to as 'tactical preferences,' 'hostility,' and 'influence').

1.1.4 To combine the three methods developed and discussed above into a model that can generate probabilistic predictions of actor behavior and measurements of corresponding changes in actors' beliefs through the course of a specific conflict scenario.

1.2 *Topics discussed:*

1.2.1 Review of decision making and social network literature
1.2.2 Development of the model
1.2.3 Simulation and experimentation
1.2.4 Future usage of the model

2. Literature Review

A wide variety of literature addresses, directly or not, topics of interest to one concerned with a social representation of conflict. Of special consideration is the literature on rational decision making and economic models of conflict. These will be considered along with the organizational theory literature on friendships, power, network information, and reasoning. Finally, developments in the social network literature attempting to link it to economic models of conflict will be considered.

2.1 *Bargaining and Emotive models of conflict*

2.1.1 Bargaining models of conflict: The notion of military conflict as an extension of public policy is thought to be first formulated by Raimondo Montecuccoli in the late 17th century (Van Creveld 2000). This notion - of military conflict as an interaction between states (with corresponding goals) is critical to modern academic notions of conflicts (Schelling 1980; Van Creveld 2000). It is useful precisely for its great explanatory power - it defines both a ground for conflict and a system of evaluation for actions taken in conflict in the same breath.

There are two difficulties with this model that limit its applicability to a more general (*i.e.*, not specifically military) conception of conflict. First, necessary to this is an implict definition of the grounds of contention; barring that, a definition of the grounds of resolution (i.e., the kind of end state that the parties involved are working towards). Barring a definition of either of these, the ability of this model to explain actions in the conflict as advancing or retarding the participant's position breaks down (and hence, its explanatory power). Second, the bargaining model is most effective if the conflict is taken to be granted. It has distinct difficulty in explaining why conflicts do not happen, especially when the situations of either party are analogically equivalent to other situations where conflict existed.

2.1.2 Need for a social component to the conflict model: It is widely recognized in the literature of rational decisions in conflict that "we seriously restrict ourselves by the assumption of rational behavior - not just of intelligent behavior, but of behavior motivated by a conscious calculation of advantages, a calculation that in turn is based on an explicit and internally consistent value system" (Schelling 1966).

It would be remiss to argue that modeling the social interaction can explain away all of the 'irrationality' in real conflict situations; however, it can be used to effectively model behavior that is not internally consistent (at least without a organizational metric component to the definition of utilities) and is quite often NOT motivated by a conscious calculation of advantages.

2.1.3 Conflict models that incorporate social reasoning: The 'organizational behavior' and the 'governmental politics' models described by Alison & Zelikow in *Essence of Decision* are both examples of decision making models where the decision to be predicted are results of social interactions (Alison & Zelikow, 1999). Edward Luttwak described a state in which the bureaucratic apparatus was divided into separate and encapsulated units as a necessary precondition for a coup (Luttwak, 1978) - a thesis that is reminiscent of the governmental politics model but without the assumption that the factors within the government are working to the same (or even similar ends).

Both of these theories imply of the participants a level of ideological allegiance. In *Essence of Decision*, elements of the United States government interact with other elements to produce the United States' decision. This implication oversimplifies the problem, however - sub-elements of the individual organization (*e.g.,* agencies in the government) are no different in kind than other entities without formal affiliation to the analyzed organization.

2.1.4 Irrational determinants of conflict situations: To this point, the discussion has centered around rational models of conflict, their weaknesses, and expansions or variations on the theme. There is a wide literature on 'irrational' models of conflicts - *i.e.*, models in which the behavior of parties to the conflict is not modeled in terms of pursuit of identifiable goals with consistent value systems (*n.b.*, in order to avoid confusion with the negative connotations of 'irrational,' these models of conflict will be referred to as 'emotive'). While models of rational conflicts tend to take the conflict for granted, models of irrational conflict tend to take feelings of hostility or enmity for granted and argue that the existence of these feelings precipitates conflict.

The majority of the literature on these types of conflict centers on the Marxist notion of class warfare. Preexisting feelings of hostility between classes (caused by deprivation, etc.; but an explanation for the hostility is not necessary to the conflict model) cause conflict; conflict will not end until the class hostility ends (with the destruction of the bourgeoisie). More current literature focuses on conflicts between ethnic or religious groups - tribal conflicts in Africa, long-standing hostility between Israelis and Palestinian groups, or ethnic tensions in the Balkans (Halberstam, 2000). Halberstam, in particular, gives an extremely interesting description of rational political reasoning on the part of Slobodan Milosevic that explicitly exploited and propagated feelings of hostility to political ends.

2.2 *Application of organization theory literature*

2.2.1 Representation of conflicts: Social network literature has been used widely to represent organizations in conflict situations - traditionally businesses or organizations under stress; however, more recently, there has been a trend towards the representation of military and terrorist networks in organization theory terms.

2.2.1.1 *Representation of organizations in conflict situations:* Alison & Zelikow's second model, the organizational behavior model, is a distillation of a long trend of organization theory responses to organizations in conflict situations. Relevant literature studies of organizational response to stressors, and studies of organizational performance for military units. Though establishing a foundation for the theoretical *internal* response of organizations to the hostile environment (see also Lawrence and Lorsch 1967), they do not dwell specifically on the organization's reasoning about the *external* environment and their social position in it.

2.2.1.2 *Representation of the conflict itself:* The meta-matrix approach developed by Krackhardt and Carley (Krackhardt and Carley, 1998) has been used to model the steps of conducting an amphibious assault. This approach, while limited to analyzing one participant in a potential conflict (it does not model enemy behavior in the same terms), allows for a compact and computationally useful representation of interdependencies between actors and exogenous entities (tasks, resources, etc.) in the conflict.

2.2.2 Evolution of Conflict & Cooperation:

2.2.2.1 *Strategic reasoning in populations:* Beginning with Axelrod 1987, a fair amount of literature has developed applying iterated repetitions of "prisoner's dilemma" games to populations of agents with different response strategies (see Axelrod 1987, 2001,). This was developed on by Hampton to argue against evolution of social contracts in a Hobbesian state of nature (Hampton, 1980). Burt varied Axelrod's basic formulation to argue that in certain network configurations (specifically, sparse networks of random interaction) between certain actors of various types, hostile players will generally win out; while the uniformly cooperative never win (Burt, 1999) These papers describe situations in which general cooperation or conflict can evolve, but do not concern themselves with the nature behind the actor decisions that lead to that situation (except in the most general terms). None of these models describe the formation of alliances or groups, or social reasoning beyond the scope of the next instance of the prisoner's dilemma game.

2.2.2.1 *Social theories of conflict origin*: Several theories of conflict origin deal with actor preference and similarity (analogically similar to emotive theories of conflict listed above). Macy describes a model of social interaction in which adversarial networks can develop based on similarity/homophily between the actors in a social network (Riolo, Cohen, Axelrod 2001) Contractor argues for a more comprehensive model of conflict network formation using a multi-theoretical approach (Contractor, forthcoming). However, both of these conflict models are concerned with the evolution of specific groups in the conflict, not with the nature of their antagonism.

2.2.3 Strategic and tactical reasoning in social network literature:

2.2.3.1 *Tactical reasoning based on adversarial network structure:* Given the recent vogue of social analysis of terrorist networks, and coincident with theories of team or group design that increase performance through tailoring of the network structure, there has been a spate of recent papers on the ability to disrupt or destabilize adversarial networks (Carley, Lee, Krackhardt, 2002); usually related to the identification of nodes in the network that would cause the most disruption if they were removed. In general, these treat the actor of concern (the actor that would be destabilizing the network) as exogenous to the network; however, they may be useful for predicting the power of coalitions in networks with allied parties.

2.2.3.2 *Strategic reasoning within networks:* Burt, in developing the theory of structural holes, has argued that a participant in a network can increase personal power by removing communication ties between selected others in the network. Friedkin, in analyzing the effects of changes in influence networks, has shown how modification of certain influences can result in drastically different equilibria. In doing so, he has argued for a theory of structural influence manipulation (Friedkin 2002)

3. Model Development

In order to generate predictions based on conflict scenarios a framework for discussing and quantifying conflict variables, a model social and resource relations will be developed, and a method of generating the probabilities of actions based on these relations will be developed.

3.1 *Meta-matrix representation of conflict scenarios*

3.1.1 Network entities: The meta-matrix representation of social situations expands upon the standard social network formulation (sets of actors linked by social ties) to describe varied sets of entities which can be related to themselves or each other by separate, quantifiable relations.

3.1.1.1 *Actors:* The list of actors enumerates the decision makers in the conflict. Depending on the scope, extent, and nature of the scenario, these can range from individuals and informal groups to nations or international organizations.

3.1.1.2 *Goals:* The list of goals of all actors in the scenario. "Goals," for the purpose of scenario design, indicates general desires that guide actor behavior. They are generically phrased, in order to allow parties to share specific goals.

3.1.1.3 *Actions:* The list of courses of action available to all actors in the scenario. This list will vary widely between scenarios depending on the scope of the scenario and the natures of the decision makers.

3.1.1.4 *Resources:* The list of resources that affect actors' goals. The resource entity can list both resources in contention between multiple actors and those valuable only to single actors. Additionally, the resource entity can be used as a rule-basis in simulated scenarios to determine the courses of actions available.

3.1.2 Primitive relations: primitive relations indicate relationships between certain entities in the scenario; they are inputs to the model and guide the relations between and development of some aspects of the model.

3.1.2.0 *Notation convention:* In order to avoid confusion about the types of entities being related, matrices will be indicated as **(Entity-Entity)**. For matrices that are used in several relations, another given abbreviation may be used for notational simplicity. Because of the number of matrices used, the abbreviation names will tend to indicate something about the relationship being modeled. All matrices will be indicated in **bold**. Scalar values will be indicated in *italics.* Transpose matrices will be indicated by **(Matrix)'**

3.1.2.1 *Actor goal values* - **(A-G)**: $A\text{-}G_{ij}$ indicates the relative importance actor i imparts to goal j (compared to i's other goals). Individual elements are coded between 0 and 1 such that the row total (total of any specific actor's goals) will sum to one.

3.1.2.2 *Goal-resource correspondence* - **(G-R):** $G\text{-}R_{ij}$ indicates the effect on goal i of a 1-unit change in resource r. Individual elements are coded between -1 and 1, where a value of -1 indicates complete opposition, 0 indicates no relation, and 1 indicates complete correspondence.

3.1.2.3 *Action effects* - **(R-N):** $R\text{-}N_{ij}$ indicates the effect on resource i of action j. Individual elements are coded between -1 and 1, where a value of -1 indicates loss of all of a resource, 0 indicates no effect, and 1 indicates a gain of all of a resource (*n.b.*, this indicates relative resource levels, defined exogenous to the scope of the simulation. For instance, if money is a resource, a value of 1 would correspond to gaining an extremely large amount of money relative to a value of .5).

3.2 *Derivation of action probabilities*

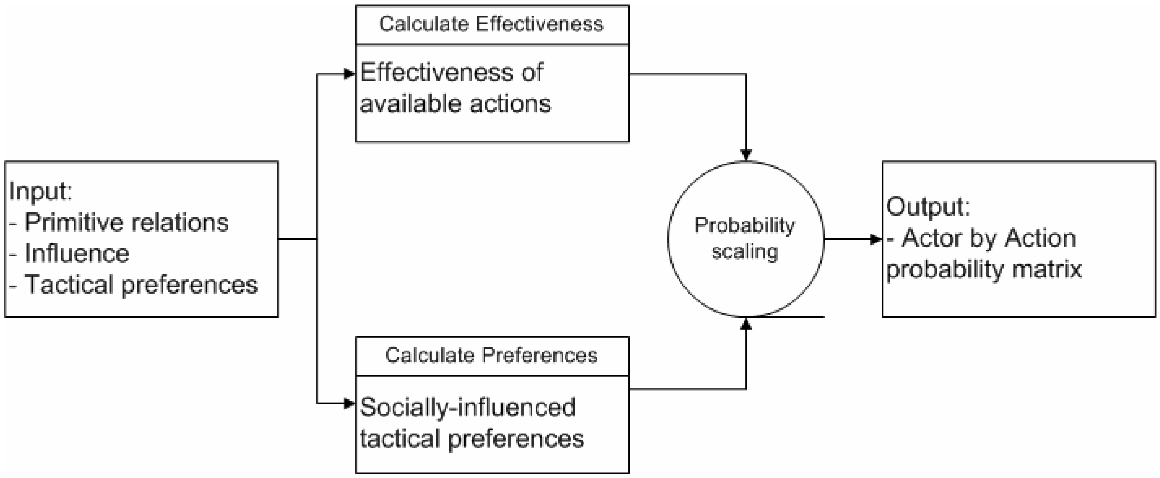

Figure 1: Flow diagram of probability matrix

Action probabilities are calculated as a relation between the action effectiveness and the actor's preferences for certain actions. Intuitively, actors will not consciously take actions that are contrary to their interests; however, they will not always take the action that best supports those actions. Actors are also spurred to act by 'tactical preference,' which models both cultural preferences and institutional inertia for certain types of actions. This cultural preference is a product of dynamic social influences, however - as actors' feelings towards other actors change, so do the social influences effecting their behavior change. In the discussion of the calculation of actor action probabilities, we will discuss the mathematics by which the actor-action effectiveness relationship is calculated; how the actor-action preference relationship is calculated and socially influenced; and how an overall probability of action is derived from the two relations.

3.2.1 <u>Calculate effectiveness matrix:</u> Indicates how much taking a certain action will support an actor's goals. This matrix is a 'word' of the network primitives <wasserman,faust citation>, calculated by matrix multiplying **(A-N)$_{\mathbf{goal}}$** = (**goal) = (A-G)(G-R)(R-N)**, where:

$$goal_{ij} = \max\left(\sum_l \left[\left(\sum_k (A-G)_{ik}(G-R)_{kl}\right)(R-N)_{lj}\right], 0\right)$$

for *i* actors, *j* actions, *k* goals, and *l* resources.

Equation 1: effectiveness matrix

Or, $goal_{ij}$ is equal to the sum weights of actor *i's* goals, multiplied by the resource correspondence with that goal ($A\text{-}R_{ik}$), for each resource *k*, multiplied by the effects of action *j* on that resource. $Goal_{ij}$ is artificially constrained between 0 and 1, but is not a probability (*i.e.*, the row sums for each actor *i* do not equal 1).

3.2.2 <u>Calculate tactical preference matrix:</u> Indicates how much an actor 'believes in' certain actions, based on both the actor's initial preferences and the influence of other actors. The fundamental formula is the cornerstone formulation of Friedkin's structural influence theory (see Friedkin 1998, 2002). The formula measures the effect of the beliefs on actors upon other actors, to yield an actor-action belief matrix **(A-N)$^{\mathbf{t}}_{\mathbf{preference}}$ =**

(Pref)^t = (I-S)(Influence)^t(pref)$^{t-1}$+(S)(pref)^1, where **I** indicates the identity matrix and the other components are described below.

3.2.2.1 *Influence matrix -* **(A-A)$^t_{influence}$ = (Influence)^t***:* $Influence^t_{ij}$ indicates the amount of influence actor *j* exerts on the beliefs of actor *i* at time period *t.* Influence values are constrained between 0 and 1, where 1 indicates that actor *j* is responsible for all of actor *i's* preferences, and 0 indicates that actor *j's* beliefs have no effect on actor *i's*. The sum of all influences on actor *i* equals 1. Note that $Influence^1_{ii}$ has special meaning - it is the effect of the actor's initial preferences on its preferences at any given time period; referred to, by the author, as the 'stubbornness' attribute. These are combined into the stubbornness weighting relation described below. Note that the influence is a dynamic relationship; that is, as discussed later in the model, actors change their influences based on the outcomes of other's actions.

3.2.2.2 *Weights:* weighting relations are **(Entity-Entity)** diagonal matrices that indicate the relative weight between two components of the model. Of specific concern to the calculation of the belief matrix is **(A-A)$_{stubbornness}$ = (S):** where S_{ii} indicates the tendency of actor *i* to value initial tactical preferences compared to 'learned,' or changed, preferences. As mentioned above, S_{ii} equals $Influence^1_{ii}$.

3.2.2.3 *Tactical Preference* **(pref)^t:** The tactical preference matrix is the most complicated relation in the model. The tactical preference matrix is a dynamic matrix that indicates the willingness to adopt, or opinion about, certain actions; possessed by the various actors. It is dynamic, because actors learn from each other over various time periods. For the purposes of this model, 'time period' represents both an arbitrary rate at which actors learn and the time it takes to make a decision.

3.2.2.4 *Interpretation of preference matrix elements:* $Pref^t_{ij}$ indicates actor *i's* preference for action *j* at time period *t*. The preferences for each actor do not have to sum to one; rather, they indicate a relative value compared to the actor's preferences for other actions.

$$pref^{\,t}_{ij} = (1 - S_{ii})\sum_j \left(Influence^{\,t-1}_{ik} \times pref^{\,t-1}_{kj}\right) + (S_{ii})pref^{\,1}_{ij}$$ for *i* = *k* actors and *j* actions.

Equation 2: Tactical preference matrix.

Or, $pref_{ij}$ equals the sum of actor *i's* willingness to learn (1-S_{ii}) multiplied by the sum of its and its allies' preferences for action *k,* and its 'stubbornness' multiplied by it's initial (*t*=1) preferences.

3.2.3 <u>Calculate overall probability of action:</u> From the matrices calculated above - the effectiveness and the tactical preference matrices, the model calculates an overall probability of action matrix, **(A-N)$^t_{probability}$ = (P)^t**, where:

$$P^t_{ij} = \frac{\left(goal_{ij} \times pref^{\,t}_{ij}\right)}{\left(\sum_j goal_{ij} \times pref^{\,t}_{ij}\right)}$$ for *i* actors and *j* actions, such that $\sum_j goal_{ij} \neq 0$ and $\sum_j pref^{\,t}_{ij} \neq 0$; else, $P^t_{ij} = 0$.

Equation 3: Probability of action matrix.

Or, P^t_{ij} equals the effectiveness of action *j* multiplied by actor *i's* preference for it at time period *t*, divided by the actor *i's* sum of the above for all actions. This is necessarily constrained between 0 and 1, unless all of an actor's tactical preferences or action effectiveness's are 0; in which case the actor will decide to do nothing.

4. Simulation and Experimentation

4.1 *Usage of the model for simulation*

The model, as written, is suited for modeling in a computer simulation. Both the influence and belief formulae represent inherently dynamic behavior; and the model itself describes complex, multi-agent, non-linear, dynamic behavior.

In order to develop a simulation from the model described above, two primary modules must be implemented - a model to describe the decision that actors actually take, and a model to update the scenario state based upon the effects of the decisions made.

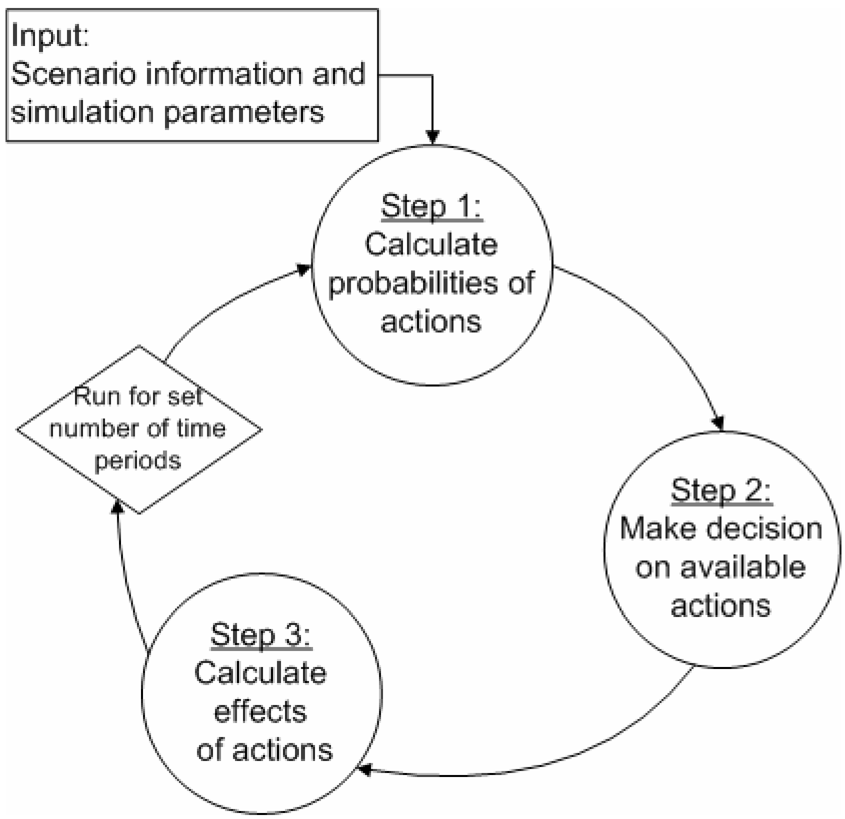

Figure 2: Basic simulation flow diagram

4.1.1 Decision model: The decision model used in the simulation is extremely simple. Given that the model outputs probabilities of action based on the actors' tactical preferences and goal effectiveness, the simplest decision algorithm would be to generate a random number for each actor and select the corresponding actions.

The decision model actually used is slightly more complicated. After the probability matrix is generated in step 1, the simulation determines if each actor has enough resources to take the actions it would be inclined to take (*i.e.*, $P^t_{ij} > 0$ for all j actions), based on a $\mathbf{(N\text{-}R)_{requirements} = (Req)}$ resource requirements matrix and an $\mathbf{(A\text{-}R)^t_{available} = (Avail)^t}$ resources available at time t matrix. That is to say, if $Avail^t_{ik} < Req_{jk}$

then $P^t_{ij} = 0$ for all actors *i,* actions *j*, and resources *k*. In other words, if an actor *i* has more resources than action *j* requires, then *i* will be able to take ($P^t_{ij} > 0$) action *j*.

The updated probability matrix is then rescaled:

if $\sum_j P^t_{ij} > 0$;

then the positive action probabilities are rescaled such that they sum to one; else, the actor takes no action. At this point, a random action is selected. This decision model offers the advantages of modeling the resource dependence of actions - otherwise, actors have 'bottomless pockets' to act, regardless of other actors' actions against them.

4.1.2 Calculation of action effects: Once an action (or lack thereof) has been determined for each actor, the simulation determines the effects of all of the actor's actions. These effects include both the direct effects on available resources, and indirect social effects.

4.1.2.1 *Resource effects*: The direct effects on available resources are simply modeled by summing the resource effects of all actions taken and adding them to available resources. The updated resource available **(Avail)** matrix is then passed to the next run of the decision making model.

4.1.2.2 *Influence effects:* The indirect, social effects of actions taken are a much more complicated relation. The changes to the influence matrix each turn are given by $\mathbf{(A\text{-}A)^t_{influencechange}} = \mathbf{\Delta Influence^t} = \mathbf{(A\text{-}G)(G\text{-}R)(R\text{-}A)^t((R\text{-}A)^t)'(G\text{-}R)'(A\text{-}G)'}$; where $(R\text{-}A)^t_{ij}$ is the effect on resource *i* of the action taken by actor *j* at time period *t.*

Essentially, $\Delta Influence^t_{ij}$ indicates the magnitude of the effects of actor *i's* actions on actor *j* times the magnitude of actor *j's* actions on actor *i*. Ideally, the more actors affect each other (either positively, if both actions are positive; or negatively, if both actions are negative) the more they will influence each other; while if one actor 'betrays' another (one actor acts positive to the other while the other acts negative) the less they will influence each other.

This relation is scaled against initial influences by an additional weight. $\mathbf{(A\text{-}A)_{volatility} = (V)}$ is a diagonal matrix of weights, where V_{ii} indicates the actor's tendency to change their influences. V_{ii} is constrained between 0 and 1.

From these calculations, the updated influence is calculated by $\mathbf{Influence^t = \Delta Influence^{t-1} V + Influence^{t-1}}$. For an actor *i* with no volatility ($V_{ii} = 0$), $\Delta Influence^t_{ij}$ will equal 0 for all actors *j*; therefore the actor will never change influences.

4.1.3 CORES simulation development: This simulation model was developed in conjunction with the Complex Organizational Reasoning Simulation (CORES), a joint project between CASOS and Aptima, Inc. Virtual experiments conducted on parameters for this simulation were conducted in CORES.

4.1.2.1 *Hostility model:* Cores implements an additional decision making model, based on a 'hostility' relation. Actors become more or less hostile to other actors depending on the other actors' actions. Once an actor's hostility towards another actor reaches a certain threshold, that actor will arbitrarily 'retaliate' against the other actor. Though not implemented, this feature demonstrates the flexibility of the decision model used in the simulation.

4.1.2.2 *Resource-dependent action tendencies:* The CORES model also expands on the standard resource implementation. In order to demonstrate actors specifically targeting resources possessed by other resources (rather than community resources that actors gain a 'stake' of), CORES models specific resource holdings of individual actors. For example, instead of 'money,' CORES can model and reason based on "Actor *i's* money." This feature is implemented in the virtual experiments used, since it does not change the mathematics used in the model described above.

4.2 *Virtual Experimentation and analysis*

4.2.1 Conduct of virtual experiments: Virtual experiments conducted in the model were developed using CORES. For each experiment, 100 simulations were run for 20 time periods each. The dependent variable for each experiment were the 'tendency for violent actions' of actors in a scenario based on the second Intifada. 'Tendency for violent actions' was calculated for each actor as the number of 'violent' actions taken by that actor over the total number of actions taken by that actor.

4.2.2 Variance in model: The overall variance in individual CORES simulations was calculated by tracking the tendency for violent actions over 100 runs of the simulation. The data is summarized below:

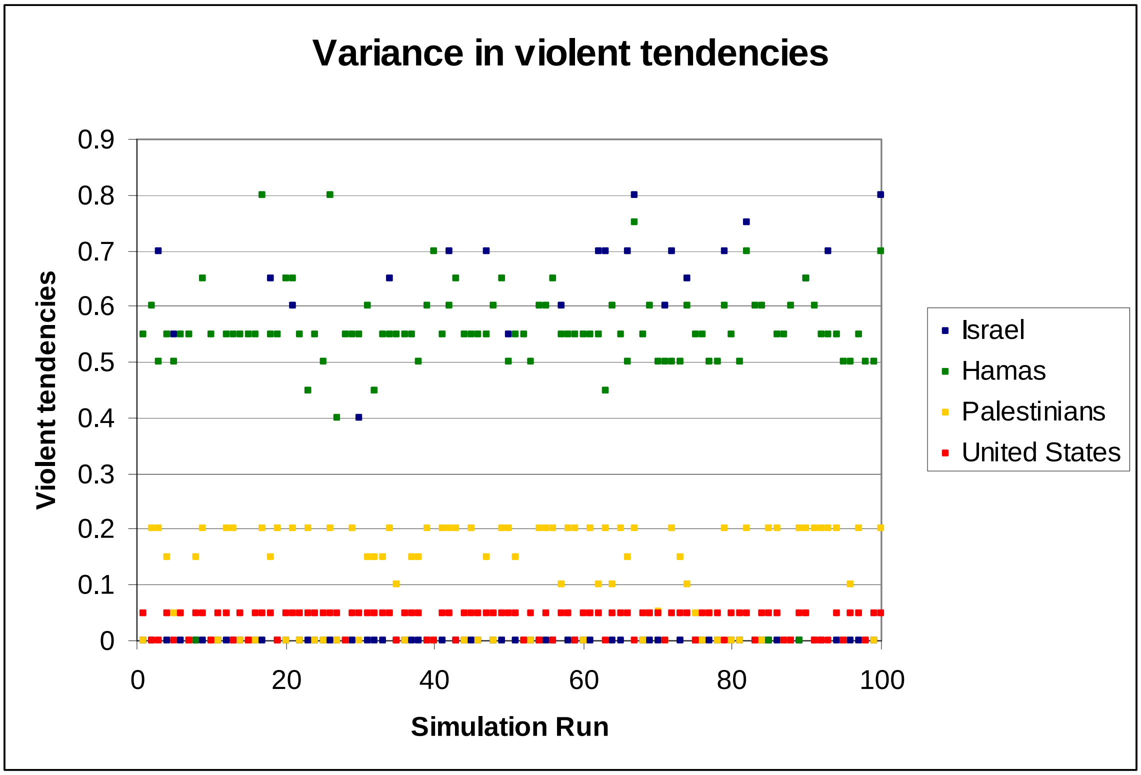

Figure 3: Variance among 100 simulation runs

Of the actors tracked, Israel yielded the most apparent variance, often taking no violent actions over the course of the simulation.

Conducting a single factor ANOVA between the 4 actors tracked yields:

ANOVA of tendencies for 100 simulation runs			
	Mean	Variance	
Israel	.15	.078	
Hamas	.54	.017	
Palestinians	.11	.0080	
United States	.035	5.3 E-4	
P Value	<.0001	F-Value	200.4

Figure 4: ANOVA of violent tendencies.

Israel demonstrated the most variance between simulation runs, and the P-value leads us to confidently reject the null hypothesis - *i.e.*, we can conclude that the violent tendencies are unrelated to the violent tendencies of other actors.

4.2.3 Sensitivity analysis of 'volatility' parameter: A sensitivity analysis of actor tendencies was conducted by varying the 'volatility' of Israel from 0 to 1 over 100 runs of the simulation, and tracking the violent tendencies of all 4 actors.

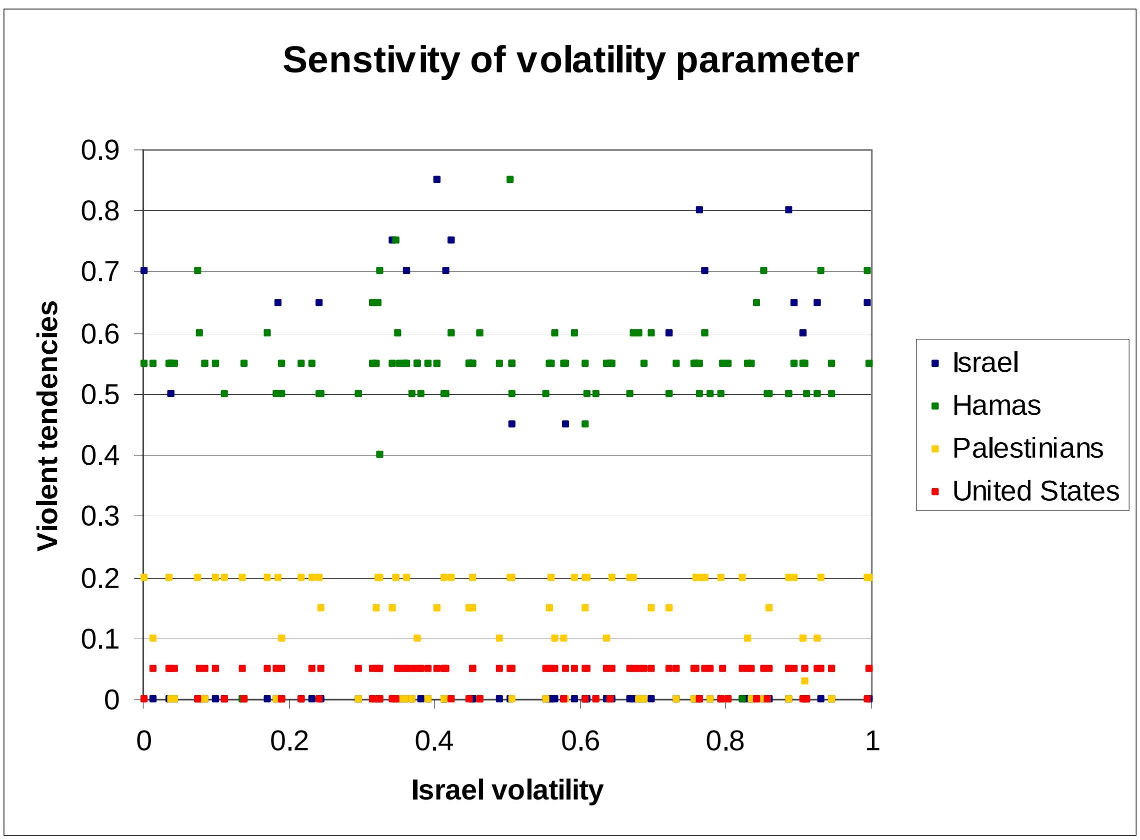

Figure 5: Sensitivity of violent tendencies of 4 actors to Israel volatility.

An analysis of variance conducted of the 4 distributions rejected the hypothesis that the 4 distributions were related; confirmed by a linear regression between Israeli volatility and Israeli action tendencies (R-square .0014)

4.2.4 Future experimentation: Since the CORES model is still under development, at this point is difficult to track other simulation metrics, such as average actor action probabilities. As additional search functionality is added to the model outputs, additional analysis will become possible.

5. Conclusions and Areas for Future Research

5.1 *Usage of the model:*

5.1.1 Military/security conflict analysis: The CORES simulation is under development explicitly for use in the analysis of military conflicts; specifically, low-intensity conflicts or insurgencies. This scenario model is well-oriented to the analysis of low-intensity conflict, for it can model multiple actors and take into account the opinions of parties related to, but not necessarily actively taking up arms in, the conflict (of specific concern is the host population of a guerilla or terrorist movement). Similarly, it is able to model evolution of cooperation or antagonism towards a primary actor in variegated or tribal populations (*e.g.*: evolution of resentment to U.S. actions in Somalia or Iraq, after demonstrated (in the case of Somalia) or expected (for Iraq) popular support.).

5.1.2 Population ecology theory: The evolution of cooperation among wide varieties of varied actors is of distinct interest to population ecology theorists. By modeling large numbers of (more or less) identical actors with distinct individual goal strategies, this model can be used to determine both convergence/divergence of population opinions and clique or group formation.

5.1.3 Cooperative bargaining / circumscribed conflict analysis: The CORES simulation, though designed for military/security analysis, is of use whenever there is an identifiable goal set for the various actors involved. This is especially relevant for situations in which actors have largely similar attitudes on a set of propositions, but varying goal weights. For example, in the case bargaining between industry and environmental regulators, while both parties would like to see a clean environment and abundant profits, the relative importance of the two can lead to divergent actions and subsequent breakdown in cooperation.

5.2 *Areas for future research:*

5.2.1 Expansion of conflict representation model: The meta-matrix conflict representation model is a readily expansible language for describing conflict situations. The meta-matrix approach is readily scalable, insofar as other relations between sets of actors can be modeled and reasoned upon in the same way as the relations presented and used in this model. Additional state metrics can be calculated for the various relations, and used in model calculations or actor reasoning. *E.g.,* various power metrics can be calculated from social network methods along the influence and resource relations, and then used by actors to calculate desirability of various actions; leading to more advanced strategic reasoning about influence and alliances (as proposed in Friedkin 2002)

5.2.2 Hypothesis testing: Given the expansibility of the conflict model, this simulation framework allows a number of varied decision making models to be compared against each other for predictive efficacy or competitive effectiveness (in the same way as the Axelrod iterated prisoner's dilemma simulations). As long as the simulation consistently evaluates the effects of actions, different decision making routines can be compared to each other across simulation runs or between actors in the same simulation.

5.2.3 Coalition integration / vulnerability model: By correctly modeling and parameterizing influence and actor-goal relations, the simulation can model coalition action between multiple parties. This coalition model, combined with a strategic influence model and the network-destabilization theories described in paragraph 2.2.3.1, can lead to effective modeling of the social elements of coalition interaction and potential analysis of the benefits and risks involved therein.

5.3 *Summary:* The developed model addresses the following concerns:

5.3.1 Representation of conflict scenarios: a robust matrix-oriented method of describing conflict situations was developed, and used to describe computationally scalable method of social decision making and action influences.

5.3.2 A framework for conflict reasoning in which goals and resources are individually modeled was developed. Parties to the conflict can act cooperatively or antagonistically, and payoffs can be shared between actors.

5.3.3 A model of social interaction in which the interdependent relationship between an actor's influences, tactical preferences, and action effects is described was developed.

5.3.4 The three goals discussed above were developed into a conflict simulation that predicts actors' actions, end-states, and belief development. Sensitivity analysis was conducted to determine the effectiveness of the model.

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