Modeling and Simulation of Course of Action (COA) Consequences in Stability and Support Operations

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ABSTRACT: *Although operations that do not include conventional warfare are not new to the military, an increasing share of military operations requires both stability and support functions. The military defines the purpose of stability operations as: "to promote and sustain regional and global stability" and the primary role of stability operations is "to meet the immediate needs of designated groups, for a limited time, until civil authorities can accomplish these tasks without military assistance." Other major functions may include keeping armed conflicts contained and quieting domestic disturbances. This paper demonstrates the interoperability of two model-based frameworks for computer generated solutions that provide multi-sided operational evolution (coevolution) for stability and support operations (SASO): the Sheherazade SASO environment which employs a co-evolutionary genetic algorithm in modeling the dynamics of the complex multi-sided simulation for generating COAs, and the PIOVRA project (Poly-functional Intelligent Agents for Computer Generated Forces) which affords the ability to model movements and attrition in areas affected by civil disorder.*

1 Introduction

Contemporary military scenarios have become increasingly complex in terms of the large number of variables and unknowns that make up the operating environment. As a result, there has been continuous growth in new tools designed to support the various stages of such operations such as visualization, analysis and planning. Very often the tools are targeted towards a particular area based on the user's needs and then specialized algorithms and frameworks are developed to address those requirements. Sheherazade is a simulation environment developed under the U.S. Army Battle Lab for course of action (COA) generation and analysis in Stability and Support Operations (SASO). Such COAs can be visualized, which is important to the development of this prototype system because the wargaming rules inherent in SASO are currently not as well defined as conventional warfare. In the Sheherazade SASO system, the environment is composed of demographic regions that represent locales or neighborhoods on a map. Entities, such as conventional military units, militias, etc., move across the various regions as specified by their plans, or courses-of-action. They also engage other entities in incidents according to these plans. Sheherazade consults the "animosity" levels of various local, civilian populations and units of varying allegiances to determine whether an "incident," such as a riot, will occur. Generally, the primary responsibility of the conventional military units will be to reduce the number of those incidents which threaten the security of the nation-building or humanitarian mission, thus reducing animosity levels. In addition to the conventional military units, a militia and terrorist unit, Sheherazade supports various new types of units such as political agitators, media, refugees, and organized crime units and explicitly models the "attitudes" of the populations in each region.

PIOVRA (Poly-functional Intelligent Agents for Computer Generated Forces) represents another tool, sponsored by the Italian and French Defense Ministries, which in effect, is working to create new CGF (Computer Generated Forces) devoted to replicate groups of interacting people, including disordered groups such as crowds as well as groups operating within some organizational structure that possesses sociological correspondence. Sociological models are devoted to reproduce group behaviors as well as the interaction dynamics between group members. Sheherazade and PIOVRA represent two different tools that address different aspects of a common problem. Of particular interest however is evaluating their potential when combined, to enhance the level of support for SASO or provide independent verification of the tools' results. In this paper, we model the consequences of the courses of action generated using a co-evolutionary approach. Specifically, we apply holonomic and vectorial movement models as well as the attrition models to gain introspection into, and to validate, the COAs in a dynamic context. A case study will be simulated by integrating both frameworks. The utility of the proposed approach is the ability to predict the impact of COAs as given by a computer generated solution.

1.1 Sheherazade

The Sheherazade simulation system is a software suite that is designed to allow a military user to quickly create a SASO scenario comprised of entities and locales, and then generate courses of action for all entities aimed at achieving a military objective. The system uses the rapid prototyping tool, ATACKS [1], to set up a scenario, define parameters for the entities, etc. and to provide 3-d visualization of the COAs generated. The coevolution module shown in Figure 1.1, which generates the COAs for user assigned groups of entities, consists of the Genetic Algorithm and accompanying routines that direct the operation of the GA. Groups of entities are represented in the coevolution module by an agent that embodies the goals of that group. The goal of an agent can be to inflict or prevent damage to various factions (a faction represents a set of entities that share a common allegiance), increase or decrease "animosities" between factions, or influence "attitudes" in a region (locale)[2]. The agents' goals also serve as the fitness criteria used by the GA for optimization of the generated COAs over a number of generations. Evaluation of the COAs is performed by the Sheherazade wargamer which takes as input a set of COAs for all entities, and returns a score for each goal parameter (attitude, animosity and damage).

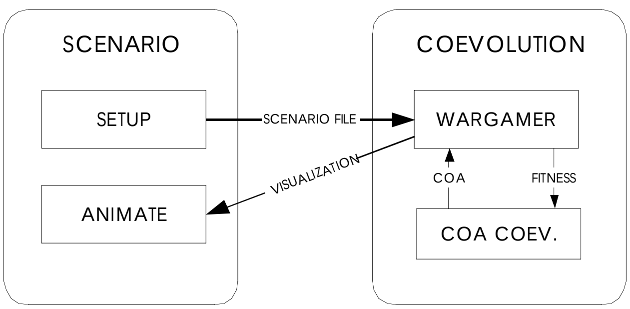

Figure 1.1 Sheherazade System Overview

Sheherazade is used to model contemporary SASO scenarios that are typically comprised of a small (5-10) number of neighboring geographic regions and agents or factions (which are usually, but not necessarily, identical sets). The number of entities in a typical scenario is between 100 to 200 entities, however, there are a large number of entity types such as terrorist units, apolitical non-combatants, militias and the traditional organized military units, many of which have level designations such as brigade, battalion or platoon that communicates size in terms of individual soldiers while retaining a single entity representation in the simulation. The goal of the system is to allow a user to create new scenarios quickly for COA generation and analysis and not to burden the user by having to specify an environment in intricate details. The user must, however, specify any information needed for a reasonable simulation of an actual scenario such as initial parameters for all entities (combat strength, intel power, footprint, etc.), locales (size, attitude, difficulty, population demographics) and factions (animosities), and assign entities to agents appropriately. Agent goals must also be specified as weights for each goal parameter – a negative weight implies the agent wishes to decrease or minimize the corresponding parameter, positive weight implies increase, and a zero weight indicates impartiality.

Informally, a COA for an entity in Sheherazade is a sequence of movements between locales and targets to attack following the movement. Figure 1.2 shows an example of a COA for an entity that describes movement at clockticks 12, 32 and 67, to locales 4, 3 and 1 respectively. A clocktick is an abstract representation of the time when a particular event (movement or attack) occurred. The total number of clockticks represents the duration of a run for the given scenario and is specified by the user during game setup. Since the number of movements and attacks allowed for each entity in the COA are fixed (usually between 3 and 5), the time scale can have an impact on the success of a COA.

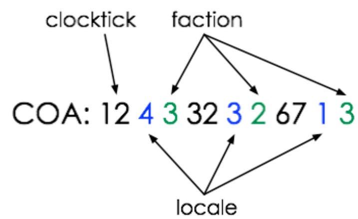

Figure 1.2 Example COA in Sheherazade

Some units such as militias and organized military and terrorist units affect the scoring criteria by perpetrating attacks on other units. Since the wargamer is only concerned about the situation between the higher level factions, the algorithm looks for any legitimate unit from the target faction to attack, and this target faction is the optional third element in each segment of an entity's COA. For the COA given in Figure 1.2, the entity will move at time 12 to locale 4, and target a unit from faction 3. A unit from faction 2 will be targeted at time 32 and finally a unit from faction 3 in locale 1 at clocktick 67. Units such as information operators and non-combatants (refugees, media etc) do not include this 'faction to attack' component in their COA representation and influence the scoring criteria simply by moving to different locales at different times. Sometimes this has a direct effect, as for example when a large number of attitude agitating units move into a locale increasing attitude in that locale and consequently the incidence of unprovoked attacks, or an indirect effect, for example concentrating information operators in a locale to increase intelligence capabilities to find and disrupt future terrorist attacks. A more detailed description of the wargaming algorithm can be found in [3].

1.2 PIOVRA

The PIOVRA environment is focusing on the creation of Agents able to direct the different units respecting some corner features such as the M&S requirements here described: [8]

- Cooperative Reactions

- Autonomous Behaviors
- ROE (Rules of Engagement) Respect
- Psychological Behaviors
- Operative Behaviors
- Scenario Awareness
- Federation

PIOVRA agents are requested to demonstrate the following features:

- Capability to Evaluate the situation
- Force Aggregating/Disaggregating Capability
- Cooperative behavior
- Distinct Friend, Enemy, Suspect and Neutral Units
- Explicit ROE justifying proper behavior
- Military reports to higher commanders
- Interoperate within PIOVRA HLA Federation

The decision to implement this demonstrator in an HLA Federation is based on the desire to guarantee direct interoperability [6].

In order to reproduce the environment the PIOVRA Federation involves three major types of types of objects: Comportment Objects, Action Objects, and Support Objects.
Comportment objects represent organizations or parties (e.g. Terrorist Movement), while action objects correspond to entities on the playground (e.g. Police Unit). All the other entities are support objects (e.g. Weather). Special algorithms have been developed in order to take care of operating the units; for instance the movement of the units are based on different approaches devoted to guarantee an intelligent path identification over the scenario considering both the terrain database and the force dynamic distribution; in addition the Agents include algorithms for calculating attrition even if the scenarios are expected to reproduce civil disorder before they reach degeneration in riots and escalation to force to force situations [10][11].

2 Integration Approach

As mentioned in the previous section, the Sheherazade simulation environment is geared towards SASO military scenarios involving a limited number of entities and regions. The limitation is only in terms of the tool designers having consciously ignored scalability issues during the software design phase because the purpose of the tool was to simulate scenarios at only a very high-level. This significantly reduces the complexity of using the tool and allows the setup time to be considerably shorter than other course of action analysis tools. Furthermore, this does not imply that Sheherazade is not capable of simulating entities at either a fine or coarse level of detail. The user is free to group the combined characteristics of a number of entities into a single representative unit with a footprint or initial strength that is the sum of the sub units, or similarly divide the capabilities of a large heterogeneous group into a smaller number of ‘representatives’.

Similar to the number of entities, a Sheherazade SASO scenario is typically comprised of a small number of locales or regions. Each region has a number of parameters such as attitude and population that is specified by the user along with the percentage of the population within each region that belongs to each faction. The locale parameters have an impact on the difficulty or probability of carrying out successful missions in that region (for example, finding terrorist units or perpetrating a high-impact attack). Movement between locales is assumed to be cost free, meaning geographical or political costs do not play a role in determining where a unit will move - the coevolution module simply assigns movements and attacks based on their effect on the final score of the entire COA.

PIOVRA deals with a large number of zones and entities and therefore includes more detailed movement algorithms than Sheherazade, which assumes movement has no cost and limits entities to a fixed number of movements per COA. The zones in PIOVRA are one type of support object (a non human actor) corresponding roughly to locales in Sheherazade. They include movement links and ground characteristics which play a significant role in the speed and course profile of action objects (units or entities). Navigation between zones requires the existence of a series of movement links connecting the zones, which can fail during the course of a simulation depending on the current situation. Sheherazade on the other hand, assumes constant no cost movement for entities, but either facilitates or hinders execution of incidents within locales depending on the current situation in the locale. Although the intention of simulating SASO scenarios in Sheherazade was to work with a high level representation, the potential for increasing the range and depth of the simulation results by incorporating additional wargaming rules or COA verification tools such as PIOVRA’s realistic movement algorithms may be highly desirable.

Figure 2.1 shows the major steps in the Sheherazade wargaming algorithm used to evaluate a set of COAs. The simulation begins by initializing all the units’ parameters and moving them to their starting regions and then enters the main simulation loop which repeats for each clocktick. Depending on the starting or current locations of the units, parameters that depend on the current locale, such as effective footprint (based on a combination of the unit’s footprint, current strength and region difficulty) and effective intel power are determined. Unit parameters are then used to update the region parameters and attitude in each region. Next, each region is processed to see if any units are scheduled to carry out attacks (terrorist, militia, demographic etc.) during this clocktick or if there are any spontaneous incidents as a result of the regional situation.

The impact of any incidents is calculated and unit parameters are adjusted and finally units are moved to their COA specified locales for the next clocktick and the entire process is repeated.

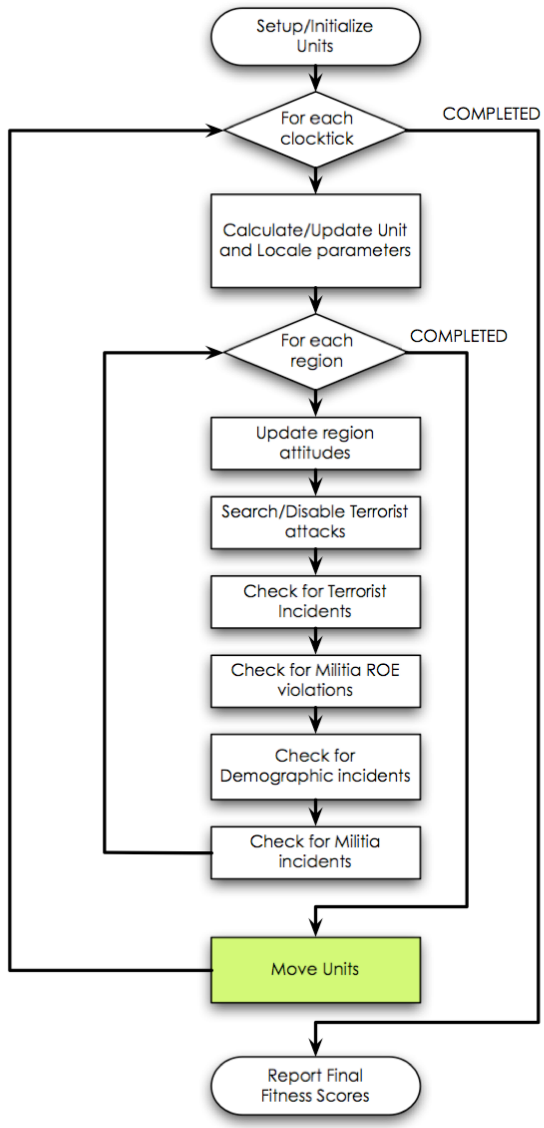

Figure 2.1 Sheherazade Wargamer Flowchart

There are two opportunities for integration of PIOVRA's more realistic movement algorithms into the Sheherazade simulation. First, the simulation can remain as is, with battle logs generated for each set of COAs in each generation. However, the movement schedules from these logs can be extracted and independently verified in PIOVRA as to whether or not those movements are indeed probable given deterioration of infrastructure in prolonged combat situations. Second, we can see that the final step in the algorithm where units are simply moved to their new locales presents an ideal avenue for integration with PIOVRA's movement algorithm which could exact a cost on the unit movements, particularly when moving through long or difficult terrain. As a demonstration of the utility of integrating Sheherazade and PIOVRA simulation models, the first approach is adopted, namely, translating the COA output of Sheherazade for input into PIOVRA for verification of the generated movement schedules.

3 Case Study

To maximize the contribution of each tool in the verification of the generated COAs, a custom scenario is developed that can be applied to both applications and take advantage of each of their strengths. The scenario includes a larger than typical number of regions (from the point of view of Sheherazade) where not all regions share a border with each other. Regardless of how the regions are laid out on the grid, Sheherazade makes no distinction internally between neighboring and non-neighboring regions. However, the proximity and connectivity relations between regions is an important parameter for PIOVRA, which also requires the specification of the movement links that define the possible paths between regions. In Sheherazade, the user must additionally specify the starting conditions mentioned previously for each region, such as the overpopulation factor, demographic distribution etc. Once the geographic representation is completely specified, the user continues the specification of a complete SASO scenario within Sheherazade that includes entities, factions, agents and goals. At this point, the user is ready to begin generating COAs for the given scenario using the multi-sided coevolution module in Sheherazade.

The output files generated by Sheherazade contain not only the COA representations for each entity over each generation for the given scenario but also execution traces of the COAs through the wargamer. The trace contains all the information needed to animate and analyze one possible execution (since the wargamer has some stochastic elements) of the COAs on the 3-D ATACKS platform. However, in order to perform a rudimentary check of the COAs integrity from an entity movement standpoint using PIOVRA, only the COA representations (which includes entity movements) are required. Depending on the configuration of regions and movement paths, PIOVRA is able to use its own movement algorithms to provide confirmation of all or a subset of the Sheherazade COAs, or even suggest improved movement schedules for certain entities based on its path cost algorithm.

In effect the movement algorithms currently are devoted to consider different approaches for path definition based on the flow chart proposed in the following Figure 3.1. Dynamically during each action object movement the entity proceeds on the path, as soon as it detect inconsistencies in the terrain (i.e. connection to new road blocked or link between two zones disabled) or in the situation (i.e.

detection of foes with a ROE devoted to stay hidden) it recall the movement algorithms with the updated configuration [7].

Each time the algorithm runs it considers the situation based on the knowledge of the specific action object and, in case of active communication with the hierarchical command chain, with the corresponding comportment object; the preference of each Action Object push forward holonomic or vector approach in order to overpass loops due to special configurations (e.g. moving forward, moving to zone without communication coverage, experiencing an impediment, re-computing the path based on local knowledge, moving forward and detecting an inconsistency that forces a move back where communications are working).

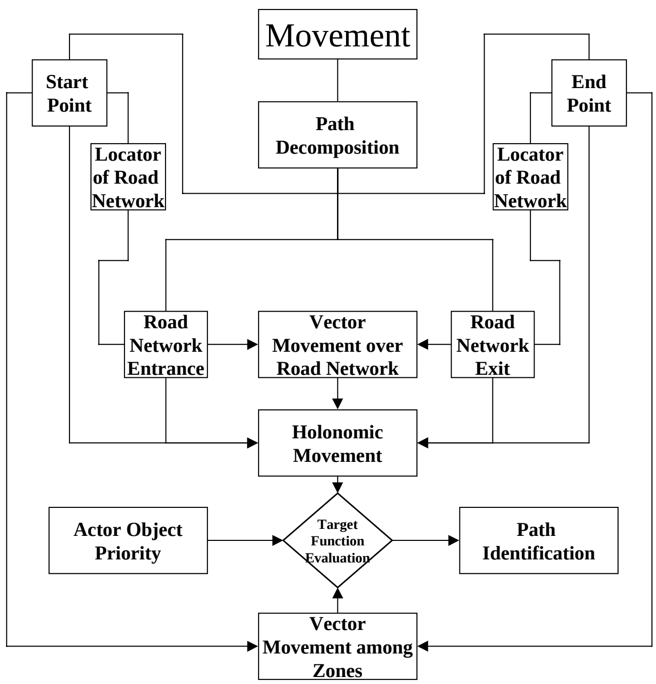

Figure 3.1 Movement flowchart

The vectorial approach can be applied both to zone or road network and it is mostly based on Dijkstra Algorithms [9] with a target function that consider the time and risk of the path based on the situation awareness of each Action Object.

It is interesting to note, since the Sheherazade output files contain not only a trace of each entity following its COA (moving from region to region and/or engaging in incidents) but also the impact and consequences of each engagement (for example, damages to units or change in regional attitudes), there is a possibility of incorporating the actual Sheherazade events in PIOVRA's evaluation of the COAs by creating the corresponding action objects at the designated times. This allows PIOVRA to also utilize its group and crowd behavior algorithms to provide an additional degree of verification of not only the movements within the COA but additional social factors not accounted for in Sheherazade that may affect the COAs success.

In terms of social effects it is interesting to note that the system is currently considering the mutual attitude of each social and ethnic group versus the other ones; the model used allows to consider that different attitudes can be concurrently present within the same group of people (i.e. someone very friendly inside a hostile group) [5]. The model configuration can be easily set up by tables as demonstrated by the following table:

Cimbrian Population vs Blue Forces				
HOSTILITY	*DIFFIDENCE*	*NEUTRALITY*	*CONFIDENCE*	*FRIENDSHIP*
50%	35%	9%	5%	1%

4 Conclusion

This paper demonstrated how a high level COA generated by the Sheherazade SASO environment can be verified using the movement algorithm components of PIOVRA to improve the utility of the recommendations produced by the tools. Although PIOVRA is High Level Architecture (HLA) compliant, making it easily interoperable with other HLA compliant simulation tools, Sheherazade was designed as a stand-alone software suite for creating and visualizing SASO scenarios and generating and analyzing COAs. As a result, the case study relied on mapping the inputs and outputs of each tool to facilitate interoperability. However, as this integration exercise has demonstrated added value in integrating simulations that address related issues in a common domain, there is strong endorsement to undertake the costs of re-engineering Sheherazade to serve as a federate in an HLA framework to support future collaborative opportunities.

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