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ADVANCES IN MODELING AND SIMULATION

In 1999, *Information & Security: An International Journal* published volume 3 that was focused on Modeling and Simulation (M&S) techniques and their applications to security related issues including defense, internal security and international cooperation. Since that time, the use of modeling and simulation (M&S) is becoming even more pervasive throughout the NATO defense environment. The value of simulations to defense establishments has been repeatedly proven by providing readily available, operationally valid environments to train jointly, develop doctrine and tactics, formulate operational plans; assess war fighting situations; and support technology assessment, system upgrade, prototype and full-scale development, and force structuring.

To address the advances made in the field, *Information & Security* has decided to publish a second issue devoted to defense modeling and simulation. We have received many papers covering the broad spectrum of topics in defense modeling and simulation.

In particular, based on the accepted papers, we have decided to organize the special journal issue on advances in modeling and simulation in two numbers. Volume 12, number 1 focuses on the following groups of topics:

- Review of Defense Modeling and Simulation
- Computer Generated Forces, and
- Agent-based Modeling and Simulation.

Number 2 deals with:

- Simulation Reuse and Interoperability
- M&S Applications, and
- M&S in Information Assurance.

Review of Defense Modeling and Simulation

The objective of the first group of papers is to provide a review of the achievements in defense modeling and simulation. While the first paper takes a global perspective, the second discusses the R&D work performed in a single country – Croatia.

Modeling and simulation are essential tools in defense planning, development and acquisition of systems, training and exercises, and operational planning. In his article, "Modeling and Simulation in Defense," Klaus Niemeyer provides a contribution to a theoretical approach to the technology, with discussion of definitions and characteristics, such as purpose of a model, reduction of complexity, and representation of real entities or systems. Klaus Niemeyer's paper discusses also specific issues in modeling of the defense system, such as the military hierarchical structure, functional areas, operational phases, planning situations, and the decision cycle.

The second paper in this group, "Combat and Security Related Modeling and Simulation in Croatia," describes the research and development activities in Croatia of state-of-the-art combat and security-related educational and training simulators. Krešimir Ćosić, Miroslav Slamić, and Dražen Penzar present individual and crew training simulators for antitank guided missiles, low altitude air defense missiles, jet fighter aircraft and hardware-in-the-loop simulators for real time testing of newly developed digital signal processing guidance and control system. Design and development work of high-resolution tactical simulations and operational aggregated combat simulations is also described. Finally, Ćosić and coworkers present a theoretical approach applied to the modeling and simulation of national power and national security.

Computer Generated Forces

Human performance in combat is a key element to success. From the humans' ability to do physical work to their ability to make sound decisions, success in combat is largely a function of the human element. Therefore, the value of computer models of combat is greatly affected by their ability to accurately represent the range and variability of expected human behavior. Computer models of complex human behavior have been around for over two decades, but their use in computer models of combat continues to be developed. The distributed simulation environments that are being used for training and analysis drive much of the new interest. Today, simulation exercises involve a few dozen real people with the remaining hundreds or even thousands of other battlefield entities being computer simulations. These computer generated forces are becoming a foundation of current and future military training and analysis.

Many researchers have worked to add realism to human representations through a variety of computer modeling techniques. And this is exactly the place where the papers in this group contribute.

Should computer generated forces systems include automated learning capabilities? This is the question posed by Mikel D. Petty in his paper "Benefits and Consequences of Automated Learning in Computer Generated Forces Systems." The idea that CGF systems can and should include automated learning capabilities has been widely asserted and accepted. The CGF research literature contains many statements by CGF experts that the ability to learn will be generally valuable, even necessary, in future CGF systems. A variety of significant benefits for CGF systems and military simulation in general are claimed to follow from automated learning. However, according to Mikel D. Petty, it seems to be not so obvious that learning by CGF systems would necessarily be beneficial for many uses of CGF systems. The author takes a respectfully skeptical position regarding CGF learning and provides arguments that CGF learning could compromise and confound the utility of CGF systems for the most common CGF applications. For each of the three broad classes of CGF applications there are categories of learning-modified behavior for CGF systems that apparently could reduce or negate the utility of the CGF system for the application. The specific applications where learning by CGF systems might be useful are a subset of CGF applications, concludes Mikel D. Petty.

In a military simulation with automated commanders, models of command behavior and decision-making that follow doctrine precisely and exhibit no variations are unrealistic due to the uncertainties inherent in military operations and the variations in human personalities. Automated commanders that exhibit doctrinal behavior are essential for training, but are not sufficient for the full range of purposes the simulation may be applied to. Simulation users would like to have an automated commander that realistically models the effects of the fog of war and the difficulty of making doctrinal decisions under stressful conditions. Such realism in simulation could better prepare trainees for expected encounters on the battlefield.

To achieve this end, the realistic modeling of human behavior is considered as a priority research area for the M&S community. The second paper in this group, "An Experimental Application of a Trait-Based Personality Model to the Simulation of Military Decision-Making," makes a contribution to this extremely difficult and challenging area.

How to represent realistic human behavior? Based on the suggestion of some psychologists, Rick McKenzie, Mikel Petty, and Jean Catanzaro use personality traits to characterize behavior. Personality significantly influences human behavior. In the context of military decision-making, different military commanders may behave differently in the same situation, depending on their personalities. Moreover, personality may cause the same commander to react differently to similar situations encountered at different times.

To investigate the inclusion of personality in models of military command decision-making, Rick McKenzie, Mikel Petty, and Jean Catanzaro have implemented and tested a simulation wherein a simulated commander must make critical decisions under multiple pressures. The commander's behavior model allows the specification of personality using a set of eight personality traits. In general, personality traits determine the predisposition of people to exhibit a particular behavior under varying situational conditions. In their research, the authors combine the commander's personality traits and the situational conditions to produce effects such as reaction time delay and decision accuracy and effectiveness modifications. McKenzie, Petty, and Catanzaro showed that modeling personality and its effects on the decision-making of a commander could improve simulation realism. Their model was implemented and used in an experiment intended to test its utility in producing more realistic human decision-making in a way that could be validated by personality and performance measurements of real human commanders. Looking farther ahead, a personality model may also be applied to the task of predicting how a particular military commander might react in a situation and how to improve that commander's performance.

Agent-based Modeling and Simulation

Computer simulation is a valuable tool for complex decision-making, especially in military and civilian operations in the land, air or sea. As we have already elaborated, simulation has been used in the military domain for the evaluation of acquisitions, missions and force development options. Modeling and simulation for this purpose is becoming increasingly complex as multi-role, multi-platform and multi-system aspects are taken into consideration. The complexity of this task is further increased by the difficulty in modeling human decision-making using conventional software approaches. Current implementations of computer generated forces have proven to be very useful, but do not model human reasoning and cannot easily model team behavior. Applications of intelligent agents in military simulations have proved highly effective. This is due to the capability of agents to represent individual reasoning and from the architectural advantages of that representation to the user due to the ease of setting up and modifying operational reasoning or tactics for various studies. In addition, intelligent agents extend the modeling of reasoning to explicitly model the communications and coordination of activities required for team behavior.

The aim of the next group of papers in this special issue on advances in modeling and simulation is to point out the importance of agent-based modeling and simulation, as a scientific concept and technological possibility, to enhance the potential of simulation in both civilian and defense applications. The interested reader may refer to a previous issue of *Information& Security* devoted especially to this important technology for modeling and simulation.

The emphasis on timely, accurate information in modern warfare, and the availability of modern communications, has led to the development of increasingly complex command and control systems. It is important to understand the behavior of these systems under a variety of circumstances. However, as they are difficult to analyze manually, advanced modeling and simulation tools for command and control systems development are required. As we have already elaborated, the challenge in these systems is to model the reasoning associated with different roles in the hierarchy. Intelligent agents can represent the reasoning and command capabilities associated with their assigned roles in the hierarchy, allowing different command and control strategies to be quickly evaluated under varying circumstances.

These intelligent agent simulation models were in the focus of the paper by James Moffat and Susan Witty published in Volume 8 of the journal. Such agent models consist of a number of entities which interact locally in order to produce global emergent behavior. In complex systems, elaborate and unpredictable properties arise from the interaction of the constituents. Examples of such emergent properties include how the system organizes itself, how it finds a balance between order and disorder, and how agents, both individually and collectively, evolve new behaviors in response to change. Some of the emergent behaviors can be surprising, and the work of James Moffat and Susan Witty published in Volume 8 of the journal described a theoretical approach to the development of mathematical "meta-models," which aim to capture the emergent behavior of intelligent agent-based constructive simulation models of military conflict. These intelligent agents capture the process of C4ISR (Command, Control, Communications, Computers, Intelligence Surveillance and Reconnaissance) in such agent-based simulation models.

The principal variables in an intelligent agent simulation models can often be separated out from the rest of the model to develop a meta-model that is aimed at decreasing the run-time of the original model while still retaining the characteristics and arriving at the same final solution as the original model. The meta-model of Moffat and Witty is a mathematical abstraction of such a simulation, composed of two parts. For the first part, the fractal dimension of a force is introduced as a parameter measuring the emergent ability of such forces to cluster locally, corresponding to local decision-making by individual agents. For the second part the authors consider the mathematics of Bayesian Decision-Making as a meta-model for top down decision processes in such simulation models.

These meta-models fall within the area of what is loosely referred to as complexity theory, and exploit the mathematical approaches which are being developed to gain understanding of natural non-linear systems. Such an approach is most likely to be relevant to future command and control structures such as Network Centric Warfare.

In the current paper, "Experimental Validation of Metamodels for Intelligent Agents in Conflict," the authors present both historical evidence and evidence from experiments using cellular automata models that support hypotheses derived from their theory.

As a means of gaining understanding, the authors have carried out a number of experiments using simple cellular automata based models that are relevant to conflict. Such models have been developed in response to the theory that human conflict is a complex, non-linear system, which in dynamical system terms, occurs far from equilibrium.

The 'new sciences' of complexity and chaos provide a way of looking at such interacting agents in conflict. In their paper, James Moffat and Susan Witty first show that historical data indicate the existence of a fractal attractor for at least some types of conflict. Then, the authors show that experimental data from runs of such simple cellular automata models supports the hypotheses, which can be derived from their theoretical meta-models of the process.

The second paper in this group, "Soft Computing Agents for Dynamic Routing," reviews and evaluates the state-of-the-art in Distributed Information Systems. The author Georgi Kirov outlines some disadvantages of distributed software. He concludes that the field of distributed network systems is in a critical need of intuitive and innovative approaches to address the growing complexity in all of its different aspects: communication, routing, performance, stability, and connectivity. In an attempt to resolve the above-mentioned problems the work of Georgi Kirov proposes an approach that combines the Bee-gent agent technology and the fuzzy-logic representation. The author presents an example of soft-computing agents for dynamic routing that uses distributed database applications as illustration of the concept.

Simulation Reuse and Interoperability

Interoperability is an operationally driven requirement in several application domains of combat simulation systems and it is stated in milestone documents such as the U.S. DoD Modeling and Simulation Master Plan and the NATO Modeling and Simulation Master Plan.

While the use of modeling and simulation for military purposes is expanding, recent work by the NATO Steering Group for Modeling and Simulation has demonstrated that most applications in the NATO nations have been developed by individual organizations to meet the explicit needs of a particular user community; are not integral to operational systems; take too long to build and cost too much; can not be used in joint applications and are not fully validated. The consequence was the proposal to develop and apply standards and interoperability procedures as provided by the High Level Architecture (HLA).

The High Level Architecture is architecture for constructing distributed simulations. It facilitates interoperability among different simulations and simulation types and promotes reuse of simulation software modules. HLA addresses a number of the limitations imposed by the data protocol approach associated with the earlier Distributed Interactive Simulation (DIS) standard. HLA has been mandated by the U.S. Department of Defense, has been published as a standard by the Institute of Electrical and Electronics Engineers (IEEE) and the Object Management Group (OMG), and is being adopted by creators of simulation software worldwide. HLA can support virtual, constructive, and live simulations from the training, engineering, and analysis applications domains. While in many respects HLA achieves these goals, it unfortunately also adds a significant amount of overhead and complexity to the development process, resulting in the need for specialist HLA skills; a lot of extra work and code is needed to build the necessary software infrastructure needed for HLA compliance.

Shawn Parr's paper, "A Visual Tool to Simplify the Building of Distributed Simulations Using HLA" outlines the problems currently faced by simulation developers wanting to use HLA, and introduces Calytrix SIMplicity product to address them. Shawn Parr presents SIMplicity, which delivers an Integrated Development Environment (IDE) HLA development, based on the OMG's Model Driven Architecture, to simplify the process of developing distributed simulations. SIMplicity enables software developers and scientists to rapidly create large-scale, high fidelity component-based simulations from new and pre-existing components in a visual environment. The product makes it feasible for developers to create HLA simulations without specialist HLA or middleware knowledge.

Due to historic constraints, the two military IT families of Modeling and Simulation (M&S) and Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance (C4ISR) were more or less developed separately. For integrated support for the needs of modern armies, however, a combination of both sides' functionality is needed. The motivation for improving the interoperability between simulations and C4ISR systems include: simulation based acquisition; development of doctrine and tactics techniques, and procedures; computer assisted exercises; embedded training; course of action development and analysis; mission planning and rehearsal; monitoring execution; and command and control. Furthermore, future military operations require interagency interoperability to enable cooperation of various national/international partners and will be conducted in joint/combined environments, often in tight collaboration with non-military and non-governmental organizations. As it is very unlikely that these organizations and international partners will use U.S. DoD standards to implement their information systems, there need to be well-understood ways to insure information exchange with such systems.

Therefore, there is a strong need to solve the interoperability issue between information systems used for Command, Control, Computing, Communications, Intelligence, Surveillance, and Intelligence (C4ISR) and combat simulation systems. A step in this direction is taken in the contribution by Andreas Tolk.

The solution to couple the simulation system delivering the needed functionality with the Command, Control, Computing, Communications, Intelligence, Surveillance, and Reconnaissance (C4ISR) system providing the necessary data is to build appropriate interfaces. Although in long term a more integrated approach will be necessary, in short and mid term, gateways and interfaces are likely to remain the standard. However, as Andreas Tolk claims, in order to succeed with the respective efforts at least on the data level of interoperability, a common solution is necessary. Subsequently, in achieving interoperability issues like a common architecture, a common set of algorithms, and a common view of the world in the form of ontology, including dynamic aspects, can be addressed as well. First of all, however, in order to make a meaningful integration possible, the common data issue has to be dealt with. The methods used to achieve this are not only applicable to the coupling of modeling and simulation and C4ISR systems, they are necessary in preparing the coupling/integration of different C4ISR systems as well, e.g., to prepare a common operation with new partners and allies. Therefore, it is a general approach to interoperability. In his paper, "Common Data Administration, Data Management, and Data Alignment as a Necessary Requirement for Coupling C4ISR Systems and M&S Systems," Andreas Tolk outlines some of the work done in this field on international level and draws some conclusions for future work.

The need for interoperability continues to be identified as a crucial element in providing more efficient and effective, multi-national and multi-agency operations. The ability to exchange information, coordinate resources, and understand each participant's capability is paramount to meeting today's challenges on the military and civil battlefields. Joint, combined, multinational training is seen as one key to the transformation required to effect interoperability. According to Ronald J. Roland, a common simulation-training platform, tested and exercised on a regular basis will lead toward interoperability. There are a large number of platform combinations that may prove effective. A potential architecture to consider, presented in his paper "A Small Step toward Interoperability" as an example, is the USAF-ESC National Military Command Center (NMCC) concept combined with the JTLS model, a worldwide standard for theater level simulations. The paper addresses the critical issues that have been resolved toward meeting the NMCC requirements of providing a common simulation software environment for both crisis management coordination at the intra and international levels and a potential candidate that can be used for combined, joint and coalition training of combat and security forces. Ronald Roland have provided information and guidelines concerning future enhancements programmed for JTLS and how each user can help guide continued upgrades and revisions.

M&S Applications

To illustrate the diversity of possible modeling and simulation applications, even confined only to defense and security, is not an easy task. The papers collected in this group provide just a glimpse at possible application scenarios. With this selection of papers we also try to provide a small but representative selection of possible modeling and simulation technologies and methodologies: fuzzy sets theory, game theory and variational calculus.

At present, the control loops of moving platforms are designed on the base of fuzzy control theory. Especially path searching in a 2D changing environment has received considerable attention as a part of the general problem of robot motion planning. A particularly interesting problem in this context is path planning with respect to a moving object. The design of such intelligent guided vehicles needs capabilities for environment recognition and motion planning. Nowadays, fuzzy control is a promising technique for intelligent system design. The most important feature of this method is that it eliminates the difference between goals and constraints and makes it possible to relate them in the decision-making process. George Georgiev and Valentine Penev propose a fuzzy control method for autonomous guided vehicle, which tracks an object in 3D space. Computer simulations verify the validity and effectiveness of the proposed fuzzy control method. In addition, techniques for path planning in an expanded fuzzy environment, including both stationary and moving obstacles, are under study by the authors.

The second paper, “Game Theoretical Modeling for Planning and Decision-Making,” turns the attention to game theory. The author, Juliana Karakaneva, applies this powerful means to modeling of real conflict situations. The approach is well known and established and there are many researchers working in this field. Recently, the importance of these techniques has increased in order to address the necessity to plan and make timely decisions in conditions of incomplete information and in asymmetric environments. In many cases it is impossible to apply mathematical methods due to the difficulties in finding adequate solutions. Modern software for optimization modeling enables to obtain credible models and solutions.

And finally, the third paper in this group, "Modeling in Shaped Charge Design," demonstrates the use of variational calculus as a tool in the development process of shaped charge geometry. Variational calculus is used for optimization of shaped charges for high-velocities forming of compact, discrete or dispersed jets. Hristo Hristov considers each characteristic function of the shaped charge geometry as a variational parameter in the Orlenko hydrodynamic model. Respectively, the author formulates the problem for determination of an unconditional extremum, as well as a subproblem for determination of a conditional extremum when an integrated condition is added.

M&S in Information Assurance

A challenge that stands before the information security community is to better prepare management, system administrators, and users to respond appropriately to information security crises while simultaneously reducing the anxiety associated with them. One clear approach to achieving this goal is to use modeling and simulation for education, training, and testing. The use of M&S can provide a better understanding of the information environment on both a concrete and abstract level. Proactively it can be used to identify weaknesses and reactively it can provide education and training using "what if" scenarios. Ultimately when new threats are introduced the ability of the organization to respond is significantly enhanced.

This group of papers will try to demonstrate just a small part of the available range of modeling and simulation capabilities in information assurance. It will also attempt to establish some principles for extending these capabilities into the community, and thus to provide a framework for future computer based modeling and simulation efforts in information security.

The first paper in this group treats the issues related to proxy signature. A proxy signature allows a designated person, called a proxy signer, to sign a message on behalf of an original signer. Many proxy signature-related schemes have been proposed due to the importance of this type of scheme. However, as Wei-Bin Lee and Tzung-Her Chen claim, these new schemes always face security challenges. To minimize security challenges, the objective of their research described in the paper "Constructing a Proxy Signature Scheme Based on Existing Security Mechanisms" is to construct a proxy signature scheme that combines existing security mechanisms, rather than attempting to invent a new scheme. Lee and Chen believe that the proposed proxy signature scheme not only satisfies the essential properties mentioned in the well known Mambo-Usuda-Okamoto's proxy signature scheme but also has additional advantages, such as provision of non-repudiation and prevention of delegation transfer. Furthermore, the authors assure that their proxy signature scheme does not affect the current security infrastructure and, thus, is more practical than the previously proposed schemes.

Intrusion detection is in the focus of the next paper. However, the authors Andrea Sanna and Claudio Fornaro put the stress more on topics such as mobile devices and visualization. Mobile devices allow a sort of ubiquitous access. This can be of great value to all disciplines, especially in defense and security, where information has to be conveyed to the user in real time independently of his/her physical location. Intrusion detection applications can take advantage of the use of mobile devices by allowing a constant monitoring of the state of a computer system.

Intrusion detection applications often produce large amount of data. The visualization of this information is a key task in order to allow the user to effectively detect attacks and intrusions. Information visualization is an important sub-discipline within the field of scientific visualization and focuses on visual mechanisms designed to communicate clearly to the user the structure of information and to facilitate the access to large data repositories. A new challenge in information visualization is the use of Personal Digital Assistant (PDA) devices.

In their contribution to this special issue, "IMoViS: A System for Mobile Visualization of Intrusion Detection Data," Andrea Sanna and Claudio Fornaro propose an integrated framework to visualize intrusion detection data on PDAs. The proposed architecture is used by a security manager to remotely monitor large buildings for computer intrusion attempts using only a PDA. The Snort ID system is used to detect attacks and intrusions and to store the collected information into a database. The information is processed by software called *Guardian* that produces the actual data to be fed to the visualization application. From the visualization point of view, this paper presents a graphical interface designed for PDAs. Data related to the building are organized hierarchically; this allows the user to discover and manage intrusions at the top level of the hierarchy, as well as at the leaf level, where detailed information about the attack can be obtained.

Finally, this special issue provides a comprehensive, up-to-date list with on-line resources on general M&S research and journals; security and defense oriented M&S research, projects, and software tools, as well as some publications. The I&S Monitor section contains a description of a simulation on defense resource management held in December 2003 at the Defense and Staff College, Sofia, Bulgaria. The Bulgarian Ministry of Defense organized the event in collaboration with the Institute for Defense Analyses. I&S Monitor contains also a description of the last report of the NATO RTO Modelling and Simulation Group "C3I and Modelling and Simulation (M&S) Interoperability."

Information & Security

MODELLING AND SIMULATION IN DEFENCE

Klaus NIEMEYER

Introduction

The use of modelling and simulation (M&S) is becoming more pervasive throughout the NATO defence environment. Simulation models use a variety of techniques, which have evolved from system dynamics, information science and operations research (OR). There are closed simulations, without human interaction, which are used primarily for research and analysis. At the other end of the spectrum there are interactive simulations with considerably active participation of operators performing, in general, the human decision making process. The latter type has been the mainstay of experimental gaming or war gaming in the past, but is now finding increasing application in the computer-assisted exercises (CAX). Thus, it can be argued that, not only are simulation models and applications expanding, but that their associated techniques can be applied across the full spectrum of functional activities of armed forces.

While the use of modelling and simulation for military purposes is expanding, recent work by the NATO Steering Group for Modelling and Simulation has demonstrated that most applications in the NATO nations have been developed by individual organisations to meet the explicit needs of a particular user community; are not integral to operational systems; take too long to build and cost too much; can not be used in concert and are not fully validated. The consequence was the proposal to develop and apply standards and interoperability procedures as provided by the High Level Architecture (HLA).[1]

M&S is an essential component for any intellectual behaviour. Human knowledge and intellect are based on the ability to create and manipulate models either cognitive or concrete, as an individual or in groups. The collection of information and the systematic creation of an image, model paradigm or construction, which represents a part of the real environment, are fundamental for the development of intellect. Only by experimenting or manipulating these representations in a goal-oriented, more or less systematic approach, it is possible to determine those solutions, which comply with the desired objectives. The intellectual search for best solutions is always based on *trial and error* application of models. Learning is possible only by making mistakes but this should not be done with a real system of high value or with processes, leading to catastrophic situations. Therefore, only models, which permit the necessary simulations and experiments, are means for finding best solutions.

With the quantum leap in the technical and methodological evolution characterised by digital information systems, modelling and simulation is contributing in high synergy to this development. Although the principles of experimenting in knowledge gathering on the basis of replicas of real systems are as old as the human intellect, models and simulations with digital computers have developed during the last few decades. The disciplines of natural sciences, in particular those with a quantitative and logical approach to fact finding, as well as the engineering disciplines, developed a huge amount of numerical and logical models that are operated on digital computers.

The essence of simulation is the development and application of explicitly formulated models, which are executed on computers. These models enable reproducible results to be generated at anytime in so-called computational experiments. These are achieved with many parameter variations and testing of assumptions and, thus, are accessible for discussion and change. The models are structured from mathematical and logical relationships, which are based on technical, physical or social insights and theories. A model can be seen as a replica of an existing perceptible system or as a precursor of a foreseeable system in the planning stages. The model enables the simulation of the system considered and the analysis of parameters, assumptions and arguments to be handled. It enables insights into sensitive areas, trends and interrelationships between parameters.

It can be stated that models and simulations are indeed the most sophisticated method of information processing and may be regarded as part of hybrid intelligence. Considering the power of existing computer technologies, the performance of which have increased far beyond all expectations during the last few decades and has so far hardly been exploited, as well as the capabilities of associated software and information systems tools, it becomes clear that models and simulations have an enormous potential with regard to thinking processes. On account of the models, the simulations have a rational basis, on which a profitable discussion may be carried out. Due to model structuring it is possible to define and control the complex relations of the real world. In a superior way, human decision-making is still given the important function of taking the responsibility, but irrationalities due to the limited human information processing capacity are eliminated. Simulations offer the possibility of analysing the systems of the future, which might be introduced one day. On account of the direct decision-making activity in these simulated systems, experimental games provide planners with information about the future. They are catalysts for group intelligence, which can define, evaluate and manipulate complex system relationships. Only in this manner the problems of the future are likely to be treated consciously and rationally.

Theory of Modelling

Operations Research (OR) was first recognised as a discipline in World War II, following use of various techniques to optimise planning of military operations.

In 1950, Morse and Kimball defined OR as:[2]

> "a scientific method of providing executive administrators with a quantitative basis for decisions regarding the operations under their control."

OR techniques have developed greatly over the years. Simulation has become a major tool. Simulation languages were developed in the early 1960s that embodied already various features found in modern computer software (e.g. object-oriented programming, list structures, and event handling). Possibilities of development of OR techniques have been greatly enhanced by the wide availability of powerful computers.

The terms *simulation* and *model* are often used. They are, however, frequently not adequately defined. Definitions, if offered, tend to be imprecise. They may increase confusion rather than aid comprehension, like the categorisation of simulations as *virtual, life* and *constructive* simulations.[3]

A model can be defined in terms of typical attributes. In this sense, a model:

- will have been developed to allow a clearly stated *objective* to be achieved
- will *represent another entity* (which may be real-world or another model)
- will be an *aggregated* representation of that other entity (reduction in complexity)
- will be intended to aid *perception* (past) or *anticipation* (future)
- may be either *conceptual* or *concrete*.

This list is not intended to be comprehensive, but only to cover the most important attributes of a model.

According to this definition, a plan may be regarded as a model, prepared with the objective of aiding the determination of an optimal approach to a future operation. The plan will embody an aggregated representation of the situation in which this operation is going to be conducted. It can be made concrete, since it can be documented and made accessible to others, not only to its creator.

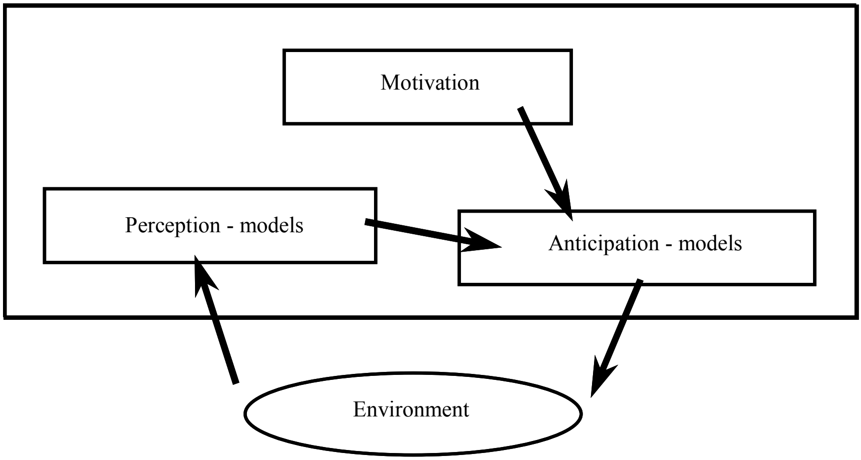

Figure 1: Intellectual System.

Simulation can also be regarded as a model, embodying an aggregated representation of the dynamics of a process. In such a model, time is the essential variable. In an interactive simulation, human participants perform real-world functions. A training exercise is one example. The objective of a training exercise is to develop participants' skills. An experimental game may also provide an example of interactive simulation. The objective in playing such a game would be to allow participants to determine the effects of altering at least one variable.

Models, particularly simulation models, can be regarded as essential elements in any intellectual system. Through intellectual systems that embody perception models (equivalent to learning processes) and anticipation models (equivalent to plans) environments can be manipulated and environmental changes anticipated (see Figure 1). The model of this intellectual system can be interpreted as an agent within the advanced information systems technology or the research domain of artificial intelligence.

Attributes of Models

Any model is by definition an image or representation of an original, the objects of the real system (see Figure 2). Therefore, models are always *virtual*. Any model is also a *construct* developed or created by humans or, more generally, by an intelligent system for a given purpose, e.g. experimentation.[4]

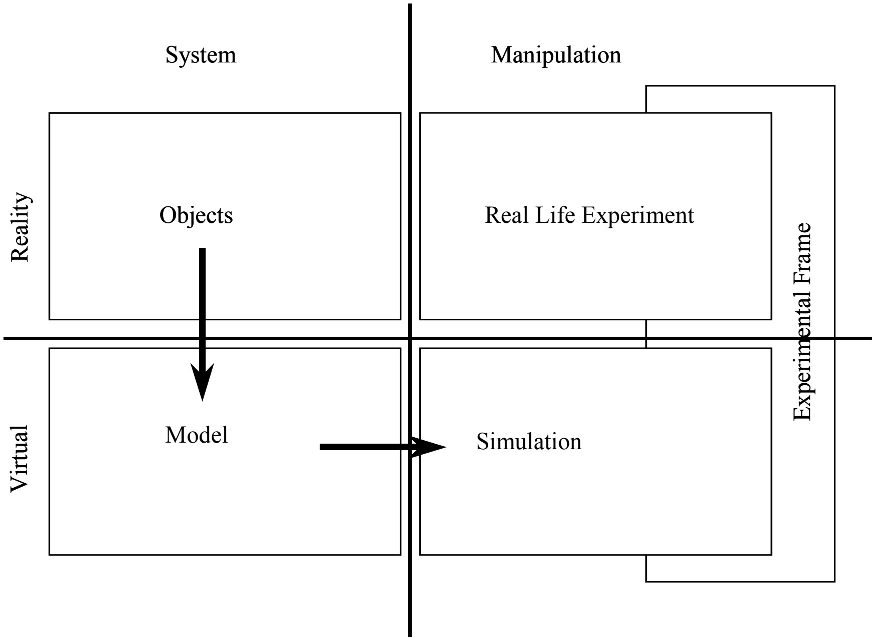

Figure 2: Modelling and Simulation.

Simulation is seen as an experimental set-up in order to perceive or anticipate the dynamics and the behaviour of the systems. Any simulation uses a model, which is designed for that purpose. Important characteristics of models as basis for simulations are:

- purpose
- relationship between model and original
- reduction of complexity.

Models are substitutes for the original for defined, cognisant or perceiving and acting, model-using subjects (intelligent systems) within defined time frames and by constraints on given mental or real actions. The most determining principle of the purpose is that models are developed and applied in order to fulfill given goals or motivations.[5]

Either a model is seen as representation of its original, or it is seen as prototype for a future construction. Thus, there is a certain relationship between a model and its original in reality or between the future construction and its model in reality. The generation of models is a directed process in time; hence the model-original relationship can be separated into two aspects:[6]

- the model is the *representation* or the image of the original
- the model is the *prototype* for a future construction.

Reduction of complexity means that models simplify the original or the future construction in order to reduce the *noise* of the reality, to systematise facts, or to transmit knowledge and information. The model does not represent all attributes of the original. It represents only those attributes that are relevant or suitable for the creator/user of the model. Normally, only a few attributes, elements, or parameters are taken into consideration, namely those that are important for the desired purpose. The many attributes, elements, or parameters that have a *noise* effect, reduce the clarity of results, or have little relevance are not taken into consideration. A model is easier and less expensive to manipulate than the original or a construction.

The dominating attribute of a model design and its simulation application is the objective or motivation for this activity (see Figure 3). Typical objectives are:

- *research*, which creates new insights in the phenomena of activities, organisations, operations, planning, procedures, technologies, etc.
- development and *engineering*, which create new options for activities on the basis of the research insights. This includes assessment of options and identification of the best solutions and prototypes.
- *testing*, which adds *flavour* or *noise* in order to test the functionality and robustness of the solutions and prototypes in stress conditions.
- *training*/exercises, which enable humans to operate and control the developed and tested solutions in quasi-real conditions.

Figure 3 shows the principal evolutionary development of models.Starting with the research, a phenomena or system in reality can be analysed by separating the noise effects and isolate the core of the problem. This core can be modelled and simulated in order to obtain the manipulation and change needed for the formation and engineering of a new entity or prototype. By adding noise and the effects of the reality, testing and experimenting, and finally, training of humans in exercises is possible. This synthesis is fundamentally different from the analysis. Simulations and models are major tools within the full sequence of developments.

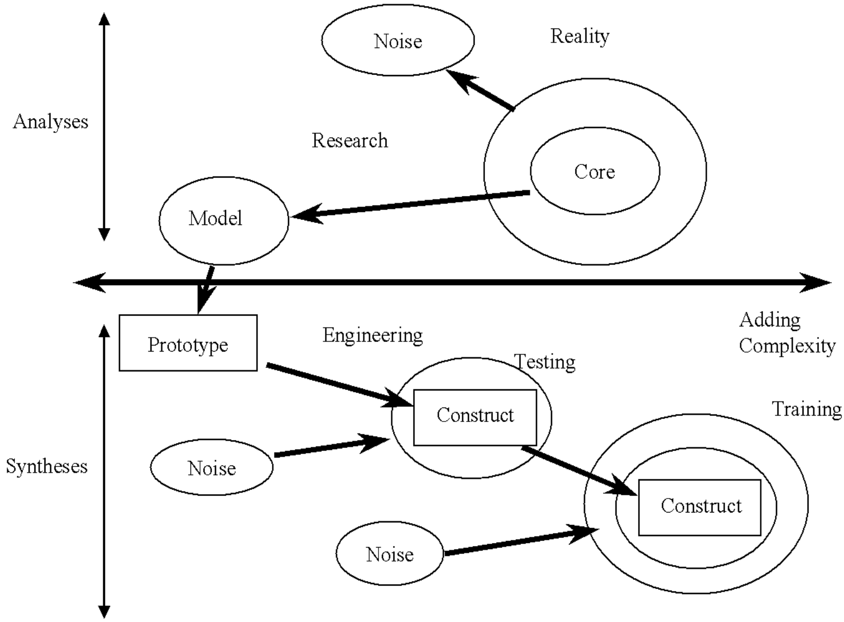

Figure 3: Evolution of Modelling and Simulation.

The objectives cannot be seen in isolation. There is a clear direction or sequence of activities. The training/exercises only make sense after *verification* of the solutions or prototypes in testing frameworks. Testing can only be done after selection of the best-developed and engineered solutions, which in turn is only possible on the basis of research insights. It is impossible to turn these sequences around, e.g. a training or exercise activity and framework is not a valid and useful approach for the research objective. The aim of the research activity is the identification of systematic insights, which can only be done by elimination of real-life noise. In training or exercises these are essential ingredients for the human trainees, since this represents the reality. The objectives of the simulations are, therefore, leading to and determining different model constructs.

Attributes of Simulations

Simulation is the dynamic application of the model that was designed for simulations. Any simulation is a representation of the system, which changes its state in time. Simulation constitutes a dynamic process in time. In any simulation, the following characteristics are important:

- Experimentation
- Dynamics
- Determination.

Simulation is an experiment on the basis of a suitable model (simulation model) and an experimental frame. The methods and principles of scientific experimentation in the implementation, application, and evaluation phases are fully applied in the case of research and analysis. The credibility and/or acceptability of the results are determined by the experimental frame, the purpose of the investigation, the model used, and the reproducibility of results. Time is the independent parameter in any simulation. From an initial state or situation, the time and state of the model are changed and advanced either continuously, in time steps or at given events until a final state has been reached (time-step simulation versus event simulation). The problem of time synchronisation has to be taken into consideration in certain applications, e.g. in simulators for training. The simulation is stochastic if relevant processes are based on random events. Starting from identical initial states, the random events produce significantly different final states within the reproduced simulations. A sample of simulation runs results in probability distribution of the final states. The simulation is deterministic if no relevant random events influence the processes. In this case, reproduced simulation runs should result in identical final states.

Interactive simulations are open to human operators who are able to interact with the model and to change parameters while the simulation is progressing. For analysis purposes or for testing of plans and procedures, this simulation is also known as experimental gaming (war gaming). For training purposes in command and control settings it is known as Computer Assisted Exercise (CAX). As games, like experiments, are rather expensive in comparison with closed simulations due to the integration of personnel (time and resources), the risk of committing errors must be reduced by careful planning in order to make the best use of time and resources. In this context, planning and evaluation of runs have to be particularly emphasised. It is frequently assumed that the restrictions on time, costs, personnel and resources do not allow an ideal experiment.

Model Categories

The models can be categorised and structured in the following types:

- Free-form games include dialectic exchange and discussion, brainstorming, the path-gaming methods or games in which conflicts, coalitions and even the rules are developed during the course of the game.
- Model games or war-games that work with computer models or are based on

rigid rules. The computer models are generally structured as simulation models, which represent the system to be played with. The model games are seen and designated as interactive or open simulations.

- Closed simulations which are intended to represent many functions as realistically as possible, in great detail. In closed simulations, in contrast to open simulations, human leadership and decision-making functions are represented not by human beings but by rule mechanisms and algorithms. The advanced technique of agent-based modelling falls also within this category.
- Analytical, statistical and operations research procedures, which include expected value models, optimisation techniques, and so on. The analytical procedures generally contain exclusively static elements.

Model Characteristics					
		Free Form Games	Interactive Simulation	Closed Simulation	Analytical Model
Components	Real, humans	x	x		
	Computer		x	x	x
Requirements	Resources	very high	high	low	very low
	Time	very high	high	low	very low
Attributes	Dynamics	x	x	x	
	Abstraction	low	low	average	high
	Reproducibility	no	low	high	high
	Transparency	low	high	high	low

A principle can be recognised for the model categories. This is of particular significance if architecture of models of different categories has to be developed:

- With an increasing degree of abstraction the models are in fact easier and quicker to handle, but depend on the results provided by the detailed models in order to represent the respective system level. This process can be seen as a methodological aggregation.
- With an increasing detail (less abstraction) the models are of higher fidelity, but evidently slower and more expensive. Thus, in the analysis phase, it is increasingly more difficult to cover an appropriate spectrum of analysis alternatives. For this reason, the number of possible alternatives can be limited with the more abstract models in order to investigate more precisely the most interesting ones, followed by the more detailed models.

In this way, the models supplement each other; no model is the replacement of another.

Interactive simulations, e.g. war games, are predominantly used where human leadership functions play an important role. This is necessary for the analysis of the defence system, as it is characterised decisively by the quality at military command and control in its effectiveness. Here the command and control process is perceived by real components of the system, the human commander himself.

When human decision-making, as well as the command and control processes in the interactive simulation, is successfully represented by corresponding modelling methods on the computer, the whole process is conducted in a closed form on the computer. In this sense, the command and control models are agents as defined in the research domain of artificial intelligence. The interactive application can be systematically used to research the command and control rules, which are needed for the decision-making logic or for modelling of the agent behaviour in the closed simulation.

With the rapid development of the information net technology and the associated software, the methodology of distributed simulations raised high interest. This methodology is supported by the standards of interoperability, e.g. HLA, and the idea of combining and synchronising independently developed simulation models for use in distributed exercises. Although this approach provides some interesting aspects for use in international or inter-organisational exercises, the disadvantages of not being able to control and understand the application and to interpret the results have to be considered as well.

Defence Applications

In the military domain, models have been primarily developed and applied in the areas of (see Figure 4):

- Defence Planning
- Development, engineering and acquisition of systems
- Training and exercises, and
- Operational planning.

Although these principal application areas require models which calculate the effects and resources for military forces, it is important to note that these areas are very different in the purpose of the application and, therefore, leading to models of quite different structures, as discussed in the evolution of modelling and simulation (Figure 3).

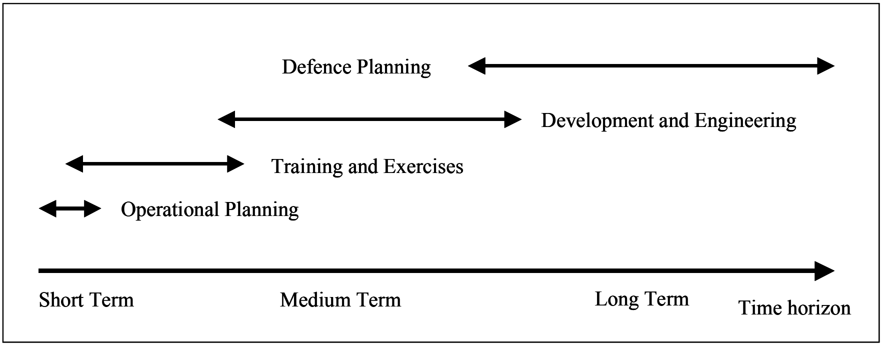

Figure 4: Military Application Areas.

Characteristics of Application Areas					
Application Areas	Time Horizon	Data Requirements	Scenarios	Reaction Capability	Objective
Defence Planning	Long term	Assumptions and estimates	Many	Very small	Robust Structures
Development of Systems	Medium term	Precise System Data	System related	Medium	Cost/effective solutions
Training and Exercises	Short term	Precise System and Environmental Data	Training related	High	Training of skills
Operational Planning	Immediate	Real Data	Real Situation	Very high	Optimal decisions and operations

Models for defence planning have to be able to calculate a huge variety of parameter variations in order to manage the uncertainties in the long-term future development and to analyse many options for the creation of robust structures. On the contrary, support in operational planning is based on situation with a given force structure and requires models with the capability of quick response and representation of real attributes and data. The objectives in the area of training and exercises are to train human operators or staff groups and, therefore, a quasi-realistic (virtual) environment has to be created with the noise and flavour of the real life. On the other hand, in developing and engineering of new systems it is important to manage the noise and the complexity of the system in order to create transparent and reproducible solutions.

Utility of modelling in the application areas				
Application Areas	Free Form Games	Interactive Simulations	Closed Simulations	Analytical Models
Defence Planning		Only for Testing	High	Very high
Development of Systems		Only for Testing	High	Very high
Training and Exercises	Limited	Very High (CAX)		
Operational Planning			High	Very high

The defence system, like any other complex live system or organism, requires steady adaptation. To this end, potential improvement options need to be continuously tested and compared with a view on their feasibility, effectiveness and robustness in a wide range of possible scenarios and taking into account all of the sensitive factors and their inter-dependence. However, as the human brain may only consider a limited number of system entities and interrelations simultaneously, modelling and simulation tools and methods become necessary to support the planning and structuring of forces. Since models permit account to be taken of the complex interactions of modern day combined arms combat and its synergistic weapon effects, simulation approaches provide the required basic instruments. Yet, it must be born in mind that any analysis has its limitations due to very practical reasons, such as the availability of data, time, and skilled personnel.

Further, it has to be considered that:

- The models are mathematical (logical, numerical) constructs for digital computers, which provide many kinds of human interfaces wherever appropriate,
- The models are operated in an experimental/procedural framework, which permits the systematic manipulation of inputs in relation to the objective of the simulation, and
- The models represent parts of the military system at several hierarchical levels, missions, functions, objectives, and within predefined constraints and environmental conditions/scenarios.

In what follows some important aspects for the areas of defence and operational planning will be discussed in more detail.

Military Structures

Large and complex systems, such as the Armed Forces, are always hierarchically organised. At low level, the system is physically identifiable in its components, such as men, weapons, equipment, and vehicles. These components are integrated into formations, which have a particular task to accomplish, although restricted in terms of location and time. The time resolution is of the order of minutes or even seconds since duels between modern weapon systems are generally decided in a relatively short time. The influence of the environment has a direct bearing, i.e. the outcome of a duel is dependent on the presence of a direct line of sight to the opponent. At a medium level, the system elements resemble the formations of the low level. These elements may be integrated into major units such as battalions, brigades, or divisions and they can undertake particular, yet wider ranging, targets and tasks. The time resolution at this level is usually of the order of hours as, in addition to the direct battle, some time is required to carry out additional functions, e.g. to take the appropriate command measures and to position the formations at the desired places. The results of a battle are determined by a large number of duels whereby it is sufficient to consider the terrain in its general features using appropriate maps. At high levels, the system is made up of the medium level units. The time resolution is in terms of days since, in addition to the combat operations at medium level, a wide variety of logistical, surveillance, command and control, preparation, support, and movement processes, all of which require time, are taking place.

It is important to define the level of simulation in the system since there are specific problems at each level. It is not possible, for instance, to create a simulation at the highest level on the basis of consideration of duels at the lowest level only.

To achieve an architectural structure for models, procedures and applications, order criteria have to be agreed, towards which the many possibilities of modelling should be oriented. As an example, here the system levels are structured in relation to the hierarchical structure of military forces as follows:

- Security system in long-term interaction between sociological, economic, ecological, political and military forces in an international context. The dimensions of time are measured in years.
- Security system in relatively short-term interaction between political and military forces in an international context for resolution of crisis. A military build-up of forces (mobilisation) falls in this category. The dimensions of time are measured in months.
- Military system of armed forces in an operation. The military area is a theatre or a region. The dimensions of time are measured in weeks.
- National armed forces, i.e. Army, Air Force and Navy, in typical sub-

scenarios of a major conflict or crisis. The dimensions of time are seen in terms of days.

- National major units or units of a respective Armed Force in typical (generic) sub-scenarios. The dimensions of time are measured in terms of hours.
- Weapon systems or individual functions at the lowest level. The dimensions of time are measured in terms of minutes.

Given this structure at various system levels, the following principles for architecture can be assumed, which are of great significance for model development and model applications.

- For a top down approach, the objectives and the assumptions at the lower level are derived from scenarios at the respective upper level.
- For a bottom up approach the input for the simulations can be aggregated from the results of the lower level, i.e. they can be so summarised that they represent sufficiently the variety of the respective micro-events.

In this way, the data flow can be defined as comprehensive model architecture.

Some aspects should always be considered for the assessment of the appropriate resolution of models for simulation. The applications should be adjusted to the particular problems at the respective levels. From a pragmatic point of view, the input and output data have to be manageable for the user, the modelling process has to be clear at least in general terms, and the data volume has to remain within the work limits of the users and the developers. The models can be constructed efficiently with modular and open software technology, e.g. object-oriented programming, if appropriate. Thus, it is possible to exchange simple, less detailed modules with more complex ones and vice versa. Given the availability of standard data structures and interfaces, such as HLA standard and agent-based modelling, comprehensive modular systems can be developed, as long as the resulting product can be kept under control. For models of higher levels of the system hierarchy it is necessary to develop procedures for aggregation of data from the detailed models of the respective lower hierarchical levels. This process demands from the user to have a relatively high abstraction capability and it is often not understood. However, as there are generally some overlaps between the hierarchical levels, it is possible to reciprocally check the model functions in an iterative manner.

The resolution of a model is to be understood as the process described by explicit state parameters or the element level of the modelled system. The greater the resolution of a model, the greater the variety of mathematical functions and the amount of necessary data and assumptions. Whereas pure conceptual models in most cases only have minor resolution, mathematical simulation models allow considerably greater resolution. On the other hand, a model that is too comprehensive and too complex cannot longer be handled due to the loss of transparency and reproducibility. This contradicts the intentional and deliberate simplification by eliminating factors, which are irrelevant to the objective. In the end, neither of the extremes, the all-intelligible trivial model and the all-inclusive no longer manageable overall model, is suitable for simulation. Another aspect of model development results from the fact that the evaluation of defence systems and even of individual components cannot be confined to one process level. For instance, duel models usually do not suffice to give enough information about the effectiveness of a weapon system. For example, the frequency and/or the importance of the respective duel situations or the availability of the weapon system must also be taken into consideration. Both parameters, however, closely depend on the next higher process level, in this case the combat or the operation. Thus, for example, the importance of the Air Force mission *Interdiction* (engagement of moving army formations by the Air Force) is not only reflected in the primary effect expressed in destroyed vehicles, or the secondary effect expressed in local disorganisation and march delay, but rather in the relief of defending in the point of the main effort of the battle. In this case, simulation models that cover several levels are needed.

Military Functional Areas and Phases of Operations

Military operations can be regarded as groups of processes occurring simultaneously or in sequence (see Figure 5). There is a wide range of processes involved in planning and executing military operations, both for generic peacetime planning and for contingency operational planning. Some of these are shown in Figure 5. They interact in complex ways and require stringent management. Intelligence in the military sense is concerned with identifying threats and stimulating political decision-making processes. In peacetime, generic plans are made to ensure readiness for operational planning if a crisis situation arises. Outcomes of operational planning form inputs for political decision-making, and govern military deployment to crisis areas. Deployment of well-trained forces and subsequent preparation for their possible future employment may deter a potential aggressor. If deterrence works, no further employment of forces may be required. Re-deployment of forces may subsequently be possible.

Simulation can be used in relation to any of these processes, to arrive at optimal solutions. Use of simulation is especially valuable in deriving solutions in the face of frequently changing circumstances.

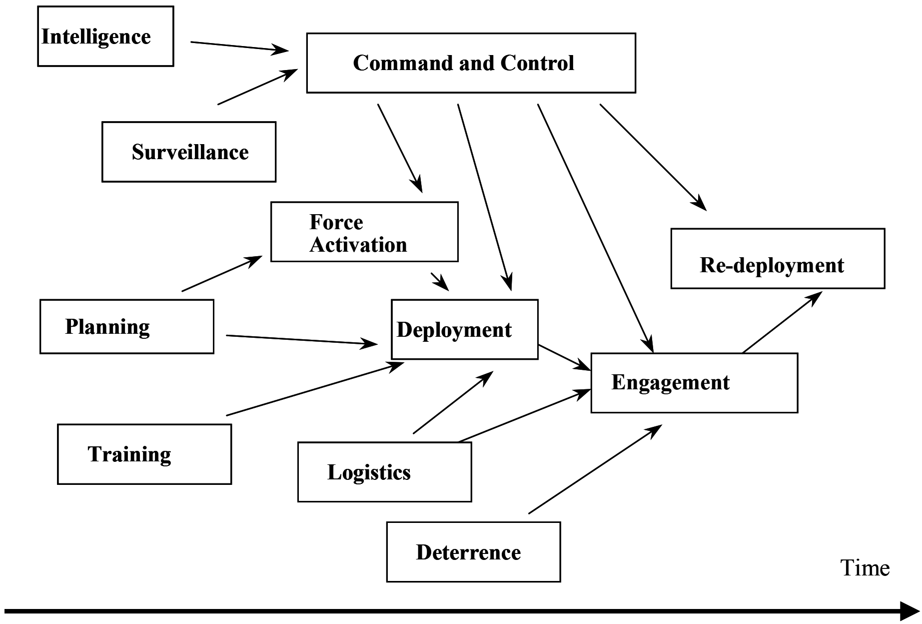

Figure 5: Military Processes and Functions.

Deterrence is not a direct phase of potential crisis. It is a very important function in all situations to create a perception in view of the opponent or warring parties that a conflict is not in their interest. Deterrence has many aspects; it has to be seen at all levels, at all phases and for all conflict types. An important contribution to create this perception is the demonstrated knowledge about the actions, the situation, the status and the capability of the opposing forces and, if possible, the intention. This can be accomplished through the use and demonstration of modelling and simulation of the respective situation. The effective reconnaissance and surveillance at all times and the careful demonstration provide also an invaluable contribution to the overall deterrence function. If deterrence works, crises can be resolved early; the extremely expensive deployment and employment of combat troops can be avoided. If deterrence fails, crises can lead to catastrophic situations with many casualties.

Utility of modelling in the functions and phases				
Functions and Phases	Free Form Games	Interactive Simulations	Closed Simulations	Analytical Models
Training	Limited	Very High (CAX)		
Planning		High	Very High	High
Force Activation		Limited	High	Very High
Command and Control			High	Very High
Surveillance			Limited	High
Intelligence				Limited
Logistics			Limited	High
Deployment			High	Very High
Operations			Limited	High
Re-deployment			High	Very High
Deterrence	Limited	Very High	High	High

Planning Situations

Planning and definition of situations, which can serve as basis for testing the effectiveness of structures, systems, plans, and concepts of operation, are closely linked. If such situations cover a set of future most likely possibilities, it is save to assume that structures and concepts based on these situations give robust solutions. From an analysis perspective, given or planned solutions should be tested against these planning situations seen as benchmarks.

From the analysis of crises a number of common factors that are relevant to generic planning situations emerge. These basic components of military planning identify the common questions confronting planners in every situation. From these common factors detailed checklists of generic planning tasks can be identified that also reflect the political and strategic guidance of generic planning.

The challenge, which exists for military planners today, is the uncertainty of potential scenarios on the background of the new space of missions for NATO and nations (see Figure 6). The number of scenarios, which have to be considered, is increasing with the time horizon for planning. At any present time, usually only one or two real life operations are of importance. For short-term planning, the given forces have to be employed and analysed in relatively well-known situations. For long-term planning, many planning situations with increasing uncertainty have to be considered and analysed. In general, the set of scenarios and planning situations should be as consistent as possible.

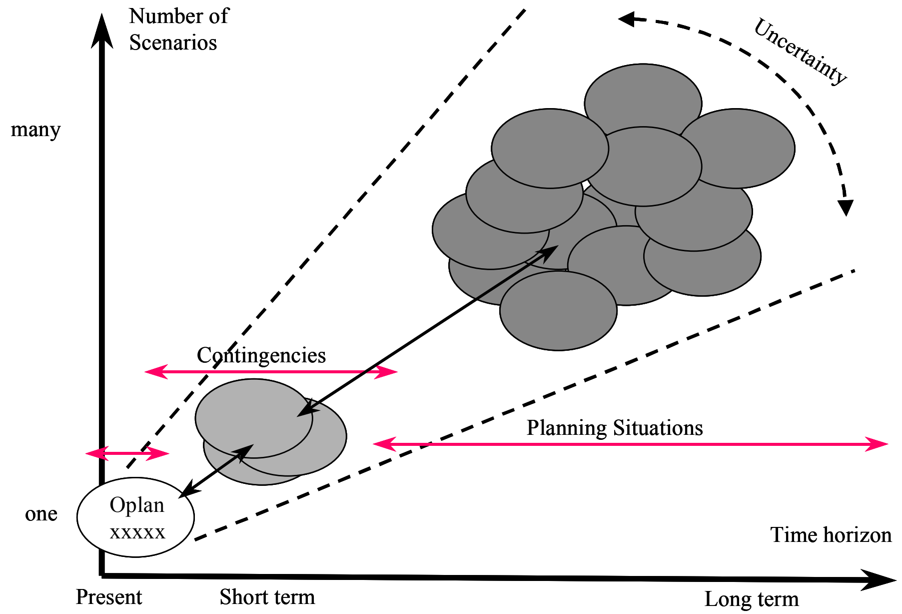

Figure 6: Uncertainty of Scenarios.

Decision Cycle

A typical cycle of actions takes place in any Command and Control (C2) process. This so-called decision cycle or Observe, Orient, Decide, Act (OODA) loop is established more or less at all levels, within all forces and is taught in most military academies (see Figure 7). It can be interpreted as an intelligent system, as defined in Figure 1.

The starting point is the definition of the desired objective. Then the status of own and opposing forces and the environmental circumstances in which they might have to operate need to be established. The potential of the forces can be compared using simulations. Environmental conditions, scenarios and planning situations can be changed in the simulation. Operational options can be developed from the results of the comparisons. The likely effects of adoption of the options can be assessed, using simulations. The best option can be selected as a basis for decision-making and further planning.

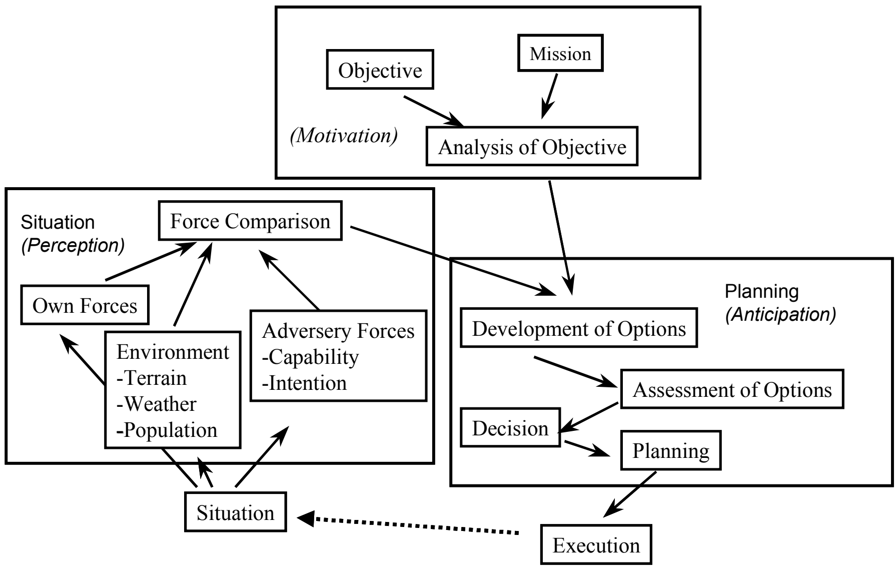

Figure 7: Decision Cycle.

The procedural elements of this classical decision process are in general:

- Situation Assessment
- Objectives
- Strategies/Options for Actions/Decisions
- Detailed Planning
- Implementation and Control.

Any military staff or crisis management teams carry out the five elements of this process repetitively during the operation. The process always begins with situation assessment. It encompasses all the activities concerned with finding out and describing what is going on; understanding the motivation of the principal actors; establishing the basic causes of the situation and the relevant drivers of the process; updating the assessments; and disseminating the assessment to other people if required.

In order to illustrate the problems of decision-making in a complex military crisis situation, three fundamental dimensions are to be considered:

- The time available to make a decision,
- The complexity of the decision, and
- The uncertainty of the available information about the situation.

These three factors reflect the risk or opportunity inherent in a military situation. The more complex a situation, the less time available, and the greater the uncertainty of the available information, the greater the present risk (and opportunities). One end of the spectrum or decision space represents the worst situation for any decision maker – almost no time available, an enormously complex problem and considerable uncertainty about the situation. When these conditions exist, the decision maker or military commander has no other choice than to use the so called *best professional judgment* to match the battle space situation to some class of well-understood military situations and act accordingly. In any case the best professional judgment and a wise commander will try to take short-term actions designed to create more time and/or more information and in this way relocate the problem to a better portion of the space. The opposite end of the decision space, defined as ample decision time available, limited complexity, and low uncertainty, provides the ideal situation for decomposition of the problem and the development of optimal military plans. Many innovations in command and control systems are designed to move the situations facing the commanders toward this region. An important contribution is provided using advanced modelling and simulation technologies.

Model Utility for decision cycle activities					
		Free Form Games	Interactive Simulation	Closed Simulation	Analytical Model
Motivation	Analyses of Objectives	x			x
Situation Perception	Environment				x
	Own Forces		x	X	x
	Enemy Forces		x	X	x
	Force Comparison		x	X	x
Anticipation and Planning	Creation of Options	x			x
	Analyses of Options		Limited	X	x
	Decision				x
	Detailed Planning		Testing	Testing	x
	Control				x

Conclusions

Military Operations Research, as well as Modelling and Simulation, has long tradition. More than 2000 years ago Sun Tsu, the oldest known philosopher of war, wrote:[7] "To win without fighting is best." He also wrote:

> "The rules of the military are five: measurement, assessment, calculation, comparison, and victory. The ground gives rise to measurements, measurements give rise to assessments, assessments give rise to calculations, calculations give rise to comparisons, comparisons give rise to victories."

Both statements indicate the requirement for the military planner and decision-maker to use methodologies, such as modelling and simulations, for the best creation of solutions. General Eisenhower wrote:[8]

> "The Army must have civilian assistance in military planning as well as for the production of weapons. Effective long-range military planning can be done only in the light of predicted developments in science and technology. As further scientific achievements accelerate the tempo and expand the area of our operations, this inter-relationship will become of even greater importance. In the past, we have often deprived ourselves of vital help by limiting our use of scientific and technological resources to contracts for equipment. More often than not we can find much of the talent we need for comprehensive planning in industry and the universities."

Many others give evidence that the rational, logical, quantitative consideration of facts results in better understanding of the phenomena of war and in improved operations and strategies.

In the past, defence planning was based, sometimes explicitly, on the view that the future would be much like the recent past. This perspective on the defence planning process can be seen as a *pipeline.* Research and development are poured into one end and eventually the results appear as fully deployed systems at the other end. A common perception has been that the value of research and development accrues only if and when fully deployed systems materialise.

On the other hand, research and development creates value in and of themselves before any production or deployment. A developed and demonstrated potential to produce or deploy certain systems is a product in its own right and can provide options and hedges against an unknown future and mitigate the consequences of surprise. Also, the potential of future deployment can influence possible adversary behaviour. In effect, research and development cast a *long shadow* forward, its influence felt long before any deployment. In addition, there is a growing difference between what is technologically available and technologies actually embodied or required in deployed force structures.

In any case, these effects should be of interest for future defence planning and detailed quantitative analysis utilising operations research methodology, modelling and simulation.

The increased emphasis on the strategies to deal with the greater uncertainty of the future and the need for projecting military potential lead to concepts, which could be characterised as virtual deployment of forces and artificial experience. Potential adversaries can perceive the virtual deployment as capability long before any actual deployment takes place. It could include various stages of development, demonstration, prototyping and limited production. In the future, military competition may be characterised more by development and by maintenance of such virtual deployed options, than by deployed real systems. The virtual deployment, in close relation to the growing gap between civil technology and deployed military technology, will magnify an already existing trend, the reliance on and the need for artificial experience, modelling and simulation.

Increased environmental concerns, smaller budgets and resource constraints have already motivated great interest in simulation techniques and capabilities. The interactions of new technologies embedded in future forces and of their counter- and counter-counter-measures will not be well understood. Virtually deployments cannot be actually tested on the field. High fidelity simulation and training techniques used not only for deployed systems but to assess the interoperability of potential developments and virtual deployments will increasingly be the tools for military planning and education.

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Mr. Niemeyer has had a long and distinguished career in Military Operations Research, Simulation and Computer Applications. In 1965, he joined the Industrieanlagen Betriebsgesellschaft mbH (IABG) in Ottobrunn with other German members of the above-mentioned team, and helped in establishing the Systems Analysis area at IABG. In 1966, he was assigned to US/GE advanced V/STOL-fighter assessment at the Wright Patterson Airforce Base in Ohio. As Project Leader he evaluated and analysed airborne and airbase systems.

In 1969 Mr. Niemeyer was appointed head of a group working on optimal air force structures. In this role he developed and operated the first German computer-assisted exercise in 1970. This formed the basis for establishment of the IABG Wargaming Centre, of which Mr Niemeyer was appointed Chief in 1972. In this position, Mr Niemeyer initiated development of several concepts, models, approaches and solutions to assessment and evaluation of force structures, and helped initiate international programmes such as the US/German European Conflict Analysis Program (ECAP), and the Joint Simulation (JOSIM) Project. He has been responsible for many national and international studies in the areas of weapon system assessments, air and army structures, command and control, force effectiveness comparisons, arms control, conflict research, operational support, long-term defence planning, logistics planning, war gaming, exercises, and information systems support.

Mr Niemeyer became Chief Scientist and Head of the Operations Research Division at the SHAPE Technical Centre (now NATO Consultation, Command and Control Agency) in May 1992. In this position he was the principal advisor on scientific matters and military operations analyses that affect SHAPE and Allied Command Europe. Among other projects the Allied Deployment and Movement System (ADAMS), the methodology for the Defence Requirements Review (DRR) and the High Level Exercises have been developed in his area of responsibility. Mr. Niemeyer initiated and co-chaired the Steering Group on Modelling and Simulation and represented his organisation in several other panels and committees within NATO. Mr. Niemeyer retired from NATO in April 99 and now he works as a consultant. *E-mail*: niemeyer.oa@t-online.de.

COMBAT AND SECURITY RELATED MODELING AND SIMULATION IN CROATIA

Krešimir ĆOSIĆ, Miroslav SLAMIĆ, and Dražen PENZAR

Introduction

One of the most important characteristics of any training simulator is related to its physical, dynamic and functional similarity to the real world. Every simulation is based on appropriate mathematical models that represent relevant aspects of the simulated reality and consist of different logical, algebraic and differential expressions. Additionally, simulators have visual, auditory, and other types of "displays" that produce a virtual synthetic environment that surrounds the trainees in a simulation-based exercise. The level of fidelity of the virtual synthetic environment produced in the simulator influences the amount of knowledge that can be transferred from the simulator to the real world. The content of the synthetic virtual environment can be controlled and adapted to the exercise objectives. Its impact on the trainees can be objectively measured. For example, the inclusion of stress-producing elements in training scenarios results in alteration of some biofeedback parameters of the trainees.

The primary goal of design and development of training simulators is the formulation of suitable mathematical and simulation models that provide the required physical and logical similarity to the real world. Logical similarity can be defined as cause-effect similarity between events in simulation and events in reality, such as similarity in processes, similarity in outcomes, or similarity in type, accuracy and amount of information provided to the trainees. The common wisdom says that there are no absolutely good or absolutely bad models; there are just appropriate and inappropriate models for the problem at hand.

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Combat Simulators: Individual and Crew Training

Individual and crew training combat simulators are realistic functional replicas of real weapon systems and their operating environment. They are used for developing relevant military skills very similar to the real skills needed to operate weapons in combat. Using adequately prepared training scenarios illustrating different combat situations trainees become skilled and ready weapon operators and crewmembers in relatively short time. Additionally, simulators eliminate the risk of personnel injuries and damage to combat equipment and the environment. Furthermore, the state-of-the-art simulators posses a very strong feature– networking capability. In this way a complete virtual battlefield is constructed, and the units can train in a realistic and consistent, yet safe and inexpensive environment.

Anti-Tank Guided Missile Simulators

The CRO_ATGM state-of-the-art simulators[1] are hosted on a high performance PC-based multiprocessor system, required for a complex and realistic simulation of real AT systems operating conditions. It has been developed as a part of the modernization and upgrade of the ATGM missile system of the Croatian Armed Forces. It has been used for gunner training in observation, detection, target acquisition, and missile guidance from launch to destruction of targets. The CRO_ATGM simulator provides highly realistic simulation of the real AT systems operating conditions,[2] including a real photography of the battlefield superimposed on a digitalized 3D terrain model. Targets, represented by means of realistic 3D models, are introduced into the scene according to the actual terrain configuration. Realistic audio effects include rocket engine sounds, sounds of explosion, and other background sounds of real battlefield. Missile flight simulation is based on accurate 6 DOF dynamic model, e.g. that of the Fagot missile. In this way, a high resemblance to the real conditions of antitank combat is achieved in a classroom-training environment. The CRO_ATGM simulator enables the selection of different types of targets and great number of target trajectories with varying speed and direction parameters. Various environmental and atmospheric conditions, such as visibility, wind, temperature, rain, can be set. It is possible to analyze missile trajectories and target tracking errors in the review process afterwards. If the target is hit, probability of kill (PK) and probability of destroy (PD) of the target are computed. All training results are automatically stored and are permanently available for individual and group post processing and analyses.

The main subsystems of the CRO_ATGM simulator are a PC-based host, a special digital signal processor board, a 3D graphic processor, and an audio processor, as shown in Figure 1.

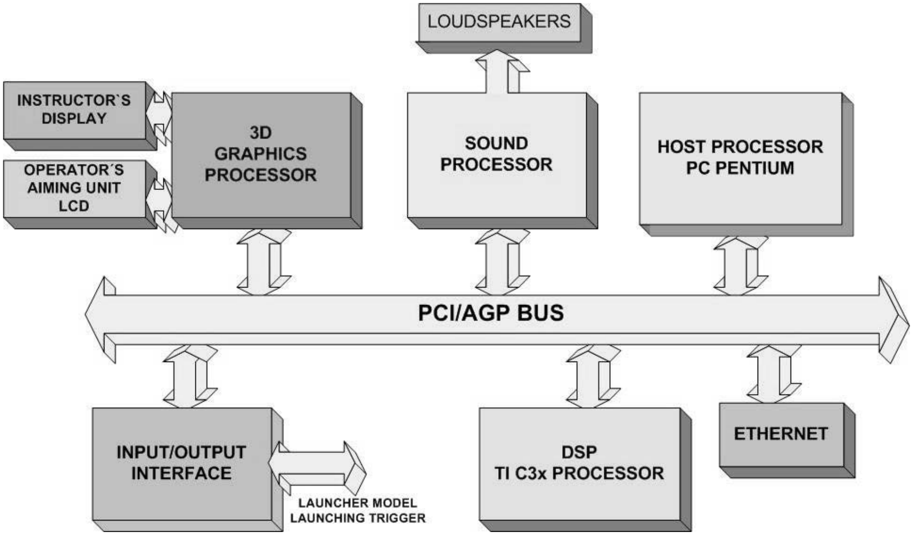

Figure 1: Block Diagram of the CRO_ ATGM Weapon-training Simulator.

Low-Altitude Air-Defense Guided Missile Simulators

The CRO_SIMIG 2000 is a low-altitude air-defense guided missile simulator based on a virtual reality technology replicating the man-portable air defense system Igla. Due to the real time simulation of all relevant weapon functions, including missile head seeker and missile flight dynamics, the trainees can be trained to operate the system in the same way as the original weapon. The simulator is identical to the original weapon with regard to design, weight and entire operation.

During mission training, the members of an air-defense team – a gunner and a team leader - appear in the virtual scene equipped with head-mounted displays (HMD) and virtual reality data gloves (see Figure 2). The gunner and his team leader, positioned at the virtual battlefield, can be trained in observation, detection and identification of flying targets, as well as in target acquisition, tracking and missile firing. Missile flight path is simulated in a realistic way, based on a 6 DOF dynamic model of the missile. Missile hit and detonation are modeled as well. Simulation of the team leader's role includes target detection and identification, pointing at the target and target assignment to the gunner, commanding fire, and missile flight observation. Simulation of the gunner's tasks includes observation of the functioning of the system, and preparation of the weapon operational readiness, system handling, target acquisition and tracking, prediction of target moving parameters, determination of the borders of launching and destruction areas, weapon activation, target lock-on, firing, missile observation and hit effect simulation. Extended training operations include fire at targets, which are periodically hidden, firing at targets protected by different types of disturbances and countermeasures, fire at unexpected targets and fire at targets during evasive maneuvers.

The equipment of the team leader includes HMD with a head movement sensor, VR data glove and contact sensor for controlling the binocular telescope's simulation. When the team leader detects a target, he takes a binocular telescope with a contact sensor. His view area is automatically magnified and the lines are displayed. In this way he can recognize and identify the target, and point at the target by the VR data glove.

The gunner is equipped with a weapon model, a launching tube movement sensor and a HMD. He can observe the battlefield, the 3D model of the weapon with simulated sight (crosshairs) and the team leader's pointing hand. When he receives a firing command from the team leader, he detects the target following the direction of the team leader's pointing hand, then aligns the sight unit with the flight target, tracks the target and fires the missile.

The exercises are prepared, started and monitored at the instructor's (trainer's) station. The instructor has access to a library of exercises, scenarios and procedures with different degrees of difficulty. In addition, he also has tools to create new exercises. During training, all events are recorded, so they can be evaluated subsequently. The trainer monitors the operation of the gunner and the team leader on his LCD monitor in two separate windows. He can directly intervene and change the parameters of the current training exercise by employing IR jammers, setting weapon faults, etc.

The CRO_SIMIG 2000 simulator is designed to operate under the user-friendly Windows 2000 environment. Each simulator's operating mode can be started by clicking on an icon in the main window, or by choosing an option in the pull-down menus. All training results are stored and available for further analysis, processing and reporting purposes. The available databases store environment settings, fully prepared exercises and target models. The simulator has a capacity to set more than 20 different battlefield layouts ranging from flat to mountainous terrain.

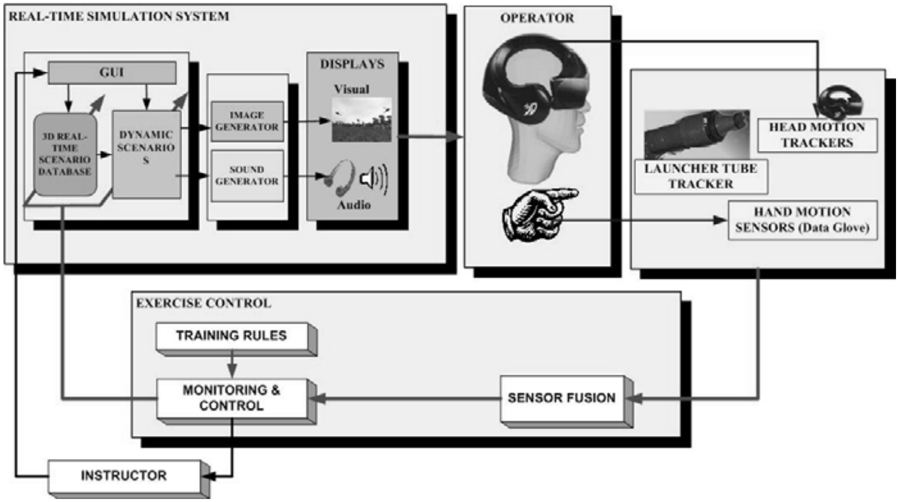

Figure 2: Block Diagram of the CRO_ SIMIG 2000 Training Simulator.

Full Flight Aircraft Simulator

The FTD TL-21 is a full flight simulator for MiG-21 BIS of the Croatian Air Forces. It provides to the Croatian pilots a unique opportunity to conduct safe, cost-effective and comprehensive pilot training in a high fidelity environment. This simulator facilitates the development of pilot skills from basic to advanced flying operation and complex combat fighting missions. The main training objectives supported by the simulator are related to cockpit familiarization and checkout, preparation for flight; engine start procedures, taxiing and pre-takeoff check; takeoff and landing, flying in all aircraft regimes, navigation by on-board instruments and radio-navigation systems, visual navigation during take-off, approach and landing, flying in a variety of weather conditions, such as crosswind, fog, clouds, flying during different time of day and various lighting conditions, weapon procedures and operations in simulated air-to-air and air-to-surface missions, flying in formation, emergency procedures on ground, during takeoff, in-flight and landing operations. The architecture of the FTD TL-21 flight simulator for MiG-21 BIS is based on a set of networked COTS personal computers. A modular distributed architecture (see Figure 3) facilitates the efficient assembly of hardware and software modules and hosts complex simulation functions. This modular approach gives two advantages. First, it makes possible the partitioning of the simulator functions in a logical and straightforward manner. Second, the overall performance of the simulator is achieved by parallel processing across a network of PCs.

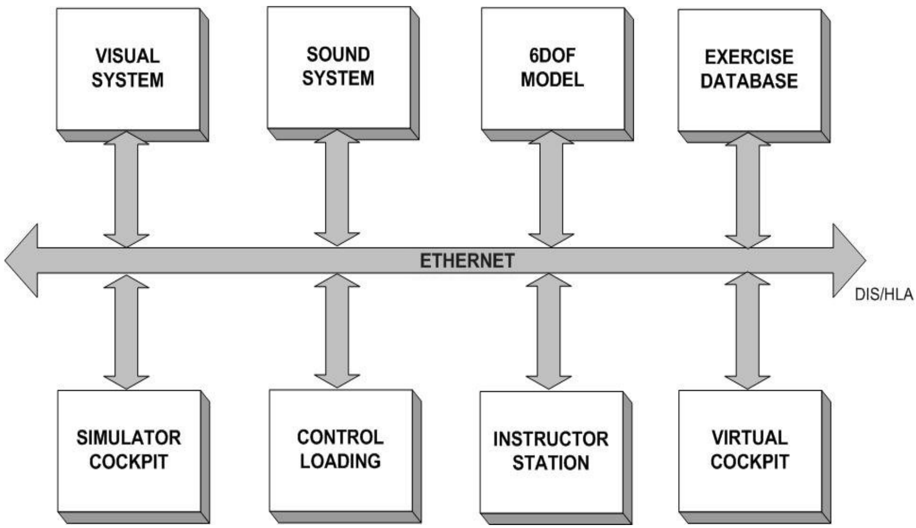

Figure 3: Distributed Architecture of Flight Simulator – Main Functional Modules.

The simulator is implemented on an Intel PC platform and Fast Ethernet (100 Mb/s) network and runs on Windows NT and Linux Operating systems. The software is written in C++ programming language.

The individual PCs perform real time simulation of one or more of the software modules, performing different functions of the full flight simulator, such as modeling of airframe and engine dynamics. This simulator configuration includes also a real-time image generator, a sound generator and DIS/HLA capability for connecting the simulator to other DIS simulators on the network. The main functional modules of this modular distributed architecture are: an aircraft 6DOF model, an instructor station, a simulator cockpit, including a 3-channel control loading system, a motion platform, a sound system, a virtual cockpit, a visual system, a flight database and an electrical supply system.

Hardware-in-the-Loop Simulators

Hardware-in-the-loop simulators (HWIL) represent infrastructure equipment for testing and evaluation of new weapon systems.[3] For example, they can be used in design and development of new digital guidance methods and algorithms for guided missile systems.

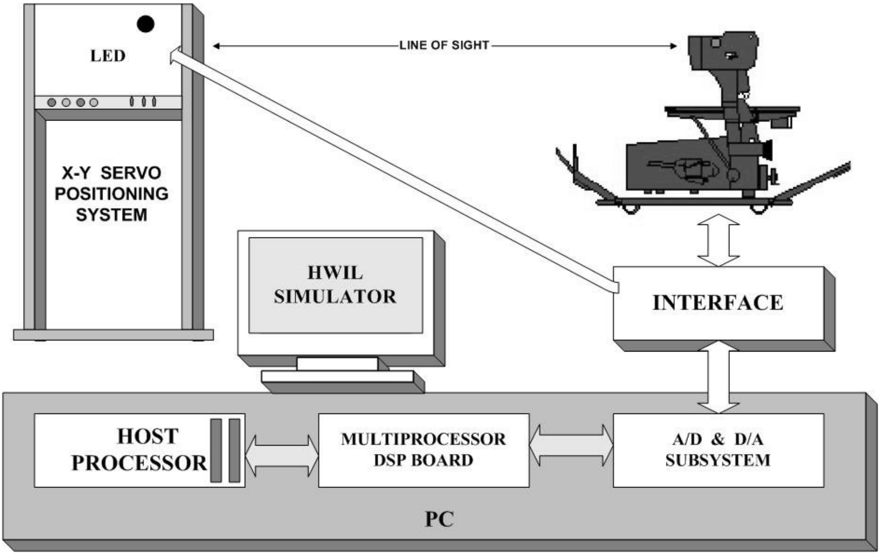

Figure 4: Hardware Structure of the HWIL Simulator for ATGM System.

The architecture of a HWIL simulator,[4] designed as a reconfigurable simulator for different levels of hardware-in-the-loop (HWIL) and software-in-the-loop (SWIL) testing of missile systems, is shown in Figure 5. HWIL simulations based on modern digital signal processors represent a cost-effective approach to non-destructive technology for design, development, testing and evaluation of new sophisticated weapons and industrial control systems. The modular multiprocessor architecture based on powerful DSPs, such as the TMS320C40, provides high processing power.[5] In any multi-level complex simulation a functional decomposition of a complex system to logically interconnected physical subsystems has to be made. Next, the system decomposition is mapped to a given multiprocessor platform in a transparent manner.

The main part of our HWIL simulator is an industrial PC chassis containing a standard Pentium motherboard, a multiprocessor PC board for digital signal processing, and two PC boards with I/O subsystem. This HWIL simulator was primarily intended for laboratory testing and development of the SACLOS subsystem modifications. A high-speed X-Y servo-positioning system with light emitting diodes of appropriate spectrum is used as a low cost emulation of the moving missile's IR source. Information about actual co-ordinates of such IR spot in relation to LOS is produced by a 6DOF missile model and sent to the X-Y servo's analog inputs.

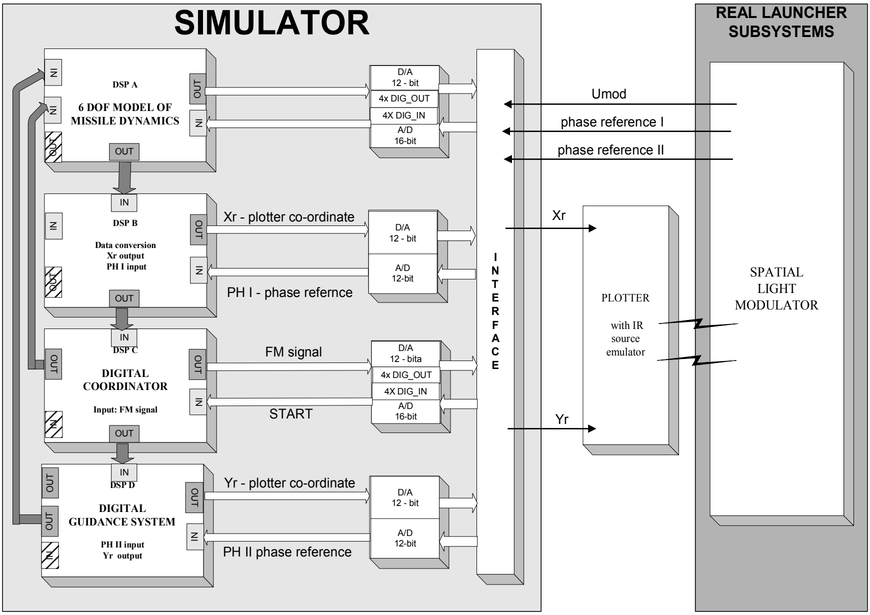

Figure 5: Physical Implementation of the one HWIL Simulation Scenario.

A custom signal interface between the real hardware of the SACLOS system's launching unit and the simulator's I/O subsystem was also designed. This hardware configuration, illustrated in Figure 4, reproduces a closed guidance and control loop, which consists of IR spot, launcher optics, launcher hardware, simulator models, 6DOF missile model, and IR spot co-ordinates. It provides exhaustive and non-destructive low cost platform for realistic modular analysis, evaluation and testing of the SACLOS subsystems during the missile modernization processes.

Tactical Unit Training – Simulator Networks and Tactical Simulations

Combat simulations do not primarily represent a single physical or technical system, but a whole range of processes and phenomena that take place on a battlefield. Combat simulations are used for commander and staff training, for analysis – primarily in force planning and procurement activities, and for operational planning. The resolution of mathematical models used in combat simulations[6] is often used as a distinctive characteristic of combat simulations. In high-resolution combat simulations each individual weapon system is represented as a separate entity. The model tracks each tank, infantry group or individual soldier, fighting vehicle, airplane, howitzer, radar and other military asset individually.

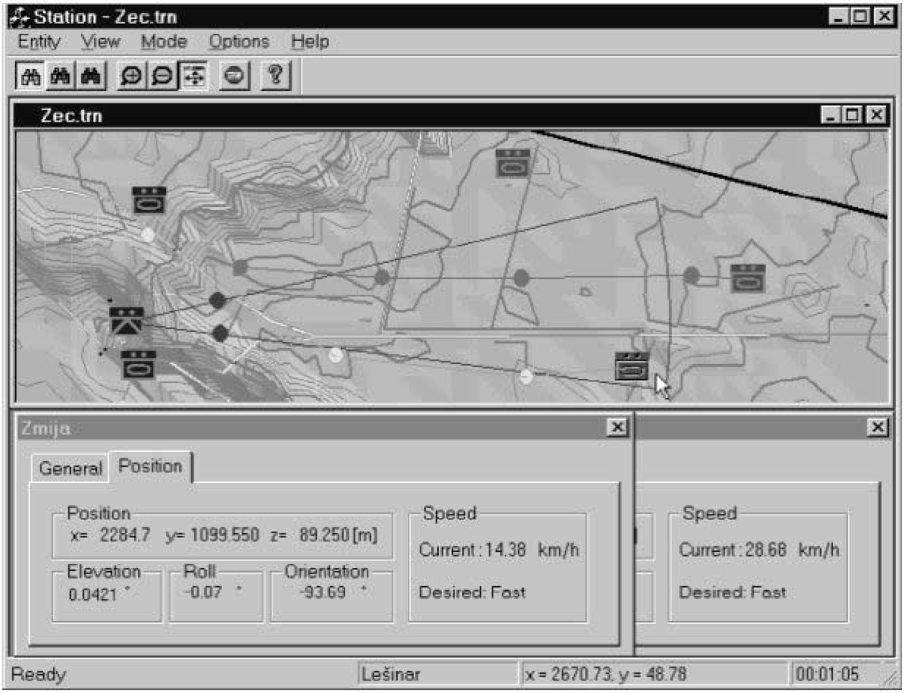

Figure 6: Tactical Simulation of Anti-armor Combat.

Record is kept of the state of each entity, including its position, operational state, speed, firing activities, damage suffered, situational awareness, and commands to execute (see Figure 6). In low-resolution simulations individual weapon systems are aggregated into composite entities, usually battalion or higher-level units. The state of each unit is known, including the number and type of weapon systems at its disposition, but the detailed state of each individual weapon system is not traced.

High-resolution combat simulations[7] are based on physical, technical and psychological models of key battlefield processes. These models include terrain representation[8] that affects line-of sight and movement control, movement models, detection models, and a set of models related to firing activities (firing frequency, firing accuracy for direct and indirect fire, and damage assessment). A special problem is related to modeling human behavior: situational awareness, decision-making,[9] and deterioration of performance due to combat stress.

Low-resolution combat models are based on the notion that combat losses are proportional to the number and strength of the enemy, and (sometimes) on the number of own troops.[10]

This notion is known as Lanchester equations, in honor of Frederick Lanchester who expressed it mathematically in a visionary book on air force in 1916. Since then, there have been two big problems for the combat modeling community. The first is how to express and calculate the force strength, since it depends on tactical situation, previous force activities, enemy structure, type of engagement, leadership and morale, and many other factors. The second problem is how to integrate non-static phenomena, such as maneuver, logistics, and commitment of reserves, into the basically static Lanchester's model of combat. The solution to the latter problem is using simulation with discrete time-increments rather than solving the original closed-form equation. The solution to the former problem is not unique, and many approaches have been proposed. More prominent among them are killer-victim scoreboards, Bonder-Farrel equations, and different types of situational scoring methods.[11]

Operational Command and Control – Aggregated Combat Simulations

During the Cold War period low-resolution combat simulations were designed to help assess events on a whole theater of operations or on similarly sized battlefields that consisted of several corps with hundreds to thousands of soldiers. It would be impossible to develop and organize a realistic high-resolution simulation on that scale. Low-resolution simulations are, however, meaningful even in much smaller context, where high-resolution simulations can be and are developed.

Brigade and division commanders think about combat in aggregated terms, and therefore it makes sense to develop an aggregated simulation for their training or assistance to their decision-making (see Figure 7).The fundamental problem here is whether the algorithms developed for theater-level operations can validly portray brigade-level conflict. Is it possible to develop a seamless family of simulations that will cover the whole spectrum of resolutions? What changes have to be implemented in low-resolution algorithms in order to use them for lower-size and lower-intensity conflicts? It seems that at lower level of organization units experience combat in very intense and short "chunks" divided by long periods of very little activity. On the higher echelon, these intense fighting chunks of individual units are averaged, and the whole organization fights at a much steadier pace. Obviously, there are a number of consequences for mathematical models in this area.[12]

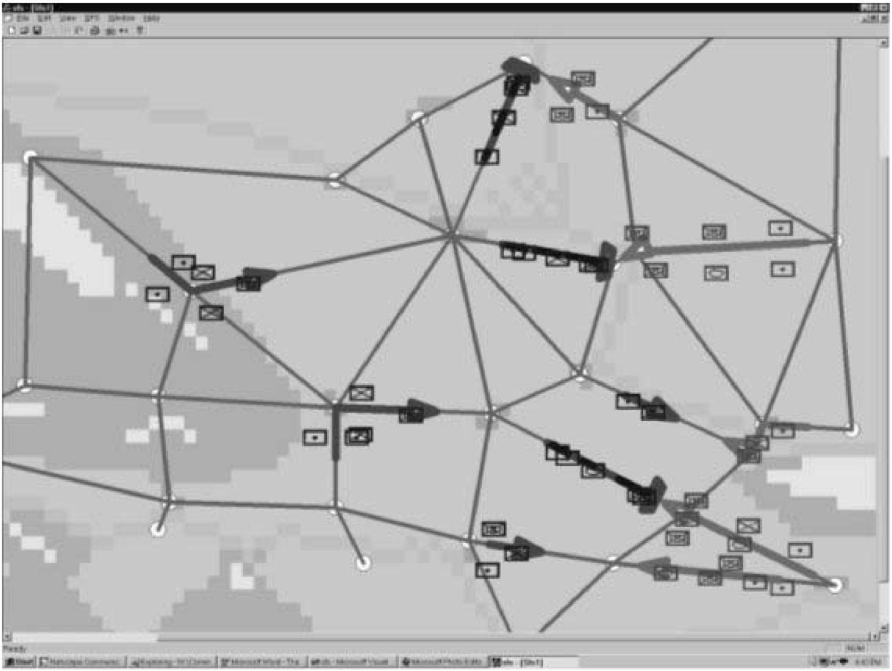

Figure 7: Graphical Representation of the Battlefield on a Low-resolution Simulation of Low-intensity Conflicts.

Developing a combat simulation one has to resolve a number of technical issues as well.[13] These mainly fall into the category of hardware and software architecture,[14] computer networking and data sharing,[15] computer security, user interface design, data collection and validation, model testing, and many others. Figure 8 represents a mechanism for ensuring logical integrity of distributed simulation based on the "proxy" design pattern used in software design. These issues, whether related to the computer technology or to the modeling activities, sometimes pose significant challenges to the development team. This applies even more to countries in transition, that lack proven expertise in many modern technologies, but even more lack the organizational capacity to undertake even moderately complex developmental projects.

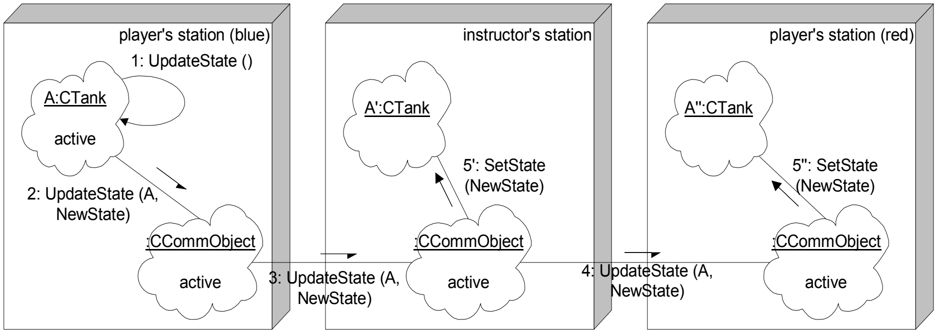

Figure 8: A Mechanism for Ensuring Logical Integrity of a Distributed Simulation.

Modeling National Security Issues

If we consider the more general problem of modeling national security, we can conclude that the range of important phenomena and the complexity of issues is much broader compared to defense-related problems (see Figure 9); the importance of the problems facing decision-makers, measured in terms of possible long-term gains and losses to the whole society caused by a particular decision, is much greater; and the tools to support professional education, analysis and decision-making in the security area are much less developed in comparison with defense-oriented analytical and educational tools.

To ensure the well-being, development and prosperity of the people of a country, two types of issues are important: physical security and economic security. All of the issues related to the physical integrity of a country are important, but there are many resources and interests of a nonphysical nature that are critical to national security. All traditional defense analyses related to military capability are still important. However, in addition to these questions, there are a number of new issues that need attention. Other issues, such as crime, mass migrations, ethnic cleavages,[16,17,18] are also of importance to physical security. Strong ethno-nationalism, including religious fundamentalism, is especially dangerous, because it involves irrational elements, and therefore has important psychological components, such as degrees of narcissism and paranoia. The high level of emotionalism can turn ethnic conflicts into “total conflicts” characterized by high degrees of barbarity.

Another problem is the changing nature of the international community. Many global multinational corporations are more powerful than many UN member states. Many non-governmental organizations and international organizations have more legitimacy than many UN member states. Foreign policy instruments, such as NATO, are no longer as effective in achieving security goals as they were in the past. It is also not possible to separate internal and external security. That adds to the complexity of national security-related analysis.

To ensure economic prosperity and development, which constitute the other essential part of national security, a nation needs a lot more than physical security (see Figure 10). The inability of many newly emerging democracies to compete successfully on the global market will be the main reason of their internal in-state tensions, conflicts, violence, and state failures. Key ingredients of national power include both “hard” and “soft” factors. According to Tellis,[19] they can be divided into two broad categories: national resources and national performance.

National resources include technology, level of entrepreneurship, human resources, financial resources and physical resources. Country’s limited technological potential critically constraints its ability to achieve more ambitious goals. The most important technologies today belong to the group of information and communication technologies, technologies related to organization of efficient and environmentally safe production of goods, biotechnologies, and material technologies. Entrepreneurship is collective expression of the level of invention, innovation and diffusion of innovation within the society. It is a natural medium for spreading technology. The quality of human resources is measured primarily by the quality of knowledge they master. In the future, knowledge and information will be more essential for economic progress than assured flow of oil. Cultures and states that do not see inherent value in education will not be able to compete on the international scene. Financial resources represent a form of resources that can most easily be converted into any other form of national power. Moreover, almost no political goal can be achieved without financial support for chosen programs and projects. Finally, physical resources represent yet another form of national resources, but they are loosing their importance in the information era.

National performance[20] is the set of characteristics of national system or society, which determine how efficient is the country in using its resources to attain its goals. National performance can be examined from four different aspects: external pressures and constraints, internal pressures, infrastructure capacity and ideational resources.

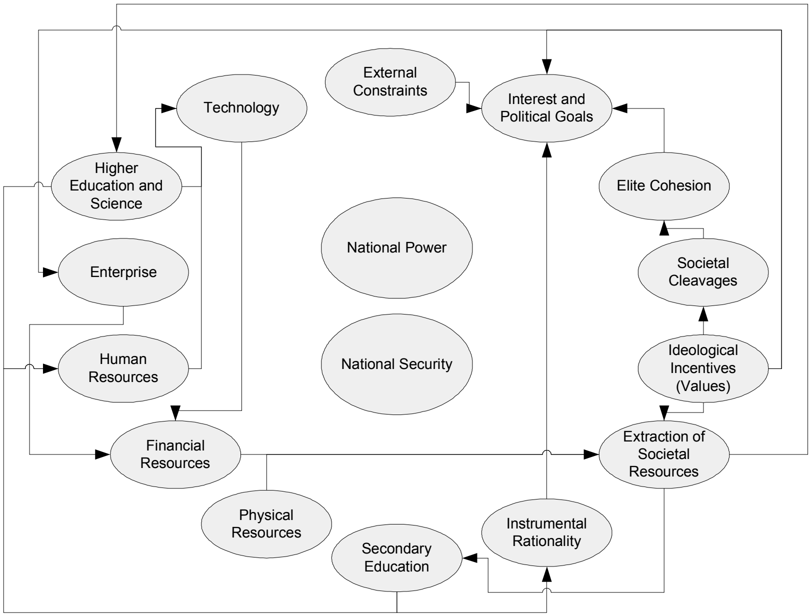

Figure 9: An Interpretation of Elements and Connections in Tellis' Model.

External pressure – global or regional competition or threats – often motivates countries to set specific goals and to try hard to reach them. Internal pressure often serves both as a motivating and a constraining factor for national growth. It is a motivating factor since it demands wealth and progress. It is a constraining factor because it resists cutting benefits or making changes needed for progress. Infrastructure capacity describes how much wealth the state can extract from the society in order to secure means for gaining political goals. It has two dimensions: the first dimension of infrastructure capacity is the ability of the state to define its goals, and it depends, among other, on the extent of elite cohesion and the depth of societal cleavages. The second dimension of infrastructure capacity is called social control, and it describes the extent of state's authority throughout society exercised in no repressive sense. Finally, ideational resources, the fourth aspect of national performance, refer to intangible capabilities that derive from problem solving and value-system of a given country. They determine whether the country has the ability to adequately relate means to ends, and whether the country has a national commitment to the pursuit of wealth and the acquisition of power and other national goals.

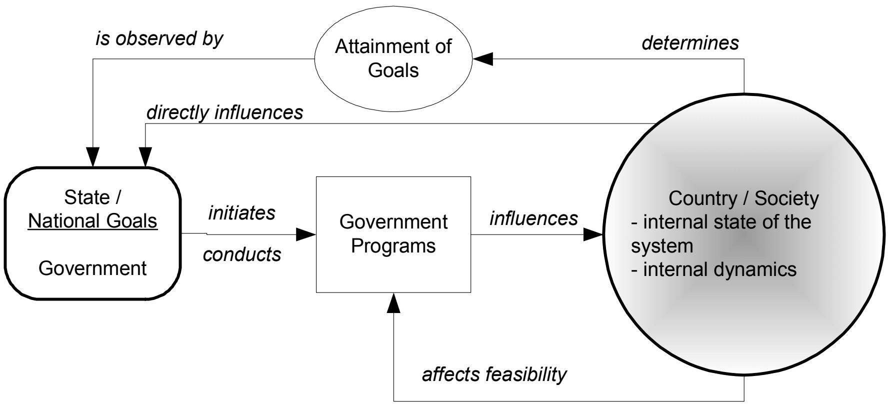

Figure 10: Key Concepts in the Dynamics of National Power.

The key analytical problem is modeling the interdependencies of these elements and the dynamics of the different aspects of national security. A better understanding of these processes should assist the decision-makers to make less sub-optimal decisions and to be more effective in their public service.

Put very simplistically, the analysis could help us in understanding the characteristics of the current state of the society, state *A*, and what should be the characteristics of the control vector $u(t)$ to reach a desired state *B*. What is the cost of vector $u(t)$, what are the constraints, what is achievable by local internal in-state control $u(t)$ (in-state administration) and what can be expected from the international community, the international organizations? How can the transition from state *A* to state *B* be achieved and in what amount of time? A lot of research, not only in modeling and simulation, but also in the fundamental social sciences, needs to be conducted to get practically applicable results. It is not only in the interest of the big and powerful countries, but it is also very important for small countries that are still in political and economic transition.

Conclusion

The paper describes the research and development activities in Croatia of state-of-the-art training simulators for antitank guided missiles, low-altitude air defense missiles, jet fighter aircraft and hardware-in-the-loop simulators for real time testing of newly developed digital guidance and control systems. Design and development of high-resolution tactical simulations and operational aggregated combat simulations is also presented. Finally, the paper presents a theoretical approach applied to the modeling and simulation of national power and national security.

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BENEFITS AND CONSEQUENCES OF AUTOMATED LEARNING IN COMPUTER GENERATED FORCES SYSTEMS

Mikel D. PETTY

Introduction

Should computer generated forces (CGF) systems include automated learning capabilities? The CGF research literature contains many statements by CGF experts that the ability to learn will be generally valuable, even necessary, in future CGF systems. A variety of significant benefits for CGF systems and military simulation in general are claimed to follow from automated learning. However, upon closer examination, it seems to be not so obvious that learning by CGF systems would necessarily be beneficial for many uses of CGF systems. This paper takes a respectfully skeptical position regarding CGF learning and provides arguments that CGF learning could compromise and confound the utility of CGF systems for the most common CGF applications.

This paper begins by defining CGF systems and grouping CGF simulation applications into three broad types. Calls in the CGF research literature for automated learning by CGF systems are surveyed. Categories of learning-modified behavior for CGF systems are defined based on what behaviors have been learned. Arguments are given, organized by application and behavior category, explaining how learning could increase and/or reduce the utility of the CGF system for the application. Real and notional examples are provided. Finally, specific applications where learning by CGF systems might be useful are identified.

Background

This section provides background information on CGF systems, types of CGF applications, and automated learning for CGF systems.

Computer Generated Forces

Computer generated forces[1] are automated or semi-automated entities (such as tanks, aircraft, infantry) in a battlefield simulation that are generated and controlled by a computer system (i.e., a CGF system), perhaps assisted by a human operator.[2,3] CGF systems are often used in training simulations to provide both opposing forces and supplemental friendly forces for human trainees. CGF systems are also used to generate many or all of the entities in battlefield simulations being used for non-training purposes, such as analysis or experimentation. CGF systems model both physical phenomena, such as terrain and combat, and behavior, such as tactical maneuvers; the latter is of primary concern here. It is intended that the behavior of the simulation entities generated by a CGF system be both doctrinally accurate, so as to provide a reliable basis for training or analysis, and plausibly human, so as to be realistic and engaging.

One example CGF system is ModSAF, which generates and controls individual battlefield entities, such as tanks or helicopters, in real-time simulation systems. It has been widely distributed and used extensively for training, analysis, and experimentation.[4] (However, in the U. S. ModSAF is being superseded by successor systems.) ModSAF includes user interface, network interface, physical modeling, low (entity) level behavior generation, and high (military unit) level behavior generation capabilities. Each ModSAF system, running on a personal computer or workstation, can generate approximately a battalion-sized force. Behavior generation in ModSAF is based on a library of doctrinal tactical behaviors that can be assigned by an operator to individual entities or groups of entities that compose military units, such as platoons or companies and executed automatically.[5] Once assigned, ModSAF automatically executes the behaviors, controlling the actions of the individual entities.

CGF Applications

For the purposes of this paper, the applications of CGF systems in simulation will be grouped into three classes: training, analysis, and experimentation.

Training. Training simulations, in general, are intended to induce learning in human trainees. The trainees interact with or participate in the simulation, which provides an instructive experience. Flight simulators and command staff exercise drivers are well-known examples of training simulation; the former teaches psychomotor skills via an immersive experience, while the latter teaches cognitive and decision-making skills by providing a realistic battlefield context. CGF systems are often used in training simulations to provide both opposing forces and supplemental friendly forces for human participants in a simulation.

Analysis. CGF systems are also used to generate entities in battlefield simulations being used for non-training purposes, such as analysis and experimentation. Analysis is the use of simulation to answer questions about some aspect of the system or scenario being simulated. Military analysis simulations are often used to assess the effectiveness of new weapons systems, force structures, or doctrine. In analysis applications simulation is used in a carefully controlled way with run-to-run initialization differences restricted to the factors under question (e.g., different weapons performance levels). Desirable aspects of analysis simulations and CGF systems used for analysis are repeatability, determinism, and the capability to isolate the cause of any particular observed effect. As an example of the analysis application, CGF systems were used in the experimental trials testing the design of a new naval surface combatant.[6] Computer generated forces are an important part of that project, providing "…friend and foe entities that make up the simulated battlespace" in which the design concepts were evaluated.

Experimentation. The experimentation application is similar to analysis, in that the simulation and CGF system is being used to answer questions, but in experimentation the questions are more open-ended and exploratory. Strict control of run-to-run differences is less important in experimentation than exploring in simulation a space of possibilities (e.g., a set of different notional weapons systems). The objective of such experimentation is "not to evaluate system effectiveness, but rather, to provide an environment and tools that will allow operators and analysts to discover new insights."[7] CGF systems have been used in large experiments conducted by U. S. military commands.[8]

Automated Learning

Learning, in general, is the acquisition of new knowledge and behaviors, usually as the result of instruction or experience. When the learner is an algorithm running on a computer system, rather than a human, the learning is referred to as machine learning or automated learning. A variety of methods and data structures have been devised for automated learning, with varying degrees of success in different applications.[9] The concern here is with the consequences of learning in CGF systems, not its implementation, so implementation details will not be addressed.

As a side note, it is worth remembering that CGF systems often include human operators. When the operator is considered as part of a CGF system, it is clear that the CGF system can (and often does) learn as the human operator becomes more skilled over time. However, it is assumed here that references in the CGF research literature to learning by CGF systems mean automated learning, i.e., learning by the non-human algorithmic portion of the CGF system.

Calls for Learning in CGF Systems

Calls for learning capabilities in CGF systems appear regularly in the CGF research literature. Some of those calls are surveyed here.

Though it does not mention CGF systems specifically in this context, a frequently cited study of human behavior modeling asserts that "learning within and by the simulations themselves" is "of potential importance" and that "Learning is an essential ability of intelligent systems."[10] Many CGF systems are placed in the "intelligent systems" category by their developers and the theme of learning as a necessary requirement for intelligent systems appears frequently. In an investigation of the application of neuro-fuzzy systems to CGF behavior representation, it is asserted that "Intelligent systems such as CGF must possess humanlike expertise in the military domain. Like a human or group of humans in a military organization they must be able to adapt and learn."[11] In a comparison of adjustable rulesets and neural nets for CGF systems, it is stated that "Intelligent systems must – among other criteria – be able to learn."[12] A list of desired capabilities for military intelligent agent architecture includes the assertion that "learning is clearly a desirable capability for a military [intelligent agent]."[13] An argument for the applicability of the recognition-primed decision-making model of human decision-making posits that "In order to realize the full benefit of a human behavioral model within an intelligent simulator, … the behavior model should incorporate learning."[14]

The perceived need for learning motivates a portion of CGF research. A report of interesting research into implementing learning within stochastic finite-state machines is introduced by statements that "learning and adaptation will become a key issue in future generation [CGF] systems" and that CGF systems lack "needed realism that relates to learning."[15] An outline of a research initiative into behavioral modeling techniques for CGF systems also sees learning as providing a "realism enhancement potential."[16] Another review of CGF research areas concurs: "Successful employment of human behavior models with the [modeling and simulation] synthetic environment requires that the models … possess the ability to integrate learning."[17]

A variety of beneficial effects are attributed to CGF learning, including cost reductions; "To enable rapid and affordable response to operational training requirements, [CGF entities] require a number of capabilities such as learning" and "By developing and inserting a learning capability into [CGF entities], the knowledge base construction expense may be reduced."[18] An examination of domain- and simulation-independent architectures for behavior generation suggests that "the ability to learn … would add to the power of the reasoning capability."[19] Learning is also expected to "… help simulations represent [CGF entities] in a more realistic manner …"[20]

Finally, learning is generally seen as a capability that future CGF systems will require. It has been observed that future CGF systems must be able to "… modify strategies based on observed successes and failures"[21] and must have "new behavior techniques to better support planning, automation, and learning."[22]

Consequences of Learning by CGF Systems

What might a CGF system learn, and what would be the consequences? This section addresses the first question by defining categories of learning-modified CGF behaviors in terms of nested subsets of possible CGF behaviors. It then addresses the second by considering how CGF behaviors in each of those categories would affect each of the three CGF application classes.

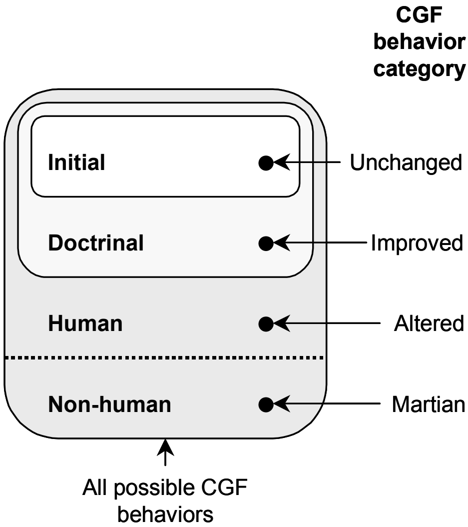

Figure 1: CGF Behavior Categories.

What Might a CGF System Learn?

While the question of what a learning CGF system might learn would be difficult to answer in detail, it can be approached at a more abstract level by considering sets of possible CGF behaviors.[23] Figure 1 illustrates a hierarchy of nested sets of CGF behaviors. The outermost, or most inclusive, set is that of all possible CGF behaviors.[24] It is partitioned into two subsets, those behaviors that are plausibly human behaviors and those that are not.[25] Within the set of human CGF behaviors there is the subset of behaviors that are within the military doctrine(s) of the force(s) represented by the CGF system.[26] Within the doctrinal behavior set there is the subset of behaviors that were initially programmed into some learning CGF system of interest.[27]

Suppose a CGF system with learning capabilities is run so that learning may occur. Its post-learning behavior can not be determined in detail without more information, but at an abstract level it can be classified into one of four CGF behavior categories based on what behaviors it has learned. If the learning CGF system has learned no new behaviors at all, its post-learning behavior is *Unchanged*. If it has learned any new behaviors from the Doctrinal set that are not in the Initial set, but no new behaviors outside the Doctrinal set, its behavior is *Improved*. If it has learned any new behaviors from the Human subset that are not in the Doctrinal set, but no new behaviors from the Non-human subset, its behavior is *Altered*. Altered CGF behavior includes behaviors not within the doctrine of the represented force. This possibility was recognized as the result of an experimental study in implementing learning for automated individual combatants, where it was observed that circumstances in the learning environment "… can cause the [individual combatant] to learn non-doctrinally correct behavior."[28]

If it has learned any new behaviors from the Non-human subset, its behavior is *Martian*.[29] Martian CGF behavior includes behaviors that are not plausibly human. Real examples of arguably Martian behavior exist. One learning algorithm presented with the task of designing a space battle fleet for a game tournament produced designs that were quite unlike any of the human-produced designs; it won the tournament.[30]

Table 1 summarizes these CGF behavior categories.

Effects of CGF Learning by Application

The effects of CGF learning can now be analyzed by considering how behavior from each of the four CGF behavior categories would affect each of the three CGF applications. Table 2 summarizes that analysis.[31] The entries in the table are coded with a "+" or a "-" to indicate an effect of learning that appears to be beneficial or detrimental, respectively, for the application. Note that in several cases there are both beneficial and detrimental effects.

Training. Learning that produces Improved CGF behavior can result in simulated entities that use better, but still doctrinal tactics, making them superior as training opponents or supplemental friendly forces to entities with Unchanged behavior. However, even in the Improved category, there are potentially detrimental consequences. As learning occurs during a sequence of training runs the CGF behaviors become unpredictable to the extent that learning changes them.

Table 1: Summary of CGF behavior categories.

CGF behavior category	Behavior changed?	Includes behavior(s) from				Description
		Initial	Doctrinal	Human	Non-human	
Unchanged	No	Yes	No	No	No	All behavior within doctrine of represented force
Improved	Yes	?	Yes	No	No	All behavior within doctrine of represented force
Altered	Yes	?	?	Yes	No	Some behavior not within doctrine of represented force, but all still plausibly human
Martian	Yes	?	?	?	Yes	Some behavior not plausibly human

This means that the person who has organized the training loses control of the experiences the trainees will have and cannot guarantee that his/her training objectives will be met. It could happen, for example, that the trainer wants the trainees to learn to defend against a hasty attack, but the CGF system learns that hasty attacks are ineffective and dangerous and uses some other tactic. It is also possible that trainees could face CGF opponents that become so proficient due to learning that the trainees are overmatched and become discouraged. Automated learning algorithms generally require numerous trials or executions to present the algorithm with cases from which to learn (e.g., the training sets of neural nets). Those trials can be costly to set up and execute. For example, in some CGF applications Soar's capability for learning "has not been employed because these [computer generated] forces have been expected to perform at an expert level without undergoing a potentially costly training phase."[32]

If the CGF system has learned Altered behavior, the trainees could face behavior that is not within the doctrine of the represented force; such non-doctrinal behavior may provide no training, or even negative training. If Martian behavior has been learned, the trainees could face non-human behavior, with even less expected training value.

Table 2: Summary of effects of CGF learning by category and application.

CGF behavior category	CGF applications		
	Training	**Analysis**	**Experimentation**
Unchanged	No effect	No effect	No effect
Improved	+ Improved behavior + Varying experience - Loss of training control - Cost of learning phase	+ Improved behavior - Loss of repeatability - Confounded results - Cost of learning phase	+ Improved behavior + Richer experiment - Confounded results - Cost of learning phase
Altered	+ Varying experience - Loss of training control - Non-doctrinal behavior	- Loss of repeatability - Confounded results - Non-doctrinal behavior	+ Richer experiment - Confounded results - Non-doctrinal behavior
Martian	+ Varying experience - Loss of training control - Unrealistic behavior	- Loss of repeatability - Confounded results - Unrealistic behavior	+ Richer experiment - Confounded results - Unrealistic behavior

Analysis. The consequences of learning for analysis applications seem to be generally more negative than for training. It is true that Improved CGF behavior can make the CGF entities' actions doctrinally better, providing better analytic subjects. But the run-to-run behavior changes due to learning have two significant detrimental effects on analysis. First, repeatability is potentially lost if the CGF system is learning so that its behavior changes between runs. Second, it could be difficult to determine if the run-to-run outcome differences are due to the subject of the analysis (e.g., the performance of a new weapons system) or to new behaviors introduced by the learning algorithm, thereby confounding the results. The cost of the learning phase applies to analysis as well.

The possible problems of loss of repeatability and confounded results apply to Altered and Martian CGF behavior as well. At the Altered level the analysis runs can include non-doctrinal behavior, possibly reducing its value, and at the Martian level they may be against non-human behavior, possibly reducing its value further.

Experimentation. For experimentation, learning has both potential benefits and detriments. The benefits of Improved CGF behavior apply to experimentation. Moreover, learning at any level could support richer experiments that explore a larger solution space, perhaps without requiring human intervention. A report on the use of the JSAF (Joint Semi-Automated Forces) system notes this: "The successful incorporation of learning into the JSAF entities would be a major step forward for experimentation. If the automated entities could adapt to new weapons systems, organizations, and tactics then the entire experimentation process could be performed in closed loop simulations."[33] Learning in a CGF system could be useful in "… the development of new tactics based on changing enemy weapons systems and capabilities."[34]

On the other hand, the risks of confounded results and a costly learning phase apply to experimentation as well. There is the possibility of reducing the value of experiments that include non-doctrinal or non-human behavior. The just-cited JSAF report warned that automated CGF learning could confound the experimentation results with learning that does not correspond to any possible reality, typical of behavior in the Martian category: "there is a danger that automated learning systems will optimize based on simulation anomalies rather than actual real world phenomena."[35] This is not merely a hypothetical possibility; an example of just such an artificial optimization was observed in the author's own early work on automated learning. In an experiment with a simulated robot exploring a hostile terrain, the robot control algorithm learned to avoid damage by remaining motionless as much as allowed by the rules of the simulation, which optimized the robot's survival time but was contrary to the exploratory mission of the robot.[36]

Some Valid Applications of CGF Learning

There are some applications of CGF learning that appear valid. Several of those are noted in Table 2. An application of CGF learning that seems particularly apt is the automated acquisition of knowledge as part of knowledge engineering for CGF behavior.[37]

Conclusions

Many redoubtable experts in CGF have stated their case for the needs of and benefits of CGF learning. These counter-arguments are offered with sincere respect. Nevertheless, there appear to be situations in each of the CGF application classes where CGF learning is detrimental. What can be concluded from this? First, CGF learning is potentially a valuable tool, but like most tools, it must be employed with skill and in the right circumstances to be useful. Second, additional research is needed, not only to develop and improve CGF learning methods, but also to find the applications where learning is truly useful.

Notes

[1] Computer generated forces are also known as semi-automated forces.

[2] Clark R. Karr, Douglas A. Reece, and Robert W. Franceschini, "Synthetic Soldiers," *IEEE Spectrum* 31, 3 (March 1997): 39-45.

[3] Mikel D. Petty, "Computer Generated Forces in Distributed Interactive Simulation," in *Distributed Interactive Simulation Systems for Simulation and Training in the Aerospace Environment*, ed. T. L. Clarke, SPIE Critical Reviews of Optical Science and Technology, Volume CR58 (Bellingham WA: SPIE Press, 1995), 251-280.

[4] A. J. Courtemanche and Andy Ceranowicz, "ModSAF Development Status," in *Proceedings of the Fifth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 9-11, 1995), 3-13.

[5] R. B. Calder, J. E. Smith, A. J. Courtemanche, J. M. F. Mar, and Andy Z. Ceranowicz, "ModSAF Behavior Simulation and Control," in *Proceedings of the Third Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, March 17-19, 1993), 347-356.

[6] D. Ewen, D. P. Dion, T. F. Flynn, and D. M. Miller, "Computer Generated Forces Applications to a Simulation Based Acquisition Smart Product Model for SC-21," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 353-361.

[7] Andy Ceranowicz, M. Torpey, B. Helfinstine, D. Bakeman, J. McCarthy, L. Messerschmidt, S. McGarry, and S. Moore, "J9901: Federation Development for Joint Experimentation," in *Proceedings of the Fall 1999 Simulation Interoperability Workshop* (Orlando FL, September 12-17, 1999).

[8] Ceranowicz, "J9901, Federation Development for Joint Experimentation."

[9] Richard S. Forsyth, ed., *Machine Learning* (New York: Chapman & Hall, 1989).

[10] Richard W. Pew and Anne S. Mavor, eds., *Modeling Human and Organizational Behavior: Application to Military Simulations* (Washington, D.C.: National Academy Press, 1998).

[11] Gary R. George and Frank Cardullo, "Application of Neuro-Fuzzy Systems to Behavioral Representation in Computer Generated Forces," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 575-585.

[12] Andreas Tolk, "Adjustable Rulesets versus Neural Nets for Order Generation in Closed Combat Simulation Models," Paper 8TH-CGF-019, in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 167-173.

[13] R. B. Calder, J. Drummey, and F. Chamberlain, "Definition of a Military Intelligent Agent Architecture," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 551-562.

[14] Keith O. Hunter, William E. Hart, and Chris Forsythe, "A Naturalistic Decision Making Model for Simulated Human Combatants," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 593-600.

15 Erol Gelenbe, "Modeling CGF with Learning Stochastic Finite-State Machines," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 113-116.

16 Denise Lyons and Harold Hawkins, "Cognitive and Behavioral Modeling Techniques for CGFs: A New Initiative," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 3-5.

17 Sheila B. Banks and Martin R. Stytz, "Advancing the State of Human Behavior Representation for Modeling and Simulation: Technologies and Techniques," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 87-100.

18 Martin R. Stytz and Sheila B. Banks, "Considerations and Issues for Distributed Mission Training Computer-Generated Actors," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 529-537.

19 David M. Patrone and Tony Nardo, "A Domain and Simulation-Independent Architecture for Creating Simulated Object Behaviors," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 63-72.

20 Susan A. Gugel, David R. Pratt, and Rafael A. Smith, "Using Q-Learning to Control Individual Combatants," in *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation* (Norfolk VA, May 15-17, 2001), 131-139.

21 B. D. Lapin, R. L. Kolbe, J. Langworthy, V. Tran, and R. Kang, "Semi-Automated Forces that Learn from Experience," in *Proceedings of the Tenth Conference on Computer Generated Forces and Behavioral Representation* (Norfolk VA, May 15-17, 2001), 141-146.

22 Anthony J. Courtemanche, "Design Patterns for Computer Generated Forces," in *Proceedings of the Eighth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 11-13, 1999), 25-36.

23 Here it is assumed that CGF behaviors can be grouped into sets and that individual behaviors can be treated as elements of sets. This assumption seems justifiable only if CGF behaviors that are generated by algorithms are considered, which can be represented unambiguously in forms like computer programs, which certainly can be elements of sets.

24 Again, if only CGF behaviors that are generated by algorithms are considered, this set is infinite but countable so. Each behavior can be mapped to the integer that is equivalent to the binary representation of the shortest computer program that generates it.

25 Is there any behavior that is not plausibly human? Even human behavior motivators as basic as self-preservation can be overridden by humans in combat situations. Perhaps behaviors that require cognitive computation beyond the capabilities of humans could exist; they would fall into this subset.

26 A singular force will be assumed hereinafter to simplify the exposition. The arguments are not materially affected.

27 Note the assumption that the CGF system was implemented correctly, i.e., that all its initial behaviors are within the Doctrinal set.

28 Gugel, Pratt, and Smith, "Using Q-Learning to Control Individual Combatants."

[29] The term "Martian" was deliberately chosen for its double meaning. Mars is both a non-human planet and the Roman god of war.

[30] Douglas B. Lenat, "EURISKO: A Program That Learns New Heuristics and Domain Concepts," *Artificial Intelligence* 21, 1-2 (March 1983): 61-98.

[31] The analysis of this section, and Table 2, assumes that the training, analysis, or experimentation is occurring over a sequence of runs and that learning is "turned on" and hence can occur during that sequence. An analysis of the similar, but simpler case where learning occurs only before a sequence of runs is omitted for reasons of space.

[32] Scott A. Wallace, John E. Laird, and Karen J. Coulter, "Examining the Resource Requirements of Artificial Intelligence Architectures," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 73-82.

[33] A. Ceranowicz, P. E. Nielsen, and F. V. Koss, "Behavioral Representation in JSAF," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 501-512.

[34] Gugel, Pratt, and Smith, "Using Q-Learning to Control Individual Combatants."

[35] Ceranowicz, Nielsen, and Koss, "Behavioral Representation in JSAF."

[36] Mikel D. Petty, Terry J. Frederick, and J. Michael Moshell, "Experiments in Routing an Autonomous Land Vehicle with a Weakly Inductive Learning Algorithm," in *Proceedings of the Third Florida Artificial Intelligence Research Symposium* (Cocoa Beach FL, April 3-6, 1990), 159-163.

[37] Larry Willis, Lashon B. Booker, Gary N. Bundy, and Paul G. Foley, "Overview of the Advanced Simulation Technology Thrust (ASTT) Program," in *Proceedings of the Ninth Conference on Computer Generated Forces and Behavioral Representation* (Orlando FL, May 16-18, 2000), 101-112.

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AN EXPERIMENTAL APPLICATION OF A TRAIT-BASED PERSONALITY MODEL TO THE SIMULATION OF MILITARY DECISION-MAKING

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and Jean CATANZARO

Introduction

Due to the uncertainties inherent in military operations and the variations in human personalities, military command and control behavior rarely conforms strictly to doctrine. (Of course, the degree of conformity to doctrine may vary.) In a military simulation with automated commanders, models of command behavior and decision-making that follow doctrine precisely and exhibit no variations are therefore unrealistic. Automated commanders that exhibit doctrinal behavior are essential for training, especially at the introductory levels, but are not sufficient for the full range of purposes the simulation may be applied to, such as advanced training and mission rehearsal. Simulation users may seek an automated commander that realistically models the effects of the fog of war and the difficulty of making doctrinal decisions under stressful conditions. Such realism in simulation could better prepare trainees for expected encounters on the battlefield.

To achieve this end, the realistic modeling of human behavior has become a pervasive topic in the modeling and simulation community. How does one go about representing realistic human behavior? Some psychologists have looked to personality traits to characterize behavior. Different humans behave differently in the same situation, depending on their personalities. Commander personality has a significant effect on command decision-making, so modeling personality and its effects on command could improve simulation realism. For some applications, realistic command simulation may require a representation of personality.

We have implemented and tested a simulation that incorporates a trait-based model of human personality into the decision-making of a simulated commander. The model was implemented and used in an experiment intended to test its utility in producing more realistic human decision-making in a way that could be validated by personality and performance measurements of real human commanders. The simulation models a decision-making scenario where a commander must dispatch and route trucks, assumed to be loaded with food and medicine, to a refugee camp with urgent requirements for the supplies. Land mines have been placed, in numbers that vary by road segment, in the road network between the supply depot and the refugee camp. The mines will disable a portion of the trucks that attempt to traverse each segment, based on mine density. The simulated commander knows the roads are mined but does not know the number of mines on the various road segments in the network and so must make dispatch and routing decisions in the absence of complete information and with the expectation of having trucks disabled. In this scenario, time does not permit the mines to be searched for or removed; the only method the commander has to learn of the relative danger of different road segments is to route trucks along them. The simulation forces the commander to make decisions under the stress of conflicting goals; the trucks must reach the refugees quickly, but the road network must be explored carefully to determine the least dangerous routes.

The following sections of this paper cover these topics. The personality traits that are the psychological basis of the model of human personality used in the automated commander are briefly reviewed. The experimental scenario and simulation of it is described. Details of the design of the automated commander, including the integration of the trait-based personality model, are given. The results of experimental testing of the model are reported. Finally, an alternative set of traits for the human personality model, suggested by the results, is provided.

Personality Traits and Decision-Making

In the context of military command it is critical to assign the right person to the right job and adequately train that person to competence. As military trainers have found, training and repetition can train out certain undesirable characteristics of a person's performance. For example, a person with sufficient training in the situation he/she faces may exhibit reduced fear and panic response, have better reaction time, and make fewer careless mistakes. Unfortunately, when in a stressful or unexpected situation, especially one, which a commander's training has not prepared him/her for, the commander's behavior and decision-making performance may revert to his/her innate psychological characteristics. In such circumstances a commander's individual personality is most visible in his/her behavior. For simulations purposes a commander model that accounts for personality would be useful for producing realistic decision-making behavior from psychological profiles of human decision-makers.

Models of personality have been considered in the past, but progress has been dependent on the existence of appropriate tools for evaluating personality traits in the context of military decision-making. The trait-based personality model used in this research is based on an extensive investigation of the battlefield behavior of 20th-century infantry[1] and has been previously suggested for applying a trait-based model in simulation.[2] The model asserts eight distinct personality traits that impact decision-making. Those personality traits are listed and defined as follows:

1. *Stability.* This is a generic trait that expresses a person's overall emotional stability, rather than a particular emotion. It serves as the "governor" of emotional expression, particularly extreme emotions such as panic.
2. *Anxiety.* This trait expresses a person's inherent fearfulness.
3. *Anger.* Broadly expressing the emotion of anger, this trait also accounts for a person's inherent aggressiveness and resentment.
4. *Humor.* Representing more than a simple sense of humor, this trait also expresses a person's capacity for emotional "bounce-back" and the ability to recover from sudden shocks, losses, and other negative impacts on morale.
5. *Acquiescence.* This trait represents a person's willingness to follow commands, orders, and other leaders.
6. *Independence.* This trait expresses the ability of a person to make decisions independently, without leadership.
7. *Charisma.* A composite trait that collectively expresses aspects of personality that others tend to find attractive.
8. *Knowledge.* This trait replaces the ambiguous term "intelligence" which has a particular meaning in military terms. It refers to military knowledge, ranging from weapons and equipment to tactics.

Whereas personality *traits* are relatively stable characteristics of a person, his/her decision-making can also be affected by the more transient condition of psychological *state*. In contrast to traits, states are dependent on the situation and relatively temporary. For example, a person may have a consistent predisposition towards anger (a trait), but may have that angry disposition overlaid or temporarily displaced by tranquility (a state) resulting from an event such as a mission success. In other words, a person's trait-based tendencies can be temporarily counteracted by event-driven states.

The personality model synthesizes the basic psychological notions of personality traits and states into composite factors that influence military command decision-making; these factors include situational stress (e.g., the friend-to-foe ratio) and morale (based on a combination of personality traits, stress, and support).

Experimental Scenario and Simulation

An experimental scenario was designed to exercise command decision-making. A simulation was implemented to specifically support that scenario.

Experimental Scenario

A hypothetical United Nations (UN) peacekeeping and humanitarian assistance force has received an extremely urgent request to deliver medical supplies and food to a refugee camp in the Balkans. The supplies are needed within the next 12 hours to avoid many refugee deaths. Extremely bad weather prevents air transport of the supplies. The UN force has assembled a group of trucks at the closest supply depot and loaded them with the needed supplies. The trucks must travel to the refugee camp as quickly as possible.

Unfortunately, what would otherwise be a simple route-planning problem is complicated by the fact that hostile militia forces have placed land mines throughout the road network between the supply depot and the refugee camp. The terrain is rugged enough to restrict truck travel to the roads. The exact locations and density of the mines are unknown to the UN commander, and there is not sufficient time to perform mine search and removal. The mines used by the militia are of a type that if hit by a truck will disable the truck but will not kill the UN drivers. The trucks are all equipped with radios and global positioning system receivers. The UN commander decides to dispatch and route the trucks individually to the refugee camp, controlling their movements centrally by radio from the command post, and to adjust later truck's routes based on knowledge of the mine locations learned from the preceding trucks.

Experimental Simulation

In the simulation of this scenario, the terrain is represented as an undirected graph, with vertices corresponding to road intersections and edges to the roads connecting the intersections. Trucks are located at vertices. Trucks move from vertex to vertex along edges. The supply depot and refugee camp are both vertices. Figure 1 is an example of a terrain graph.

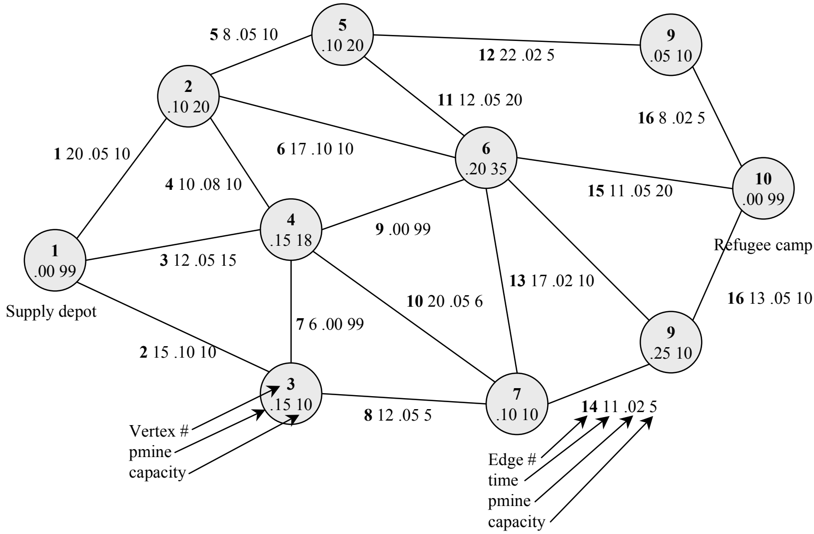


Figure 1: Example Terrain Graph.

Each edge *e* in the terrain graph has these attributes:

1. *e.time* Time required by a truck to traverse edge *e*. These values are determined by the geographical distance between the connected vertices, the average speed of truck movement, and a random increase to reflect specific road conditions.
2. *e.pmine* Probability of a truck being disabled by a mine when traversing edge *e*.
3. *e.capacity* Maximum number of trucks that may simultaneously be traversing edge *e*. This capacity limit includes trucks that may become disabled on *e*.

Each vertex *v* has these attributes:

1. *v.pmine* Probability of a truck being disabled when moving to vertex *v*.
2. *v.capacity* Maximum number of trucks that may be located at vertex *v*. This capacity limit includes trucks that may become disabled at *v*.

The simulation implementation employs the discrete-event simulation paradigm. The movement of a truck from one vertex to another is a simulation event, as is the disabling of a truck on an edge or a vertex. When a truck located at vertex v_i at current time t moves from vertex v_i to v_j, along edge e_k, it arrives at v_j at time $t + e_k.time$. At time $t + (e_k.time / 2)$, $e_k.pmine$ is used to determine if the truck is disabled while moving along the edge. If it is disabled, the UN commander is notified that the truck was disabled. Otherwise, the truck arrives at vertex v_j at time $t + e_k.time$. At that time a determination is made using $v_j.pmine$ if the truck is disabled at the vertex and the UN commander is notified of the truck's status, either arrived safely or disabled at the vertex. Because the effects of a large number of mines are being modeled probabilistically, mines are not removed when a truck is disabled, i.e., the *e.pmine* and *v.pmine* values are not changed at such events. No more trucks may be simultaneously located at a vertex v_i than its capacity $v_i.capacity$; similarity, no more trucks may be traversing an edge e_k than its capacity $e_k.capacity$.

The automated UN commander decides when to dispatch each truck from the supply depot. It also decides when each truck reaches a vertex, which connected vertex the truck will next move to. At the start of a trial, the UN commander has no knowledge of the mine distribution (i.e., of the *v.pmine* and *e.pmine* values). Over time, the UN commander accumulates an estimate of the *pmine* values based on the experiences of the trucks as they move through the graph. The dispatch and routing decisions are made using a decision model, described in the next section that may consider the estimated *pmine* values.

In addition to the simulation time taken by the trucks' movements, the automated UN commander's decisions require time. The amount of time per decision is a parameter of the commander model. A trial ends when all trucks have either reached the refugee camp vertex or been disabled.

Design of the Automated Commander

The implementation of automated commander's decision model essentially consists of two parts. The first part of the decision model is a set of graph search algorithms that find routes in the terrain graph; they generate alternatives for the commander's basic routing decisions. The routing algorithms differ in terms of whether they seek to minimize time, minimize risk of disablement, or minimize some combination of those. The second part of the decision model is the trait-based personality model. It influences the routing decisions in that it is used to select among the alternatives generated by the routing algorithms and may also cause a delayed or degraded decision.

Search Algorithms

The cost of a route in the terrain graph is a function of the time to traverse it and the probability of being disabled on the route. The set of graph search routing algorithms used in the automated commanders consider one, or the other, or both of those aspects of cost. The routing algorithms are:

1. Minimum Time Cost (MTC)
2. Least Damage (LD)
3. Least Percent Damage (LPD)
4. Minimum Time Cost and Least Damage (MTCLD)
5. Minimum Time Cost and Least Percent Damage (MTCLPD)

An A* heuristic search algorithm[3,4] is used to find the minimum time route through the road network. The minimum time route may vary over simulation time because edges in the network may become unusable when trucks are disabled and block further truck traversal on particular edges. The algorithm is executed repeatedly to update the minimum time route. This route is used as a standard to measure the performance of the search procedures used. The true risk of a route may be calculated using the true probabilities of disablement (the *e.pmine* and *v.pmine* values), rather than the estimates of those values derived from experience as a percentage of trucks disabled on the edge or vertex. The true risk of a route may also serve as a performance standard.

The other four routing algorithms consider not only minimum time but also heuristics dealing with the estimated probability of disablement on a route, based on the quantity or percentage of trucks that have been disabled at each edge or vertex on the route. These values will change as the scenario is executed and more trucks are disabled.

Some details of the routing algorithms are now given. They use these parameters:

$\#D$, $\%D$, pD = number, percentage, and probability of trucks disabled, in total

$\#D_e$, $\%D_e$, pD_e = number, percentage, and probability of trucks disabled, on edge e

$\#D_v$, $\%D_v$, pD_v = number, percentage, and probability of trucks disabled, at vertex v

Minimum Time Cost (*MTC*). As mentioned earlier, the MTC algorithm uses an A* graph search procedure to find the path of least cost (time), which is approximated by an evaluation function $e(v)$ that is calculated for each vertex v along the path. The evaluation function sums the actual time $c(v)$ required to reach v and the estimated cost $h(v)$ of getting from v to the goal vertex. The MTC algorithm uses the time required to traverse each edge *e.time* throughout the network to calculate these costs. The evaluation and cost functions for MTC are defined as follows:

$$e(v)_{MTC} = c(v)_{MTC} + h(v)_{MTC}$$

$$c(v)_{MTC} = \sum_{i \in R} e_i.time$$

$$h(v)_{MTC} = d(v) / K$$

where R is the route the truck has taken so far to vertex v, K is the average truck speed, and $d(v)$ = Euclidean distance $\sqrt{a^2 + b^2}$ assuming a and b are the horizontal and vertical distances from v to the goal vertex.

Least Damage (LD). The LD algorithm is focused on reducing risk, not time, on its routes; the LD cost function considers only the number of trucks previously disabled along a possible route segment (edge and terminating vertex). Movement is directed toward the segment with the least number of previously disabled trucks.

$$c(v)_{LD} = \#D_E + \#D_N$$

Least Percent Damage (LPD). Similar to the LD algorithm in its focus on risk, the LPD algorithm's cost function considers the percentage, rather than the number of trucks that have previously been disabled when attempting to traverse a route segment.

$$c(v)_{LPD} = \%D_E + \%D_N$$

Minimum Time Cost and Least Damage (*MTCLD*). In its cost function, the MTCLD algorithm considers both the time and number of trucks disabled for a particular route segment.

$$c(v)_{MTCLD} = \frac{\#D_E + \#D_N}{\sum_{i=0}^{AP} \left(\#D_E(i) + \#D_N(i)\right)} + \frac{e.time}{\sum_{i=0}^{AP} e.time}$$

$$h(v)_{MTCLD} = \frac{d(v)}{\sum_{i=0}^{AP} d(i)}$$

where AP denotes all paths.

Minimum Time Cost and Least Percentage Damage (*MTCLPD*). In its cost function, the MTCLPD algorithm considers both the time and percentage of trucks disabled for a particular route segment.

$$c(v)_{MTCLPD} = \frac{\%D_E + \%D_N}{\sum_{i=0}^{AP} \left(\%D_E(i) + \%D_N(i)\right)} + \frac{e.time}{\sum_{i=0}^{AP} e.time}$$

$$h(v)_{MTCLD} = \frac{d(v)}{\sum_{i=0}^{AP} d(i)}$$

Trait-Based Personality Model

Within the framework of the five routing algorithms the challenge is to define what constitutes normal and sub-optimal decision behavior and establish a link between a commander's personality and the decisions he/she makes. The automated commander's decision model is based on the assumption that a human commander would make routing decisions that closely approximate (perhaps in sub-optimal form) one of the routing algorithms previously described. Which algorithm would the commander use, and whether or not the decision made would be sub-optimal, depends on the commander's personality traits and the current state of the simulation.

As previously described, the commander's personality is specified with a set of eight personality traits. In general, personality traits determine the predisposition of people to exhibit a particular behavior under varying situational conditions. Such trait and state effects on decisions are modeled in this research as decision delay and decision optimality. For example, stress is a situational condition that may affect the decision-making performance of a military commander. The personality model causes commanders with certain personality traits to make sub-optimal decisions under high stress conditions. Sub-optimal decisions are obtained from evaluating and ranking the five search algorithms against a particular scenario. Ranking may also be chosen based on qualitative criteria. Delayed decisions are obtained by randomly increasing the decision time according to parameters that are part of the commander's personality profile (the term personality profile refers to the collection of the eight trait values for a particular commander).

The decision model design uses the commander's personality traits and current simulation state to calculate the commander's stress and morale and ultimately his/her accuracy and effectiveness. Based on those results, one of the available decision actions calculated by the five decision algorithms is selected. The decision selection also includes the possibility of a delayed decision (long decision time).

A user interface in the simulation, shown in Figure 2, is used to enter the parameters that connect the commander's personality to the process of selecting the decision of one of the routing algorithms. Via this interface the user enters the effectiveness ordering of the routing algorithms, the commander's reaction time, the commander's obedience and panic parameters, and the accuracy and effectiveness levels associated with the routing algorithms. The commander's personality traits are used to compute his/her accuracy and effectiveness in a given situation; then that value is used, based on the parameters entered in the last portion of this interface, to select one of the routing algorithms' decisions. Leaders with personalities that make them more effective in the current situation will select the decisions of the better algorithms.

Simulation Experiments

A series of simulation experiments were conducted to test the integration of the trait-based personality model into the automated commander and its effectiveness at producing realistic decision-making behavior.

Simulation Environment and Scenario Generation

The simulation's user interface allows the user to create and edit terrain graphs. Based on user inputs, vertices and edges in a terrain graph may be randomly generated and/or manually edited. Similarly, edge and vertex attributes, such as *e.time* and *v.pmine*, can be generated by the simulation and/or manually edited. Other scenario information, such as number of trucks, is also input via the user interface. Once generated, terrain graphs and scenario data can be saved.

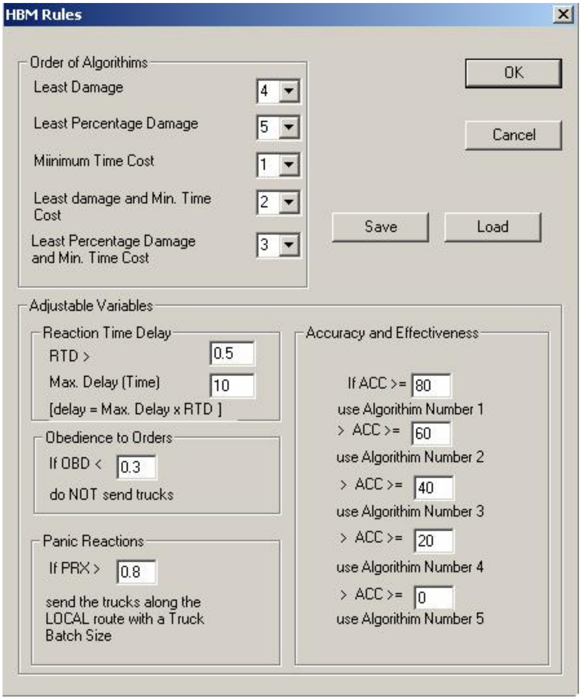


Figure 2: User Interface for Connecting Commander Personality to Decision Algorithms.

Figure 3 shows an example scenario; the example in the figure is smaller than the road networks used for the actual experiments. In the figure the circles represent the road intersections (vertices) interconnected with lines that represent the roads (edges). The color green (G) and the light lines denote a road or intersection that has been traversed without incident, red (R) indicates that at least one truck has been disabled on that road or intersection, and blue (B) means that the road or intersection has not yet been traversed by any trucks. In the figure the leftmost intersection (a white (W) node) is the supply depot and the rightmost intersection (a green (G) circle) is the refugee camp. The numbers labeling each edge and vertex indicate the number of trucks traversed and disabled.

In addition to the automated commander, the simulation has interactive capability whereby a human operator can make the trucks' routing decisions. This capability provides a mechanism to compare the automated commander's performance with that of human commanders.

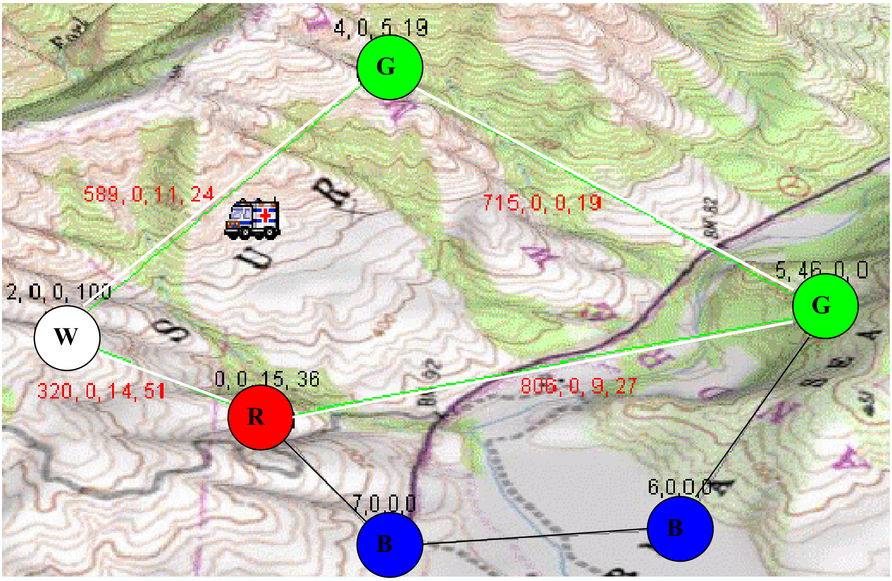


Figure 3: Example Road Network and Scenario.

Performance Evaluation Metric

The long-term goal of this research is to contribute to generating realistic decision-making behavior by automated commanders in simulations. To assess progress towards that goal, the effectiveness and realism of the decisions made by the automated commander must be quantitatively measured. The objective is not to obtain some mathematically optimum performance level for an automated commander, but rather to generate similar decision-making outcomes as would be found in human commanders.

Under the performance metric defined for the scenario, the commander seeks to maximize number of trucks arriving at the refugee camp within a given time limit and minimization of both the number and the lateness of trucks arriving after the time limit. The performance metric is defined as follows:

$$\max\left\{\sum_{i=1}^{N} \left[c_i d_i + c_i (1 - d_i)(s / a_i)\right] / N\right\}$$

where:

N = The number of trucks.
s = A constant; the time limit given for trucks to arrive at the refugee camp.
d_i = 1 if truck i arrives within the critical time limit, 0 if it is late.
c_i = 1 if truck i arrives at the refugee camp vertex, 0 if it is disabled.
a_i = The arrival time of truck i at the refugee camp vertex.

Note that for each truck the quantity $c_i d_i$ will be 0 or 1, the quantity $c_i(1 - d_i)(s / a_i)$ will be in the range 0 to 1, and only one will be non-zero. The performance of a commander will be the sum of N such quantities, divided by N, which will therefore be in the range 0 to 1 (inclusive). This normalized measure of performance allows the commanders' performance to be compared for different numbers of trucks and different terrains.

Experimental Results

A series of experiment trials were performed using typical road network topology generated over a given terrain. In preparation for the experiments the five search algorithms were executed on the experimental networks in order to determine their effectiveness ranking on those networks.

Figures 4, 5, and 6 compare the performance of the five routing algorithms without personality influence. In the figures, the horizontal axis shows time limit and the vertical axis shows performance metric values. All three figures illustrate that the more time a commander has the better he/she will perform. Figure 4 shows the performance of the five algorithms over seven trials with a common road network and increasing time limits. For these trials the road network had an equal probability of being disabled by mines at every intersection (vertex) and road (edge) in the graph. In such a road network, where no route segment is lower risk than any other, the MTC algorithm will outperform the other algorithms; Figure 4 confirms that result. On the other hand, if the probabilities of being disabled vary across the intersections and roads, the relative rankings of the five algorithms may be different. Figure 5 shows a series of ten trials, again with a common road network and increasing time limits. In the road network used for these trials the MTC had the worst performance and the LD algorithm was the best in terms of the performance metric. Figure 5 illustrates that the time delay associated with taking alternate routes can be justified if a sufficient reduction in the number of disabled trucks results from the detours.

Figure 6 illustrates that when the shortest path is only slightly riskier than a longer path there is a balance between taking the shortest path (minimizing time) and a longer patch (minimizing risk). If the time limit is large (toward the right side of the figure) detouring off the shortest path will yield better results, but when the time limit is small (toward the left side of figure) the MTC algorithm performs best.

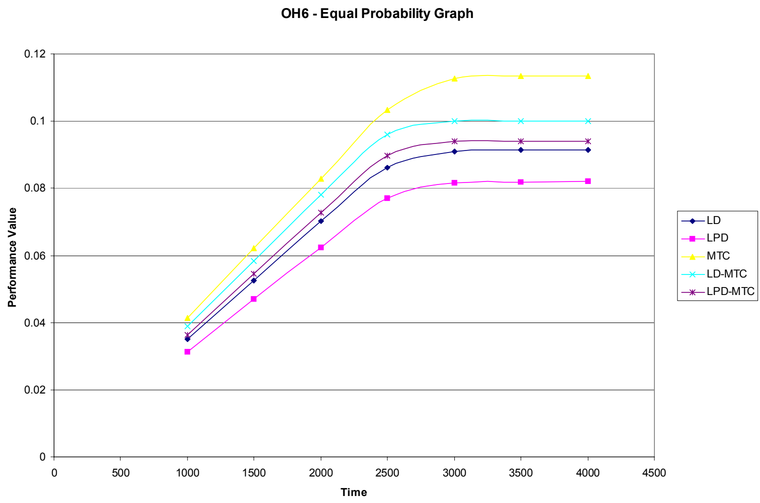


Figure 4: Results for a Road Network with Equal Probabilities of Disablement.

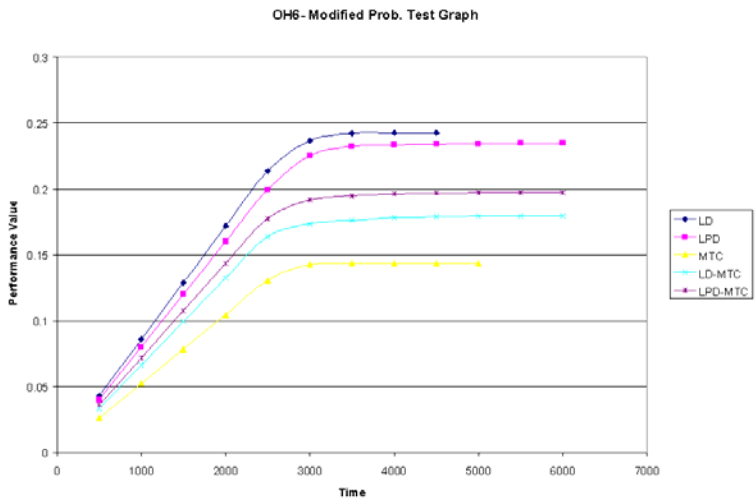


Figure 5: Results for a Road Network with Widely Varying Probabilities of Disablement.

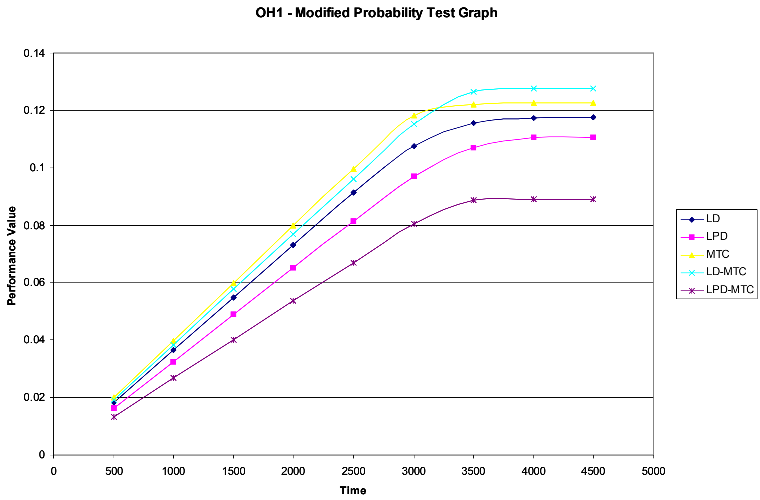
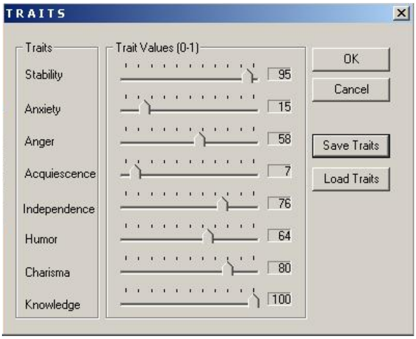


Figure 6: Results for a Road Network with Slight Varying Probabilities of Disablement.

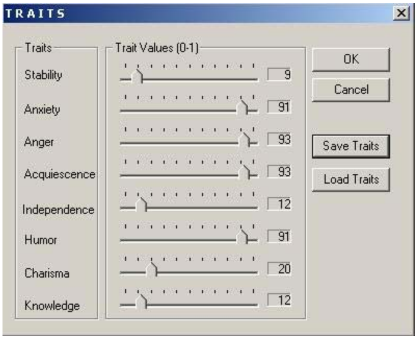
After verifying the performance of the five algorithms against various road networks, a set of several widely varying personalities were encoded into the automated commander. These personality profiles did not correspond to specific persons; there were produced by the experimenters to evaluate the model's ability to increase realism and were intended to be representative of typical commander profiles. The performance results of the representative personality commanders were then analyzed for system sensitivity and realism.

Figure 7 illustrates the personality profiles used for two of the representative commanders (as well as the user interface in the simulation for entering commander personalities). Figure 7(a) shows a generally "good" commander, with personality traits typical of low anxiety and high knowledge. In contrast, figure 7(b) shows a generally "bad" commander, with high anxiety and low knowledge.

Over multiple trials the "good" commander's average performance value was 0.15 and the "bad" commander's average performance value was 0.08. Even though the "good" commander was simply choosing among decisions made by the five routing algorithms, that commander's average performance was better than any one of the five algorithms because his/her personality allowed him/her to choose the best decision for a situation. For the opposite reason the "bad" commander's average performance was worse than any one of the five algorithms. Figure 8 compares the good and bad commanders' performance values of 0.15 and 0.08 to the performance of the five routing algorithms without any personality influence. The "good" commander performs significantly better than any of the five algorithms, whereas the "bad" commander performs worse than any of the five algorithms for time limits ≥ 3000.



(a) "Good" commander



(b) "Bad" commander

Figure 7: Personality Profiles for Representative Good and Bad Commanders.

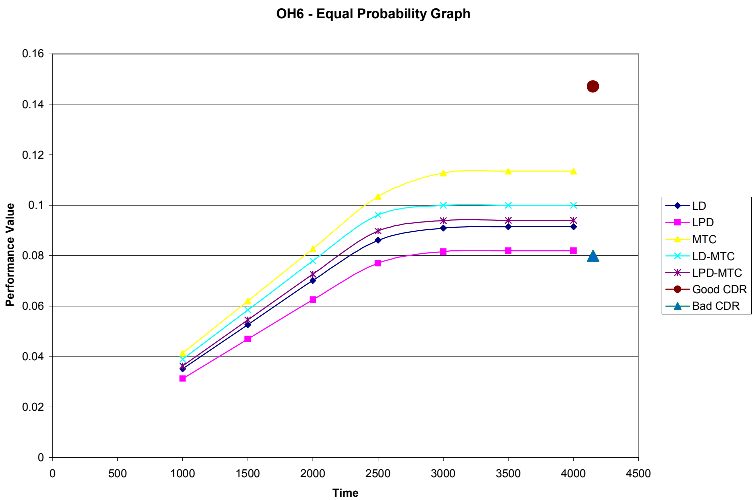


Figure 8: Average "Good" and "Bad" Commander Performance.

Comments on the Results

Though the representative "good" and "bad" commanders showed good and bad performance as expected, some of the results obtained using the other representative personality profiles were more mixed. For example, it was possible to define a "panicky" commander that would outperform a "good" commander in some situations, an unexpected result. This could be due simply to randomness in the simulation, but it is also possible that the representative personality profiles were flawed or the method used to connect personality traits to decision-making behavior needs improvement.

The next step is to encode personality traits of human commanders obtained via personality tests and use those traits in the automated commander. Eventually, it is hoped that the performance of the automated commander and the real commander will be statistically equivalent. In order to achieve these results, two issues must be addressed. First, a more objective means of providing personality profiles is needed. Unfortunately, there are no personality tests that will provide values for the model's eight traits directly. A reliable means of determining the values of a commander's personality traits is needed. Second, the additive linear relationships used to describe a commander's reaction based on personality are imperfect at best. A learning algorithm using non-linear methods to determine likely patterns of behavior may be needed.

Conclusions

The experiments showed that a trait-based personality model could be integrated into an automated command and used to influence the decision-making of that commander. Different personality profiles were seen to produce different performance in the experimental scenario.

The experiments suggest that using a trait-based personality model of a commander could improve the decision-making realism of the commander. It also seems that, if reliable personality assessment tools can be developed, the personalities of human commanders can be used within an automated commander. The performance of an automated commander could then be compared to the human counterpart as a means of validation. Looking farther ahead, a personality model may also be applied to the task of predicting how a particular military commander might react in a situation and how to improve that commander's performance.

Acknowledgement

This work was sponsored by an internal research and development grant of the Virginia Modeling, Analysis and Simulation Center.

Notes:

1 S. M. Silver, *Unpublished communication*.

2 Sheila B. Banks and Martin R. Stytz, "An Approach to Enhance Human Behavior Modeling for Computer-Generated Actors," in *Proceedings of the Fourth International Simulation Technology and Training Conference (SimTecT '99)* (Melbourne, Australia, March 29-April 1, 1999), 199-204.

3 Peter E. Hart, Nils J. Nilsson, and Bertram Raphael, "A Formal Basis for the Heuristic Determination of Minimum Cost Paths," *IEEE Transactions on Systems Science and Cybernetics* 4, 2 (July 1968): 100-107.

4 Patrick H. Winston, *Artificial Intelligence*, Third Edition (Reading MA: Addison-Wesley, 1992).

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EXPERIMENTAL VALIDATION OF METAMODELS FOR INTELLIGENT AGENTS IN CONFLICT

James MOFFAT and Susan WITTY

Introduction

As discussed in a previous paper,[1] we are attempting to develop mathematical 'meta-models' of agent-based simulation models. These meta-models fall within the area of what is loosely referred to as complexity theory, and exploit the mathematical approaches which are being developed to gain understanding of natural non-linear systems (such as ecosystems of species, or the physics of spin systems). Such an approach is most likely to be relevant to future command and control structures such as Network Centric Warfare.[2] In particular, Moffat discusses in detail the connection between the mathematics of complexity and the likely emergent behaviour of future command and control driven 'Information Age' conflict.[3]

Cellular Automata

As a means of gaining understanding, we have carried out a number of experiments using simple cellular automata based models that are relevant to conflict. Such models have been developed in response to the theory that human conflict is a complex, non-linear system,[4] which in dynamical system terms, occurs far from equilibrium. In other areas of research on the complexity of natural systems, such cellular automata models have been used to identify key emergent properties of such systems.[5]

The 'new sciences' of complexity and chaos, although not yet fully developed into a coherent theory, provide a way of looking at such interacting agents in conflict.[6] In this paper we first show in detail that historical data indicate the existence of a fractal attractor for at least some types of conflict (based on initial work by Lauren [7]). We then show that experimental data from runs of such simple cellular automata models supports the hypotheses, which can be derived from our theoretical meta-models of the process.

The experimental data presented here have been derived from a particular cellular automata model called ISAAC [8] which was developed for the US Marine Corps as part of their 'Project Albert' research initiative.[9]

An Attractor for Conflict

For non-linear dynamical systems, we know that there are only a small set of possible attractors for the dynamics of the system typically corresponding to a stable invariant final state, a limit cycle (corresponding to a periodic final state), and a 'strange attractor' (normally a fractal set), corresponding to a chaotic state.[10]

Lauren indicates that for at least some conflict situations, the dynamics of interaction of the forces evolves towards an attractor state, which is independent of the initial conditions.[11] The idea is that an essentially straight line frontage between two tactical opponents will buckle into a fractal shape, whose fractal dimension can be calculated as a function of the force ratio of the forces involved, (the number of attackers to the number of defenders), as derived from Historical Analysis of infantry battles carried out by the UK Defence Science and Technology Laboratory (DSTL). Lauren uses as a basis for his approach a regression analysis of historical tactical level conflicts carried out by DSTL, which indicates that the non-dimensional parameter:

$$F = (\textit{Number of attack infantry / Number of defence infantry})^{0.685}$$

is a multiplier for the base number of casualties of the attacking force per defence weapon. Note that from a previous work of Moffat we expect powers of non-dimensional parameters to be of key importance in such 'meta-models' of the process.[12] In fact, from the same work of the author we can say that this is a meta-model of Type 2, since the exponent cannot be derived solely from dimensionality considerations. As a consequence of this, Lauren was able to shows that the combat front will buckle over time, and in the limit will have a fractal dimension $D = 1.685$. Thus for this type of conflict, the dynamics in the time invariant state are similar to those of a chaotic system.

In this case we can derive the underlying dynamics producing this statistical effect. It turns out that this fractal factor is due fundamentally to detection of targets,[13] and comes from a model of the engagement process, which leads to the following relationship:

$$\frac{1}{R} = \frac{k_1}{T} + k_2 ,$$

where k_1 and k_2 are constants, R is the defender rate of fire and T is the number of targets in view.[14]

It reflects the asymmetry of the infantry battle in the following sense.[15] The attack force aim is to close on the defence position, and fire is used in a general suppressive mode – actual casualties caused to the defence are only a small part of the process at this point. However, from the defence perspective, the aim is to deter the attack, and casualties to the attack force are very important. Such casualties to the attack force are a direct reflection of the inter-visibility of targets to the defence force as discussed above.

As with most applications of fractal processes, the process breaks down at some point due to the granularity of the resolution. In this case, the process remains valid up to about 30 meters closing distance between the attack and defence. At that point a different mechanism comes into play, leading to local defence surrender and attack overrun of defence positions.[16]

More generally, the figure of 0.685 relates to open terrain. In urban areas it is about 0.5,[17] giving rise to a fractal dimension of 1.5 for the attractor state. The closing to overrun appears to occur differently in urban and wooded terrain as compared with open terrain.[18] For example, in open conditions, the closing part of the battle occurs across the front. By contrast, in urban conditions, the attack force is split into small subunits that individually close on defence locations leading to local surrender and overrun.

In terms of modelling such a process using cellular automata, if we assume that this process is akin to the cellular automata model of 'invasion percolation' in which one fluid is invaded by another in a porous medium, the fractal dimension of the boundary of the resulting interface lies in the range 1.33-1.89,[19] which agrees with our experimental data range (based on historical conflict regression analysis) of 1.5-1.685 for the fractal dimension of our attractor set.

Local Clustering

In order to analyse the 'swarming' dynamics of cluster formation and dissolution in the ISAAC cellular automata model of conflict, first we need to consider how to define such a cluster. In Theoretical Physics, it is usual to define neighbouring agents as those, which are North, South, East or West, adjacent to the agent in question, known as 'nearest neighbour' clustering. For a single time step in any run of a cellular automata based model, the number and size of clusters of agents can be determined using the Hoshen-Kopelman algorithm.[20]

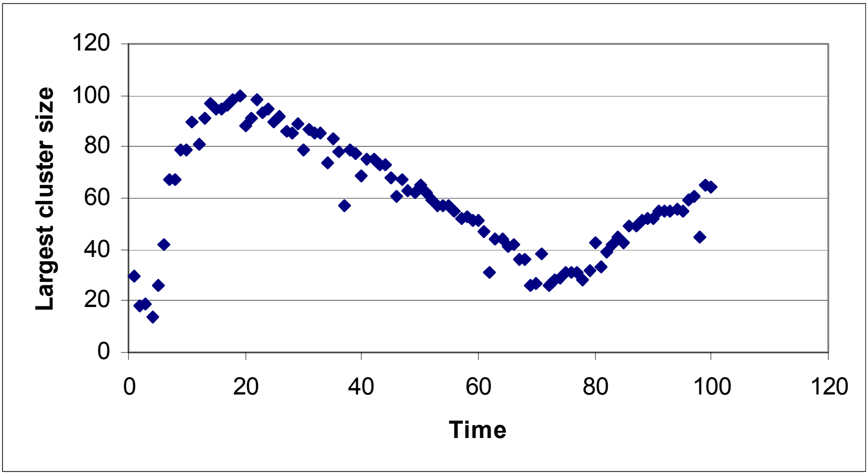

Figure 1: Evolution of the Largest Red Cluster Size within the Scenario (Red Successful).

This algorithm has been applied to a particular 'scenario' in the ISAAC model in which the Red agents attempt, by a swarming strategy, to reach a high value objective defended by a smaller number of Blue agents. The particular interest of this scenario is that in all stochastic replications (over 100 in total) of the model except one, the Red agents reach and take control of the high value objective. In the exceptional case, Blue is able to defend this objective successfully.

Once the cluster numbers and sizes can be determined for each experimental replication of the scenario, there are a number of ways to analyse the data. First we look at is the size of the largest cluster. This gives an indication of the ability of the agents to cluster or the amount of dispersal of the agents. For example, if the largest cluster size is near to the total number of agents, we know that that is the only cluster. However, if the largest cluster is small, then we know that the agents are dispersed in many small clusters.

Figure 1 shows a typical evolution of the largest cluster size for the Red agents, in the case where Red is successful in taking control of the high value objective. Each break in the slope of this plot corresponds to a new phase in the operation – first the move to infiltration and engagement with Blue agents, secondly the infiltration and engagement phase, and finally clustering around the objective.

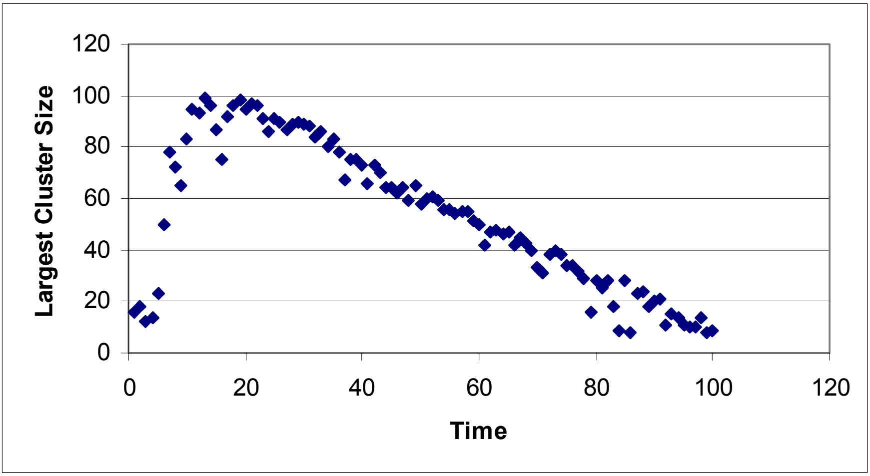

Figure 2: Evolution of the Largest Red Cluster Size within the Scenario (Red Unsuccessful).

When Red is unsuccessful, only the first two phases are visible, as shown in Figure 2. (Note all plots of clustering consider only the agents, which are still alive at the moment of sampling).

Let us look now at the spectrum of cluster size. The Red agents are able to generate a wide range of different cluster sizes. This can be seen by examining the frequency plot of the largest cluster size, over a replication of the scenario. Figure 3 shows two representative plots, for two replications of the scenario corresponding to cases where Red was successful (replication 1) and Red was unsuccessful (replication 40).

For the replications of the scenario where Blue was unsuccessful in its defence of the high value objective, Blue only generated a narrow spectrum of largest cluster size across the time evolution of the scenario. However, for the singular case where Blue was successful, Blue was able to generate a wider spread. This is illustrated in Figure 4, where the narrow spread of largest cluster size is shown for a number of unsuccessful Blue replications, and compared to the singular case (replication 40) where Blue was successful.

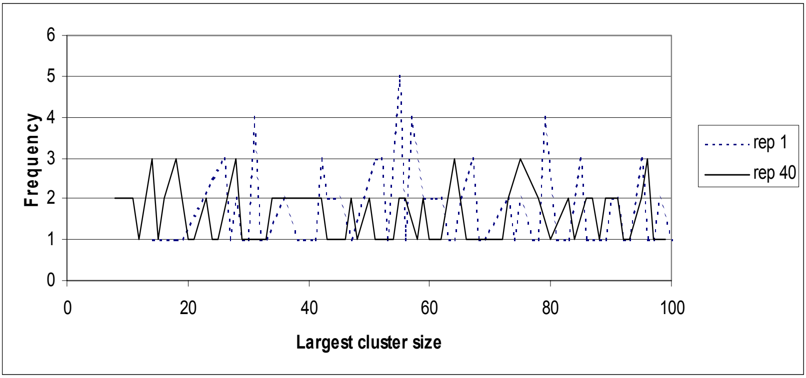

Figure 3: Frequency Distribution of Largest Red Cluster Size.

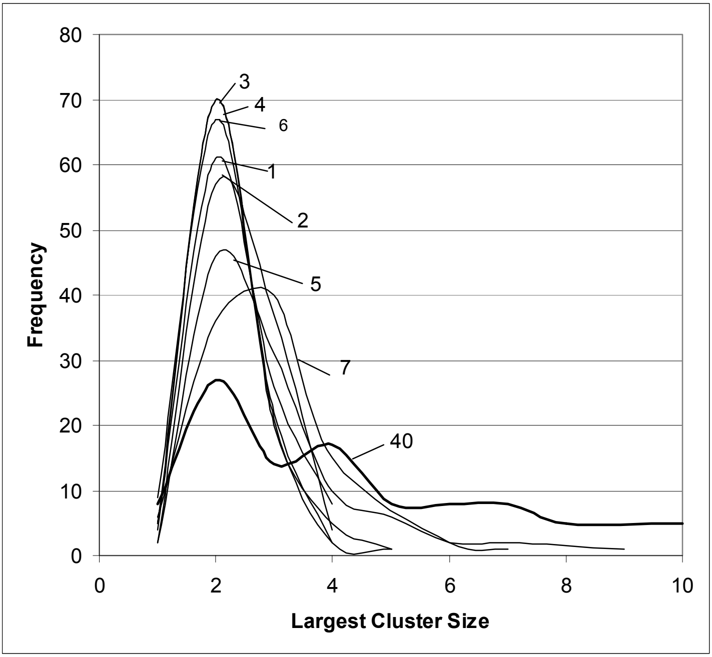

Figure 4: Frequency Distribution of Largest Blue Cluster Size.

Cluster Size Distribution

All of this experimental evidence, based on looking just at the largest cluster size at a given time step in the simulation, indicates that clustering is a key component in determining the emergent behaviour of the agent simulation, as is also predicted by our previous theoretical analysis.[21] Let us now look at the statistical distribution across *all* cluster sizes, averaged across a scenario replication. From theory we expect this to be a power law distribution, i.e. of the form:

$$P(S): \quad S^{\alpha}$$

where S is the cluster size, and α is a power law exponent. On a Log-Log scale, this implies a straight-line relationship. We would expect to see 'cut-off effects' at each end of such a plot where the relationship breaks down due to finite scaling effects (for example we cannot consider a cluster size smaller than 1). Figure 5 shows such a Log-Log plot of cluster size for the Red agents, over a number of replications. It is clear from this that there is such an intermediate regime of system behaviour, as expected from theory, where the cluster size distribution follows a power law distribution. This is indicative of a fractal relation for cluster creation.[22]

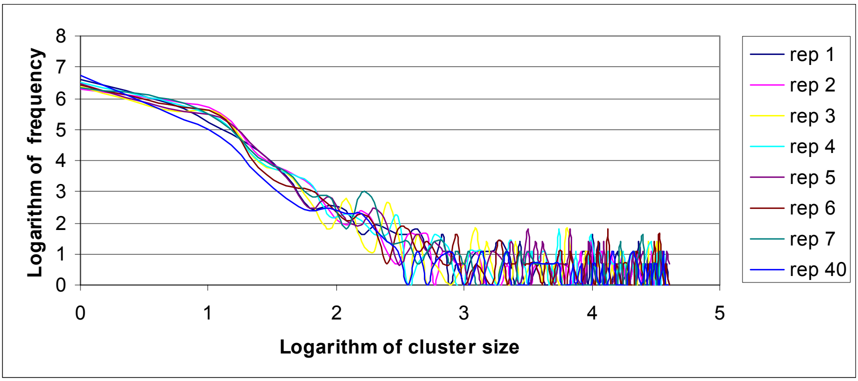

Figure 5: Distribution across All Red Cluster Sizes.

Conclusion

We have first shown in detail how, for certain types of conflict across a frontage, the dynamics of the conflict evolves toward a fractal attractor whose fractal dimension lies in the range (from historical experimental data) of 1.5-1.685. This is shown to be compatible with results of the cellular automata model of 'invasion percolation' that produces a fractal front with dimension in the range 1.33-1.89. We have then shown that clustering is a key contributor to the emergent behaviour of the ISAAC cellular automata model of conflict. The nature of this contribution is as expected from our earlier theoretical analysis. In particular, the distribution of cluster size follows a power law in the intermediate regime; a signal of fractal clustering.

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16 Rowland, personal communication.

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20 J. Hoshen and R. Kopelman, "Percolation and Cluster Distribution. I. Cluster Multiple Labeling Technique and Critical Concentration Algorithm," *Physics Review B* 1, 14 (October 1976): 3438-3445.

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SOFT COMPUTING AGENTS FOR DYNAMIC ROUTING

Georgi KIROV

Introduction

The strength of the distributed systems[1] as a new approach derives not only from its ability to allow people to communicate across big distances and at different times, but also from the ability of machines to help people communicate and manage information.

The pace of change in the software industry is so great that the traditional distributed solutions may run out of steam in the not too distant future. The forces of competition, regulation, convergence and globalization are driving change. Each one of these forces is changing the way we realize interconnected applications and the nature of networks and services. At present, the existing software technologies and network management infrastructures are getting old and information distributed systems cannot cope with the speed of response required in tomorrow's world. It is questionable whether traditional computing technologies can cope with the total information management demands of global network applications that companies will need to field in the early 21st century in order to remain competitive.

Increasingly, a great variety of different software applications and worldwide information services, such as WWW servers, databases, software packages, distance learning, video on demand, are being connected through the Internet, intranets, and other network systems. With the arrival of new technologies it is necessary to attempt to coordinate the action of these disparate entities within a cohesive framework. Standard distributed systems rely on message-based exchange with fixed connections, and as such, these systems are of limited efficiency when one attempts to use a large number of applications. Situations like these are prohibitively expensive in both time and resources, unless network applications cooperate effectively through an appropriate communication infrastructure. The field of distributed network systems is in a critical need of intuitive and innovative approaches and novel algorithms to address the growing complexity in all of its different aspects: performance, stability, security, connectivity, efficiency, routing.

Current lines of research give the promise of stopgap solutions that will suffice for the next five to ten years. Areas such as distributed artificial intelligence (agent technology) appear to offer good term solutions for distributed network applications and service management. Current engineering technologies could breathe a breath of fresh air into management information systems. But whilst these newer approaches will partner humans in dealing with the forthcoming explosion in scale and complexity, they only offer better, proactive, access to information stores and expert system solutions that we enjoy today. Soft computing could multiply the benefits of such systems many times.[2,3]

Distributed information systems can be viewed as two level structures:

- A network level that deals with network traffic, management, and control; and
- A service level that deals with applications, inter-application communications, and service provided to the customers.

Soft computing technologies have had an impact on these two levels to a varying degree. One of the most popular soft computing technologies, fuzzy logic, has been applied to the network level for network routing, traffic modeling, and congestion control.[4]

The service level, the area of inter-application communications in particular, creates an opportunity to address problems within the Artificial Intelligence (AI) domain, e.g. within the intelligent distributed information systems and the intelligent multi-modal interfaces. Soft computing in conjunction with other AI techniques and software agents[5] can be used for knowledge representation and reasoning, information retrieval, search and optimization to make the resulting systems more robust, flexible and adaptive.

In an attempt to resolve some of the above-mentioned problems in network communications the author proposes an approach that combines the Bee-gent agent technology with the fuzzy logic representation.

The Bee-gent Technology

Basic Concept

Bee-gent is a communication framework based on the multi-agent model.[6] It has been developed by the Toshiba Corporation. It provides applications with autonomous network behavior by "agentifying" them. Bee-gent supports agent-based inter-application communication, facilitating co-operation and problem solving.

This environment is based on two types of agents – Agent Wrappers (AW) and Mediation Agents (MA). The main function of the agent wrappers is to agentify existing software applications, while the mediation agents are responsible for inter-application coordination by handling all communications. The MA can move from an application to another, interacting with the AW. The AW themselves manage the state of the applications they are wrapped around. The Bee-gent applications are suitable for many software fields: distributed databases, management systems, and system optimization.[7] Figure 1 illustrates the relationships between existing applications, the agent wrappers, and the mediation agents.[8]

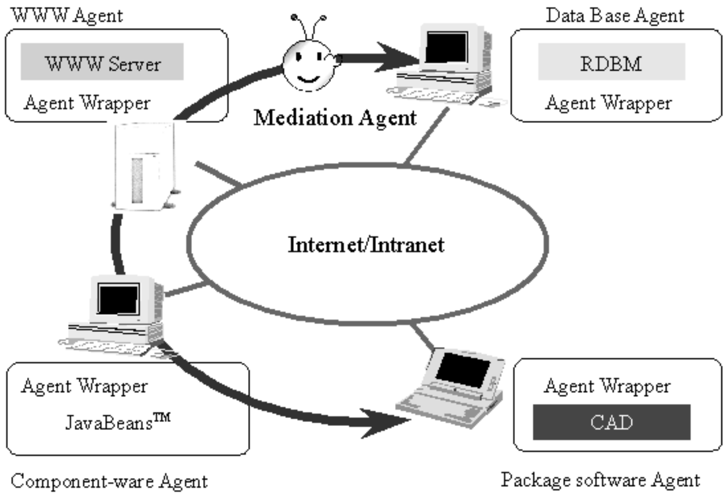

Figure 1: Relationships between Agent Wrappers and Mediation Agents.

The main characteristics of the Bee-gent technology can be defined as follows:

- Capabilities to connect distributed network applications via Internet, Intranet, and other network types;
- Ability the standard network users to receive requested data by information retrieval from databases distributed across the network.

Motivation to Use the Bee-gent Technology

The motivation to use the Bee-gent agent-based technology is inspired by the new capabilities built in the two agent types of the framework. The mediation agent controls the interaction protocol between applications in a standardized manner. It makes it easy to add to and modify the system configuration and the coordinating interactions. The mediation agent can migrate from one application to another and can preserve its present state – program code and data. Compared to the traditional message-based distributed technologies the network load decreases. The main reason for this is that the mediation agent communicates with the applications locally and the communication links can be disconnected after migration. The agent wrapper realizes interoperability between the applications. It provides a common communication interface. The communication between the agents is very appropriate for Internet use due to the fact that it is based on the XML/ACL representation format. Figure 2 shows the Bee-gent's system architecture.[9]

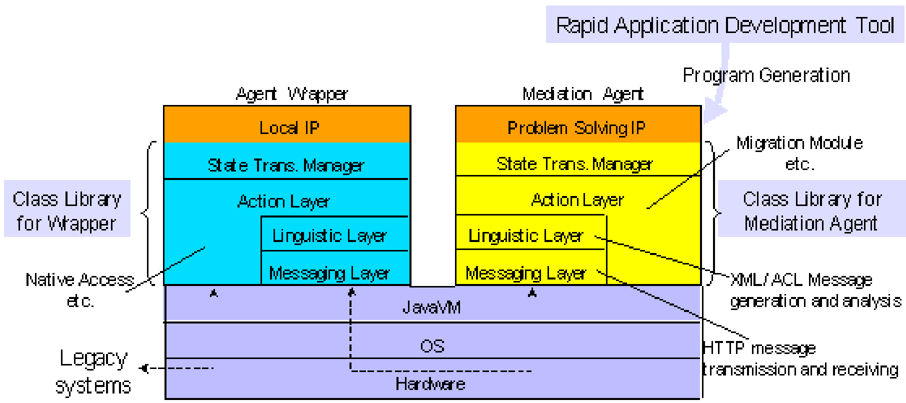

Figure 2: Bee-gent's System Architecture.

Comparison of the Bee-gent Technology with the Conventional Distributed Development Framework

The reason to have distributed object technologies is to create powerful, yet maintainable, applications. The "distributed" nature makes the system powerful, enabling scaleable solutions that can overcome the limits of the single machine performance, as well as the geographical boundaries. This section will describe the existing technologies, as well as a comparison of them. These technologies include the Object Management Group's (OMG) Common Object Request Broker

Architecture (CORBA), Microsoft's Distributed Common Object Model (DCOM), and the Java Bee-gent solutions.

The main objective of CORBA is to enable interoperability between objects on distributed systems. With the newest specification of CORBA, different vendors can now communicate, creating the "intergalactic object bus." Thus, CORBA provides a good architecture for working with distributed objects on a heterogeneous network; this aids greatly the integration of legacy applications. CORBA works by allowing clients and servers to communicate without worrying about network protocols and other communication aspects. In this specification of CORBA, the "client" is the process that uses an object and the "server" is the process that contains the instantiated object. The client does not need to know where the server is; the client can work just as if the object it works with exists in the same process space. A CORBA implementation achieves this by creating client stubs, server skeletons, and standard communication interfaces.

Distributed Component Object Model (DCOM) allows applications to work with objects on other computers. DCOM is a good infrastructure for compiled programs that need to make use of objects. Each interface in DCOM is compiled into a code, similar to CORBA stubs. DCOM interfaces, however, do not provide as much flexibility and speed for dynamic invocations. Unlike DCOM, it is not important for CORBA how implementations handle the objects. It is only required that a CORBA ORB be accessible through code created with the IDL. DCOM, however, is a binary specification. It matters very much what the compiled code looks like. DCOM works with pointers and arrays of pointers. A disadvantageous side effect of this fact is that executables created with Microsoft's Visual C++ will work with DCOM, whereas those created with other compilers may not.

There are no individual communication units programmed in the communication model of Bee-gent, in the "mediation agents," but procedures how to communicate and with which destinations. The mediation agents move to the individual destinations and communicate with them according to the procedures.

Soft Computing Agents for Dynamic Routing

This section presents a fuzzy distributed approach for dynamic network routing based on the Mobile Software Agents (MSA) paradigm.[10,11] The proposed routing technique combines Soft Computing Technologies (SCT)[12], more precisely fuzzy logic, with Software Agents (SA). The suggested solution is a distributed information system that allows interoperability between applications distributed across the network. The system consists of three parts located on different network nodes (see Figure 3):

- User application;

- Database applications that store the routing tables;
- Mobile Agent.

Taking into consideration the above-mentioned parts, it is appropriate to use the Bee-gent agent framework as a working shell. Agent wrappers agentify the first two constituents of the distributed system, while mediation agent realizes the third.

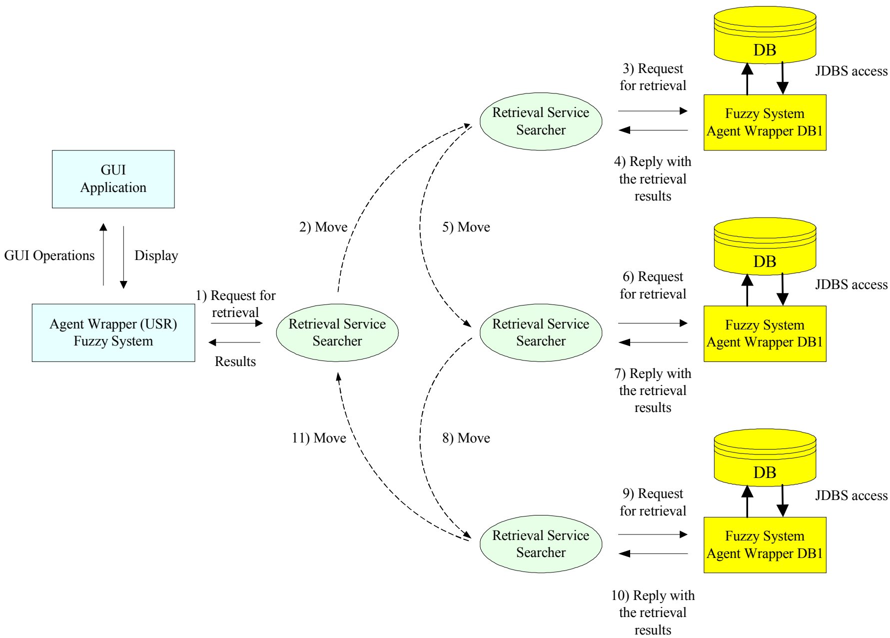

Figure 3: Soft Computing Agents for Dynamic Routing.

The main function of the user application is to evaluate user preferences. The application provides a user-friendly interface for the definition of some parameters and a fuzzy system for decision-making. The task of the fuzzy routing system is to generate a request for retrieval of the best routing path to a given destination based on the user's preferences.

The mobile mediation agent defines the interaction protocol between the user and the database applications in a standardized manner. The MA migrates from one application to another and can preserve its present state – program code and data. The mobile agent transfers the user's request to the destination databases and sends the result back.

A Fuzzy Routing Model

The main idea of the approach is to use more than one routing parameter by means of a fuzzy system in order to produce affordable link quality.[13] Fuzzy routing is treated as a multi-criteria optimization task that depends on the following input variables: time delay of a packet (*del.*), waiting queue (*que.*), cost of proposed routing (*cos.*), link capacity (*cap.*), priority of transmitted messages (*pri.*). Each variable is defined as a fuzzy linguistic variable with three inputs corresponding to small (*s*), middle (*m*) and large (*l*). It is assumed that all the necessary information about the investigated routing path is available. All variables are normalized in the [0, 1] interval:

$$p_{reli,j} = \frac{p_{absi,j}}{p_{\max i,j}} \qquad \rho_{reli,j} = \frac{\rho_{absi,j}}{\rho_{\max i,j}} \qquad t_{reli,j} = \frac{t_{transi,j} + t_{servi,j}}{t_{\max i,j}} \qquad l_{reli,j} = \frac{l_{absi,j}}{l_{\max i,j}}$$

where p_{rel} is the relative cost of the proposed routing, $\rho_{reli,j}$ is the relative link capacity, $t_{reli,j}$ is the relative time delay, t_{trans} is the transmission time, t_{trans} is the processing time, and $l_{reli,j}$ is the relative queue length.

Figure 4 shows a fuzzy routing system of the Sugeno type.

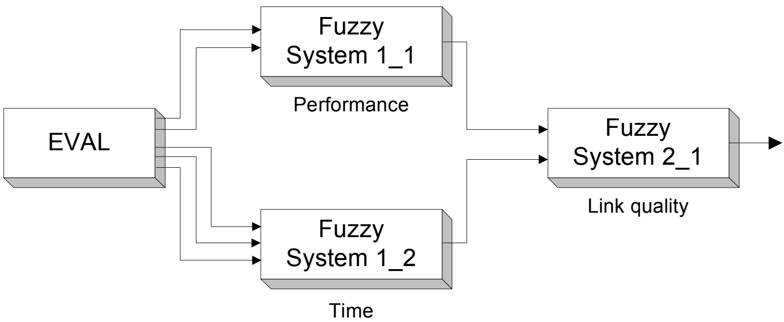

Figure 4: A Fuzzy Routing System of Sugeno Type.

The system consists of three fuzzy subsystems arranged in two hierarchical levels. This leads to:[14]

- Decreasing of fuzzy rule base size since the original system is decomposed into several similar fuzzy subsystems,
- Improving expert assessment by acknowledging intermediate results.

The system output is interpreted as a crisp value of link quality in the [0, 1] interval: the bigger the value – the better the link quality. A number of experiments have been performed in order to assess the usefulness of the fuzzy routing approach. All fuzzy systems have been implemented in FuzzyJava. Figures 5, 6, and 7 show the experimental results for the following user preferences: Cost = 0.5, Capacity = 0.5, Delay = 0.35, Queue_length = 0.73, and priority = 0.53. The fuzzy systems produced crisp results: Performance = 0.5, Time=0.524, and Link_quality = 0.495. The value of 0.495 means that the searched path has to have Link quality more than 0.495.

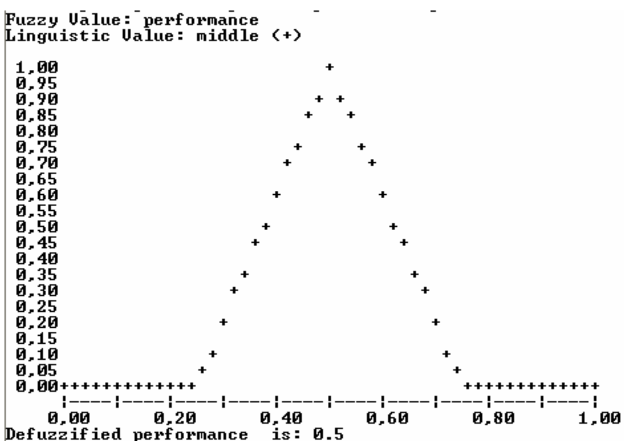

Figure 5

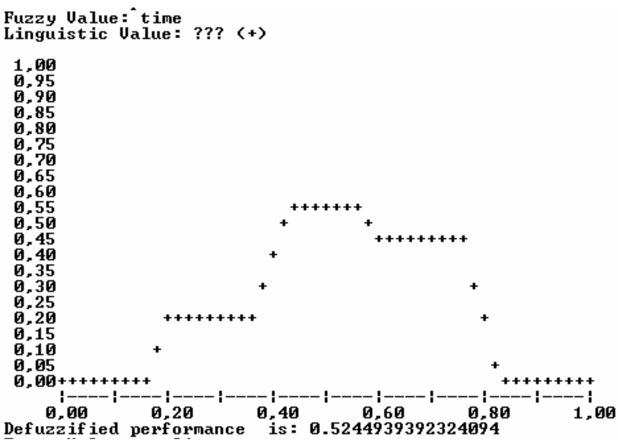

Figure 6

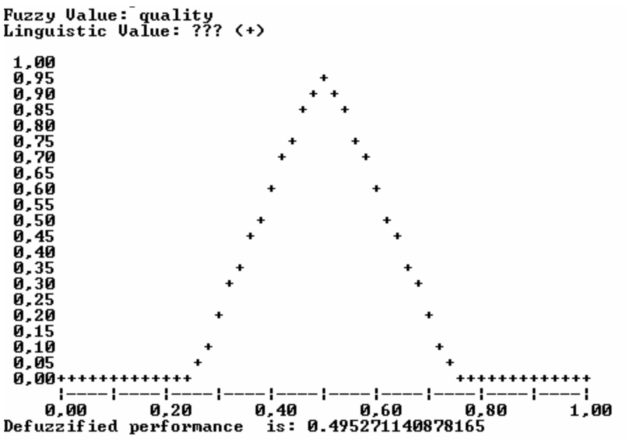

Figure 7

Implementing the Fuzzy Bee-gent Development Infrastructure for Dynamic Routing

The first step in the development procedure is to define the services provided by the distributed applications and the way in which these services are realized. The second step is to design the communication between the applications. The communication procedure is realized by the MA (see Figure 8).

In the proposed fuzzy Bee-gent system, the MA receives fuzzy request from the AW that agentifies the user interface application. The MA migrates then to the database application and requests the local database agent to perform a fuzzy search. The AW of the database application processes this request.

The MA and the agentification of applications using AWs turn every component of the Bee-gent distributed system into an agent. This facilitates the autonomous behavior of each system component and provides flexibility in such a way that if problem solving fails alternative procedures can be activated. The behaviors of the MA and the AW are individually described in the form of state transition diagrams. The agent functions (see Figure 3) can thus be represented in fixed form. The behavior of the mediation agent is described by the GUI tool of the Bee-gent framework (see Figure 8). In addition, the interaction between the MA and the AW is described by state transition diagrams.

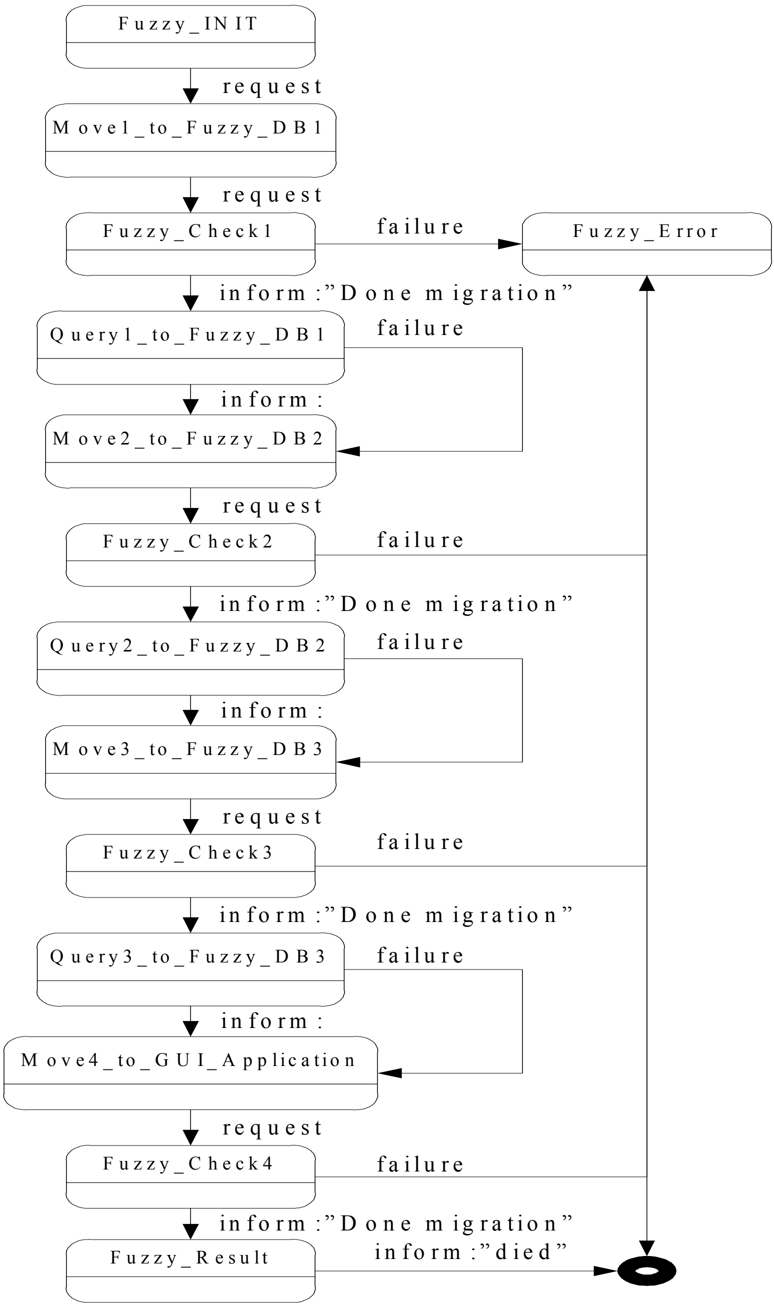

Figure 8: The Behavior of the Mediation Agent.

An Example

The user interface of the fuzzy routing system is shown in Figure 9. The user can define his/her preferences for the five input criteria and can select the destination node. The fuzzy system estimates user's preferences and generates fuzzy value that is a criterion for the best routing path. The resulting best routing path is shown in the control window.

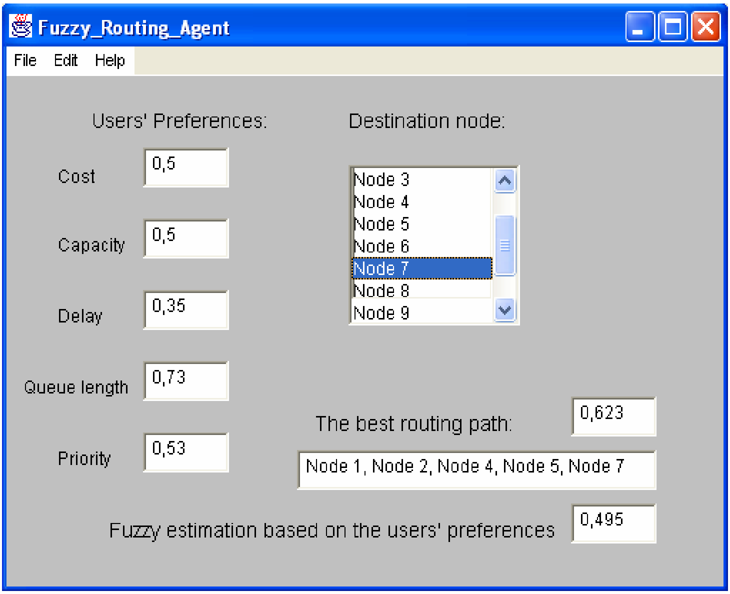

Figure 9: User Interface of the Fuzzy Routing System.

Conclusions

The most important conclusions of this study can be summarized as follows:

- The main idea of the proposed system is to use more than one routing parameter and a fuzzy system to obtain a crisp value for link quality. The fuzzy routing approach estimates five important criteria for network routing.
- Every routing strategy depends on individual user requirements. The fuzzy routing system can be easily adapted to different routing criteria. Tuning the linguistic variables and the rule bases might be promising and a different set of input parameters, which act according to other goals of the routing strategy, could be tested. In this sense the system is open and flexible.

- Compared to the traditional message-based distributed technologies, the Bee-gent technology decreases network load. The main reason for this is that the mediation agent communicates with the applications locally and the communication links can be disconnected after migration.

Notes:

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MODELING AND SIMULATION INTERNET SOURCES

U.S. DoD M&S RESOURCES

GENERAL RESOURCES

The Defense Modeling and Simulation Office (DMSO)

https://www.dmso.mil/public/

The Defense Modeling and Simulation Office (DMSO) was established to serve as the executive secretariat for the Executive Council on Modeling & Simulation (EXCIMS). The DMSO is the catalyst organization for modeling and simulation (M&S) activities within the U.S. Department of Defense. They are a technology transition and support organization charged with maximizing the efficiency and effectiveness of M&S efforts across the Department and fostering interoperability and reuse among the DoD's models and simulations. DMSO projects include:

- HLA- High Level Architecture, a method for writing simulation communications standards
- MSRR- Modeling and Simulation Resources Repository
- MSIAC- Modeling and Simulation Information Analysis Center.

Defense Modeling, Simulation, and Tactical Technology Information Analysis Center (DMSTTIAC)

http://dbweb.csie.ncu.edu.tw/~ljr/idbm/related-www/defense.html

The Defense Modeling, Simulation, and Tactical Technology Information Analysis Center collects, analyzes and disseminates scientific and technical information in modeling, simulation and training; test and evaluation; tactical technology; and special operations.

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DoD High Level Architecture Management Group (AMG)

https://www.dmso.mil/public/dod/amg/

The Architecture Management Group (AMG) is chartered by the DOD Executive Council for Modeling and Simulation (EXCIMS) and is made up of representatives of major DOD simulation programs.

Modeling and Simulation Operational Support Activity (MSOSA)

http://www.spawar.navy.mil/sti/publications/pubs/sd/007/sd007.html

To improve coordination of U.S. DoD's M&S activities and to advance DoD M&S capabilities from within existing resources, the Executive Council on Modeling and Simulation (EXCIMS) established a prototype activity to provide expert operational assistance to the DoD M&S community. The MSOSA also provides assistance for the Modeling and Simulation Resource Repository (MSRR). The MSOSA is a contractor staffed activity operating under the direction of the Defense Modeling and Simulation Office (DMSO) Director of Operations. The M&S community can turn to the MSOSA for immediate assistance and information about the use of M&S assets, exercise and event schedules, models, simulations, and algorithms. MSOSA pulls together the existing DoD M&S infrastructure to focus initial support efforts in the Training community and quickly expand over time into support of selected Acquisition programs and Analysis projects.

Modeling and Simulation Information Analysis Center (MSIAC)

http://www.msiac.dmso.mil/

MSIAC is a Department of Defense Information Analysis Center sponsored by the Defense Technical Information Center and the Defense Modeling and Simulation Office. Its mission is to access, acquire, collect, analyze, synthesize, generate, and disseminate scientific, technical, and operational support information in the area or modeling and simulation. The MSIAC is a single integrated modeling and simulation support activity with the following functions:

- Defense Modeling and Simulation Information Analysis Center (traditional IAC functions)
- Modeling and Simulation Operational Support Activity (operational support functions)
- Modeling and Simulation Resource Repository (re-use of M&S resources)

Functional Description of the Mission Space (FDMRS) Resource Center

https://www.dmso.mil/public/transition/fdms/

This Resource Center has been developed to assist in the design, storage, and reuse of Mission Space (or Conceptual) Models. These models provide a basis for the development of consistent and authoritative simulation representations. The Defense Modeling and Simulation Office (DMSO) is leading a Department of Defense (DoD)-wide effort to provide an integrated framework for developing Functional Description of the Mission Space (FDMS). FDMS provides simulation-independent descriptions of real world processes, entities, and environment. The FDMS, High Level Architecture (HLA) and Data Standards programs constitute the three major components of DoD M&S Common Technical Framework. The FDMS provides the simulation developer with support for Functional Description creation, integration, and maintenance within DoD simulation programs, and interoperability across DoD simulation programs:·

- Integration and interoperability standards
- Common Semantics and Syntax (CSS)
- Data Interchange Formats (DIFs)
- Closed-loop engineering process
- Operational infrastructure.

JOINT RESOURCES

Joint National Integration Center (JNIC)

http://www.jntf.osd.mil/

The Joint National Integration Center (JNIC) provides missile defense related analysis, system level engineering, integration, and test and evaluation support for the development, acquisition and deployment of air and missile defense systems and architectures. It supports the development of joint and combined missile defense doctrine, requirements, and concept of operations (CONOPS). Supports combatant commands by integrating missile defense concepts, space asset exploitation, battle management/command, control, communications, computers, and intelligence (BM/C4I) and by conducting joint and combined simulations, war games and participating in exercises as directed.

Joint Training Analysis and Simulation Center (JTASC)

http://www.jtasc.jfcom.mil/

United States Atlantic Command Joint Training Directorate - Joint Training Analysis & Simulation Center (JTASC). The JTASC represents a state-of-the-art technology center that supports joint training simulations for the Joint Warfighting Center, interoperability testing by the requirements and integration director's Joint C4ISR Battle Center, and joint experiments by the joint experimentation director.

Joint Interoperability Test Command (JITC)

http://jitc.fhu.disa.mil/

The Joint Interoperability Test Command (JITC) is part of the Defense Information Systems Agency. Its missions are joint interoperability testing, evaluation and certification of Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems; testing of DISA's acquisition programs; and support of war fighters on operating and troubleshooting C4ISR systems. JITC will strengthen the test and evaluation (T&E) process by applying modeling and simulation (M&S) technology.

These baseline capabilities are currently available at the JITC:

- Joint Tactical Data Link (JTDL) Network
- Modeling Environments
- Communication System Stimulators
- Sensor Signal Emulators
- Joint Distributed Engineering Plant (JDEP).

Joint National Test Facility (JNTF)

http://www.jntf.osd.mil

The Joint National Test Facility provides missile defense related analysis, system level engineering, integration, and test and evaluation support for the development, acquisition and deployment of missile defense systems and architectures.

ARMY RESOURCES

Army Model & Simulation Office (AMSO)

http://www.amso.army.mil/

The Army Model and Simulation Office (AMSO) provides the vision, strategy, oversight, integration, training and management of Model and Simulation activities across all M&S domains and environments

National Simulation Center (NSC)

http://leav-www.army.mil/nsc/

The National Simulation Center provides simulation support to major military training exercises throughout the world. The NSC, through its TEMO, TPIO-STE and TPO functions, serves as the Combat Developer and Integrator of Live, Virtual, Constructive and STOW M&S requirements to ensure the Warfighter is provided with state-of-the-art training and mission rehearsal models, simulations and simulators that interface with operational C4ISR Battle Command Systems.

Logistics Exercise and Simulation Directorate (LESD)

http://www-leav.army.mil/nsc/lesd/

The mission of the Logistics Exercise and Simulation Directorate of the National Simulation Center (NSC) is to plan, prepare, and provide Combat Service Support (CSS) simulation support for stand alone CSS exercises and CSS simulation support for linked WARFIGHTER, Commander-in-Chief (CINC), and Joint exercises.

Center for Strategic Leadership (CSL), at U.S. Army War College

http://carlisle-www.army.mil/usacsl/index.asp

The mission of the Center for Strategic Leadership is to serve as an educational center and high technology laboratory, focused on the decision-making process at the interagency, strategic, and operational levels – in support of the Army War College, the combatant commanders, and the senior Army leadership. The center's objectives are to expand and refine the study of strategic use of land power and its application in joint and combined operations, and to help senior leaders solve strategic problems with information-age technology.

The Army War College's Center for Strategic Leadership (CSL) has its genesis in the CSA's decision to increase use of simulation and war-gaming at the strategic level.

CSL competencies include: Joint operations, educational gaming, Army's Title 10 roles, political-military interfaces, mobilization and deployment, theater logistics, joint and multinational war-fighting, worldwide threats and operations other than war (OOTW) such as, humanitarian assistance and support to civil authorities, peacemaking and peacekeeping.

U.S. Army Simulation, Training, and Instrumentation Command (STRICOM)

http://www.stricom.army.mil/

STRICOM is the Army's leading provider of training devices, simulations, simulators and instrumentation for both training and testing. Uses large scale simulation exercises with the Distributed Interactive Simulation tools.

The Ballistic Missile Defense System (BMDS) Integration Data Center

http://bmdssc.jntf.osd.mil/

The Ballistic Missile Defense System (BMDS) Integration Data Center is a Center of Excellence in web-based modeling and simulation expertise, services, and information. The BMDS Data Integration Center places BMD information (M&S, Exercises, Flight and Ground Test, Wargames) on the BMD analyst's desktop.

Foundation Initiative 2010 (FI 2010)

http://www.stricom.army.mil/PRODUCTS/FI2010/

The Foundation Initiative 2010 (FI 2010) project is an interoperability initiative of the Director, Test, Systems Engineering and Evaluation, Office of the Under Secretary of Defense (Acquisition and Technology), funded through the Central Test and Evaluation Investment Program (CTEIP). The Army is the lead service for execution, with Navy and Air Force support. The FI 2010 effort is postured to improve systems development, testing, training and fielding through the application of object-oriented systems interoperability between simulations, hardware-in-the-loop (HITL) test laboratories, live/operational tests, and training systems.

NAVY AND MARINE CORPS RESOURCES

Navy Modeling & Simulation Management Office (NAVMSMO)

http://navmsmo.hq.navy.mil/

This is the web site of the Navy Modeling and Simulation Management Office (NAVMSMO). It serves as the web-enabled single point of public access to the

Navy's Modeling & Simulation Information Service (NMSIS). The NMSIS is a central repository for collecting, maintaining, and distributing information about Navy Modeling and Simulation to Navy program managers, engineers, model builders, and others in the M&S community.

Modeling, Virtual Environments and Simulation (MOVES) Institute, Naval Postgraduate School

http://www.movesinstitute.org/

The mission of the Modeling, Virtual Environments and Simulation Institute is research, application and education in modeling, virtual environments and simulation. The MOVES' research directions include 3D visual simulation, networked virtual environments, computer-generated autonomy, human-performance engineering, technologies for immersion, defense and entertainment collaboration, and combat modeling and analysis.

AIR FORCE RESOURCES

Air Force Agency for Modeling and Simulation (AFAMS)

http://www.afams.af.mil/

http://www.afams.af.mil/links/individual_cat.cfm?cat_id=2

The Air Force Agency for Modeling and Simulation (AFAMS) was created in June 1996 to coordinate growing requirement of the Air Force for modeling and simulation. The agency's mission is to support implementation and use of the Joint Synthetic Battlespace by: implementing AF/DOD M&S policy and standards; managing, coordinating, and integrating major AF M&S programs and initiatives; supporting corporate Air Force M&S operations; and promoting and supporting technology improvements.

Air Force Modeling and Simulation Master Plan

http://www.afams.af.mil/webdocs/afmsmp/

Air Force Modeling and Simulation Master Plan, 1 December 1995, Prepared by Directorate of Modeling, Simulation, & Analysis (HQ USAF/XOM)

M&S RELATED ORGANIZATIONS

U.S. National Center for Simulation (NCS)

http://simulationinformation.com/index2.html

The National Center for Simulation (NCS) is composed of governmental agencies, defense contractors and educational institutions. NCS members design and develop commercial interactive instructional tools utilizing computer technology, virtual reality, simulation, artificial intelligence and multimedia technologies. NCS is headquartered in Orlando, Florida which is home to 140 simulation and training companies, the Institute for Simulation and Training at the University of Central Florida, two major military simulation and training commands, and the Air Force Agency for Modeling & Simulation.

U.S. Conflict Simulation Laboratory (CSL)

http://www.llnl.gov/nai/technologies/techmod3.html

CSL is at Lawrence Livermore National Laboratory. The researchers at the Conflict Simulation Laboratory exploit advances in computers and computing science to develop large-scale, high-resolution simulations for realistically modeling combat scenarios. Their conflict simulation models are used by the U.S. military commands and services and by various U.S. security forces for training, tactical analysis, and mission planning. The models are also useful for planning law enforcement operations, fire fighting and disaster relief coordination, drug interdiction actions, and similar activities. Over the past 20 years, the CSL has developed increasingly capable multisided, interactive, entity-level conflict simulation models. The Conflict Simulation Laboratory developed and supports Joint Conflict Simulation (JCS), Joint Tactical Simulation (JTS), and Joint Conflict and Tactical Simulation (JCATS). The Joint WarFighting Center and the US Marine Corps used one of the CSL Simulations, Joint Conflict Model (JCM), successfully in Operation Just Cause in Panama and Operation Desert Storm in the Persian Gulf. The Urban Combat Computer Assisted Training System (UCCATS), a predecessor to the Joint Tactical Simulation (JTS), was used for operational planning in Somalia and Bosnia as well as to simulate other international incidents.

Simulation Interoperability Standards Organization (SISO)

http://www.sisostds.org/

http://siso.sc.ist.ucf.edu/

The Simulation Interoperability Standards Organization (SISO) focuses on facilitating simulation interoperability and component reuse across the U.S. DoD, other government, and non-government applications. SISO provides forums, educates the M&S community on implementation, and supports standards development.

Team Orlando

http://www.stricom.army.mil/TEAM_ORLANDO/

Team Orlando and the Center for Excellence for Simulation and Training, a triad of government, industry, and academia, was chartered in 1985. Team Orlando Objectives are: to prepare Army, Navy, Marine Corps and Air Force warriors to meet the challenges of the future battlespace; to emphasize effective employment of new simulation technologies, dual use technologies, and leveraging between services, other Government agencies, academia and industry to minimize costs to the taxpayer; and to support continued growth of the global synthetic environment to include our Reserve Component forces and multinational partners.

Military Operations Research Society (MORS)

http://www.mors.org/

The web site for the Military Operations Research Society (MORS)

MITRE

http://www.mitre.org/

MITRE is a not-for-profit corporation working in the public interest. It addresses issues of critical national importance, combining systems engineering and information technology to develop innovative solutions that make a difference.

Institute for Defense Analyses (IDA)

http://www.ida.org/

IDA's mission is to bring the best scientific and analytic minds to bear on the most important issues of national security while maintaining rigorous objectivity and professional excellence.

Arizona Center of Integrative Modeling and Simulation (ACIMS)

http://www.acims.arizona.edu/

Arizona Center of Integrative Modeling and Simulation actively collaborates with the M&S community in expanding and contributing to research, education, and outreach supporting leaders of M&S in government, industry, and universities. ACIMS fosters research into M&S methodologies and environments that contribute to a broad range of technologies being sought under such comprehensive initiatives such as Simulation Based Acquisition.

Society for Computer Simulation International (SCS)

http://www.scs.org/

The international, multidisciplinary forum dedicated to applications, development, education and research in modeling and simulation.

EUROSIM Federation of European Simulation Societies

http://eurosim.tuwien.ac.at/eurosim/

EUROSIM, the Federation of European Simulation Societies, was set up in 1989. The purpose of EUROSIM is to provide a European forum for regional and national simulation societies to promote the advancement of modeling and simulation in industry, research and development.

NASA AMES Research Center Simulation Laboratories

http://www.msiac.dmso.mil/journal/nasa_44_1.html

The National Aeronautics and Space Administration's Simulation Laboratories at Ames Research Center is a leading research and development facility offering capabilities for conducting exciting and challenging research experiments involving aeronautics and aerospace disciplines. The entire collection of simulation components, support equipment, associated facilities and buildings are known as SimLabs.

Institute for Simulation & Training (IST), University of Central Florida (UCF)

http://www.ist.ucf.edu/

IST is an internationally recognized research institute associated with University of Central Florida. IST focuses on advancing modeling and simulation technology and increasing the understanding of simulation's role in training and education.

The World Game Institute

http://www.worldgame.org/

The World Game Institute is a 25-year-old not-for-profit education and research organization whose mission is to supply the perspective and information needed to solve the critical problems facing global society.

ACM Special Interest Group on Simulation (SIGSIM)

http://www.acm.org/sigsim/main/frame.html

SIGSIM is the ACM Special Interest Group on Simulation. Its mission is to promote and disseminate the advancement of the state-of-the-art in simulation and modeling. SIGSIM is committed to provide new exceptional electronic services.

Association for Business Simulation and Experiential Learning (ABSEL)

http://www.towson.edu/~absel/

ABSEL is a professional association whose purpose is to develop and promote the use of experiential techniques and simulations in the field of business education and development. The association was organized in Oklahoma City in 1974. Currently the organization is on the leading edge of developing and assessing business simulations and experiential exercises. ABSEL's annual conferences are a meeting place for professionals to exchange information and network with colleagues working in related areas. ABSEL also has an interdisciplinary and global membership and associations with ISAGA, JASAG, and NASAGA.

International Simulation and Gaming Association (ISAGA)

http://www.isaga.info

ISAGA is an international virtual organization for scientists and practitioners developing and using gaming, simulations and related methodologies (policy exercises, role-play, experiential exercises, play, case studies, structured experiences, game theory, operational gaming, active learning, virtual reality, and debriefing). The aim of the association is to enhance and stimulate the development, application and use of these methods in the social, human and technological domains throughout the world.

North American Simulation and Gaming Association (NASAGA)

http://www.nasaga.org/

The North American Simulation and Gaming Association is a growing network of professionals working on the design, implementation, and evaluation of games and simulations to improve learning results in all types of organizations. Started in North America, NASAGA has members from more than 50 countries from around the globe. Membership is open to all.

Modelling and Simulation Society of Australia and New Zealand (MSSANZ) Inc.

http://mssanz.org.au/index.html

The Modelling and Simulation Society of Australia and New Zealand Inc. (MSSANZ), formerly the Modelling and Simulation Society of Australia (MSSA), and the Simulation Society of Australia Inc. (SSA), is an affiliate of the International Association for Mathematics and Computers in Simulation (IMACS), and the Society for Computer Simulation (SCS). The aims of the Society are to promote, develop and assist in the study of all areas of modeling and simulation. The Society has more than 500 members from 50 countries, including Australia, Canada, China, France, Germany, Japan, New Zealand, the Netherlands, South Africa, Spain, Switzerland, the United Kingdom and the United States. Members are from a wide range of professional disciplines including hydrology, agricultural science, economics, engineering, atmospheric science, ecology and many others.

M&S RELATED COMPANIES

Distributed Simulation Technology Inc. (DiSTI)

http://www.simulation.com/

DiSTI is an engineering and software development company in Orlando that can provide a wide range of services to support development of distributed simulation and real time visual applications. It is also a training company that specializes in distributed simulation training.

Advanced Simulation Technology Inc. (ASTi)

http://www.asti-usa.com/

ASTi specializes in all aspects of communication and aural cueing for military simulation production programs. Stand-alone simulators, complex networked training suites, command and control facilities, long-haul communications network installations, and live-to-simulation integrations all benefit from ASTi’s extensive experience in the military training and simulation industry.

ASTi's experience also reaches the commercial training and simulation market with applications including: FAA level "D" certified full flight simulators, air traffic control facilities, emergency response training, civilian ground vehicle simulation, and even nuclear power training simulators.

Teledyne Brown Engineering

http://www.tbe.com/technologies/model_sim.asp

Teledyne Brown Engineering has provided modeling and simulation and applications for a wide spectrum of defense programs including strategic missile defense, extended air defense, theater and tactical weapons, anti-satellite, and ground combat. The company has developed a large and versatile set of analytical tools and applications. The scope of these applications includes top-level operations research and system-level analysis tools; minutely detailed, high-fidelity analysis codes; and integrated analysis utilizing distributed simulation protocols and hardware-in-the-loop exercise and training testbeds. The Extended Air Defense Simulation, developed and maintained by Teledyne Brown, is used worldwide by friendly nations for assessing effectiveness of defense systems against extended threats.

Bissada Management Simulations (BMS)

http://www.bissada.com/

Bissada Management Simulations (BMS) is a company specialized in the design and delivery of business simulations for management education.

M&S RELATED JOURNALS

DEFENSE RELATED M&S JOURNALS

The MSIAC's M&S Journal Online

http://www.msiac.dmso.mil/journal/

The M&S Journal Online is released quarterly to the M&S community. It is sponsored by DTIC and DMSO as part of the Modeling and Simulation Information Analysis Center (MSIAC).

JDMS: The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology

http://www.scs.org/pubs/jdms/jdms.html

The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology is a quarterly refereed archival journal devoted to advancing the practice, science, and art of modeling and simulation as it relates to the military and defense. It has been established by the U.S. Army Model and Simulation Office and the Society for Modeling and Simulation International (SCS). The journal covers all areas of the military/ defense mission, maintaining a focus on the practical side of systems simulation.

GENERAL M&S JOURNALS

SIMULATION: Transactions of the Society for Modeling and Simulation International

http://www.scs.org/pubs/simulation/simulation.html

The monthly refereed journal SIMULATION: Transactions of The Society for Modeling and Simulation International is devoted to providing information on the developments in the field of computer-based modeling and simulation. The journal presents both theoretical and application oriented papers, with clear relevance to general modeling and simulation issues.

Modeling & Simulation

http://www.modelingandsimulation.org/

The general interest publication of the Society for Modeling and Simulation International.

Simulation & Gaming: An Interdisciplinary Journal of Theory, Practice and Research

http://www.unice.fr/sg/

Simulation & Gaming: An Interdisciplinary Journal of Theory, Practice and Research is the official journal of ABSEL, NASAGA, JASAG, and ISAGA. Simulation & Gaming, edited by David Crookall, serves as a leading international forum for the study and discussion of simulation/gaming methodologies used in education, training, consultation, and research. This quarterly journal publishes theoretical and empirical papers related to man, man-machine, and machine simulations of social processes. Featured are theoretical papers about simulations in research and teaching, empirical studies, and technical papers on new gaming techniques. Published by Sage Publications, Inc., Thousand Oaks, CA.

M&S RELATED CONFERENCES, WORKSHOPS AND COURSES

SISO Conferences and Workshops

http://www.sisostds.org/confandwork.cfm

This is the official web page with information about various SISO organized events.

Simulation Interoperability Workshop

http://www.sisostds.org/siw/

The Simulation Interoperability Workshop is a semiannual event encompassing a broad range of modeling and simulation issues, applications and communities. The Workshop consists of a series of forums and special sessions addressing interoperability issues and proposed solutions; tutorials on state-of-the-art methodologies, tools and techniques; and exhibits displaying the latest technological advances.

European Simulation Interoperability Workshop

http://www.sisostds.org/siw/eurosiw.htm

The European Simulation Interoperability Workshop is an annual event, consisting of tutorials on the state-of-the-art methodologies, tools and techniques; topical survey sessions as well as a series of forums addressing interoperability issues and proposed solutions.

Conference on Behavior Representation in Modeling and Simulation

http://www.sisostds.org/cgf-br/

The Conference on Behavior Representation in Modeling and Simulation is an annual event that provides a forum for the exchange of information on the application of leading-edge cognitive science to the behavior representation challenges faced by the modeling and simulation community.

Workshop on Ultra Large Networks: New Research Directions in Modeling and Simulation-based Security

http://www.acims.arizona.edu/EVENTS/ULN03/ULN03MainPage.htm

The workshop brings together users of cyberspace networks and researchers in networking, modeling, and simulation. Their task is to identify key user requirements for network security and to translate these requirements into definitive simulation-based design approaches for future robust and secure ultra-large networks.

ACIMS Modeling & Simulation Conferences

http://www.acims.arizona.edu/EVENTS/events.shtml

This is the list of the M&S events of the Arizona Center for Integrative Modeling and Simulation

U.S. DoD M&S Education Project

http://www.education.dmso.mil/

The site of the U.S. DoD M&S Education Initiative includes information on DMSO's Modeling & Simulation Staff Officer's Course.

Modelling and Simulation in Defence

Klaus Niemeyer

Keywords: Modelling, Simulation, Evolution of modelling, Defence planning, Acquisition, Training and Exercises, Operational planning, Decision-making.

Abstract: Modelling and simulation are essential tools in defence planning, development and acquisition of systems, training and exercises, and operational planning throughout NATO and nations. In the article a contribution to a theoretical approach to the technology is provided, with discussion of definitions and characteristics, such as purpose of a model, reduction of complexity, and representation of real entities or systems. On the other hand, the defence applications are different in many aspects, e.g. objectives, time horizon, scenarios, data requirements, or reaction requirements, which leads to different utility of the model categories. Specific issues in modelling of the defence system are discussed, such as the military hierarchical structure, functional areas, operational phases, planning situations, and the decision cycle.

Combat & Security Related Modeling and Simulation in Croatia

Krešimir Ćosić, Miroslav Slamić, and Dražen Penzar

Keywords: training simulators, hardware-in-the-loop simulators, high-resolution tactical simulations, aggregated combat simulations, simulation of national power and national security.

Abstract: This paper describes the research and development work performed in the last ten years at the University of Zagreb and some other institutions in Croatia on design and development of state-of-the-art combat and security-related educational and training simulators. This overview paper begins with a conceptual description of individual and crew training simulators for antitank guided missiles, low altitude air defense missiles and MIG-21BIS fighter aircraft. Design and development concept of hardware-in-the-loop simulators for real time testing of newly developed digital signal processing guidance and control system is also presented. Then the authors describe the design and development of high-resolution tactical simulations and operational aggregated combat simulations. Finally, the paper presents a theoretical approach to modeling and simulation of national power and national security.

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Benefits and Consequences of Automated Learning in Computer Generated Forces Systems

Mikel D. Petty

Keywords: Computer generated forces, automated learning

Abstract: Computer generated forces (CGF) are automated or semi-automated entities in a battlefield simulation that are generated and controlled by a computer system (the CGF system), perhaps assisted by a human operator. The idea that CGF systems can and should include automated learning capabilities has been widely asserted and accepted. However, it seems to be not so obvious that learning by CGF systems would necessarily be beneficial. For each of the three broad classes of CGF applications there are categories of learning-modified behavior for CGF systems that apparently could reduce or negate the utility of the CGF system for the application. Real and notional examples are available. The specific applications where learning by CGF systems might be useful are a subset of CGF applications.

An Experimental Application of a Trait-Based Personality Model to the Simulation of Military Decision-Making

Frederic (Rick) D. McKenzie, Mikel D. Petty and Jean Catanzaro

Keywords: Computer generated forces, personality modeling.

Abstract: Personality is a significant influence on human behavior. In the context of military decision-making, different military commanders may behave differently when faced with the similar circumstances, depending on their personalities. Moreover, personality may cause the same commander to react differently to similar situations encountered at different times. The effect of personality on decision-making behavior is intrinsically complex and is further mediated by such factors as stress and situational context. This research investigates the inclusion of personality in models of military command decision-making. A simulation was implemented wherein a simulated commander must make critical decisions under multiple pressures. The commander's human behavior model allows the specification of personality using a set of personality traits. In general, personality traits determine a person's predisposition to exhibit a particular behavior under varying situational conditions. In this research, the commander's personality traits and the situational conditions were combined to produce effects such as reaction time delay and decision accuracy and effectiveness modifications. The research showed that incorporating trait-based personality models of human behavior into simulations is feasible and can produce realistic effects on the decision-making of a simulated commander. It also revealed opportunities for further development of the approach.

Experimental Validation of Metamodels for Intelligent Agents in Conflict

James Moffat and Susan Witty

Keywords: intelligent agents, agent-based simulation, dynamics of conflict, cellular automata model of conflict, fractal clustering.

Abstract: In previous papers, the authors have described a theoretical approach to the development of mathematical meta-models, which aim to capture the emergent behaviour of intelligent agent-based constructive simulation models of military conflict. These intelligent agents capture the process of C4ISR (Command, Control, Communications, Computers, Intelligence Surveillance and Reconnaissance) in such agent-based simulation models. In this paper, the authors present both historical evidence and evidence from experiments using cellular automata models that support hypotheses derived from their theory.

Soft Computing Agents for Dynamic Routing

Georgi Kirov

Keywords: soft computing agents, fuzzy logic, distributed information systems, fuzzy routing.

Abstract: This paper reviews and evaluates the state-of-the-art in Distributed Information Systems. It outlines some disadvantages of distributed software applications (world-wide information services, databases, and software packages that are connected through the Internet and other network systems). It is concluded that the field of distributed network systems is in a critical need of intuitive and innovative approaches to address the growing complexity in all of its different aspects: communication, routing, performance, stability, connectivity. In an attempt to resolve the above-mentioned problems an approach is proposed that combines the Bee-gent agent technology and the fuzzy-logic representation. The paper presents an example of soft-computing agents for dynamic routing that uses distributed database applications as illustration of the concept.