TOWARDS MULTI-LEVEL SIMULATION OF CONFLICT AND PEACEKEEPING

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ABSTRACT

This paper presents a multi-level simulation approach for analyzing a conflict opposing two groups (ethnic, political or religious groups) with a third actor, an armed policing force playing the peace keeping role.

The opposing groups are modeled at the macro-scale by a continuous logistic event-history model (Myers 2008) and at the lower scale by Discrete Event behavioral units representing the different roles at play within each group, interacting through a cell based terrain.

Keywords: conflict, peace keeping, DEVS

1. INTRODUCTION

Traditionally, simulation efforts designed for analysis, planning, or training in the military domain focus on operational and tactical issues. Such applications have been termed Computer Generated Forces (CGF) or Semi Automated Forces (SAF), combining Systems Engineering and Artificial Intelligence techniques to model aspects of military activity. These approaches generally model highly detailed human and technical systems in 2D or sometimes 3D Virtual Reality environments.

Strategically, it has been recognized that Military conflicts are drifting from pure force on force scenarios to situations in which societal dynamics are gaining more and more importance. This evolution is reported in numerous works *ex.* (Hammes 2006). The contemporary armed conflict is more likely intrastate, asymmetric, and urban, with civilian populations, activists, peacekeeping forces, and humanitarians interacting (Hobbs 2003).

As a consequence of this multiplication of roles and higher degree of complexity, the attrition models of the Lanchester-type (Schaffer 1967) or classical Computer Generated Forces (CGF) can no longer be used to gain full insight on the complex phenomena involved.

The social dynamics at play in present day armed conflicts call for more holistic simulation approaches more likely to be found in the social simulation research community, especially in agent based simulation studies. A number of authors have approached Low Intensity Conflicts, Peacekeeping, Civil Violence, or Counter Insurgency issues through multi-agent simulation.

This paper presents a multi-level simulation approach for analyzing a conflict opposing two groups (ethnic, political or religious groups) with a third actor, an armed policing force playing the peace keeping role. The opposing groups are modeled at the macro-scale by a continuous logistic event-history model (Myers 2008) and at the lower scale by Discrete Event behavioral units representing the different roles at play within each group, interacting through a cell based terrain.

2. GENERAL MODEL DESCRIPTION

This section presents the simulation model of a conflict involving two communities and an armed force playing a peace keeping role. The proposed model recognizes the necessity of multi-scale representations in complex social systems simulation, to this end, both macro-level (opinion dynamics) and lower level behaviors (individual activities of behavior units) are represented.

2.1. Macroscopic level

The macroscopic dynamics are captured by a logistic model adapted from Myers & Oliver's Opposing Forces Diffusion (OFD) model (Myers 2008).

Underlying the model is the idea that two competing *ideologies*, i.e. *Provocation* and *Repression* (P, R), shape the expression of collective action within a population. Collective action events are seen as the consequence of the two competing ideologies' diffusing within the population through imitation. The intensity of the provocation ideology can be interpreted as the extent to which contentious behavior is seen as an efficient strategy within the population, thus causing mobilization. Conversely, the repression force is interpreted as an ideology promoting demobilization. Event probability is obtained by P-R.

We consider two forms of collective actions in this model, namely, *Peaceful Demonstration* and *Violent Behavior,* each of these has an instance of the OFD model simulated in each community:

- The *Peaceful Demonstration* represents the tendency of the population to express its grievances through peaceful demonstrations, (although a demonstration could develop, given specific circumstances and local interactions, into violent rioting behavior).

- The *Violent Behavior* represents activist groups engaging in provocation activities during peaceful demonstration or perpetrating terrorist acts.

OFD models for both behavior types are simulated to influence and be influenced by lower level agents.

2.2. Micro-level

In contrast to the higher level continuous behavior, lower level models interact discretely. They consist of agents that we term Behavioral Units (*BU* in what follows). These are aggregate autonomous agents belonging to a community or to the policing force, interacting dynamically through the terrain.

A *BU* models a collection of individuals pertaining to the same community and acting collectively at some instant in the conflict. Because major actions in armed conflicts are collective, we choose not to model individuals explicitly, but rather a collection of them inheriting their properties from their community of origin. In the current model, two behavior unit types exist in each community:

- A *Crowd* agent, representing a *mild* and numerous subset of the general population whose salient actions, depending on the environment, can be: '*inactive*', to '*demonstrate*', and to '*riot*'. This *BU* is activated by the *Peaceful Demonstration* OFD model.

- An *Activist* agent, representing a more *engaged* subset of the population whose salient actions can be: '*inactive*', '*provocation*', '*terror*'. This *agent* is activated by the *Violent Behavior* OFD model.

The outcomes of *BU* actions are compiled and synthesized in a model component also responsible for updating the OFD models imitation indexes, thus realizing the micro to macro link. The same model component activates the *BUs* with the event probabilities computed in the OFD models, thus realizing the macro to micro link. This component also communicates asynchronously with its counterpart in the adverse population model, thus representing the way one population's actions can be interpreted by the other population (useful for simulating concepts such as retaliation or intimidation).

The *agents* receive activations in a discrete-time fashion, i.e. with a predefined time step.

The Peace Keeping force is represented by several BU *agents*. In the current model, three *agent* types pertaining to the armed forces are modeled.

- A *Reconnaissance Patrol agent*, sequentially visiting locations in the terrain for information gathering purposes.
- A *Combat Patrol agent*, sequentially visiting locations in the terrain to harass and/or destroy *Activist agent.* This *agent* also collects information on current activities in the terrain.
- A *Crowd Control agent*, representing a subset of the force dedicated at quelling contentious collective actions on both sides, its possible actions can be: '*monitor*', '*block*', '*disperse*'. To become active, it must be called by a *Combat Patrol* or a *Reconnaissance Patrol agent.*

The terrain is a check board of *location* objects with the following attributes:

- symbolic value to population A (real [-1,1])
- symbolic value to population B (real [-1,1])
- proportion of population A (real [0,1])
- proportion of population B (real [0,1])
- accessibility (integer [0,1])
- units in presence (and their current activity)

Each location constitutes a cell in a board representing the territory.

Communication in the model is achieved in two different ways:

- Message passing through the DEVS transition and output functions,
- Terrain attributes read/write by *agent*s

3. MODELING FORMALISM

We adopt in this work the framework for modeling and simulation established by Zeigler and colleagues (Zeigler 2000). This framework has the benefit of separating concerns regarding modeling, simulation and experimentation. Conceptual models, whether continuous or discrete, are represented in a mathematical formalism, with predefined high-level modeling constructs (e.g. *events, states, transitions functions, output functions, coupling*). Regarding simulation, abstract simulators are proposed, completely specifying the operational semantics necessary to run model instructions. This approach facilitates verification and validation by separating conceptual and implementation issues, which is particularly useful in the case of discrete event simulation. As one would expect, these advantages come with a cost: for efficient communication, it is necessary to share a common understanding of the modeling formalism constructs. In this section, we briefly introduce the DEVS formalism, before providing the models' graphical specification.

DEVS is a modeling and simulation formalism for Discrete EVent Systems. First proposed by Zeigler in 1976, it consists of **sets** *(input values, output values, and states),* and **functions** applied to the latter sets *(internal transition, external transition, output, and time advance)* allowing complete and unambiguous specification of systems according to the discrete event abstraction and a simulation according to the event scheduling worldview. Atomic DEVS models are basic components for specifying behavior. Predefined atomic models can be composed hierarchically to represent complex networks called Coupled DEVS models.

An atomic DEVS model is a structure (Zeigler 1986):

$$M = < X, S, Y, \delta_{int}, \delta_{ext}, \lambda, ta >$$

Where:
X is the set of input ports and values
S is the a set of states
Y is the set of output ports and values
$\delta_{int}: S \rightarrow S$ is the internal transition function
$\delta_{ext}: Q \times X \rightarrow S$ is the external transition function,
where $Q = \{(s,e) | s \text{ in } S, 0 \leq e \leq ta(s)\}$ is the total state set
e is the time elapsed since the last transition (internal or external)
$\lambda : S \rightarrow Y$ is the output function
$ta: S \rightarrow R^{+}_{0,\infty}$ is the time advance function
where $R^{+}_{0,\infty}$ is the set of positive reals, including 0 and ∞

At any time, the system is in a given state s. State change can only occur through an event, either internal or external:

- An **internal event** takes place when ta(s)= e, meaning when the lifetime of the state is reached, in other words, when the accumulated time since the last transition has reached the value defined in the time advance function ta(s). As a consequence, the system **outputs** the value y in Y through the $\lambda(s)$ function and makes an **internal transition** to a new state, say s', defined as δ_{int}(s)=s'.
- An **external event** corresponds to the arrival of an **input** (x in X) on one of the models input ports before the lifetime of the state has expired, meaning that the elapsed time, e, is $0 \leq e \leq ta(s)$. As a consequence, the system changes to a new state, say s'', through an **external transition** that depends on the current state, the elapsed time, and the input, as defined by δ_{ext}(s,e,x)=s''.

Atomic components can be connected hierarchically to form coupled models. For brevity, the formal specification of coupled models will not be presented in this paper because it plays no significant part in basic behavior understanding.

Another advantage of this formalism is its readiness for interoperability with other classical modeling approaches, in particular the differential equations systems specification formalisms.

In this paper, the graphical representation of DEVS models is used. As shown in Figure 1, the atomic DEVS model is represented in a box with input and output ports. A phase defines an explicit subset of the state set. Phases are represented by nodes and transitions by arcs. Nodes are circles with a continuous line when the phase is passive and with a dotted line when the phase is active (A phase is active when an internal transition can fire to another phase and is passive otherwise.) In the case of an active phase, the lifetime function is represented. Labelled arcs represent transitions. External transitions are represented by continuous line arcs. Above the transition is noted the input port followed by a "?" symbol and the event value when the latter is defined. Internal transitions are represented by dotted line arcs. Above the transition is noted the output port followed by a "!" symbol and the event value. Under arcs, an expression defines the conditions of the transition.

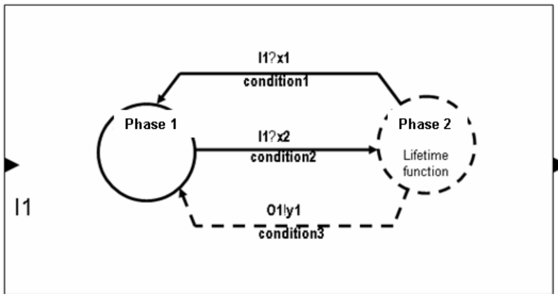

Figure 1: Graphical representation of a DEVS atomic model

4. MODEL SPECIFICATION

The general structure of the model is presented on Figure 2. Plain arrows represent event driven communication between sub-models; dashed arrows represent communication through common variables, such as the terrain. This section provides the specification of some model components.

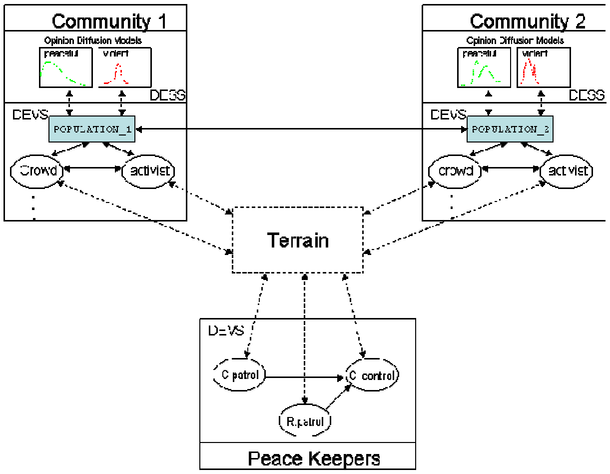

Figure 2: General model architecture

4.1. Opinion Diffusion Models

The Opposing Forces Diffusion model of collective behavior assumes the existence of two competing ideologies, *provocation* and *repression*, shaping the dynamics of any collective behaviors. Here,

> *"Ideology refer[s] to a system of beliefs about action and its consequences."* (Myers 2008).

In (Myers 1999), *provocation* (P) and *repression* (R) are formalized as two similar logistic functions representing the proportion of adopters of two competing ideologies. The intensity of collective actions depends on the size of the difference between P and R, when P > R as in equations (1) and (2).

$$P^*(t) = \frac{1}{1 + \frac{1 - N^*_0}{N^*_0}\exp[-pt]}, \quad R^*(t) = \frac{1}{1 + \frac{1 - N^*_0}{N^*_0}\exp[-rt]}. \tag{1}$$

Where N^*_0 represents the initial proportion of adopters in the population, p and r represent, respectively, the provocation and repression ideologies' infectiousness.

Event probability at any instant is obtained by:

$$\frac{dV(t)}{dt} = P^*(t) - R^*(t). \tag{2}$$

The OFD model is a theoretical and explicative model. It fits well various datasets collected in the USA race riots of the 1960's (Myers 2008). Its theoretical grounding and straightforward parameter interpretation make it a good candidate for a simulation application.

The logistic model is specified as a DEVS model with an active phase making a transition back to itself indefinitely. To model the changes in the conflict state as a consequence of the interactions between the factions and the military force, we allow N^*, p, and r to change. Figure 3 shows an OFD model on which the repression ideology's infectiousness is increasing preiodically, and causing the event probability to decrease.

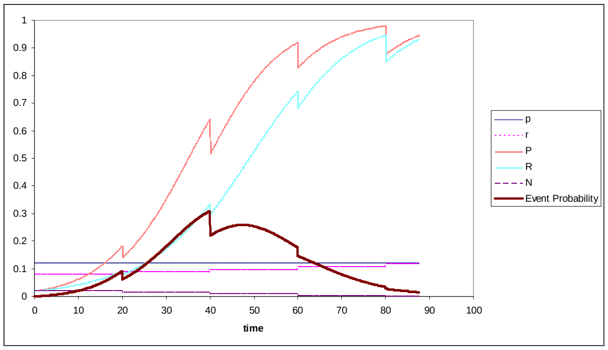

Figure 3 : Opposing Forces Diffusion Model with changing parameters

4.2. POPULATION sub model

The Population model has two roles, 1) transferring event probabilities from the OFD components to Behavioral Units at predefined time interval, and 2) synthesizing the outcomes of local interactions to adapt OFD models' diffusion indexes. Adapting diffusion indexes as a result of micro scale outcomes necessitates hypotheses regarding how for example, a terror act will have a future effect on the adoption of the violent *provocation* ideology in both the source population and the enemy population. Theories and possible hypotheses concerning influences between peaceful and violent ideologies within a community or between opposing communities can be diverse. From a modeler's perspective, it seems more useful to propose a generic scheme capable of representing any of such assumptions.

Behavioral Units generate outcomes after each action, depending on local interactions. These outcomes are the following:

- (o_1) Efficient crowd control : *a peaceful demonstration did not escalate to rioting*
- (o_2) Rioting : *a peaceful demonstration escalated to rioting*
- (o_3) Failed terrorist act : *the force was able to counter a planned terror act*
- (o_4) Successful terrorist act : *activists were able to perpetrate a terrorist act*

Each outcome in the model can be predefined to have a null, positive, or negative effect on peaceful and violent ideologies' diffusion indexes (p and r) in both communities. Table 1 shows a possible set of such modeling assumptions. Line 'o4' on the table defines the assumption that a successful terrorist act by an activist group affiliated to Community 1 has the following effects:

- strengthens *provocation ideology* for demonstrations in Community 1
- does not have any effect on the *repression ideology* for peaceful demonstration in Community 1
- strengthens *provocation ideology* for violent behavior in Community 1
- does not have any effect on the *repression ideology* for violent behavior in Community 1
- does not have any effect on the *provocation ideology* for peaceful demonstration in Community 2
- strengthens *repression ideology* for peaceful demonstrations in Community 2
- strengthens *provocation ideology* for violent behavior in Community 2
- does not have any effect on the *repression ideology* for violent behavior in Community 2

Table 1: Action outcome effects on repression and provocation ideologies

	SELF				***OTHER***			
Beh.	Peaceful Demonstration		Violent Behavior		Peaceful Demo.		Violent Behavior	
	Δp_P	Δr_P	Δp_V	Δr_V	Δp_P	Δr_P	Δp_V	Δr_V
O_1	0	+	-	0	+	0	+	0
O_2	-	+	+	-	+	-	+	-
O_3	+	0	0	+	+	0	0	+
O_4	+	0	+	0	0	+	+	0

The DEVS specification of the population sub-model is given in graphical form (Song 1994) on figure 4. External transitions are represented in continuous arrows, internal transitions in dashed arrows, states are represented by nodes. The symbols '?' and '!' respectively represent inputs and outputs.
The population sub model is represented on Figure 4. The other DEVS sub models will be directly presented in their graphical form.

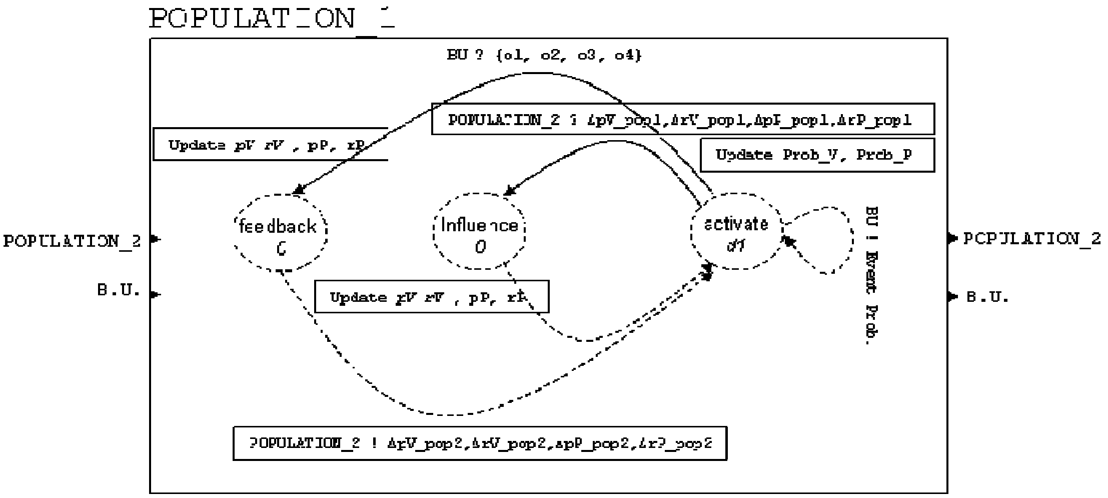

Figure 4: Graphical representation of the POPULATION model.

Every 'd1' time units, the POPULATION model updates the event probability calculation retrieved from ODF model and transfers the result as an activation message to BUs.
When BUs terminate their action execution, the action outcome is received by the population model which updates *provocation* and *repression* parameters of the OFD models according to the assumptions specified as on table 1.

4.3. CROWD model

The crowd model is one of the Behavioral Units considered. It represents a subset of the general population whose salient actions can be a demonstration or riot. This *BU* is activated by the *Peaceful Demonstration* OFD model.

When the activation message is received from the population atomic model, the crowd goes to the decision state named 'Decide' and either goes back to the inactive state or to the state 'demonstration'. The decision here is stochastic and is based on the probability generated by the OFD model as in Figure 3. When changing the state to 'demonstration', the activists in the same population are informed. 'demonstration' is an active phase that lasts for a predefined time period dn, after that, the terrain is read to obtain information about the other units in presence. Depending on elements like the presence of activist provocateurs, enemies or the peacekeeping force's perception and control policy, the demonstration might escalate to a riot or disperse. The outcome is sent as an event to the POPULATION atomic model and interpreted as in table 1 to alter provocation and repression indexes. Figure 5 depicts the graphical representation of the 'Demonstration' model.

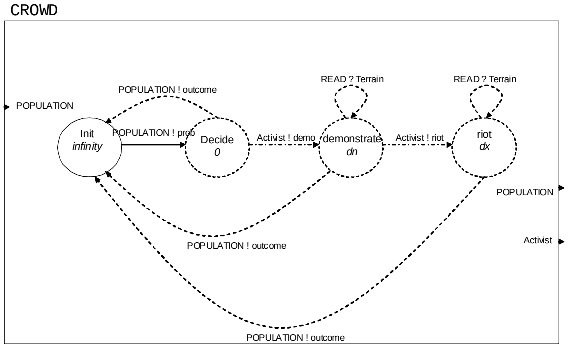

Figure 5: Graphical representation of the CROWD atomic model.

4.4. Activist model

Activist is a subset of the population whose salient actions can be: '*inactive*', '*provocation*', '*attack*. This *agent* is activated by the *Violent Behavior* OFD model. When the activation event is received by the activist model, it goes to a decision phase which either decides to stay inactive or to perpetrate an attack. The decision is based on the possibility to find a favorable location. The attack can succeed or fail, based on the presence of the force.

In case the activist model is inactive and a demonstration is organized by a CROWD of the same population, the activists can try to join the demonstration and turn it into a riot.

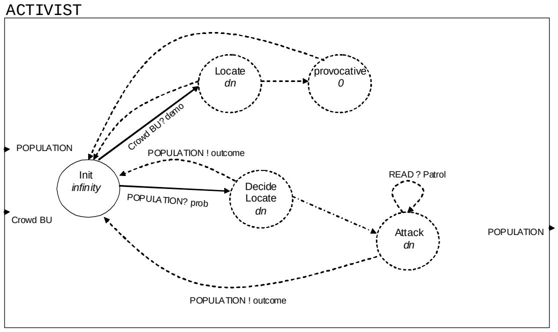

Figure 6: Graphical representation of the 'activist' atomic model.

4.5. Combat Patrol

The Combat Patrol agent sequentially visits locations in the terrain. If an Activist group is detected, the Combat patrol agent can intervene. This agent also collects information on current activities in the terrain and can send a message to a Crowd Control agent in case of a riot. This model component's behaviour is autonomous as it receives no incoming event.

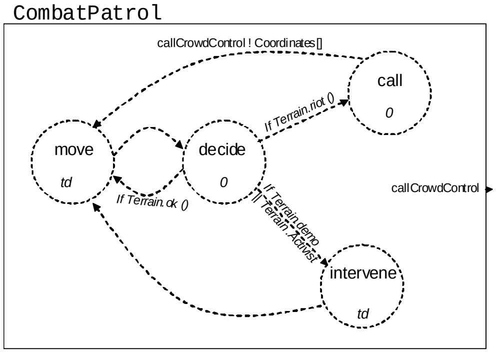

Figure 7: Graphical representation of the 'Combat Patrol' atomic model.

5. MODEL DYNAMICS AND DISCUSSION

This section looks at the model's dynamics over time. To understand the general dynamics that we wish to portray with the model, let us study the simplified scenario displayed on figure 7. The diffusion model for violent behavior in one population is initialized with the values (0.2, 0.12, and 0.08) for the parameters N^*_0, p, and r. As time elapses, P and R evolve. Because p is higher than r, provocation ideology quickly dominates, and the event probability starts growing, as a result, the likelihood of an attack by the activists gets stronger and stronger. At time 12, an activist agent manages to conduct a successful attack. Based on table 1, this results in an increase in the value of p, while r remains unchanged. The increase in p also causes a slight increase in N^*_0 which represents the current status of the conflict. The same happens at time step 23. At time 34, an attack by the activists is countered by a combat patrol. This leads to a decrease in the infectiousness of the provocation ideology and an increase in the repression ideology as specified on table 1. This event again transforms the stage of the conflict and makes the probability of activist actions lower.

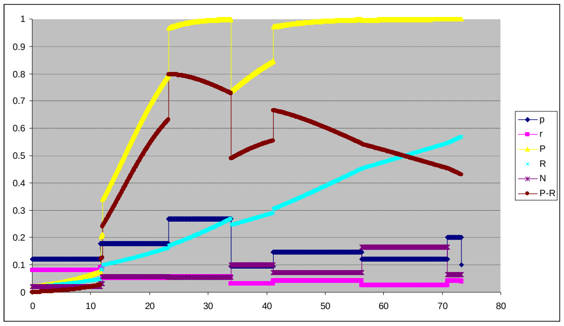

Figure 8: Model dynamics

The presented framework aims at capturing some of the complexity of conflicts through simulation.

The approach recognizes the necessity of multi-level representations with upward and downward influences. A design choice is also made to leave room for the implementation various assumptions of sociological relevance, making the model extensible.

To make full use of its potential, a validation and calibration with a well documented historical case is envisioned. This will allow making analyses on the effect of different peace keeping strategies with the simulation. The model would as a result be possible to use in analysis, planning and training, as well as serious gaming applications.

A number of additional improvements will be considered in future works, including a visualization of the conflict theatre, the inclusion of other sociological factors such as culture, economical status or religious determinants.

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