Chapter 13
A History of Military Computer Simulation

Raymond R. Hill and Andreas Tolk

Abstract The history of military simulation dates back to the earliest ages of conflict. Throughout the history, military personnel has employed cognitive devices to comprehend and plan for conflict. This chapter provides a history of military simulation, starting with a review of the board-based war games, progressing through the computerization of those war games and completing with a discussion of the modern world of military simulation encompassing desktop-based analytical simulations, video games, and distributed training and analytical environments. It provides a background for the contributions of the military track that has been a pillar of the Winter Simulation Conference for many years.

13.1 Introduction

The military is a big consumer of models and simulation. In the United States (US) Department of Defense (DoD) alone, there are over 3300 simulations registered as in use. This number is quite reasonably a lower bound given not all simulations are registered. Arming, training, and preparing the DoD to accomplish its myriad tasks is incredibly complex. The DoD, as with the military organizations of all nations, comprises multiple components, each of which might feature multiple commands with thousands of personnel across hundreds of career fields, operating and supporting thousands of systems to accomplish their broad range of missions. One of those missions, armed conflict, is arguably the most complex of human endeavors. Since the history of conflict between groups, clans, tribes, on up to nations parallels the history of mankind, it is not surprising that the use of simulation as a decision aid to help understand and prepare for conflict has a similarly long history.

R.R. Hill (✉)
Air Force Institute of Technology, Hobson Way, Wright-Patterson AFB, OH 2950, USA
e-mail: rayrhill@gmail.com

A. Tolk
The MITRE Corporation, Hampton, VA, USA
e-mail: atolk@mitre.org

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The immediate reaction to the above statement was likely something along the lines of "that is not possible, computers are too new of a device." This of course is true, but when presenting a history of military computer simulation one must really start with the use of thought-based or group-discussion models by the military, and that type of use does not require the computer, it merely requires the use of experienced, thinking individuals.

Within this chapter, we want to give our own interpretation of an overview of the developments that led to computer simulation first, as many ideas developed in the early phases still dominate our conceptual view of simulation to this day, such as figures with well-defined capabilities following a set of common rules on a common game board. We then look into some of the main developments in a computer simulation that influenced work presented and discussed in the military track before giving a short history of the military track itself.

This chapter has been written from the viewpoint of professionals who organized, conducted, and participated in the military track of the Winter Simulation Conference over several years. We are well aware of many historical overviews of military simulation, many of them written to commemorate anniversaries or special recognitions, such as Bergin (2000), Davis (2010), Thorpe (2010), or Shiflett (2013). Several chapters in textbooks are giving historical perspectives too, such as Little (2006), Banks (2009), and Loper and Turnitsa (2012). These are only examples of additional approaches to capture the history of military simulation, and many additional worthwhile publications are published not covered in this enumeration. All these works, like ours, are necessarily incomplete. We, however, seek to provide a more comprehensive chronology of military simulation and provide an overview of the contributions of the Winter Simulation Conference and its Military Track, to this history.

Our history of military computer simulation starts with a brief look at the beginnings of the war games and war planning efforts that qualify as thought-based simulation modeling and analysis. From that, we will progress into the early use of training devices for simulation and the early use of the computer for the computational implementation of training and war games. At that point, we will then move into the modern era of military simulation; the era explicitly involving the computer and all its inherent power and flexibility.

13.2 War Games Preparing the Way for Simulation

Humans are incredible problem solvers. We consider problems facing us and consider how various courses of action might solve the problem. With experience, we typically get more efficient, and effective, at the problem-solving process. Fortunately, or unfortunately depending upon your point of view, combat experience is not easily gained meaning other mechanisms are required to build up military experience necessary for military success.

This motivation to find another mechanism to hone military skills led to the early development of "war games." As far back as 3000 B.C., the game of Wei Hai employed colored stones to represent opposing forces. Personnel would position and move the stones to represent the deployment and employment of forces. The simulated conflict would be resolved, or "adjudicated" based on expert judgment. The game could be used to practice and hone strategic planning skills or to plan upcoming engagements. The game of chess similarly evolved out of military war games and references are found as early as 500 B.C. in India. The game was used by leaders, and their subordinates, again to hone their strategic planning skills (Smith 2010).

These board games evolved over time, growing in size and complexity, to meet changing needs. The games eventually evolved into table top versions more aligned with group deliberations on plans or actions. Early Vikings and Celtics are credited with explicitly considering various scenarios using these table top games (e.g., imagine a map laid out on a table with various pieces placed to represent forces (Smith 2010)). These games were likely largely adjudicated based on the experience of those arrayed around the playing table. Such an approach would likely have led to decisions biased by the beliefs of those involved, particularly those more senior in the group.

In the mid-1600s, these board games had evolved to include more independent adjudication of game moves, with the rules of these decisions based often on actual combat experience. Kriegsspiel, appearing around 1811, is arguably viewed as the first real war game simulation as dice were employed to introduce randomness into the outcomes of the moves implemented during the game (Loper and Turnitsa 2012). The left side of Fig. 13.1 depicts a modern version of a game while on the right is a drawing of the German staff employing the game in their planning efforts.

Over time, game complexity increased. New Kriegsspiel in 1798 involved 3,600 squares on the playing board and 60 pages of rules governing the conduct of the game. By the early 1800s, the Prussians had replaced the board game with map-like charts, moving pieces, realistic movements, and randomness in the outcomes (via a dice roll). This hard-to-learn game came to be known as Rigid Kriegsspiel and was replaced in the late 1800s by the easier to learn, faster to play, essentially rule

Fig. 13.1 On the left, a depiction of a Kriegsspiel board game. On right, depiction of German staff engaged in Kriegsspiel (PreparedX 2017)

free version which came to be known as Free Kriegsspiel. This Free version stepped back in complexity to rely more on player experience and judgment to adjudicate the moves made by the players. Despite the detail involved and use of actual combat data to define the rules, the Rigid form was simply too complex to learn and too slow to play. The Free form moved quicker and became the favored approach finding success through WWII (Shrader 2006). In America, war games arose in the late 1800s having similar detailed rule structures as found in the European games. While used in military schools, the operational impact of these games was minimal due to the excessive time required to perform the requisite mathematical calculations (Loper and Turnitsa 2012). Furthermore, General W.T. Sherman, as the Commanding General of the US Army, still under the impression of the brutal encounters of the Civil War that required many more human factors than could be captured in wargaming, has been said to discourage the use of this approach by stating: Men are not wooden blocks!

Throughout history, war gaming played a significant role in military training and planning. Many of the successful military campaigns were thoroughly war gamed (Shrader 2006). It is unclear whether the unsuccessful campaigns were not war gamed; losers in military actions rarely get their history told. Improving the accuracy of these war games was possible and was actually achieved, but humans can only calculate so fast. Thus, as noted above with the American experience, the detailed war games were found too cumbersome for regular use. What was needed was a way to free the modeler from the tedious calculations required by the rigid games allowing them to experience the flow of the Free games with the accuracy of the Rigid games.

13.3 Military Computer Simulation

Modern computer simulation ties back to the military needs of WWII. It was the intense calculations associated with military system engineering and analysis that really raised interest in mechanical computing calculators. Areas such as ballistics and crypto-analysis, which had required many hours of manual calculations, could be done in seconds when using the automated device. For instance, calculating a 60 s missile trajectory required 20 h of manual calculations, but just about 30 s on the mechanical calculator (Shrader 2006). The Electronic Numerical Integrator and Calculator (ENIAC) appeared in 1946 and is often viewed as the first modern computer.

As related by Metropolis (1987), the combination of statistical sampling and this new advanced calculating machine led to what we now routinely call Monte Carlo simulation. In those formative years, this computerized statistical sampling method was used to calculate the complex equations arising in the US Nuclear Program. Not surprisingly, Monte Carlo simulation was initially a classified method. Clearly, computer calculations changed the nature of computing and with its engineering and development. Motivated by early success, computing technology continued to meet the increasing demand.

The business world took notice of the computer and its capabilities as well. This naturally prompted more rapid growth in the technology. By the 1950s and 1960s, computer use, albeit of the very large, time-sharing type, were quite commonplace. In the military, optimization and simulation were among the most popular of the analytical uses of the computer (Shrader 2006).

Computing technology enabled the return of the more rigid war games by reducing the time required for the necessary calculations. Detailed war games became feasible (and practical) providing the growing cadre of operational researchers with a means of iteratively hypothesizing, learning, and improving their understanding of military weapon systems and their employment. The US Army experience is a great example, the Army Operations Research Office (ORO) in particular.

13.3.1 The Computer Mainstreams the War Game

In the early 1950s, the Army ORO became an early adopter of the computer-facilitated war game. These computerized games were largely used as a research tool, not really for the development of strategy or doctrine. The various divisions within the ORO focused on issues associated with nuclear attack and response, tactical battle capabilities, intelligence management, logistics planning, and continental air defense (Shrader 2006). One of the premier models, Carmonette, examined company-level ground operations involving infantry, tank operations, and mortar operations. Despite the early limitations of computing systems, Carmonette could represent up to about 200 entities in the simulated battles (Shrader 2006).

Computer support for wargaming initially involved running the calculations required to determine move outcomes based on the input from the players. The games provided insight to develop models to answer questions regarding resources and operations. Some of the early computer games really were intended to provide just enough insight to facilitate defining a more comprehensive wargaming approach. These early computer games were digital representations of the board games; however, it did not take a long time for the modelers to realize they could build more mathematically rigorous representations of the scenario. Soon games focused on the effects of weapons, systems, tactics, and logistics, among other aspects. Thus, the use of the computer quickly evolved from helping the top-level nature of the wargame (infer details from the high-level game response) to an environment in which the model output could provide insight on all levels (Shrader 2006).

A problem with wargames is repeatability and replication. It is hard for human participants to fully repeat their actions, especially when those participants believe another approach may work better. It is also tough to do the same task many times, even if there are allowances for freedom of action. Computers, however, are quite adept at repeatability and replication. The full automation of wargames thus arose as a natural consequence of the needs for military analysis and thereby created the area of analytical (now more often called constructive) simulation that arguably dominates the military use of simulation.

13.3.2 Rise of the Analytical Simulations

As military modeling and simulation matured, coupled with the subsequent advances in computing machinery, military simulation quickly grew associated with quantitative representations of combat in computer programs. The "art" of military modeling, actually military science in general, is the integration of modeling and simulation output with operational context to generate meaningful insights useful for decision making. In the growing technology of computer-based military simulation, this art closely aligned with the continual challenge of trading off simulation detail with the uncertainties associated with those details.

Changes in simulation modeling details, as the simulation models moved further away from just automating wargames, involved adding fidelity in the systems representations, adding greater diversity in the systems simulated within some scenario, and expanding the time frame considered in the simulation scenario. It turns out there is a very close relationship among the number of entities modeled and the corresponding level of detail and time period considered. This correspondence leads to initial characterizations of these emerging simulations as few-on-few, many-on-many and force-on-force (Battilega and Grange 1984).

Carmonette developed in the 1950s focused on small unit ground combat. Factors modeled included weapons aiming, target acquisition, the firing of the weapon and an assessment of target strike and destruction (Battilega and Grange 1984). An example analysis involving Carmonette would be tank duels or interactions between two ground force platoons.

In the mid-1970s, models of air, combat seemed to have really come into use. TAC AVENGER modeled a two aircraft air duel. The aircraft performance was modeled using fairly detailed engineering data. Aircraft engaged each other using a gun and/or missile systems. The corresponding projectiles from each system were modeled at engineering level detail. Aircraft within the simulation chose maneuvers, determined weapons to employ, and the firing actions to take. End-game outcomes assessed the projectile impact and kill probabilities against the specific target.

During the early 1900s, systems of differential equations were developed to describe force-on-force combat, as summarized among others in Taylor (1983). These abstract concepts were well suited to combat simulation use in force-on-force situations since engineering level detailed data was not necessary for their use. By the mid-1970s, force-on-force, or campaign-level models, used these systems of Lanchester equations to model large-scale combat. BALFRAM was an early example of such a model. It integrated land, sea, and air forces to examine aspects of combat analysis such as force planning, systems utilization, and of course operational effectiveness.

These early models collectively helped examine myriad scenarios to help answer a wide variety of questions. Naturally, the nature of any question–answer dialog is the generation of yet more questions. Couple this growth in the number, type, and depth of analysis needed to answer the questions with the rapid growth in computing capabilities, and it is quite logical to find that the military simulation models quickly expanded in size, scope and complexity. Model expansion involved greater modeling details, larger-sized forces and greater time periods modeled. In addition, the models improved in terms of data required and its fidelity, graphical displays of the combat scenario modeled, and the output data generated and subsequently processed into information used to inform decision making.

Over time, these models came to be classified into four broad categories: engineering models, engagement models, mission models, and campaign models. These categories differentiated models by the level of detail in the modeling of simulation entities, the number and diversity of the forces considered, and the time frame captured in the simulation.

Engineering simulation models featured the greatest level of detail and consider systems over a very short time frame. Examples include a torpedo or missile flyout. The engineering models will often capture environmental aspects as well as the physics involved in the system operation. These models might even involve human input in configurations known as human-in-the-loop simulation. Typical model outputs are aggregated for use in other models.

Engagement simulation models are concerned with short duration events, such as an air-to-air duel, a tank duel or the firefighter between two ground force squads. These encounters typical last minutes to hours. Engineering detail, often aggregated from engineering model output, are used to accurately capture the physics as well as the operational aspects of the scenario. They are usually applied on the tactical level.

Mission simulation models are concerned with events that last hours and involve potentially many diverse systems. These models have less engineering detail than in the previously described models as they are typically more concerned with the operational aspects of the interactions among these disparate systems (Hill et al. 2001). Exceptions, of course, exist such as the engineering level detail that might be required in a mission model used to assess the impact of radar-based protection systems; such simulations would need to model the radar signal at a fairly high level of fidelity. As a rule, these models cope with the operational level.

Campaign simulation models cover the longest period of time, encompass the largest number of assets, in multiple mediums and multiple service components. A campaign model will usually model Army assets at the Corps level, Naval forces, and full Air Force wings. The focus is on the battles that comprise a war against some adversary and thus the time frame in these simulations will generally be on the order of weeks to months. These models focus on the strategic level, including questions of logistics and long-term sustainability of military operations.

A common model of these military simulation categories arose in the mid-1990s and is often referred to as the DoD Simulation Pyramid or the Hierarchy of Models (Hill et al. 2001). Figure 13.2 is one such instance of the hierarchy. Each of the four levels depicts a category of military simulation (as labeled to the right of the pyramid). As we move up the pyramid, the models are increasingly aggregated in terms of model detail; model fidelity increases as we move down the pyramid. The shape of the pyramid also captures the general use of the simulations within each category. The wider, lower levels cover a much broader range of issues than do the narrow levels, whose models have a more focused purpose. Entries within each level

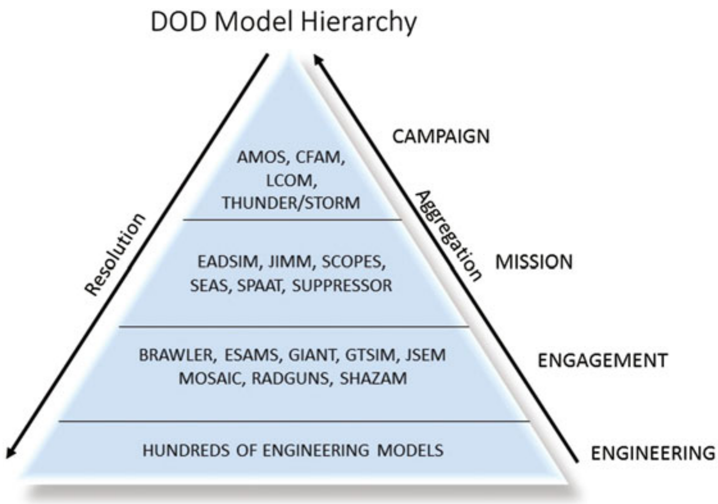

Fig. 13.2 The well-know model pyramid adopted and extensively used within the US DoD simulation world. The pyramid depicts the four general categories of models, how the categories vary in terms of modeling resolution and aggregation, and provides modern examples of models within each category

are representative models associated with that level/category. In general, results from lower levels are aggregated and used as inputs to models on higher levels.

This construct of families of models required human intervention to move data (and scenarios) among the models. A natural challenge to the technologists thus arose, why not let the simulations interconnect, or "talk to each other" to remove the time and labor intensive process of modeling data among the models. The answer to this simple question required complex software and communications engineering but yielded a result that now drives the predominant form of military simulation.

13.3.3 Military Simulation Goes Distributed

While computer simulation for war gaming was often considered a topic for special defense conferences, and many papers dealing with analytical simulation targeted the military operations research community, the rise of distributed simulation was in the focus of the simulation community. Military training was and is a challenging environment that draws lots of research interest and was also the main topic featured in WSC. With the maturing of computer technology, distributed simulation transformed the way the armed forces conducted planning, training, testing, and many of its other functions and tasks. In parallel to the growing importance of computers for command and control tasks, the development of training systems utilized, modernized, and sometimes even revolutionized the use of computer simulation. Thus, distributed simulation augmented the traditional methods of war gaming, although war gaming still has its place in many modern applications of military problem domains, such as in cybersecurity (Turnitsa 2016).

13.3.3.1 SIMNET and Distributed Interactive Simulation

The modern story of distributed simulation starts in 1983 with the Simulator Networking (SIMNET) program. It was initiated by the Defense Advanced Research Projects Agency (DARPA) as one of the first attempts to exploit the developments in communications technology for simulation. First-hand accounts are given by Miller and Thorpe (1995) and Cosby (1995). The idea was to network a group of simulators together and exchange information that would allow the teams using these simulators to collaborate like they would do in their operational systems. This was surely a DARPA project, as the best the US Air Force could manage at the time were two simulators, and the SIMNET first target was using 20 simulators (Hapgood 1997). SIMNET objectives were to bring armor, mechanized infantry, helicopters, artillery, communications, and logistics components together into a common, situated, virtual battlefield. Simulator crews were supposed to observe each other, communicate via radio channels, and observe each other effects. Per Loper and Turnitsa (2012), SIMNET was based on six design principles:

- Object/Event Architecture—the world is modeled as a collection of objects which interact using events.
- Common Environment—the world shares a common understanding of terrain and other cultural features.
- Autonomous Simulation Nodes—simulations send events to other simulations and receivers determine if that information is relevant.
- Transmission of Ground Truth Information—each simulation is responsible for local perception and modeling the effects of events on its objects.
- Transmission of State Change Information—simulations transmit only changes in the behavior of the object(s) they represent.
- Dead Reckoning Algorithms—simulations extrapolate the current position of moving objects based on its last reported position.

The demonstration used commercially available computer networks to interconnect simulators and represent the virtual world graphically. The companies Delta Graphics, Inc., Perceptronics, Inc., and Bolt, Beranek and Newman (BBN), Inc., were contracted with the development of graphics, network, and vehicle simulators. Three years after the project start, a platoon-level system had been developed, and after 3 more years, approximately 250 simulators were used by the US Army for their team training in Fort Benning, GA, Fort Rucker, AL, Fort Knox, KY, Fort Leavenworth, KS, and in Grafenwöhr, Germany. These technical and application success stories spawned growing interest with industry, and soon after the demonstrations, the IEEE 1278 Standard on Distributed Interactive Simulation (DIS) emerged (Calvin et al. 1993). The idea was to keep the standard easy to understand, easy to implement, and open for future developments. It was developed over a series of Workshops, mainly organized by the Institute for Simulation and Training (IST) of the University of Central Florida in Orlando. In 1993, the first version of this standard was agreed upon. The participation of the US Army Simulation Training and Instrumentation Command in Orlando, FL, ensured the applicability of these standardized solutions for the military customer. The design principles of DIS remained the same as those of SIMNET. As the focus had been on proving the principle and feasibility in applicable form for SIMNET, with DIS it shifted to the production of good guidelines and the definition and standardization of protocol data units (PDU): a standardized information exchange specification with fully agreed upon syntax and semantics.

DIS rapidly became a worldwide standard that was adapted for countless simulation systems and continues to support military training. Many of the new methods include migration support by providing DIS interfaces or gateways to facilitate the integration of simulation systems supporting the DIS principles. Additional details are provided in U.S. Congress, Office of Technology Assessment (OTA) (1995).

13.3.3.2 The Aggregate Level Simulation Protocol

While DIS focused on the networking of simulators, DARPA also recognized the need to support computer assisted exercises (CAX). As described by Cayirci and Marincic (2009), a CAX is an exercise using computer models designed to place the command and control element of a headquarters in a realistic, stressful combat-like environment to stimulate decision making, command and control staff interaction and coordination. While the focus of simulator training lies on training of individuals and small teams operating the weapon system simulated, the whole headquarter with its different cells and command and control systems builds the training group. Supporting a CAX, therefore, required another approach to interconnect the operational environment used by these Headquarters personnel. Thus, they defined the infrastructure that supports the military user with all information necessary to optimize the decision process with a focus on Command and Control Information Technology.

To support this new application domain, DARPA initiated the Aggregate Level Simulation Protocol (ALSP) extending distributed simulation to the force-level training community. In contrast to the tactical level supported by DIS, different aggregation levels of unit representations are possible, the exercises were distributed over a larger geographic domain potentially worldwide, and causality played a more important role. Because of the evaluation of these new requirements, the ALSP recognized that various time management schemes and more complex simulated object attribute management requirements were needed. The resulting design principles were the following (Weatherly et al. 1991):

- Simulations need to be able to cooperate over a common network to form confederations.
- Simulations must be able to publish objects of common interest and subscribe to objects they are interested in. Objects controlled by other simulation systems are ghosted.
- Within a confederation, temporal causality must be maintained.
- Simulations should be able to join and exit a confederation without major impact on the balance of the other participating simulations.
- The system should be network-based with no central controllers or arbitrators.
- Interactions among participating components do not require knowledge of confederation participants and should support an object-oriented view of interactions.

To implement these principles, ALSP focused on developing a special communication infrastructure, the ALSP Infrastructure Software (AIS), allowing for an extended set of services as well as a new format for the information exchange elements, the Interface Control Document (ICD), provided the capability to communicate the higher variety of information to be exchanged between the headquarters and the supporting combat simulation systems. The AIS comprised two software module categories with different tasks.

- The ALSP Common Module (ACM) was the interface to the simulation systems. It provided the interface to exchange messages in form of human readable text between the ACM and the simulation systems. These messages are defined in the ICD. This provided a high flexibility regarding what type of information could be exchanged, but also required a higher degree of coordination when the ICD content was agreed upon in the preparation phase for an exercise.
- ALSP Broadcast Emulator (ABE) provided the infrastructure services to orchestrate the execution of the distributed exercise. These software modules did not interface with the simulation systems, but they connected the ACM. ABE provided a set of services to support confederation, data, time, and event management.

The resulting ALSP specification was successfully implemented and supported over several years. The Joint Training Confederation (JTC) was the largest application of ALSP. The JTC has been used since 1992 to train military officers all over the world, including the United States, Germany, Korea, and Japan. In 1997, twelve simulation systems from varied armed services participated in a JTC worldwide exercise (Prochnow et al. 1997). Although ALSP was never standardized by an official standardization body, it proved new concepts and their feasibility shaping the current parallel and distributed simulation community. The reason for not going for standardization was the emergence of another new idea: the development of a common simulation interoperability standard that could merge both worlds of DIS and ALSP, the Standard for Modeling and Simulation (M&S) High Level Architecture (HLA).

13.3.3.3 The High-Level Architecture

The successful DIS and ALSP experiments did lead to the realization by the US Congress that distributed simulation technology could yield great benefits to the Department of Defense (DoD). The National Defense Authorization Act of 1991 called for a joint office to *"establish a coordinated DoD-wide approach to simulations and training devices for both acquisition and training..., to establish interoperability standards and protocols, and to develop a long-term plan to guide the development of simulators and training devices."* The Defense Modeling and Simulation Office (DMSO) was soon established to foster joint interoperability and model reuse among the armed service M&S efforts. The development of common simulation interoperability and related standards was a high priority objective. After review of alternative solutions, an Architecture Management Group (AMG) was established in 1995 to develop the High-Level Architecture (HLA), with significant political and financial support. This program was very ambitious. The DoD Joint Requirements Oversight Council (JROC) originally even planned to stop funding for simulation efforts that would not support the new standard after a certain adjustment time, and even exclude non-compliant solutions completely from the use in the DoD. This idea proved to be infeasible over time and was not enforced, but it shows the seriousness of the efforts.

In parallel to these national efforts, DMSO was also active within NATO. DMSO actively pushed for the development of a NATO M&S Master Plan (MSMP) that would ensure international support of the new vision of a common family of standards that would enhance the multi-national training capabilities. The Conference of National Armament Directors (CNAD) chartered a Steering Group on NATO Simulation Policy and Applications in 1996 and developed the MSMP, which was endorsed by the Military Committee and the CNAD, approved by all NATO nations, and issued in December 1998 by the North Atlantic Council. The MSMP also identified HLA as the common standard.

The design principles of HLA are described by Kuhl et al. (1999). They are realized in all implementations.

- Simulation systems communicate via the common Runtime Infrastructure (RTI) via standardized interfaces. Simulation systems are called federates and build together with the RTI the federation.
- The information exchange elements are defined using the standardized Object Model Template (OMT) which defines persistent elements (objects with attributes) and transient elements (interactions with parameters). Ten basic rules define the principles for this information exchange.
- The RTI provides services for the management of the federation, time, and the information exchange between the simulation systems and ensures consistency within the federation:
  - Federation management: Creating, joining, and managing federations, saving and restoring federations, and synchronizing federates.

– Declaration management: Defining publication and subscription of information exchange elements types for the federate.
– Object management: Defining the use of instantiated objects and interactions information exchange element objects for the federate.
– Ownership management: Defining ownership of objects, including how to transfer it.
– Time management: Defining the time paradigms and their synchronization.
– Data distribution management: Defining constraints allowing for the optimization of data traffic between federates.

The development and standardization of HLA happened in various phases. Supported by the US DoD, the first phase resulted in the definition of the HLA 1.3 NG. To foster a high adoption rate, the necessary software packages developed for the prototypical implementation were distributed for free to interested members of the simulation industry.

With the acceptance by NATO, the international community pushed for an international standard, comparable to the IEEE 1278 DIS standard, which at the time was the standard of choice for NATO simulation groups. Because of this international effort, HLA was submitted to IEEE for standardization, and this resulted in the IEEE 1516–2000 HLA standard family. Within the standardization process, the HLA 1.3 NG solutions were generalized and elevated to the current technologies, i.e., the number and possible values of calibration parameters were generally captured as extensible enumerations, and the definition of structures was transformed from Backus-Naur-Form to XML.

The review of the HLA standard family 10 years later resulted in additional adaptations of new technical solutions, such as semantic web technologies and increased modularization of HLA components. The updated IEEE 1516–2010 HLA is the current version.

Beside the technical specifications of the guiding rules, the interface between RTI and federates, and the structure of the information exchange in form of the OMT, the standard family comprised also guidelines for the federation development and execution processes (FEDEP) as well as how to conduct verification and validation for federations.

13.3.3.4 The Test and Training Enabling Architecture and Mixed Approaches

In parallel to the HLA, another effort to provide increased benefits led to the development of the Test and Training Enabling Architecture (TENA). In contrast to the HLA, TENA purposefully focuses on support of test ranges for military applications (Powell and Noseworthy 2012). TENA allows for the definition of an object-oriented Logical Range Object Model that avoids, similar to the standardization of PDUs within DIS, ambiguities. The TENA philosophy is based on the understanding that interoperability requires not only a common architecture, but also the ability to meaningfully communicate, which requires a common language and a common communication mechanism. Furthermore, a common context in form of a common understanding of the environment, a common understanding of time, and a set of common technical processes is needed. The TENA infrastructure provides integrated solutions, plus it provides places to store reusable components in form of TENA repository. This systemic support for interoperable solutions comes with a price: TENA is difficult to extend beyond the focus of test and training on ranges. While HLA had the objective to be broadly applicable for all simulation paradigms and all application domains, TENA was designed to optimize the support of its application domain.

The recent years of distributed simulation development are characterized by the insight that one common standard that fits all purposes is unlikely to be ever accomplished. This resulted in the increased implemented and utilization of mixed approached that allow for the use of various simulation interoperability standards within the same architecture. The resulting multi-domain architectures connect the various solutions using mainly proxies or gateways. To support these endeavors, the HLA specific FEDEP has been generalized to support such mixed approaches, resulting in the IEEE 1730–2010 Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP). DSEEP has been extended to support Multi-Architecture Overlays that support more than one simulation interoperability standards.

Distributed simulation is now accepted as a training support that is expected and taken for granted by members of the armed forces. Pilots train and practice on simulators before they enter the aircraft for many hours. The latest US fighter F-35 does not even have a trainer version with an extra seat for the instructor any more. Instead, the new pilot learns everything in the simulator, including flight formations with others within a distributed training environment. Within NATO, the use of CAX to train and practice international units is standard practice. Bruzzone and Massel (2017) present a view of the military history of distributed simulation from the NATO perspective.

13.4 The Military Track of the Winter Simulation Conference

Over the last few decades, there have been just a few outlets for publicizing military simulation activities and results. Arguably the leading conference on simulation has been the Winter Simulation Conference. Initiated in 1967, the WSC has gained the respect of simulation professionals worldwide, especially with its focus on high quality papers and presentations. There are other quality conferences with a defense focus: Western Decision Sciences Institute, the Annual Conference of the Institute of Industrial and Systems Engineers, the Summer Computer Simulation Conference (SCSC), and the Interservice/Industry Training, Simulation and Education Conference (I/ITSEC), recognized as the world's largest modeling, simulation, and training conference. The symposiums of the Military Operations Research Society (MORS) also contribute to simulation-related research. However, our focus here is on the WSC.

The very first WSC in 1967 featured a military keynote while the general chair was with the Air Force. Various military papers appeared in those early years. An interesting paper on a pure military topic was presented at the WSC75 in the Simulation for Government track on the topic of "A Security Force-Adversary Engagement Simulation" by H.A. Bennett from the Sandia Laboratories (Bennett 1975).

At the WSC77, the session on Military systems was introduced, involving two papers. Alfonso A. Diaz from the US Training and Doctrine Command presented "A Cost and Operational Effectiveness Analysis of the Army Utility Tactical Transport Aircraft System," (Diaz 1977) and the paper on "The Generation and Use of Parameterized Terrain in Land Combat Simulation" was presented by Sam H. Parry from the Naval Postgraduate School (Parry 1977).

Although some papers with military references were presented thereafter, it was not before 1983 that a permanent Military Application session was introduced to provide a permanent home for such application studies. These sessions attracted between two and five papers per year, with peaks in 1988 (12 papers) and 1991 (9 papers). It was not until 1993 that the Military Application topic attracted enough papers that a track with several sessions could be established in the WSC program. This increase was likely connected with the congressional recognition and following support of modeling and simulation, as described in the distributed simulation subsection.

In 1995, the Military Track introduced its own keynote session with a clear focus on defense related issues. There were a significant number of technical HLA-related papers during the years of 1995 and 2000, but they never dominated the track. However, motivated by the new technical perspective, more technical papers were submitted that not only focused on the application domain, but evaluated new technologies or methods regarding their applicability.

Since 1998, the Military Application track was conducted as one of the main tracks in the WSC, with full day sessions for all days of the conference. Since 2007, the numbers started to drop some and sessions were combined together with the Homeland Security track, which was established in 2004. Although many interesting papers continued to be presented, the number of accepted papers dropped to 10 in 2014, so that the program committee decided to merge the Military Application and the Homeland Security tracks into the new track on Military, Homeland Security & Emergency Response, covering all aspects of defense and security application in a common track, again with full day sessions for all days of the conference. Figure 13.3 provides a summary of the activity in the military track over the years. These numbers do not include papers with military application topics that were featured in other tracks.

Since its instantiation, the Military Application track has conducted keynotes, panel discussions, and paper sessions highlighting the requirements, benefits, and technology challenges and solutions. New concepts such as distributed simulation, multi-resolution and multi-domain modeling, high resolution visualization,

Fig. 13.3 A compilation of the papers falling under the Military Track for the Winter Simulation Conference. The number of papers is provided for each bar. Note that for many years, the Military Track has featured a keynote speaker, meaning no or at most one paper is associated with a full session

applicability of web-based applications, cloud-based, and many more were presented and discussed in the international context. Tutorials were also supported.

Early military papers in the WSC were parametric, or deterministic in nature. Early efforts by Bennett (1975) and Link and Shapiro (1979) examined small force engagements based on difference equations or detailed scripts. Mekaru and Barclay (1984) modeled deep space intercepts while Graves and Clark (1983) modeled the budget planning process. However, early languages like Q-GERT, SLAM, and Simscript allowed military modelers to take advantage of computer simulation capabilities. Parry (1978) used Simscript to examine battalion-level engagements, Mortenson (1981) used Q-GERT to model aircraft repair centers (called depots), and Armstrong et al. (1983) used SLAM to study mobility aircraft scheduling. Clark et al. (1984) seem to provide the first WSC military paper using experimental design to examine model results, in their case focused on logistics policy analysis. This work preceded the tutorial nature of the Roberts and Morrissey (1986) work that explained using design of experiments to examine a targeting algorithm.

As simulation capabilities evolved so did the application of these capabilities in papers featured in the military track. By 1987, training simulation discussions really started appearing; Childs and Lubaczewski (1987) discuss such a system for battalion and brigade commanders. By 1988, the military simulation track seemed to take hold with its first truly sizable track, and this growth resulted in a military track with focused sessions by 1992. Those sessions in 1992 interestingly enough were focused on airlift, wargaming, and decision support based on simulation modeling; topics that are still examined today.

Combat support-focused topics began appearing about this same time. Schuppe (1989) examined pilot workload, which continues to be a major research issue. Human factors modeled associated with various aspects of the military mission garnered 1–2 sessions per track in the early 2000s. The influence of DIS and ALSP appeared in the military track by 1994 with a focus paper on the topic in 1999 (Nance 1999). Unmanned vehicle research and agent-based modeling applications are hot topics in 2017; these emerged in the military applications track by the early 2000s. The military track even seems to have the distinct honor of having a Winter Simulation session in the Winter Simulation Conference (it was a session focused on seasonal issues in military operations).

Over the years, the Military Track has featured numerous important defense leaders as keynote speakers, held five important panel discussions, one involving the senior operational research analyst from each of the services, and provided numerous papers covering a plethora of important topics to military planning and operations. The current Track on Military, Homeland Security & Emergency Response continues to be a pillar of the annual WSC program and a track that influences military decision making with its scientific contributions.

13.5 Examples for Current Challenges

Given the long history of military simulation and the broad range of specific topics that fall into the realm of military simulation, any history of military simulation is necessarily incomplete. In this history, we have tried to touch on many of the influences in a military simulation that have led to current state of military computer simulation. Fortunately for those involved in military simulation, now is an exciting time. There are a wide variety of challenges and opportunities in the military simulation. Our intent here in this last section is to highlight some of these opportunities and challenges.

13.5.1 Live, Virtual and Constructive Simulation

The tremendous advances in distributed simulation have evolved into an environment in which live assets can communicate with training systems involving humans in the loop (virtual assets) and with purely analytical models (constructive models). The resulting LVC environment provides access to the range and number of military systems not available on the physical test ranges. Thus, LVC holds tremendous promise for the system demonstration and training challenges in the future. The LVC also holds promise for the test and evaluation world. In such applications, new systems can be embedded in the complex, interconnected military environment envisioned for the future while communicating and interacting with the systems of today, all within some common environment to ascertain the new system appropriateness in a system-of-systems context. The latter application requires new ways of thinking about the humans in distributed simulations, but does provide an opportunity to fundamentally change the way the military tests and considers new weapon systems and the various support systems (see discussion in Hodson and Hill (2013)). This research must address how to fully integrate games into the LVC. Games and their physical engines can provide valuable functionality to federations, as shown by Valerde and Sun (2017). Games also have been proven useful for rapidly generating sufficiently realistic behavior of entities without requiring a huge amount of personnel to do so. Games are providing valuable means to support generating realistic visual representation, e.g., of avatars in simulated teleconferences, or realistic video streams of simulated drones that fly through synthetic environments. Finally, the use of augmented reality opens new training possibilities by mixing simulated reality with real environments. Current research focuses more on convergence instead of simple integration.

13.5.2 Web-Based and Cloud-Based Simulation

The military track featured several papers on the efficient use of web-based and cloud-based technology, such as Cayirci (2013). With the progress of general computational methods supporting distributed and high performance computing, the adaption of such technologies in support of military and defense simulation is gaining increased interest. M&S as a service is often seen as the possible technology solution enabling the convergence of solutions, although conceptual challenges remain, as shown in Taylor et al. (2015).

This does not only address the use of such emerging technologies within simulation systems and to support their distribution and execution, but also tools that allow better governance of such complex endeavors: how to manage the development and execution of such simulation systems? How do these new developments affect ideas of common services to be shared with partners, definition of reusable simulation components in repositories, etc.

13.5.3 Computational Social Sciences

The human element has always been a key determinant of military success or failure. Throughout the history of military simulation, we have included human behavior in our analyses. The revolutionary changes brought about by the computer in the 1940s and the 1950s did much to improve our mathematical representation of combat, but our representations of the human in that combat scenario has been slow to catch up. The use of agent-based simulations has brought about tremendous advancements in the social sciences and some of these advances will surely find their way into combat modeling. There has already been steps in this direction particularly with the work in the Naval Postgraduate School SEED Center—promoting simulation experiments and efficient designs—and prior to that, the work under Project Albert. Currently, the use of generative simulation, as envisioned in Epstein (1999) and today increasingly supported by Agent Zero model implementations Epstein (2006). The usefulness for defense related analysis, but also potentially for training and education, is a topic of current research.

13.5.4 Unmanned Assets

Unmanned assets, particularly unmanned aerial vehicle (UAV) assets hold great promise for future combat operations. Unfortunately, it is unclear which parts of that promise are achievable and which parts are hype. The use of advanced simulations can go a long way to discerning the achievable and not so achievable aspects of the autonomy challenge facing the military in the future. One of the pressing issues in this context is the need to command and control mixed units, made up of human soldiers as well as robots, including the necessary human-robot interfaces needed to enable efficient combat operations. These concepts also must be represented in training systems, so that officers learn how to utilize such mixed units efficiently. Several aspects of these challenges are currently evaluated by the Modeling and Simulation for Autonomous Systems (MESAS) workshops organized by the NATO Center of Excellence, see among others Blais (2016).

13.5.5 Other Emergent Challenges

The topics listed in this section are neither complete nor exclusive. Many additional challenges have been and are identified, and their number grows steadily. Among these are the following ones.

- The community is still looking for good solutions for multi-level security protocols that allow data sharing in an exercise with all participants on various levels of trust. This includes multi-domain challenges as well.
- Urban operations in Megacities will become a challenge, as more and more people are moving into big cities, mostly on the coast. While traditional military operations in the age of the Cold War avoided urban areas, in the future the combat in such environments will become a likely option. Burns et al. (2015) address the fragility of the Global Positioning System in such an urban scenario.
- Many scenarios already include massive cyberattack activities, but only as an event, not as a simulated operational activity. Cyber warfare needs to be modeled by itself as well as an integrated activity of combat operations. This includes, but is not limited to, the cyber-attacks against command and control systems. Unfortunately, there is still the question of just how to model cyber.

Many more topics can be added to this list of emergent challenges. Over the years, the military application domain has proven to be one of the most challenging fields to be supported by M&S. The problems are complex and require solutions that draw from research from many related domains in the technical as well as the operational realm. New technologies and methods continuously contribute to innovative solutions that are worth to be presented and discussed with international peers, in particular as the focus of military operations is no longer limited to the traditional combat sphere.

13.6 Concluding Remarks

The focus of this chapter was to provide a framework of main events and topics, not the presentation of main research results. However, many methods and tools resulting from the research such as they are presented and discussed in the military track are presented in more detail in textbooks and research reports. Examples for such textbooks are Bracken et al. (1995), Cayirci and Marincic (2009), Deitz et al. (2009), Washburn and Kress (2009), Strickland (2011), and Tolk (2012). The interested reader is referred to this literature for further studies.

This chapter is titled "A History" for a specific reason; it is by no means neither a complete nor a comprehensive history. It is "A" history because its content and presentation is influenced heavily by the biases and experiences of the authors. It is fully expected that anyone reading the history presented will react with a "Why wasn't N" included, and the reaction is fully justified. For instance we did not cover the tremendous infusion of funding into modeling and simulation through organizations like the Defense Modeling and Simulation Office or the hundreds of millions of dollars spent on the Joint Simulation System (JSIMS) (Bennington 1995) or the Joint Warfare System (JWARS) (Stone and McIntyre 2001). We also chose to not discuss the incredible wide range of engineering models used in weapon systems design, in weapon system survivability studies, or in weapon systems lethality studies, to name just three areas. We also left off important areas like gaming technology to military use or simulation support to large-scale exercises; these could constitute entire theses on their own. Our intent was to layout a cogent flow of how military planning and analysis has evolved into the computer-reliant complex that exists today and entertain a little along the way.

To this end, our chronological coverage is more complete than found in some of the other histories and we provide insight into the evolution of the Winter Simulation Conference, Military Track, and the contributions made in that forum to the field of military simulation.

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