CRC Handbook of Dynamic System Modeling

Military Modeling

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Introduction

The military has always been a very heavy user and innovative developer of modeling techniques and technologies. The nature of military missions requires that they rehearse missions in order to better understand their complex interactions and to estimate outcomes. This need has led them to apply modeling and simulation to a number of different activities over the last 300 years. In this chapter we will explore the major applications of military modeling and will discuss the most common forms of dynamic modeling.

Applications

The United States military has made its own unique definitions of the terms “modeling” and “simulation.” For their purposes, modeling is often defined as, “a descriptive, functional, or physical representation of a system” (NSC, 2000). These representations may take the form of a mathematic equation, a logical algorithm, a three-dimensional digital image, or a partial physical mock-up of the system. Models are applied so widely that the variety of systems of interest is almost without bounds. In these systems military weapons systems are usually very prominently represented, to include land, air, and sea vehicles; communications and radar equipment; hand-held weapons; and individual soldiers. But models also represent the decision-making process and automated information processing that occurs inside the human brain and within battlefield computers. They extend to representations of the environment that is made up of terrain, vegetation, cultural features, the atmosphere, ocean, and RF environment. Different combinations of all of these are needed in order to accurately represent potential military situations.

One military definition of simulation is, “a system or model that represents activities and interactions over time. A simulation may be fully automated, or it may be interactive or interruptible” (NSC, 2000). This definition attempts to encompass human-in-the-loop simulators for training, as well as systems that serve as analytical tools for computing outcomes without the aid of a human participant.

The official categorization of the use of models and simulation within the military is to divide them into three large application groups.

The first is for use in “research, development, and acquisition”. In these applications, models are used to provide insight into the cost and performance of military equipment, processes, or missions that are planned for the future. These use scientific inquiry to discover or revise facts and theories of phenomena, followed by transformation of these discoveries into physical representations.

The second category is in exploring “advanced concepts and requirements”. These models present military systems and situations in a form that allows the military to conduct concept exploration and trade studies into alternatives. These trade studies often explore multiple variations on a new weapon or tactic and attempt to measure the effectiveness of each of them. The result is a general appreciation for the different options available and some rough measure for ranking them. The models may be used to understand physical weapons or equipment, but they may also explore different processes for organizing and executing a mission. These require an understanding of processes and the interactions that occur between the different steps in the processes. The models assist the military in creating a doctrine of operations, constructing an internal organization, and selecting materials for acquisition.

The third category is in “training, education, and military operations”. Models that are embedded in a simulation system are used to stimulate individuals and groups of personnel with specific military scenarios. The goal is to determine the degree to which they have learned to execute the doctrines they have been taught. It also gives them the opportunity to experiment with new ideas and to determine how useful these might be in a real warfare situation. All of this can be done in a controlled environment that is free of the life threatening situations that are part of real combat operations.

Finally, it should be noted that military modeling and simulation has always been the basis for a large segment of entertainment products. Many of the modeling concepts behind paper board-wargaming in the 1950’s were developed simultaneously by the RAND Corporation for serious military training and by Charles Roberts at the Avalon Hill game company for popular entertainment (Perla, 1990). This trend has continued for over fifty years and can be seen today in comparing realistic three-dimensional military training systems and the product of the very popular computer gaming industry. Systems like America’s Army provide an environment for experimentation and training in the military, a device to enhance Army recruitment and education about the military lifestyle, and a game for use by anyone looking for a little excitement in their free time (America’s Army, 2006).

Representation

Models, by their very nature are an abstraction or simplification of the real world. Therefore, is it possible to create an almost infinite number of variations on the representation of objects, actions, and events in a simulation. Over the past several decades, a number of different types of models have been developed for representing a military system or mission. These have gradually converged into commonly recognized categories of representation. These categories have significantly improved the ability of military modelers to communicate with each other and to exchange models with a better understanding the differences between the products being created.

Engineering

Engineering models focus on the details of what a system does. These capture the physical properties of materials, liquids, aerodynamics, servomechanisms, and computer control of specific systems. They also include interactions between two physical objects or between an object and its environment. An engineering model attempts to understand the physical capabilities of the system at a level that is accurate enough to be used to design the system. Historically, physical prototypes were used to conduct these experiments. However, advanced computer technologies and modeling techniques have allowed us to create digital models of systems that are nearly as predictive as are live physical tests. These models offer many advantages over their physical counterparts. They are almost infinitely malleable so that experiments can be conducted on many thousands of variations rather than just a few physical prototypes. They are nearly infinitely instrumentable. It is possible to collect data from all points in space and time around the event of interest. When using physical prototypes we are often limited by our ability to place sensor, communication, and recording equipment at the precise place and time of interest. Engineering models become a more prominent part of creating or studying military systems because of the accessibility of the required computers and more mature methods for representation real systems.

Virtual

A "virtual model" often refers to a three-dimensional representation of a system that is operating in a digital three-dimensional environment. The focus is usually on the visual appearance of the object and the environment, more than on the properties of physics that are the focus of engineering models. Because of its visual focus, the objects most often represented are military vehicles and humans that would appear on a battlefield. This category is closely aligned with the more popularly recognized term, "virtual reality".

A virtual model and environment are usually constructed to simulate individual soldiers who are immersed in a system that generates visual, aural, and tactile stimuli. The goal is usually to train, test, or measure the ability of the human to respond in a desirable manner to the stimuli. Flight simulators are the most popularly recognized form of these models and systems.

Constructive

A "constructive model" represents objects that are separate from the human user or player, but which are under the control of this person. The user sends commands to these objects, but is not immersed in the middle of the battle as he or she would be in a virtual environment. Historically, constructive models have often been aggregated as well. Rather than representing individual vehicles or people, the model represents groups of these in an attempt to reduce the number of details about each and to make it possible for the computer and the human to control many more of them. More recently, constructive simulations that represent individual objects have become very popular and very powerful. These are often referred to as Semi-Automated Forces (SAF) systems because of the way that control of the objects is shared between a human user of the system and intelligent models of the human behavior embedded in the software. A human may provide the overall mission and direction, but the SAF will supplement this with detailed control of activities like movement and engagement.

A constructive model may represent a flight of four aircraft as a single item in the simulation or it may represent each aircraft individually. What separates the constructive from the virtual is usually the method of human interaction, the lack of a three-dimensional representation of the object, and the number of objects that are controlled by a single user. A constructive may also group several hundred vehicles, humans, and equipment into a single object model. This model must then represent the aggregated behaviors of its many different constituent parts. There are a number of motivations for this type of modeling. First, it allows the simulation system developers to capture the operations of a much broader battlefield in a form that can be run on a reasonable computer suite. Second, in many cases the behavior of groups of objects are not understood at the engineering or virtual level, but can be represented as a higher-level aggregate. Third, this type of model mimics the organization, representation, and information that are used in the real military organizational hierarchy.

Very basic constructive models of military operations can be seen in many board and computer games, such as Chess, Stratego, and Risk. Constructive simulation systems differ from virtual systems in that the human operator or player is often positioned outside of the battle. Engagements are not usually targeted at the human player, so they are in a position to think more strategically about the situation and are not required to react to individual events that appear to threaten them personally, as would occur in a virtual system.

Live

Though a “live model” appears to be an inappropriate description, the term has been adopted to refer to activities in which live humans, vehicles, and equipment engage in mock combat. The combat events do not involve real munitions and attempt to avoid situations that could have lethal outcomes. Using computer, communication, navigation, and laser technologies, training areas have been constructed in which combatants can use their real weapons in a form that is as physically realistic as possible. Laser beams and radio often replace bullets and radio messages indicate where bombs are dropped.

Live modeling allows humans to train in the real environment, to experience the physical hardships of traversing rough terrain, operating in the desert sun, and experiencing the effects of dirt and water on the equipment. The humans and vehicles become living models in a living simulation. In many cases, these live participants are also supplemented with virtual and constructive models to enrich the entire training experience. The largest, and in many ways, the definitive live exercise, was the Louisiana Maneuvers that were conducted in 1941 and used to prepare United States forces for entry into World War II. These maneuvers involved over half a million soldiers operating over an area of 3,400 square miles of terrain in Louisiana (Sanson, 2006).

Environment

The model of the environment has typically been a static representation of terrain, vegetation, roads, rivers, wind, clouds, rain, ocean waves, salinity, ocean bottom, and any number of other features. This environment has provides a medium within which the above models could operate. The environment impedes the movement of objects, obstructs sensor visibility, and changes the outcomes all types of operations (Mamaghani, 1998). However, in the midst of all of this activity, the environment itself usually remained static and unchanged. A bomb dropped on a truck may destroy the truck, but make no change to the underlying terrain or the surrounding vegetation.

Recently, this has been changing. Military simulation systems have included dynamic models of the interaction between military systems and environmental features. Simulated objects are able to knock down trees, crater roads, dig holes, build barriers, and destroy buildings. To support this, a new form of environmental model has evolved which understands the physical effects of vehicles and weapons on dirt, trees, and masonry block structures. Representing these changes has required better understanding of the physical properties of environmental features, especially as they relate to military operations. It is also driving advances in the representation of environmental features as both data structures and three-dimensional rendered scenes. As with all models, those of the environment contain almost an uncountable number of variations on how objects and events are represented. It is not possible to identify or enumerate all of these, but an interested reader is encouraged to explore this area more at the SEDRIS web site given as the end of the chapter.

Dynamics

To this point we have focused on defining and categorizing military modeling according to its application. Those categorizations were meant to illustrate the unique situations, problems, and interests of the developers and customers for military models and simulation systems. In this section we will describe the most dominant forms of dynamic modeling that are used in the community. Because military systems and problems are so diverse and such a large investment has been made in exploring them, there are many more unique forms of dynamic modeling than can be captured in a single chapter or an entire book. However, the forms that are described here are some of the most dominant in military systems.

Dynamic modeling of military systems and missions often focuses on activities like:

- Movement,
- Perception,
- Exchange,
- Engagement,
- Reasoning, and
- Dynamic Environment.

In this section we describe the dynamics that are included in each of these categories. This is followed by a section that explores multiple approaches to modeling these dynamics.

Movement

Dynamic representation of movement captures the change in an object’s position over time. Models may represent position as a coordinate in two-space, three-space, or as a velocity vector. Two-space coordinates usually include a position in X and Y, such as latitude and longitude. For models that represent only ground-based vehicles like trucks, tanks, and foot soldiers, this can be sufficient. The object may have no variation in elevation, or the elevation may come from the underlying elevation of the terrain on which it sits. Position may also include orientation, which in two-space would be limited to a 360 degree angle around the vehicle. A common reference system for this angle is with the zero point being aligned with true north and proceeding clockwise with 90 degrees being east, 180 being south, and 270 being west.

In three-space, the coordinate system includes a representation of elevation. This third dimension may be height above the local terrain, elevation above mean sea level, or distance from the center of a sphere that represents the Earth. The latter measurement evolved during the creation of distributed heterogeneous simulation systems. When networking multiple simulations, differences in the terrain representation within each system led to significant differences in vehicle position with respect to the terrain. Therefore, a non-terrain referenced coordinate system was needed to overcome these differences. When a three-space orientation is added to this model, it includes the pitch, roll, and yaw of the object, creating a six degree-of-freedom (6-DOF) model. When represented as a vector, this may also include the velocity of the vehicle along the axis of orientation.

In their basic form, movement models change the position and orientation coordinates according to a logical or physical representation of movement, as described in the next section. However, most implementations go further to include the effects that movement has on the object and the environment. The movement model may be linked to a model of the fuel consumption of the vehicle. This adds a limiting factor that can stop movement when the fuel is depleted. The inclusion of a fuel model leads to the need for the simulation system to represent a process for replenishing fuel as well. Otherwise, the objects in the simulation will eventually grind to a halt as fuel is depleted and there is no mechanism to refuel. In military modeling, the addition of each detail often leads to the need for more models to drive the additional variables that are added. Systems can grow far larger than can be developed, funded, or hosted on a computer if there is not a strict management of the details that are included in the models. Many authors have warned against this gradual creep in features that leads to the eventual failure of the system being developed (Law and Kelton, 1991). This type of growth is not limited to movement modeling, but can occur throughout the system if the designers do not control it.

A movement model may also calculate the number of hours of operation that the object has been used. This information is the root of most system failure and maintenance representations and drives the mean time between failure (MTBF), repair (MTBR), or other similar models.

The interaction of object movement with the terrain can generate environmental changes that trigger yet another model, such as the generation of smoke or dust clouds in the wake of a vehicle. If these changes to the environment are represented, then they call for specific environmental models that can calculate the size and density of the cloud created, as well as its drift and dispersion over time.

Perception

Military objects move about the environment in order to interact with other objects. One of the first steps in this interaction is to perceive or detect the existence, position, and identification of the other object. Sensor models capture the signatures of those objects, as when a visual sensor captures reflected light from an object to the sensor. In most cases, the sensor model does not actually represent the path of a light vector, but instead considers the range and orientation between the target object and the sensor and calculates whether the target is potentially detectable based on the effective range and field-of-view of the sensor. A sensor model may also include information about the environment in which the detection is being attempted. For a visual sensor, atmospheric factors like the presence of smoke, dust, fog, and lighting may be used to diminish the possibility of detection. Also, environmental features like hills, trees, and buildings may be interposed between the target and the sensor and impact the detection of an object. The physical characteristics of the target may also be considered. Its size, contrast with the background, rate of movement, and material composition may significantly impact its detectability. Larger targets may be easier to see than smaller ones. Targets may have a higher or lower degree of camouflage, changing the ability of the sensor to separate them from the background image.

In military simulations, visual sensors are just one of a large variety that are available. Many systems include sensor models that collect signature information in the infrared spectrum, sound, emitted radio and radar signals, magnetic properties, and movement and vibrations. Models of each of these can be constructed at a number of different levels of detail, but each must determine whether to include the properties of the sensor, sensing platform, paired geometry, environment, target, and external interference. As illustrated earlier, as the sensor model becomes more complex, it drives the complexity of the entire system. Including all of the categories just listed would trigger the need for additional detail in the sensor model, but also the need for additional details in all target objects and the environment. Often the limitation in creating a high-fidelity sensor model is not driven by our understanding of the sensor, but, rather, by our ability to represent the characteristics of the target and environment that are needed to implement such a model. In a military simulation system, the detail included in a model may be limited both by the needs of the customer and by the desire to keep the entire system balanced, not allowing one model to drive others to a level of detail that is not necessary or affordable (Pritsker, 1990).

Exchange

After moving and detecting, models are needed to allow objects to exchange materials and information with each other. Battlefield operations often lead to the depletion of materials like fuel, ammunition, food, medical supplies, vehicles, and people. A logistics model may be used to represent the ability of the military to constantly deliver these materials to units and objects in operation. Such models are often based on an understanding of the rates of consumption, the pre-deployment of supplies to locations that are close to the operation, and the constant replenishment of supplies through a network of supply nodes. Replenishing supplies within an object on the battlefield is the culminating model of a much more complex representation of the logistics infrastructure that can stretch across an entire country or even around the world. The logistics model must also include mistakes and interference that cause it to breakdown and deprive the military objects of the supplies that keep them operating. A logistics model may be driven by textbook ratios of consumption or it may be include specific messages from the military objects about the levels and rates of consumption. In the latter case, a communications model is needed to carry information about what materials are being consumed, by whom, and where they are located.

Communication is another model of exchange. The thing being exchanged is information rather than physical items. In the modern military, the amount of information that is carried around in a physical form, such as a book, letter, or paper map, is quite small compared to the amount that is transmitted in digital form. Therefore, modern models focus on communications in the form of digital computers and networks, as well as analog radio networks. A model of radio communications, like that of a sensor, may include the characteristics of the transmitter, transmitting platform, environment, the receiver, the geometry between the sender and receiver, and interference by other objects. Details in the representation of the radio or the signal it generates call for corresponding details in the receivers, environment, and countermeasures.

Military models of digital computer communications are similar to the tools used to study Internet traffic. They can represent the senders, receivers, relay nodes, interference from competing traffic, multiple paths for the information to travel, and the loss of a message or the failure of a network. Modeling how people, objects, and units respond to the receipt of this information is included in the section on reasoning.

Engagement

Strictly speaking, engagement is another form of exchange. However, it is listed separately because it has been the central focus on military simulations for decades. The item being exchanged is a weapon and the effect is the degradation of the operational capabilities of the target. Most military simulations perform movement, perception, and exchange specifically so they can put themselves in a position to engage enemy targets. Engagement has historically been the pivotal centerpiece of a simulation system and one of the most important models in the system. Certainly, not all objects engage the enemy, but those that do not are often referred to as support elements whose mission is to make engagement possible for combat equipped units (Smith, 2000).

An engagement model typically includes the exchange of weapons or firepower from a shooter to a target. This exchange decrements the capability of the shooter by expending ammunition in one of its many forms (e.g. bullets, missiles, bombs, rockets, grenades, artillery rounds). Just as in the perception and communication models described above, this exchange is usually impacted by the geometry between the shooter and the target. Environmental features like trees, terrain, water, and buildings may interfere with the optimal delivery of the weapon and reduce its impact on the target. The target may also contain defensive systems that counter the effects of the engagement. A defensive model may represent the effects of flares or chaff in deceiving and misleading a guided missile or the protective effects of armor to deflect the weapon.

If the weapon successfully impacts the target and is powerful enough to overcome any interference or defenses, then a level of attrition must be calculated for the target. Different approaches to modeling attrition are described in the next section. Attrition is usually directed at the model state variables that control its ability to perform its primary functions. These may include health or strength, fuel levels, communications capabilities, and mobility. Models may also make a binary decision about whether a vehicle, human, or unit it completely destroyed or not. Models of engagement have been of great interest to both the training and analysis communities for decades. A great deal in study and a number of publications dedicated to these exist. Interested readers may consult sources like Ball, 1985; Epstein, 1985; Parry, 1995; and Shubik, 1983. They should also visit the web site of the Military Operations Research Society given later.

The attrition model may be linked to communications and medical models. Communications models propagate the outcome of an engagement so that units or operators are aware that an engagement has occurred. These communications may trigger a medical model that will attempt to conduct extraction and provide medical treatment to simulated humans that are wounded. It may also trigger the logistics model to extract and repair vehicles.

Reasoning

Within large military simulation systems, there are usually many models of human decision-making and behaviors. These have become more prevalent as systems have grown in both the breadth of coverage and the depth of battlefield detail that are represented. Representing human thinking and even some computer reasoning are some of the most challenging parts of the current practice of military modeling. This type of information processing is largely not understood and requires general approximations and simplifications in models.

Reasoning models often rely on the techniques developed within the Artificial Intelligence field. Techniques like finite state machines, expert systems, rule-based systems, case based reasoning, neural networks, fuzzy logic, means-ends analysis, and others are used to organize information and create decisions that are similar to those of living humans. FSMs are currently the most widely used approach to modeling reasoning in both military models and commercial games. These reasoning models are challenged to perform a wide array of operations, to include commanding subordinate units, decomposing and acting on commands from higher level units, reacting to enemy attacks, selecting maneuver routes, identifying threats and opportunities for engagement, fusing sensor data, and extracting meaning from intelligence reports. Each of these functions can be extremely complicated and require significant computing resources to execute. Reasoning models must balance their level of realism between robotic reactions to stimuli and detailed consideration of the situation prior to selecting an action.

The variety of reasoning models that are required on a battlefield cannot be fit to a single modeling technique. In practice, multiple techniques are required, each applied to a reasoning problem for which it is best suited (Russell and Norvig, 1995).

Dynamic Environment

Earlier we described the evolution of the simulated environment from static state structures to dynamic representations of features and their interactions with military objects. Military objects interact with the environment both through direct intention and through accidental collocation. An engineering unit may be tasked to destroy a bridge or a road. This is an operation in which the effects on the environment are the specific intent of the action. In another case, an aircraft may bomb a convoy of trucks moving on a road. In this case, the trucks are the primary targets, but the road may sustain damage because of its collocation with the trucks.

Until recently, military simulations seldom included impacts on the environment. However, with the current focus on precision operations, there is much more interest in destroying specific buildings, roads, bridges, communications equipment, and pieces of the social infrastructure. Since this data is usually found in the environmental database, models that accurately modify environmental information are needed.

For decades, military organizations have worked on models that accurately represent the engagements that take place between two tanks, soldiers, airplanes, or ships. It is becoming necessary for those models to also impact the trees, terrain, and roads in the vicinity of the targeted objects. This means that information on the effects of weapons on trees is necessary, as well as their effects on buildings, roads, bridges, and a host of other types of surrounding terrain.

Though the type and level of damage done to a tree is seldom the focus of the experiment or exercise that is being conducted, similar damage to buildings, power grids, and command facilities may be the focus of an experiment. As a result, the military modeling and simulation community is pursuing new methods for accurately representing these types of engagements and doing so within the constraints of available computer systems.

Modeling Approach

In the previous section we discussed many patterns of relationships that exist between multiple models and described in very general terms what would be represented in those models. However, we did not explore specific mathematic or logical algorithms that could be used in those models. In practice, the number of techniques, algorithms, and equations that are used in military models is close to uncountable. It is not possible to describe all of them or even those that might be considered “the best”. So many different problems are studied with military models that there is no “best” approach that can applied universally when representing a specific vehicle, human, or unit. However, the techniques that are used do exhibit characteristics that allow us to talk about them in terms of general categories. However, it is not unusual for a model or a simulation system to combine techniques from any of these categories to create the effects that they need for training or experimentation. The categories aid us in explanation, but should not be considered a universal ontology of approaches. Figure 1 illustrates this with a missile that can be modeled using any one of the four modeling categories that will be described.

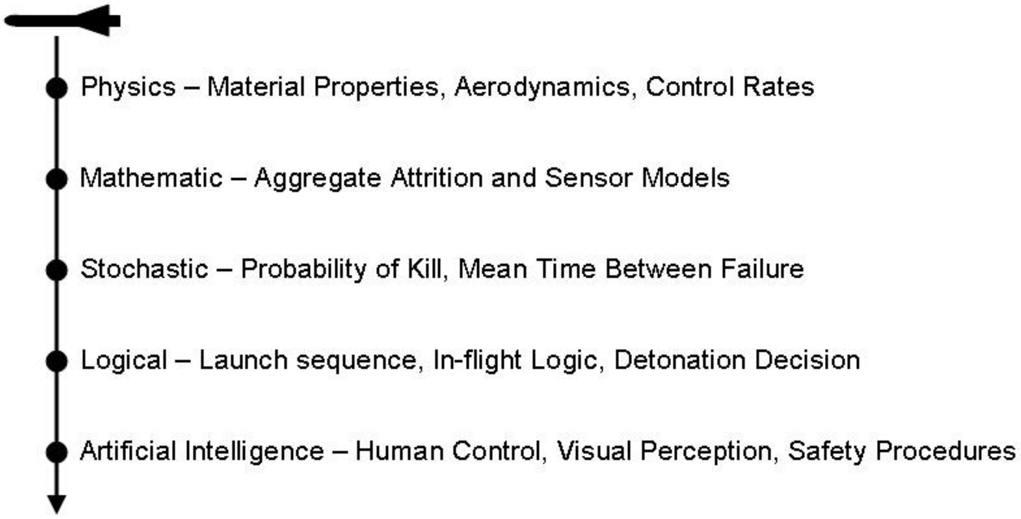

Figure 1. Five different approaches to modeling the behavior of a missile.

Physics

Physics-based models are most often found in engineering and virtual simulation systems. For example, a missile pursuing a target would be represented by the physics of motion, momentum, mass, and aerodynamics. Changes in the fin positions would drive aerodynamic equations and change the vector of the missile based on the forces at work on the mass of the missile. Similarly, the seeker head in the missile would scan the environment electronically using the same pattern, revisit rates, and sampling rates of the real missile. This behavior would allow the simulated missile to collect data about a target in the same way that the real missile does.

Physics-based models are most often used to analyze the behavior of an existing weapon or to assist in the design of a new weapon. Understanding exactly how the pieces of the system will behave is an important part of exploring the design space to find optimum capabilities and combinations of capabilities that are optimum for the entire system.

Physics models require a great deal of data and mathematics. The data must be available for the system being modeled, the environment in which it is operating, and any other objects that it will interact with. Mathematic equations are required to represent a number of different behaviors of the system, interactions that occur within the system and interactions that occur with other objects. Given this need, it is not sufficient to collect data and build equations only for the missile that is to be studied. The model builders must do the same for the environment and for any objects that will interact with the missile.

Because of the volume of data, and the number and complexity of the equations that are required, physics models are necessarily reserved for smaller scenarios that involve only a few objects. Once constructed, the models can be computationally intensive, requiring high-powered computers or accepting extremely long simulation times. The budget of the project limits the former and the schedule limits the latter. Therefore, the models can literally be a compromise of what the project can afford in time, money, and skilled staff. These types of limitations are one of the primary causes of the diversity of military modeling solutions.

Mathematic

Though a physics model is certainly mathematic, there are a number of modeling techniques that are based in mathematics, but which neither represent the physics of the situation, nor employ stochastic methods of representing aggregate behaviors. In military modeling, the classic example of this is the Lanchester Equations. In his 1912 and 1916 publications, F.W. Lanchester attempted to represent the attrition experienced by large military forces in combat using differential equations. These assume that the combat power of each side can be represented accurately with fire power scores and that the weapons of each side can be brought to bear equally on all targets and under all conditions. This creates a model which will “grind down” both sides as they engage in combat over time. Each side loses capabilities at a rate proportional to the size of the enemy that is attacking it, and in some cases, also incorporates the size of the targeted unit. Lanchester equations have been used widely since their introduction and have only been displaced relatively recently as the military has sought to represent combat situations that are not symmetric between the attacker and the defender (Davis, 1995).

Lanchester’s differential equations may be a useful way of representing a large barrage of missiles engaging targets. Instead of modeling the engagement and attrition of every individual missile, these equations would model the overall impact of a large number of such engagements and determine the attrition to the target as a result of all engagements. There have been many variations to and criticisms of Lanchester’s equations. But they remain a foundational part of military simulation techniques.

Stochastic

Stochastic processes, probability and statistics, are most often found in virtual and constructive models. As simulation systems grow larger in their scope of representation, there is a need to capture many more activities and interactions in models. Lacking the detailed knowledge, breadth of expertise, access to data, time to build, and compute power to run a pure physics-based system, modelers have often resorted to a statistical representation of objects and interactions. In this case the models capture the behavior of many iterations of an event and represent individual event results using a probability function and the results of a pseudo random number generator. This type of modeling was introduced to the military modeling community by Stanislaw Ulam when he was working on the design of atomic weapons during World War II. Ulam encountered a number of problems for which the specific physical behaviors were not known, but where the pattern of outcomes had been measured. Therefore, he chose to use the statistical properties of the event and rely on multiple simulation runs to arrive at an accurate behavior for the entire system (Metropolis, 1987).

The previous missile example lends itself well to stochastic models. Instead of representing all of the minute physical interactions, a modeler could choose to represent the outcome of a missile engagement given a limited number of input variables governing each event and recourse to a probability distribution. The use of a pseudo random number in decision-making means that no one engagement contains all of the details of the event as in a purely physics-based model. However, if the model is run a number of times, the randomness of multiple replications will blend together and create an accumulated result that is representative of the system behavior that emerges from all of the interacting models.

Stochastic modeling has proven to be extremely useful because it allows modelers to study problems that were previously beyond our understanding our understanding of the physics of an event and perhaps beyond the computational capability of accessible computers. This has led to the creation of very large simulation systems capable of representing tens of thousands of events and objects on a battlefield. However, these models also require that their creators understand both the physical behavior of the system and the statistical aggregation of those behaviors in order to create accurate stochastic models.

Logical Process

A logical model of the missile's behavior may capture the sequential steps and the branching decisions that are used to control the flight of a missile. This model represent the programmed logic within the missile's computers, allowing scientists to explore all of the possible branches and to mach logical decisions with the environmental stimuli that the missile will encounter.

When an object is controlled by a simulation system rather than a human operator, most of the time it is following a logical set of defined processes. These instructions tell it when to move, which direction to go, how fast to proceed, which objects to focus on, and which to ignore. These may be very complex processes, but they do not necessarily involve equations of physics or random decision points. In situations when an object should follow some form of "textbook" operation, logical models are an excellent method of encoding this.

Finite State Machines (FSMs) are often used to assist in organizing very complex sets of behaviors. FSMs allow the modeler to capture hierarchical behaviors, set triggers for changing from one behavior to another, and encapsulate behaviors that can be reused in multiple FSMs. These structures are so useful that they often form the framework in which models of all types of all types are organized. As mentioned earlier, Semi-Automated Forces (SAF) systems and computer games are dominated by FSMs for decision-making.

Artificial Intelligence

Many military simulations require the representation of complex human decision-making that goes beyond the capabilities of logical models. These attempt to model the behavior of individual soldiers, groups, and commanders. The community has turned to Artificial intelligence as a source of unique and powerful methods for representing human behavior. Adopted techniques include FSMs, expert systems, case-based reasoning, neural networks, means-ends analysis, constraint satisfaction, learning systems, and any other technique that shows promise in accurately capturing the complex reasoning process of humans.

To illustrate this category, the missile guidance and navigation example that we have been using needs to be augmented with a simulated human-in-the-loop as it pursues a target. Though a missile model may use a FSM to represent its movement, it is not attempting to create a model of human intelligence; rather it represents a logical process that is followed robotically by the weapon. If the missile were being controlled remotely by a human who was viewing the target on a computer screen, then the behavior of the human might be represented using an AI technique. A neural network may represent the human's ability to discriminate a target in the scene and means-ends analysis may represent the human's decision process in selecting a target, leading its position, and switching from one target to another opportunistically.

AI techniques usually focus on processing information in a human-like manner. Using databases or rule sets, the algorithms attempt to make deductions that lead to behavior selection. These models may incorporate deterministic or stochastic methods in representing human behavior (Russell and Norvig, 2000). As we pointed out at the beginning of this section, these categories are not necessarily mutually exclusive; they are simply useful for explanation and understanding.

Military Simulation Systems

Modeling is one part of creating a military simulation system. Within any one of these systems there can be a large number of models. Using the major categories of models described above, Figure 2 illustrates the relationships that often exist between these models to create a working simulation system. This figure includes only the major categories. For a specific system, the number of models would be much larger and the relationships between them would be more complex. This figure illustrates many of the causal relationships that were described in the earlier sections.

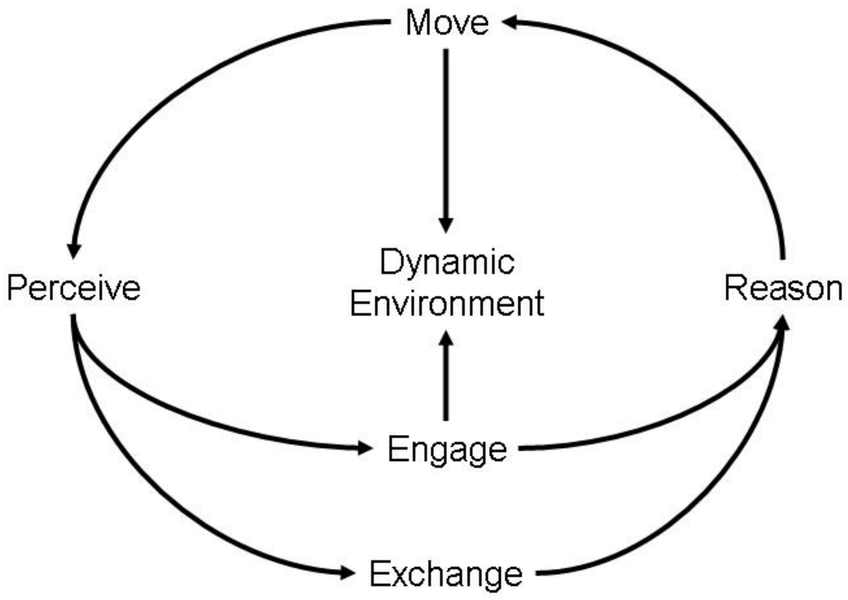

Figure 2. Model relationships for a simple battlefield simulation system.

The movement model is a good place to begin tracing the models in the figure. When this model calculates the new location, orientation, and velocity for an object, it may also trigger the dynamic environment model to represent the creation of smoke, dust clouds, or tracks in the sand. Once completed, the objects are in a position to execute perception models that can detect other objects from their newly achieved position. The perception model provides the necessary information to allow the objects to engage each other or to exchange information or material with each other. Engagement also triggers the dynamic environment models to create effects like road craters and destroyed buildings in the environment. An engagement between two objects may create collateral damage to surrounding trees, buildings, and roads. In some cases, the engagement is actually targeted at an environmental feature like a road or bridge. The exchange model calculates functions like refueling an aircraft or transmitting a message. Following the sequence of move-perceive-engage, the system may allow the objects to reason over what has just happened. This reasoning can take into account the results of each of the engagement, exchange, and perception, integrating them to enable the reasoning model to select the next action to be taken. Once completed, the cycle can begin again with a new objective that is received from a human user or from the reasoning models.

This cyclic diagram is a simplification of a real system. In actual implementation, the reasoning model may be activated at the completion of each of the other models, providing much finer control over the decision-making process. That is characteristic of virtual-level simulations in which the reasoning component is providing very detailed control of a computer-controlled entity. The reasoning model may also be triggered much less frequently than the other models. This occurs in constructive-level simulations where the reasoning is at a much higher level of command and decisions are made infrequently with respect to the rate of activities in the other models.

Conclusion

This chapter has provided a high-level overview of the dynamic modeling necessary to create military simulation systems. The very large number and variety of military systems that have been created, makes it impossible to describe the most common or “best” approach to modeling. Existing military systems focus heavily on movement, perception, and engagement. But, they may also include models of medical operations, communications, intelligence processing, military engineering, logistics networks, and command and control.

The mission of military organizations changes in response to the political situation in the world. The changes that have occurred in world politics are influencing the types of things that are being modeled in military systems. Newer simulation systems are focusing more on communications, social influence, police actions, one-on-one interactions with noncombatants, and urban environments. These call for scenarios that study smaller interactions between competing military forces or between the military and the civilian populace, rather than large theater-level models involving thousands of combatants on each side.

Models of the threat or opposing forces are also changing significantly. New models are being created that represent suicide bombers, improvised explosive devices, riots and protests, and active avoidance of direct engagement.

The future of military modeling will include increasing level of dynamics in the modeled world. Rather than focusing only on the combat-relevant activities of an object, we will be creating objects that have a much more extreme range of dynamic properties. These "extreme dynamic" models will create a more realistic world in which the human users and the automated objects will be able to interact with the virtual world in all of the ways that a real person would. This could include being able to assemble primitive objects into more complex ones, breaking objects into multiple pieces, tapping into the electrical systems of buildings, digging holes in the terrain, or interfering with the normal operations of a vehicle by flattening its tires or inserting rocks in its gun barrel. Such a dynamic representation of the world is far beyond our current capabilities, due to limitations in both our modeling capabilities and the processing capacity of current computers. But, within a decade or two, military models will represent a world that is "McGuiver-ready". This means that the modeling is so rich that a user will be able to do almost anything he can imagine in the world and a model will be there ready to represent those actions realistically.

Computer games like The Sims illustrate some of the richness that we are looking toward in military simulation systems. These games often focus on mundane activities like creating a meal, painting a house, mowing the grass, and reading a book. Though these activities will probably never be the primary focus of military simulations, they can play an important part in creating a realistic world in which to rehearse or experiment with military actions. During the Cold War, the primary military problem changed very little and this had a direct impact on the evolution of military models and simulations. In today's more chaotic and every changing environment, the military is being forced to look for ways to represent a much wider variety of objects and interactions. This will lead to significant changes in the dynamics that are modeled in future simulation systems.

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Further Information

Conferences

Interservice/Industry Training, Simulation, and Education Conference.

http://www.iitsec.org/

Simulation Interoperability Workshop

http://www.sisostds.org/

Computer Generated Forces and Behavioral Representations Conference

http://www.sisostds.org/

Winter Simulation Conference
http://www.wintersim.org/
Military Operations Research Society Conferences
http://www.mors.org/
Society for Computer Simulation Conferences

http://www.scs.org/

Game Developers Conference

http://www.gdconf.com/

Parallel and Distributed Simulation Workshop

http://www.acm.org/sigsim/

Journals & Trade Magazines

ACM Transactions on Modeling and Computer Simulation (TOMACS)
http://www.acm.org/tomacs

NTSA Training Industry News
http://www.ntsa.org/ and http://www.ndia.org/

National Defense Magazine
http://www.ndia.org/

Military Training Technology Magazine
http://www.mt2-kmi.com/

Training and Simulation (Annual Issue)
Published by the Armed Forces Journal International
http://www.afji.com/

Phalanx and Military Operations Research Journal
http://www.mors.org/

SCS Journal of Defense Modeling and Simulation
http://www.scs.org/pubs/jdms/jdms.html

Web Sites

ACM Special Interest Group on Simulation - http://www.acm.org/sigsim/

Army Modeling and Simulation Office - http://www.amso.army.mil/
Center for Army Lessons Learned - http://call.army.mil/call.html
Defense Modeling and Simulation Office - http://www.dmso.mil/
Institute for Simulation and Training - http://www.ist.ucf.edu/
MSRR - http://www.msrr.dmso.mil/
National Simulation Center - http://leav-www.army.mil/nsc/
National Training Center - http://www.irwin.army.mil/
Program Executive Office for Simulation, Training, and Instrumentation - http://www.peostri.army.mil/
SEDRIS - http://www.sedris.org/
Simulation Interoperability Standards Organization - http://www.sisostds.org/
Simulation Technology Magazine – http://www.simulationtechnology.org/