Using Agent Based Distillation to Explore Issues Related to Asymmetric Warfare

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ABSTRACT

In this paper we present advantages and limitations of agent-based distillations in understanding and gaining insight into irregular/asymmetric military operations. Our study is based on experiments using NetLogo a cross-platform multi-agent programmable modeling environment under continuous development at the Center for Connected Learning and Computer-Based Modeling of Northwestern University, Evanston (IL), USA. The presented work is very much a work in progress, and this preliminary paper is intended to stimulate discussion, garner feedback, and foster refinement.

1.0 INTRODUCTION

Recent research shows that both conventional and asymmetric warfare are characterised by nonlinear behaviours and that engagement is a Complex Adaptive System (CAS) [26]. Furthermore, there is no doubt that the nature of warfare has changed in the last few decades, as indeed it has been constantly changing since pre-historic times. While this fact creates some uncertainty for defense planners, there is at least one thing we can be sure about: warfare will continue to change [3]. According to the Irregular Warfare Joint Operating Concept, OSD and Joint Staff, Version 1, Irregular[1] Warfare is defined as "*A violent struggle among state and non-state actors for legitimacy and influence over the relevant populations. Irregular warfare favors indirect and asymmetric approaches, though it may employ the full range of military and other capabilities, in order to erode an adversary's power, influence, and will*" [21]. Asymmetric warfare emphasized then social phenomena such as legitimacy and influence well known in social sciences studies. Despite conventional warfare models that often use simple physics equations[2] to back decisions on courses of action and resource allocation, irregular warfare models should incorporate complex social phenomena to guide decisions of the military planners.

Modelling & Simulation tools and methodologies are needed to capture the uncertain, complex and varied space of asymmetric warfare even if social science theories, unlike physics theories, are not yet agreed upon. In this paper, we suggest an Agent Based Distillation (ABS) approach to capture some critical issues of asymmetric warfare. This approach offers an opportunity to analyse the behaviours intuitively expected on the battlefield. Through the use of this approach, analysts are able to gain understanding of the overall shape of a battle and what factors are playing key roles in determining the evolution of an engagement.

[1] In USA, the Army Capability Integration Center (ARCIC) declared in 2007 that there was no need for an official definition of asymmetric warfare, considering that its use was redundant to irregular warfare [30].

[2] Such as the Lanchester Equations.

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15. SUBJECT TERMS

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The objective of this preliminary work is not to publish innovative models of complex military or social behaviours involved during asymmetric engagements. Our concern is mainly to provide a reflection about the suitability of Agents Based Distillations for modeling asymmetric warfare. To illustrate our discussion NetLogo has been selected among a large number of platforms available. A similar study was published in 2005 by Scott Wheeler to evaluate benefits of NetLogo for modelling civilian assistance and guerrilla warfare [14].

This paper is organized as follows:

- The following section briefly recalls main issues related to asymmetric/irregular/hybrid warfare,
- Section 3 introduces Agent Based M&S as a powerful approach to model military applications including complex social behaviours,
- In section 4, we introduce the Distillation paradigm as a means to reach a trade off between sophistication and usability. We will focus on its ability to naturally discover emergent behaviours even when they are not explicitly programmed,
- Section 5 provides an example of ABS platform through NetLogo,
- Finally, section 6 is devoted to conclusions and future trends.

2.0 THE ROLE OF ASYMMETRY IN WARFARE

Asymmetric or irregular warfare originally referred to war between two or more belligerents whose relative military power differs significantly. Contemporary military thinkers tend to broaden this to include asymmetry of strategy or tactics. Today "asymmetric warfare" can describe a conflict in which the resources of two belligerents differ in essence and in the struggle, interact and attempt to exploit each other's characteristic weaknesses. Such struggles often involve strategies and tactics of unconventional warfare, the "weaker" combatants attempting to use strategy to offset deficiencies in quantity or quality [1], [2] and [22]. Perhaps a more concise definition of asymmetric warfare is an action that does not involve one conventional military force pitched against another. Flying an aircraft into a skyscraper is an asymmetric attack because (at least prior to Sept 11, 2001) there were no (military) measures in place to explicitly defend against it (although there were broader anti-terrorist measures) [3]. Irregular warfare situations include civilian assistance, peacekeeping operations under threat of insurgent activity, handling humanitarian tasks, guerilla warfare and manipulating the media.

Moreover, as the recent campaigns in Iraq and Afghanistan have manifestly demonstrated, victory is no longer achieved with the defeat of a conventional army through massive force-on-force engagements with clearly demarcated front lines and division rears. The modern commander must now define the operating theatre of operation in more than just kinetic and geographical terms, including political, economic, diplomatic, social and cultural factors.

While asymmetric warfare encompasses a wide scope of theory, experience, conjecture, and definition, the implicit premise is that asymmetric warfare deals with unknowns, with surprise in terms of ends, ways, and means. The more dissimilar the opponent, the more difficult it is to anticipate his actions. Knowledge in advance of how an opponent planned to exploit dissimilarities, could allow developing specific doctrine to counter his actions. Against asymmetric opponents, doctrine should provide a way to think about asymmetry and an operational philosophy that would take asymmetry fully into account [16], [17].

In [29] (in French), Jean-Jacques Patry and Jean-Luc Marret suggest that the definition of asymmetric warfare depends on the country in the following way:

- For USA, asymmetry hampers the maximum yield offered by conventional military facilities,
- For Great Britain, asymmetry provides a strategic effect through unconventional means,
- For France asymmetry refers to understandable or not understood engagements.

3.0 AGENT-BASED M&S FOR MILITARY APPLICATIONS

3.1 Agent-based Approach

In order to support decision makers in those changing and complex environments, decision support and/or analysis tools must be capable of capturing the complexities of a broader and constantly evolving operational landscape. Agent-based paradigms are a relatively new technology within the simulation domain. They emerged as an expansion from work on Cellular Automata and initially focused on the simulation of primitive insect colonies. Today, Multi-Agents systems have been used in a plethora of applications including modeling of nations, economic factors and business activities. Nevertheless, there is no universal agreement on the precise definition of an agent-based simulation. In their most basic form, agents are software autonomous objects that perceive their environment through sensors and act on that environment.

Agents may be able to communicate directly with other agents, are driven by a set of tendencies in the form of individual objectives or satisfactions, possess resources of their own, are capable of perceiving their environment, possess skills, and whose behaviour tends towards satisfying its user-defined objectives [9]. In short, an agent can sense its environment, communicate with other agents, build perceptions, make decisions, and take actions in an attempt to simultaneously satisfy multiple objectives. ABSs are based on the idea that is possible to represent in computerized form the behaviour of entities which are active in the world, and that it is thus possible to represent an emergent collective behaviour that results from the interactions of an assembly of autonomous agents. Interesting and often unexpected emergent behaviours have been discovered in a diverse set of application areas. Since military conflicts can have many attributes that are consistent with complex adaptive systems, agent-based simulation continues to be increasing interest in military applications [18]. The agents within these simulations range from simple agents that follow a basic set of rules to highly detailed models with complex knowledge bases and rules sets. Their purpose are diverse including agents that control battlefield entities, command agents that act as high level commanders, information filtering agents and decision support agents.

3.2 Using Agent-based Technologies for Modelling Asymmetric Warfare

An illustration of using agent-based modeling and simulation of asymmetric operations (Afghanistan) has been recently given by the United States Joint Forces Command (USJFCOM) who conducted experiments using models and simulations that represent the cultural context of societies, through Synthetic Environments for Analysis and Simulation – Virtual International System (SEAS-VIS) from Simulex Inc [19]. This framework is an agent-based, multi-theory tool capturing the social, political, cultural and economic elements of society and the dynamics that form between them [5], [6], [7] and [8]. SEAS-VIS represents each virtual community using five primitive constructs: individuals, organizations, institutions, infrastructures, and geographies (IOIIG). These five primitives are used to model the emerging higher order constructs such as geographical entities (nations, provinces, cities), political systems (type of government, political parties/factions), military (soldiers, institutions), economic system (formal and informal structures), social system (organizations, groups), information systems (print, broadcast, internet, social networks), and critical infrastructures (banking, oil and gas, electricity, telecommunications, transportation).

To represent a synthetic nation such as Afghanistan through SEAS, individual citizen agents are constructed as a proportional representation of the societal makeup of the real nation. Each citizen agent is encoded with static traits, such as gender, nationalism, ethnicity, race, income, education and religion, as well as dynamic traits, such as their political, societal and religious orientations, and well-being. In this way, agents in SEAS-VIS are made to be culturally specific, holding opinions towards other entities and reacting to their perception of their needs. Agents also have memories, enabling individuals to respond based on personal experiences. SEAS-VIS is based on Kahnemann's concept of subjective well-being [11], which refers to a person's assessment of their perceived state of happiness. A citizen agent's well-being consists of nine fundamental needs: basic, political, financial, security, religious, social, educational, health, and freedom of movement. Daniel Kahnemann was Nobel prized in 2002 "for having integrated insights from psychological research into economic science, especially concerning human judgment and decision making under uncertainty". SEAS-VIS includes a hierarchical model of needs proposed by Abraham Maslow [12]. An interpretation of Maslow's hierarchy of needs can be represented as a pyramid with the more basic needs at the bottom (physiological needs such as breathing, food, water, sleep) and the highest level needs at the top of the pyramid (self-actualization needs such as morality, creativity, problem solving abilities).

Agent-based modeling and simulation provides a powerful methodology to represent complex systems and interactions among them, aiming at studying self-organization properties arising from a set of individual rules (emergence) [9], [10]. However, complex tools such as SEAS-VIS are difficult to use, to maintain and to validate [6]. Those drawbacks motivated the appearance of a new approach of agent-based modeling commonly referred to as agent-based distillations.

4.0 AGENT-BASED DISTILLATIONS VS. CONVENTIONAL AGENT-BASED SYSTEMS

Agent-based distillations trade sophistication for speed and lower simulation costs. As a result simulations tend to be less scripted with less user input than high fidelity high cost combat simulation software or seminar war games.

Broadly speaking, distillations can be defined as simulations that attempt to model warfare scenarios by implementing a small set of rules that allow agents to adapt within each scenario [4]. Distillations are far less detailed than traditional simulations and rely on sensible global behaviour to emerge naturally, unlike traditional models that require this behaviour to be explicitly programmed. This simplicity gives distillations the characteristics of speed, transparency, ease of configuration and the ability to use the systems with minimal training. Unlike the traditionally firepower and equipment centric simulations, distillations can be considered to maneuver centric meaning that insights are predominantly gained not through the numerical results of simulation runs, but rather from an understanding of how the agents adapt to each other's tactics [20]. Agent-based distillations provide a bottom-up approach to modelling combat scenarios [4]. Unlike traditional constructive simulations which specify an overall scenario, and then layer more and more levels of detail as they generate the components of that scenario, distillations require the analyst to develop the individual components and then observe the overall behaviour that emerges within the model [4].

Several engines, platforms and toolkits have already been proposed. Some of them have been extensively used for modeling Complex Adaptive Systems such as Crocadile[3] [4], [20], MANA[4] [31] or ISSAC[5] while others are general purpose platforms such as StarLogo [32], NetLogo [15], [36] and Repast[6] [33].

MANA has been recently used for comparing efficiency and performances of movement algorithms [35] and for validating human behaviour representation models [34]. NetLogo and StarLogo were designed in

[3] Conceptual Research Oriented Combat Agent Distillation Implemented in the Littoral Environment.
[4] Map Aware Non-uniform Automata.

[5] Irreducible Semi-Autonomous Agent Combat.
[6] The Recursive Porous Agent Simulation Toolkit.

the spirit of the Logo programming language that is to enable easy entry by novices and yet meet the needs of high powered users. NetLogo was designed and authored by Uri Wilensky, director of Northwestern University's Center for Connected Learning and Computer-Based Modelling, Evanston (IL), USA. NetLogo has many thousands of active users, is freely available for download and comes with an extensive models library including models in a variety of domains such as economics, biology, physics, chemistry, psychology and many other natural and social sciences.

5.0 USING NETLOGO FOR MODELLING ISSUES IN ASYMETRIC WARFARE

In this section, we describe the main features of NetLogo including its powerful programming language allowing modelling behaviour of thousands of agents (turtles), and its both 2D and 3D viewer environment[7]. Explanations will be based on a "simple mind" model of asymmetric terrain where several kinds of agents have to compete. This model consists of a deep adaptation of the rebellion model designed by U. Wilensky [37], itself adapted from a model of civil violence proposed by Joshua M. Epstein [23].

5.1 The Simulated Models

As stated before, models are not realistic and are only used to experiment the ability of the platform in rapid prototyping behavioural models according to a bottom up approach. Several agents (turtles) are involved:

- Agents '*individuals*' are characterized by their influence, energy and force. When an individual agent is hungry, he becomes 'dislocated' and from this moment will actively use brute strength to fight with individuals in the neighbourhood. The strongest individual wins and the lowest die. At each step of the simulation, each individual moves and tries to reach a restaurant. If any restaurant is available in the surroundings his energy value decreases. On the contrary, the energy increases as soon as the individual finds a restaurant. Individuals influence each other and at any time each individual can be influenced by only one leader. At each simulation step, the individual who has the greatest influence becomes the leader of all people in the neighbourhood,
- Agents '*food*' represent restaurants with an initial quantity of food which decreases when an individual eats and which increases periodically. When an restaurant becomes empty, it disappears from the simulated landscape,
- Agents '*media*' represent information media but are not yet implemented,
- Agents '*airplanes*' represent fighter bombers dropping bombs randomly. When a bomb hits the ground, it can destroy a building or a restaurant and kill an individual.
- Finally, agents '*houses*' represent buildings,

The simulation algorithm is straightforward:

> *Create a set of agents (individuals, food, media, airplanes and houses) according to a normal distribution*
>
> *While (individuals are not all dead) do*
>
>> *Simulate a bomb explosion from a fighter bomber if any*
>>
>> *Verify if the individuals become dislocated and in case of true, simulate a fight with an individual in the vicinity if any*
>>
>> *Manage leadership of individuals*

[7] We used the 3D NetLogo 4.1RC3 released available since June 2009.

Manage restaurants

Move individuals

Move fighter bombers

EndWhile

5.2 The Platform Interface and 3D View

Figure 1 depicts the interface allowing the user to interact with the model. This figure is a screenshot of the interface before running the simulation.

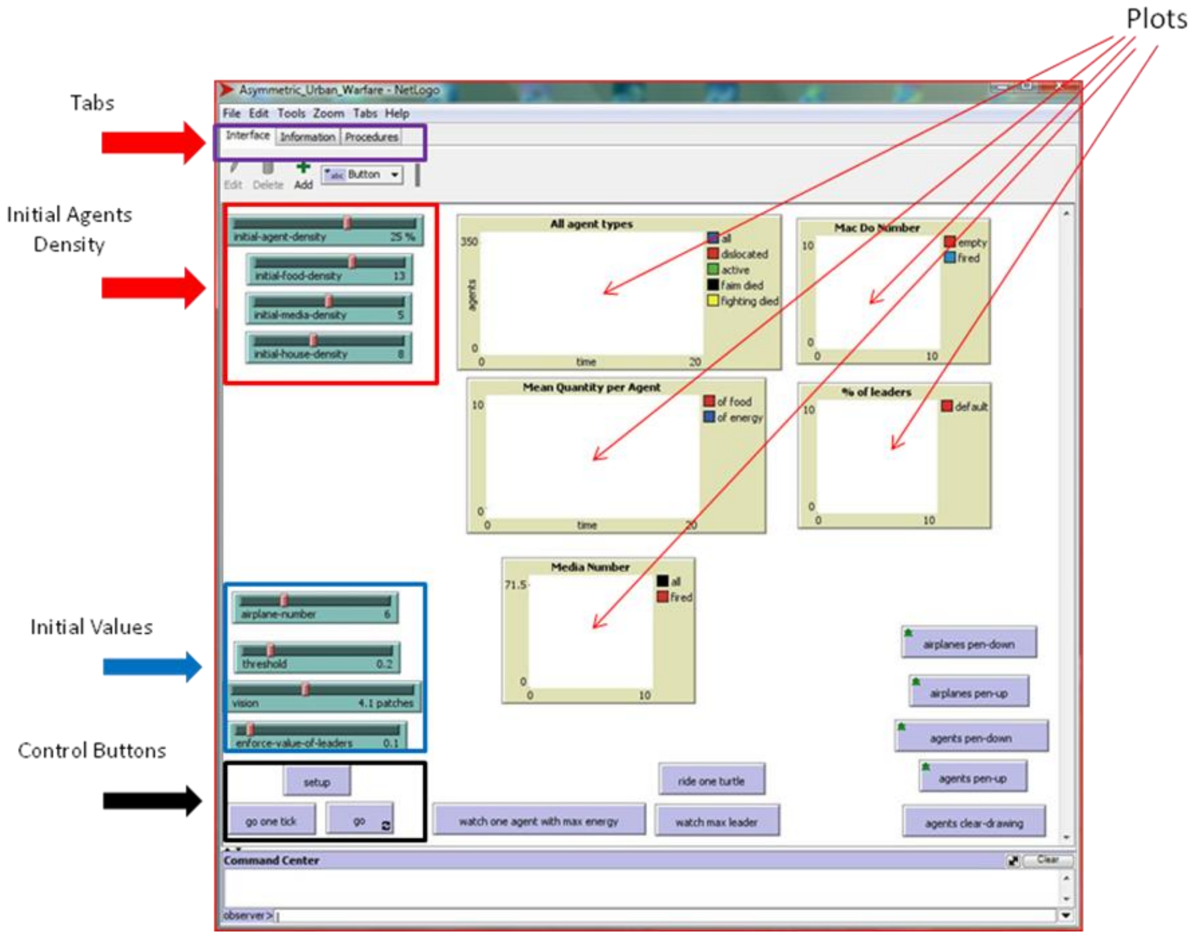

Figure 1: Example of NetLogo interface

At the top of main window are 3 tabs: ‘Interface’ tab is used to interact with the model; ‘Information’ tab displays explanations about the model itself and the corresponding terms of copyrights; ‘Procedures’ tab shows the program. ‘*Initial Agent’s Density*’ (density of individuals, foods, media and houses) are set through four sliders which represent global variables accessible by all agents.

They are used in models as a quick way to change a variable without having to recode the program every time. ‘*Initial Values*’ are sliders to set global variables (airplanes #, enforced influence #, radius of the agent’s neighbourhood and energy threshold). ‘*Control Buttons*’ are used to manage the simulation (setup, go one step, go continuously).

Finally, ‘*Plots*’ are created by the user and will be drawn as the model is running allowing to display the evolution of the corresponding variables. In this model, types of agents, media number, foods number and leader percentage are displayed. Figure 2 is a snapshot of the 3D view providing a visual representation of the world. Figure 2a displays the landscape after setting up the simulation, showing buildings, airplanes and other agents. Figure 2b shows the landscape after zooming. At the bottom of the window there are buttons to move the observer or change the perspective from which the user is looking at the world.

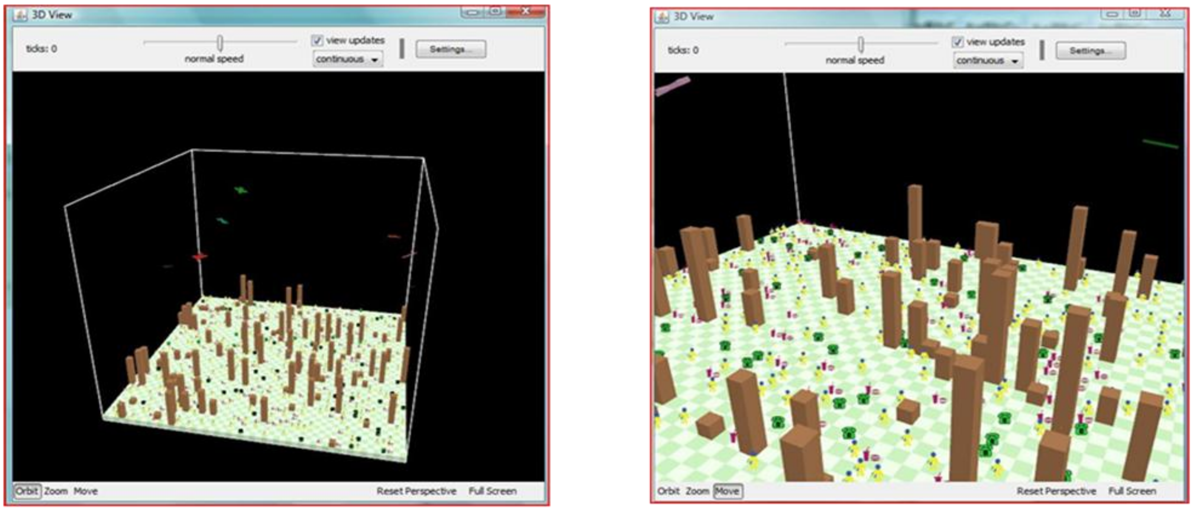

Figure 2a   Figure 2b

Figure 2: The 3D view

A lot of functionalities are offered by the 3D viewer to control the simulation and the representation of world. Presentation of those functionalities is beyond the scope of this paper. Refer to the user manual for additional explanations[8].

[8] http://ccl.northwestern.edu/netlogo/docs/

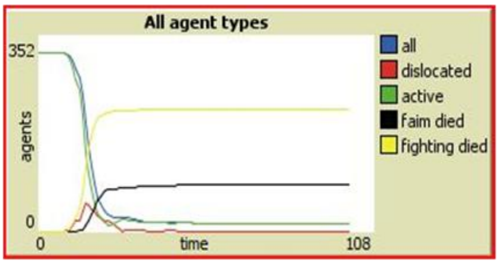

Figure 3a

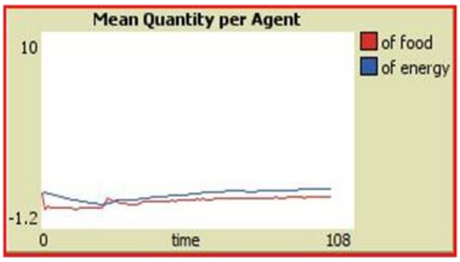

Figure 3b

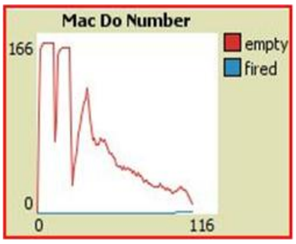

Figure 3c

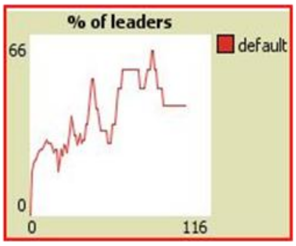

Figure 3d

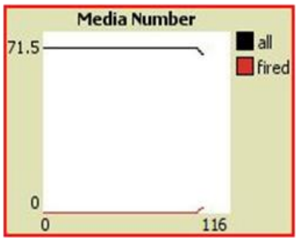

Figure 3e

Figure 3: Plotting some variables after 100 simulation steps

During the simulation, NetLogo displays in real time current values of selected variables as shown in figure 3 representing the status after one hundred steps. Although the models are rudimentary, some kind of stability appears after a few tens of steps. For example, Figure 3a plots the number of individuals according to their current status (dislocated in red, active in green, died of hunger in black and killed in combat in yellow). We observe that the system reaches a balance after a few tens of ticks. Respectively, the 'foods' number of empty restaurants (Figure 3c) rapidly decreases because the number of individuals decreases too. Notice that the number of both restaurants (Figure 3c) and media (Figure 3e) destroyed by bombs from fighter bombers, begins to increase after approximately one hundred of simulation steps. This is because the probability of being hit by a bomb increases drastically with time.

Those plotting tools are very useful to discover from a qualitative point of view some emerging behaviours that have not been explicitly programmed within individual agents.

The 3D viewer provides also the ability to select a given agent by clicking by the mouse as shown by the Figure 4 screenshot. The platform displays then the quantitative values of all attributes belonging to the selected agent.

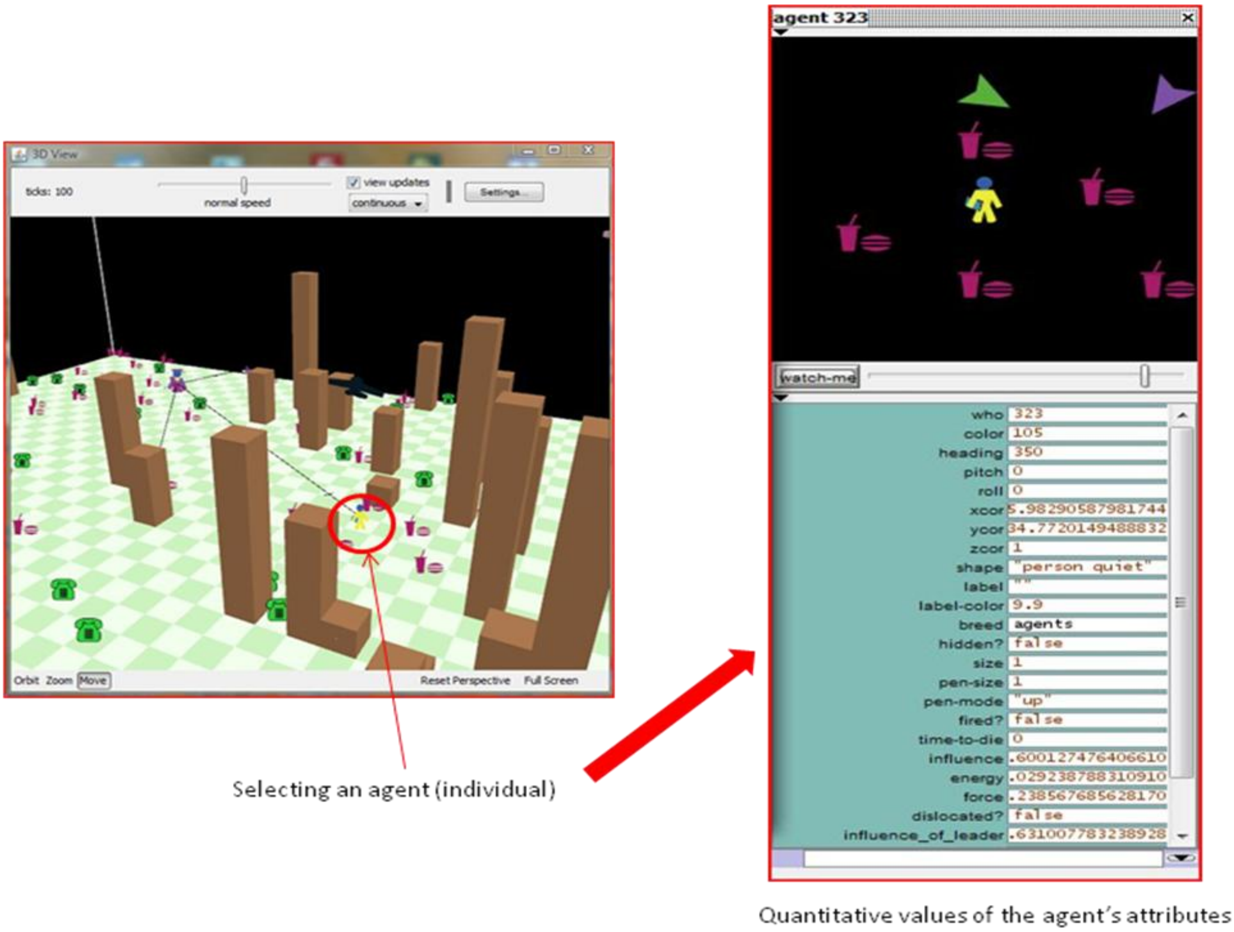

Figure 4: Displaying quantitative values of agents' attribute

Finally, Figure 5 represents the situation at the end of the simulation (about 6000 steps) when all individuals have died either because they have been killed or due to the lack of food. In this model, since restaurants can be destroyed by fighter bombers, individuals have more and more difficult to find food and then finally disappear.

Figure 5a

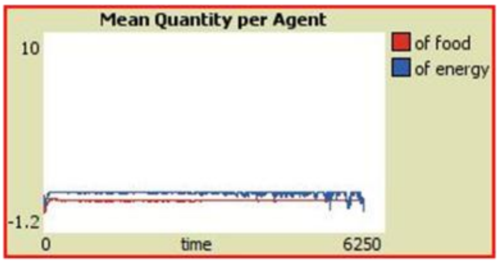

Figure 5b

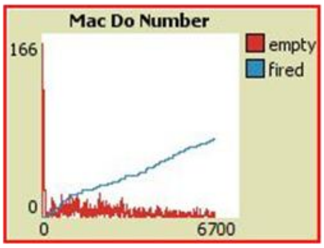

Figure 5c

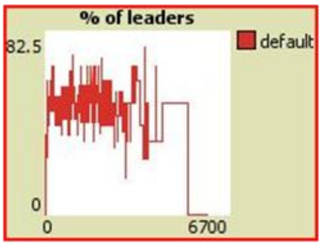

Figure 5d

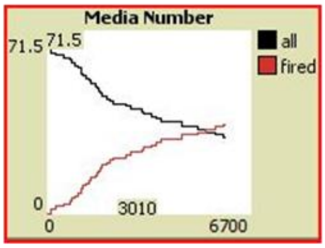

Figure 5e

Figure 5: Plotting status at the end of simulation

This interpretation is confirmed by the last experiment consisting of disabling bombing from fighter bombers. Figure 6 depicts the situation after about 25 000 simulation steps.

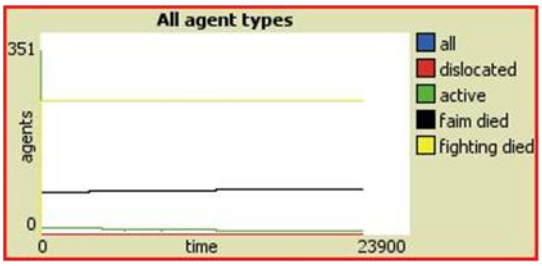

Figure 6a

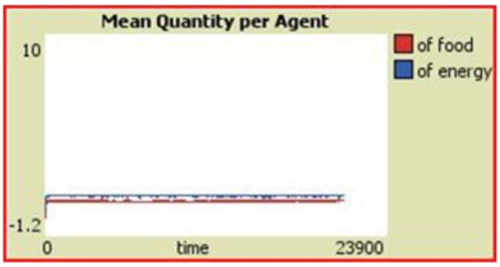

Figure 6b

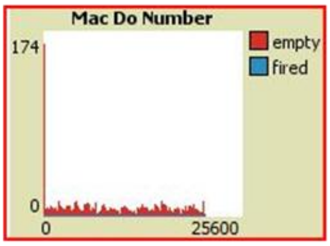

Figure 6c

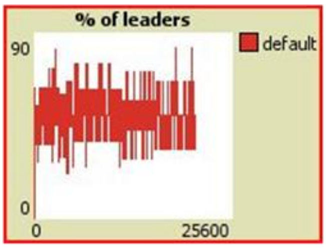

Figure 6d

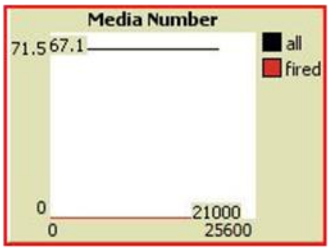

Figure 6e

Figure 6: Plotting status after 25 000 simulation steps

We observe that very soon the system reaches a steady state.

5.3 The Behaviour Space and Additional Tools

The Behaviour Space is an integrated software tool that allows the user to perform experiments with models. It runs a model many times, systematically varying the model's settings and recording the results of each model run. It lets the user explore the model's 'space' of possible behaviours and determine which combinations of settings cause the behaviours of interest. Through the main 'Tools' menu the user opens a dialog box that lets him create, edit, duplicate, delete, and run experiment setups. Experiment setups are considered part of a NetLogo model and are saved as part of the model.

Additional tools include a shape editor for turtles and patches, a system dynamics modeller and an impressive library of models. Extensions to the NetLogo platform include a link with Mathematica[9], a performance profiler as well as the ability to load vector GIS[10] data.

5.4 NetLogo Programming Language

NetLogo is written in Java language. Nevertheless, it supports a higher level agents oriented language allowing applying commands to agents. To design a model, the user has to switch to the 'Procedure' tab of the main menu, since a program is considered as a set of procedures. Figure 7 is a screenshot of the 'Procedure' tab displaying the main procedure of our model[11].

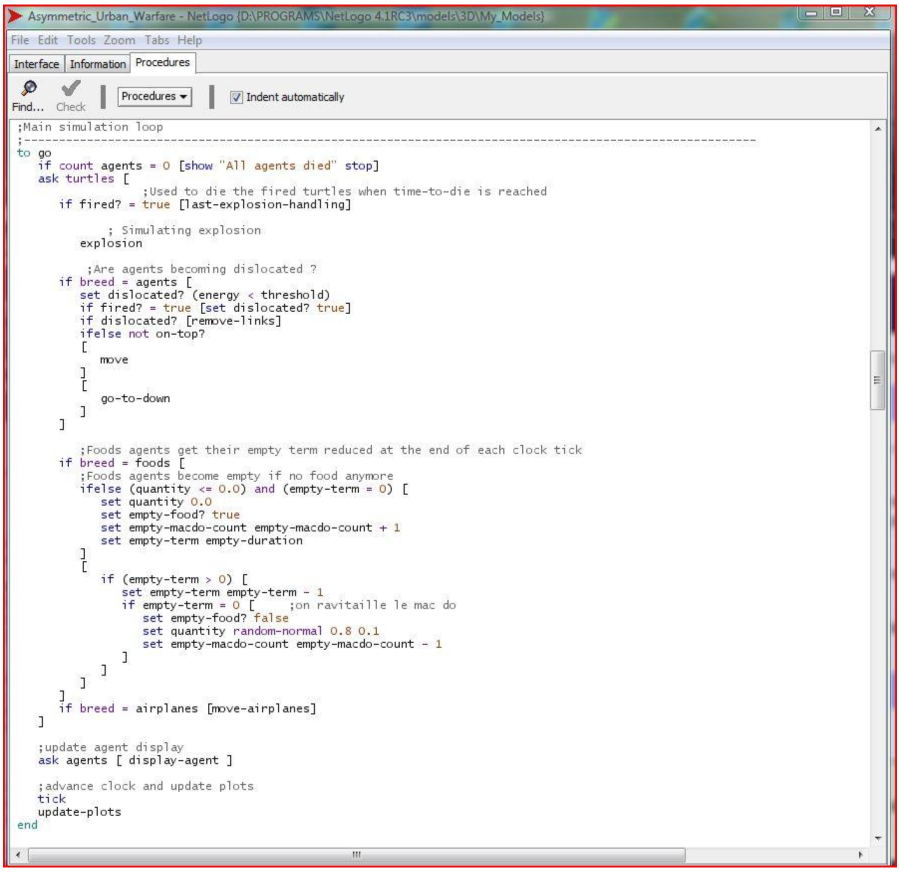

Figure 7: Screenshot of the 'Procedure' tab

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[9] http://www.wolfram.com/

[10] Geographic information system.

[11] The name of the main procedure is mandatory (go).

The 'Procedure' tab supports a conventional text editor allowing the user to write his code and immediately check its accuracy since neither compilation nor linking phase are needed.

A procedure consists of a set of commands that are applied to a set of agents (turtles). For example the following declaration[12]

```
breed [agents agent]
```

defines a set of 'agent' turtles as a breed called 'agents'. Those turtles represent 'individual' agents. Attributes of each 'agent' belonging to the 'agents' breed are defined through the following declaration:

```
agents-own [
  influence                   ;Agent influence ranging from 0-1
  energy                      ;Agent energy ranging from 0-1
  force                       ;Agent force used only when dislocation is true
  dislocated?                 ;if true, then the agent is actively using brute strength
  influence_of_leader         ;Influence of the leader of agents. Used to avoid multiple interactions
  leader_agent                ;Number of leader for an agent
  number-of-influenced-agents       ;How many influenced agents has this leader
  on-top?                     ;Is the agent on top of a building?
]
```

Creation of a set of 'agent' turtles and setting the attributes is performed though the following powerful construct (z-of-agents is equal to 1):

```
create-agents round (initial-agent-density * .01 * (count patches with [pzcor = z-of-agents]) / (z-of-agents - min-pzcor + 1))
 [
   move-to one-of patches with [not any? turtles-here and pzcor = z-of-agents]
   set heading 0
   set influence random-normal 0.7 0.2
   set energy random-normal 0.8 0.1
   set force random-normal 0.6 0.3
   set dislocated? false
   set influence_of_leader -1
   set leader_agent -1
   set number-of-influenced-agents 0
   set on-top? false
   display-agent
 ]
```

The first complex construct (create-agents) calculates the number of agents as a density of the total number of patches in the 3D world. The keyword 'pzcor' is the z coordinate of the corresponding patch. The '*move-to*' construct moves each agent on the floor (pzcor = 1) to the first patch that is not already occupied by an agent. Since individual agents have to check if other turtles are in their vicinity, we define a neighbourhood for each agent as follows (z-of-agents is equal to 1):

```
ask patches with [ pzcor = z-of-agents ]
[
  set neighborhood patches in-radius vision with [ pzcor = z-of-agents ]
]
```

[12] Keywords are in red colour.

At each step of the simulation loop (within the 'go' procedure), the following code is performed:

```
ask turtles [
                        ;Used to die the fired turtles when time-to-die is reached
  if fired? = true [last-explosion-handling]
                        ; Simulating explosion
    explosion
                        ;Are agents becoming dislocated ?
  if breed = agents [
    set dislocated? (energy < threshold)
    if fired? = true [set dislocated? true]
    if dislocated? [remove-links]
    ifelse not on-top?
    [
      move
    ]
    [
      go-to-down
    ]
  ]
]
```

The block of the '*ask turtles []*' construct will be applied to all turtles created by the initialisation phase. In that way only the behaviour of elementary agents are explicitly coded. On the contrary, the block of the '*if breed = agents []*' construct will be applied only to turtles belonging to the 'agents' breed (individuals). 'move', 'go-to-down', 'remove-links', 'last-explosion-handling', and 'explosion' are user defined procedures. The meaning of the remaining code is straightforward.

The following 'fight' procedure is interesting:

```
to fight
  let targets other neighborhood with [any? agents-here]
  let agent_force force
  if any? (agents-on targets) [
    let victim one-of (agents-on targets) with [force < agent_force]
    if victim != nobody [
      set count-fighting-died count-fighting-died + 1
      move-to victim
      ask victim [
        die-behavior
      ]
    ]
  ]
end
```

This code allows selecting a weaker individual occupying a patch in the neighbourhood of each individual. If a victim exists, the winner moves to its position and the victim is killed ('*died-behavior*' procedure).

6.0 CONCLUSIONS AND FUTURE TRENDS

From preliminary experiments, the agent-based distillation approach seems to be a valuable technique for designing preliminary models, in minimal time and with minimal effort. We claim that in the domain of asymmetric/irregular warfare where complex behavioural models from social sciences have to be taken into account, M&S platforms such as NetLogo are suitable to first examine and validate less detailed models before integration within operational decision support systems at higher resolution level. For example, complex psychological components of human individuals/groups behaviour such as legitimacy, influence, violence tendency or evolution of attitude towards leaders, institutions or governments, needs an iterative bottom up approach with higher and higher resolution, to understand how agents interact with themselves and how overall behaviours emerge. Agent based distillation and associated tools provide efficient and useful means to successfully gain understanding of those complex psychological components.

In this paper we have not talked about emergence of phenomena or/and behaviours. Nevertheless, a simple example of emergence is given by the Figure 8 which is a snapshot of the 2D viewer of the 'Traffic Basic" model taken from the model library of NetLogo [38]. This example models the movement of cars on a highway. Each car follows a simple set of rules: it slows down (decelerates) if it sees a car close ahead, and speeds up (accelerates) if it doesn't see a car ahead. Simulating the model provides the emergence of a traffic jam from the simple set of rules applied to individual cars.

Figure 8: A simple visual example of emergence

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