Observations on the Development and Implementation of Distributed Simulation

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ABSTRACT

Future developments in the use and capabilities of distributed simulation will be based largely on seminal developments that have occurred in the last thirty years. This time period witnessed the set of interrelated events that led to the development of the original Simulator Network (SIMNET) program through those that culminated in the achievements of the Close Combat Tactical Trainer (CCTT). These events have collectively formed the infrastructure that supports current and future achievements in distributed simulation. Having some knowledge about the facts surrounding this set of achievements is useful. Understanding the rationale behind the events, including the shaping constructs and influences, can transform simple knowledge into enabling wisdom. The primary goal of this paper is to set the conditions that will allow widespread growth of such wisdom.

This paper provides historical context for four related periods of systems development efforts that have enabled the robust distributed simulation capability that we enjoy today. First, the pre-SIMNET concept-formation period focused on operational tank and weapon system development. Second, the SIMNET era provided the initial demonstrations and uses of distributed simulation as a provably-valuable training vehicle. Third, the formalization era where the government's understanding of the power of these developments led to the formation of the Defense Modeling and Simulation Office (DMSO). Finally, the paper discusses the era of transformation where formal programs of record, like CCTT, replaced the more DARPA-like development environment. Each of these time periods included key events that, when fully understood, will serve as guideposts to drive future development efforts.

This paper fundamentally attempts to build on and amplify the lessons and views for our community's future provided by two previous I/ITSEC Fellows. Colonel (USAF, Retired) Jack Thorpe (2010 I/ITSEC Fellow) and General (USA, Retired) Paul Gorman (2011 I/ITSEC Fellow) provided their interpretation of events during this same period of development for distributed simulation. As such, this paper is much like the field of distributed simulation itself; progress is made by those who stand on the shoulders of giants.

ABOUT THE AUTHOR

James E. Shiflett is a retired Army Colonel who is now Vice President for Program Management with Science Applications International Corporation and has served as the Director of FCS Training Systems. During his military career, he served as the Project Manager, Combined Arms Tactical Trainer Systems (CATT) from 1992 to 1997. In the 1970s and 1980s he served with operational Armor units in the 3rd AD and the 3rd ID. He also served in assignments that developed, tested and fielded the M60A1E3 and the XM1 Abrams tank. From 1991 to 1992 he served as the first Technical Director of the Defense Modeling and Simulation Office (DMSO). He set the DoD on a clear and certain course for military use of modeling and simulation by creating simulation standards, common architecture, and communications protocols. From 1988 to 1990, Colonel Shiflett served as Program Manager, SIMNET, and Defense Advanced Research Projects Agency (DARPA). He managed the highly successful, large-scale Simulation Network (SIMNET) program and was responsible for the transfer of SIMNET technology from DARPA to the services. Colonel Shiflett was fundamental in establishing the Distributed Interactive Simulation (DIS) IEEE standards. He was the leading proponent of the Synthetic Environment Data Representation and Interchange Specification (SEDRIS) project. Colonel Shiflett served on the Executive Committee (EXCOM) for the Simulation Interoperability Standards Organization (SISO) for over 6 years. From 2001 through 2003, he was an Industry Team Member of the Inaugural Certification Board for the Modeling and Simulation Professional Certification Commission.

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INTRODUCTION

Today's modern armed forces rely on training, planning, rehearsing and mission execution capabilities as an accepted component of their operational norms. These components have been developed through pioneering efforts in several domains that include technology advances as well as management and policy guidance on how to employ the advances. Modern simulation capabilities have emerged relatively rapidly, based largely on accomplishments of insightful and dedicated people who built on their personal experiences, striving to achieve a shared vision of the future. This paper is a brief discussion of their achievements and the resulting key events that have been formative. It is not an attempt to provide a lesson in history, but rather an attempt to extract lessons from history. Thus, the paper has a focus on the causative factors behind the developments, rather than on the developments themselves. The well-known quote "Those who cannot remember the past are condemned to repeat it" (Santayana, 1905) partially characterizes the narrative that follows. However, a better characterization is "Those who cannot ***understand and learn from*** the past are condemned to repeat it".

This paper provides historical context from four related periods of systems development efforts. First, the pre-SIMNET (SIMulator NETwork) concept-formation period focused on operational tank and weapon system development. This was an initial period of simulator use at the tactical level. Second, the SIMNET era provided the initial demonstrations and uses of distributed simulation as a provably-valuable training vehicle. Third, the formalization era where the government's understanding of the power of these developments led to the formation of the Defense Modeling and Simulation Office (DMSO). Finally, the paper discusses the era of transformation where formal programs of record, like the Close-Combat Tactical Trainer (CCTT), replaced the more DARPA-like development environment. Each of these time periods included key events that, when fully understood, serve as guideposts to drive future development efforts.

Recent I/ITSEC Fellows papers from Colonel Jack Thorpe (USAF, Retired) (Thorpe, 2010) and General Paul Gorman (USA, Retired) (Gorman, 2011) have also looked to the last 30 years as a period of seminal development for the simulation and training community. Both have provided thoughtful analyses of the period's major events and used them to exemplify key principles to create their vision for the future. This paper reinforces and builds on several of their observations. As an example, General Gorman cited many examples of need he observed, and their solutions, from his viewpoint as a senior commander. Here, many of his observations are reinforced from the separate point of view of lower levels of command. That is, the principles and truths General Gorman discovered from a top-down, senior-level command are equally valid when viewed from the bottom-up perspective of lower levels of command. In particular, the paper cites examples from our shared history pointing to:

- the necessity for a continuously available simulated conflict that can be joined as needed at any time from any place
- the requirement for alignment and integration of command and control systems with simulation systems to create a seamless, persistent resource for operations and training
- the importance of the ability to rapidly create or adapt digital representations of the physical environment using scale, accuracy, and fidelity appropriate for the immediate task
- the value of using simulations as integral parts of each phase in a system life cycle
- the central role of standards development
- the need for department-wide uniform, forward-looking, and integrating policies

The following sections develop these key points, provide personal historical evidence of their importance, and discuss their collective value for the future of training and simulation, both from the user and provider perspective.

THE PRE-SIMNET PERIOD (early 1970s to mid-1980s)

Our view of the world is influenced by our collection of experiences. During this period, my experience was with tactical Amor units with the Third Armored Division (3 AD) in the early 1970s and the Third Infantry Division (3 ID) in the mid-1980s. One of my clearest observations from my days as a Tank Platoon Leader, Executive Officer (XO) and Company Commander was that proficiency at mission tasks had consistently been fundamentally impacted by the interaction between training type, training cycle, and personnel rotation. Unit proficiency consistently and predictably rose and fell on an annual basis. In the early 1970s in 3AD, our units prepared and executed Tank Gunnery in the spring, culminating in tank crew qualification at Grafenwoehr, Germany. In this period, the emphasis was entirely at the crew level and there was no effective concept for training at higher echelons, not even at the platoon level. We reached our highest level of gunnery (crew) proficiency following tank crew qualification as we returned from Grafenwoehr to home station. At this point, emphasis shifted to preparation for maneuver training, scheduled to be conducted later in the summer at Hohenfels, Germany. Unfortunately, this was also a period typically accompanied by the majority of personnel rotations occurring on an annual basis. Thus, the preparations for intensive maneuver training also included widespread personnel adjustments and breaking up of many of the crews just qualified at Grafenwoehr. With the added burden of personnel turmoil, crew proficiency declined as training focus shifted and crews lacked integral gunnery training resources. With the manpower turbulence, the unit simply did not have any practical methods to practice, reinforce, and thus retain the gunnery task crew-level proficiency that had just been attained.

The cycle tended to repeat along another tactical-capability axis in the following months. The unit would reach peak proficiency in maneuver training at the platoon and company level (and to some degree the battalion task force level) following the month-long training experience at Hohenfels. Following the maneuver training, the next events were command post exercises (CPX) and field training exercises (FTX). These exercises expanded maneuver training and staff coordination while the unit was deployed on the German countryside. Again, the cyclic nature of unit proficiency became a factor. Personnel changes at the culmination of each of these major events, due to the nature of the training and the established annual 1/3 personnel rotation (coupled with the lack of home station or integral-training resources), resulted in seemingly unavoidable capability and proficiency loss.

It should now be clear that unit-level proficiency is multi-faceted. Tactical units must be proficient with their weapon systems, be able to maneuver to employ those systems, and have adequate command and control to coordinate maneuvers and fires. Proficiency in each area is necessary and individual "islands of proficiency" invite degraded overall effectiveness if paired with substandard capability in any of the other areas. The normal operating cycle in the pre-SIMNET period tended to foster the latter. In large part, this was a consequence of a lack of adequate integral, home station training resources to maintain an acceptable level of proficiency in one area while achieving heightened capability in another.

I carried these operational experiences and observations with me as I left unit command and transferred to the XM1 Tank Program Office were I served as the User Representative. I too was a part of the annual rotation problem, but also an example of the benefits of personnel rotation. In my new position, it became clear to me that the technology to create a simulator to train and practice gunnery with tank commander and gunner combinations was both feasible and affordable. The unit conduct of fire trainer (UCOFT) and driver training with a motion based driver trainer could be used at home station, without need for the expense, advance scheduling, and infrastructure of a major exercise or training event. My recent experience validated the need for this type of capability and convinced me these devices could achieve a great step forward by allowing repetitive practice of critical skills to supplement field training.

Both the ABRAMS COFT and the ABRAMS driver trainer were fielded in the mid-1980s at Fort Knox, Kentucky. Initially, acceptance of these training devices was less than enthusiastic. However, LTG Brown, (USA, Retired) was adamant and directed all leaders would qualify in Tank Commander and Gunner pairs and that each must achieve a minimum level of demonstrable proficiency in the COFT progressive training matrix. The COFT system was finally accepted as a normal part of the training cycle only after the leaders understood capabilities offered by the simulation and COFT-simulation-trained field units obtained better performance in less time at lower cost.

By 1984, the Army was beginning to take notice of new developments made by the simulation industry. As an example, *Armor* magazine (Brown, 1984) reported that a Munich-based firm, Industrieanlagen-Betriebsgesellschaft, had produced an “Interactive Combat Simulator” under sponsorship of the German Ministry of Defense: “This simulator, called APKA, is a computer-aided device that supports tactical exchanges of combat power.” The concept was that APKA could replace traditional war games conducted using scaled terrain boards and “ministered by scores of tactical players, umpires, and recorders.” APKA was an initial instance of a free-play simulation that focused on man-in-loop simulations where humans made decisions based on their understanding of the situation and their actions or non-actions, as well as those of their human opponents. The driver and the tank commander were soldiers and the other crew positions were represented inside the computer. The results from the simulation (target acquisition, hits, kills, etc.) were directly tied to human actions in this simulation. Digital terrain was created in forms that were useful to both the human players (a plan-view, two-dimensional map with moving icons) and to the computer for calculations, such as line-of-sight determinations.

The US Army's interest in this simulation was founded in APKA’s potential to support collective training requirements; nothing like this was available in the US at this time. General Otis, as the US Army, Europe (USAREUR) commander, saw this potential immediately. As a result, the US Army tracked this research and eventually purchased a set of the simulation for the 3rd Brigade 3rd Armored Division in Friedberg, West Germany. A set of this equipment for the Army was referred to as TACMASS.

APKA, and TACMASS as later modified in the US Army to support training, embodied several concepts and design decisions that were innovative, powerful, and enduring. First, the simulation was not created to support training, but was designed as a means to understand tradeoffs in weapon and sensor capabilities. One of the primary research uses of the system was to determine the benefit of information of the BLUEFOR and OPFOR based on distance with other than just line of sight. The research focused on determining the value or benefit of such data BEFORE expending any resources on new system development, a novel approach to requirements determination at the time. Second, computers could be employed usefully, even in domains requiring highly cognitive skills (adaptation, innovation, rapid planning and reaction), by creating human-computer “cooperative teams” where the computer functioned in its areas of strength (like line-of-sight calculations) while the human provided the cognitive skills and decision component. Third, digital representation of terrain offered far more capability than battle-boards or other scaled mock-up devices and these digital terrain models could be created in ways useful for both human visual systems and computer calculation systems. The digital terrain and entity representation also served as the coordinating mechanism for human – computer interaction.

A final and most interesting fundamental concept was derived from observing a US platoon leader’s actions as vehicle exposed range was parametrically varied. Sometimes the simulation was set to show vehicles within line-of-sight (LOS) at up to 1000 meters and other times within LOS and up to a range of 2000 meters and so on. One platoon leader, knowing the location of the opposing force (OPFOR), positioned a portion of his platoon in overwatch and attacked the OPFOR with his own force, leading from the front. Another platoon leader placed his tank in an overwatch position and maneuvered the other portions of the tank platoon to attack while he directed the action based on observing the unfolding events. Both of these approaches resulted in BLUE success and defeat of the OPFOR. This demonstrated the concept that there is not a single solution to all situations and successful leaders made decisions based on their understanding of their own-force capabilities (crews and people) and personal style of leadership. The after-action review (AAR) was used to understand the cause and effect relationship, what happened, when, and why.

Similar observations showing the values of simulation became evident when I served as a battalion commander (1986 – 1988) with the 1st Battalion, 1st Armor Regiment. This was a period of government austerity and as a cost-reduction measure, our units were compelled to reduce actual driving miles per soldier from about 36 miles to about 6 miles per student. We replaced actual driver miles in the field operating the actual tank with training in the tank driver simulator. Driving the actual tank itself evolved to become the final exam, only attempted after first demonstrating proficiency in the driving simulator. This approach not only had the tangible benefit of greatly reducing cost (approximately 50 dollars per mile in 1987) but also allowed increases in the scope of training so that tasks previously determined unsafe for students could also become part of the training program. These are oft-cited examples of the benefits of simulation. In this experience, the claimed benefits were actual benefits.

Summarizing the Lessons Learned

The events of these early, pre-SIMNET, years are remarkable in that they demonstrated several enduring principles that will be tenants of successful simulation systems, both now and in the future:

- Unit-level proficiency is multi-faceted and is best supported by continuously available training resources punctuated by periodic major training events
- Simulator-based training can be effective in developing a variety of skills while decreasing cost and increasing the number and type of skills
- Simulations can and should be used throughout the system lifecycle and, most importantly, to influence decisions in the earliest stages of systems design and acquisition
- Linking humans and computers together into a logical, single "semi-automated" system offers an extremely viable approach to training tasks requiring cognitive skills
- Digital terrain can be multi-faceted, supporting both human visual systems and computer calculation systems with coordinated representations of place, ultimately reducing cost and improving training realism and applicability
- Leadership can be improved with training, but is often based on context-dependent intangible factors not currently amenable to computer representation.

THE SIMNET PERIOD

In April 1983, DARPA initiated the SIMulator NETworking (SIMNET) program. At that time, there was an emerging set of experiences with networking (based on the ARPAnet, DARPA's precursor to today's internet technologies) that was combined with several ideas from a 1978 white paper (Thorpe, 1978) which described networking a set of simulators together for collective training. A dominant view, at the time, was that mastery of combat skills was equivalent to mastery of force-on-force engagement training at specialized facilities such as the Army's National Training Center (NTC) or the Air Force's Air Combat Maneuvering Instrumentation (ACMI) ranges. The inception of the SIMNET program was based on the potential to replicate the specialized facility training value and experience by networking large numbers of people together via connected simulators to conduct force-on-force training. Moreover, some of the capabilities and potential emerging from experience with the APKA program made this ambitious goal seem realizable, at least from a DARPA perspective. However, as with most DARPA programs, research was a significant component of the program and no formally-defined requirements for SIMNET capabilities were specified, contrary to what is currently required today.

The heart of the SIMNET design was that the network was the system. The design provided a harness, linking together an emerging collection of technologies, including the internet, computers, human-computer lash ups, and graphics, together with a set of simple (although it did not seem so at the time) simulation network protocols allowing formations of people to train together without leaving their home stations. This is a fairly commonplace occurrence today, but was incredibly innovative and far-sighted in 1983. The full story of SIMNET development has been elegantly recorded (Thorpe, 2010) and, given this brief introduction, need not be repeated here. Instead, the following focuses on several significant problems, their solutions, and the guiding principles emerging from the experiences. Again, a key for the SIMNET design was that the network was the system. This allowed great system flexibility so new computer and graphic capabilities could easily be incorporated as they became available. The high-level SIMNET design is indicated in Figure 1, below.

In the earliest implementations, the opposing forces in SIMNET were all fully controlled by human operators, using the same type of design implemented and proven successful with the APKA system. Different icons (vehicle graphics) were used to represent forces on each opposing side. The US forces were depicted using an Abrams tank appearance and the opponents appeared as T-72 tank icons (even though all crews were in Abrams SIMNET simulators). However, it was not long before this design approach became infeasible for programmatic more than technical reasons. A salient difficulty was that the OPFOR were really US soldiers using SIMNET models of US equipment and, for the most part, US tactics and doctrine. It was deemed unaffordable at the time to have a special set of manned threat simulators and a professional OPFOR like those assigned to the NTC.

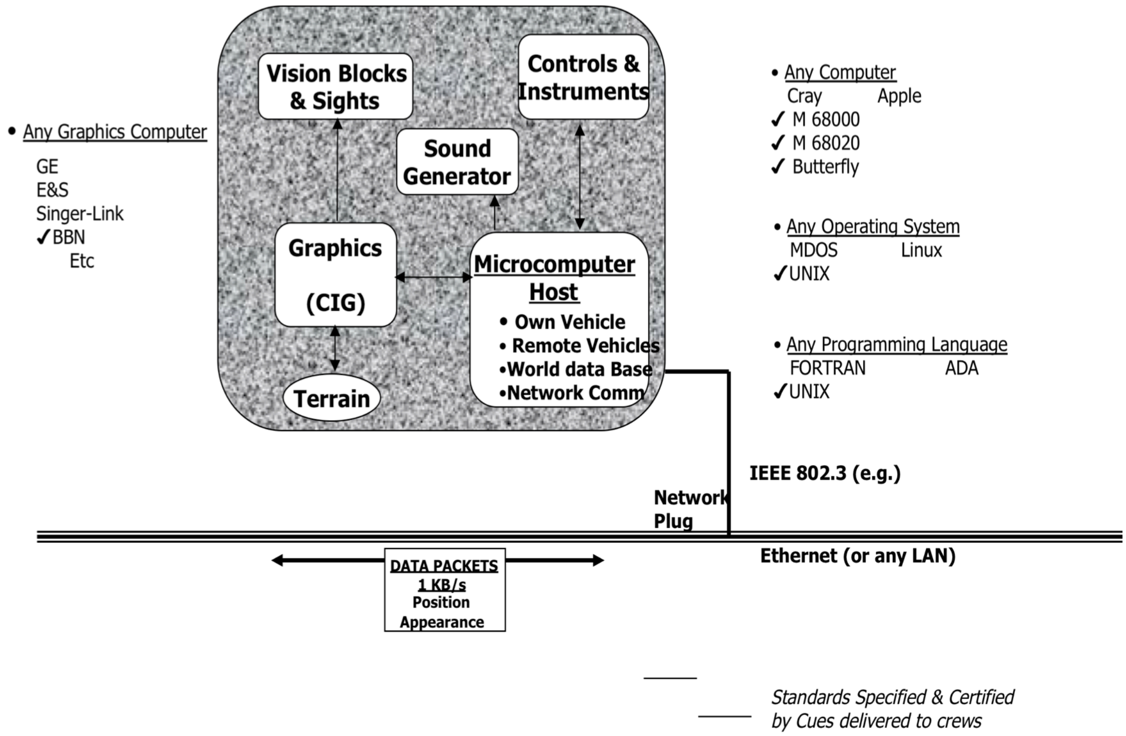

Figure 1. The SIMNET Design for Flexibility

The challenge was to replace some human operators with a computer-driven intelligent opponent controlling electronic entities while using the correct OPFOR doctrine. This presented an incredibly large research task well beyond the approved scope (and budget) of the SIMNET program. In essence, the necessary solution seemed to require a capability to pass the "Turing Test", so anyone observing the virtual battlefield would be unable to determine which entities represented manned simulators and which ones were computer-controlled entities. However, while the actual need was for fully automated forces, the pragmatics of the situation required pursuing a less ambitious goal. Management of the program required definition of limits for the effort that would result in clear closure criteria and thus allow determination that portions of the program had been completed (an ultimate program goal was transition of completed capabilities to the Army). The decision was to further extend the cooperative human-computer lash up, first demonstrated in a more simplistic form by APKA. The SIMNET concept was to devise computer instruction sets good enough to control lower echelon entities and units for limited time. When the computer needed higher-level reasoning, a human operator controlling these forces would have to provide updated instructions.

This capability extension was to be a significant effort and required its own name. Eventually, it was agreed that the name "Semi-automated Forces" (SAF) was descriptive and appropriate. The SAF became a critical piece of the SIMNET technology initiated well after the system and simulator initial design. Retrofitting a major component like the SAF into the system clearly demonstrated the robust system design and protocols. Also, an early decision was made that the best way to include SAF was to use the same network interface as the simulators, so that the SAF computer instructions controlled electronic entities on the electronic virtual battle's digital terrain, functioning very much like the human operators.

A major difference occurred with the SAF's use of terrain. A human SIMNET operator relies on visual data presentations in the virtual world. Roads are depicted as a collection of black (or gray) polygons connected together and usually having a white stripe down the middle of the road presentation. Human SIMNET operators can observe this presentation and maneuver their vehicles to interact properly with the road feature. The SAF, of course, does not have any human sensory systems and its interaction with the road is derived from graph search algorithms applied to a graph of connected road arcs including attributes to describe the width, length, material type, and potentially other characteristics of the road segment. SAF reasoning was supported by a completely different database than the one used to permit human reasoning based on sensory-system perception. This design decision was enduring; simulations continue to utilize different, but related, physical databases of the same environmental information where each database has been implemented to optimize the performance of specific data uses. The situation is depicted in Figure 2 (note that "CGF" denotes computer-generated forces, referring to the computer-driven portion of SAF).

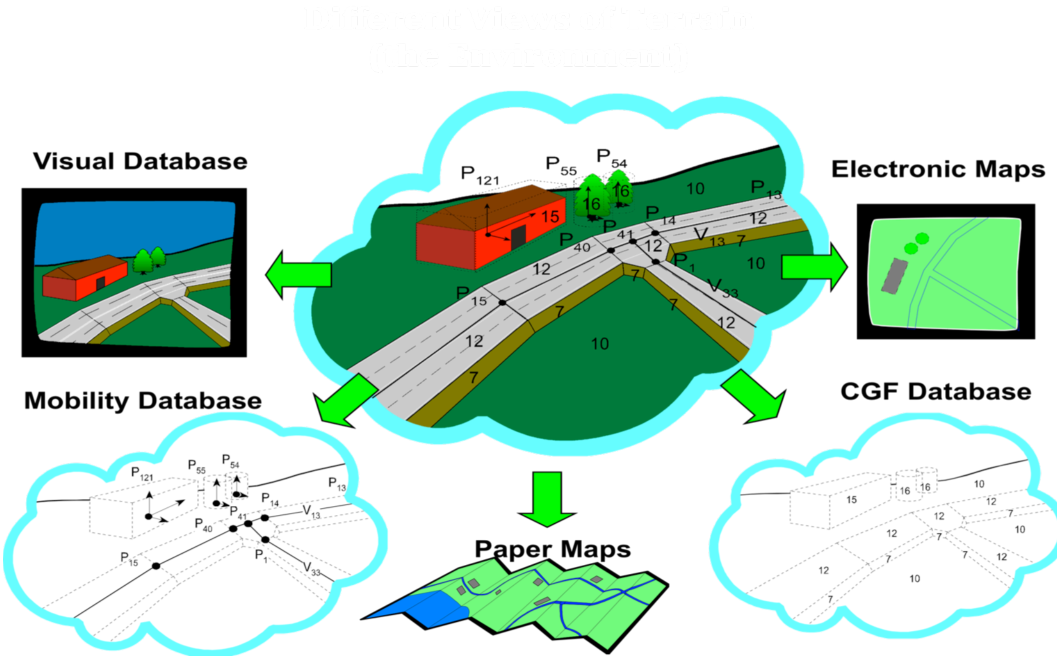

Figure 2. Many Different Tailored Databases of the Same Information

Soldiers training with the simulation were interacting with the system using devices intentionally designed to appear and function as much as possible like the weapon system they represented (e.g., an Abrams tank). The inside of a tank simulator looked like the inside of the actual tank, so humans in the simulation were quite naturally able to operate normally within SIMNET simulators (assuming they were able to operate the actual weapon system). Conversely, SAF was born late in the process and out of a need to create an intelligent opponent (OPFOR) and to create flanking forces and rear-echelon forces that were required to support training, but were not part of the training. SAF was never designed to be controlled by soldiers within units and, unfortunately, the SAF user interface has proven difficult to master. The "use your warfighting equipment" interface design approach was not extended to apply to the SAF operator who had to navigate menu choices and master "buttonology", often requiring knowledge of terms meaningful to SAF computer programmers, but not to the average soldier. So, while SAF represented a significant and fundamentally enabling advance in technology, it was not without limitations. Obviously, it did not resolve the need for fully-automated forces. More importantly, it now seems clearly evident that, from its inception, the SAF should have been controlled by an operational command and control (C2) system. This was not a trivial task at the time, and several related problem areas remain to be solved today, primarily because humans can interact through C2 systems at levels far above the level of SAF comprehension and capability. As an example, a command sent via a C2 system might simply be "proceed to the assembly area" which also implies the unit would deploy using a correct formation, relative to the assembly area terrain and forces already present. The SAF is not proficient in reasoning about supporting formations or terrain, so much more detail must be provided for the SAF to achieve this action. Similarly, use of C2 systems requires temporal reasoning, understanding the past, present, and future. This is also a current SAF limitation. Finally, use of C2 systems requires that live and operational forces be easily identifiable, so adequate safety measures can be applied to live forces and ignored when not necessary to preserve the "health" of simulated forces.

According to the original program goals, as capabilities were completed, related parts of the SIMNET system were to be turned over to industry for further development into systems deployable to the field. Impressive as they were, the elegant design and integration of the simulators, computers and graphics were not the most important aspects of the SIMNET program. Rather, the glue holding and binding these pieces together, the SIMNET network protocols, eventually demonstrated the greatest and most enduring value. If the benefits of the DARPA effort were going to be successfully transitioned to the Army and Department of Defense (DoD), then all the SIMNET technologies would have to be available to others. SIMNET would have to have an open architecture derived from standards development processes jointly developed and widely accepted. A successful SIMNET program transition of technology to the services would require a clearly defined and documented standard, independent of the SIMNET hardware and software implementation. The transition target for the DARPA SIMNET program was the Army's Close-Combat Tactical Trainer (CCTT) program.

The first related standards development conference was held in August 1989. Initial conferences were primarily focused on educating the simulation community concerning the design, capabilities, and requirements of SIMNET, but there was also substantive debate on the type of standards to be produced. Some argued for a government standard (MILSPEC) while others felt a commercial standard would be superior. The decision was made to pursue a commercial standard, following the lead of standardizing the Internet developments. IEEE was selected as the standards organization and a congressional budget addition went to the University of Central Florida, Institute for Simulation and Training (UCF IST) in Orlando to support the standards development effort. Once this was accomplished, the effort become one of transitioning from the system-specific SIMNET protocols to a more widely applicable Distributed Interactive Simulation (DIS) set of protocols. In March 1993, the DIS protocols became IEEE 1278 standards. A key figure in successfully creating the DIS standard was Ducan Miller of BBN. Without his commitment and passion for developing the necessary standards, the DIS standard would have not been successfully created. He was able to exert enduring leadership throughout the sometimes frustrating commercial standards process, a fully open system allowing virtually anyone to comment and recommend changes. The standards process started with the SIMNET protocols as the baseline, and then recommended changes to the baseline so that the final standard could be implemented by more than one company. This development was an excellent example of the truism - often, the hardest job of all is turning over a successful program to others. Eventually, the community set up the Simulation Interoperability Standards Organization (SISO) in Florida as a not-for-profit organization. The SIMNET technology transition and standards development converged in Orlando, Florida.

One assumption of the DIS (and later HLA) standard was that the terrain database would be completely distributed before the simulation execution; there was to be no run-time passing of environmental data. This design was necessary due to the very nature of SIMNET technology that focused on sending out incremental changes as asynchronous updates as a means to reduce network bandwidth and maintain human perception of a synchronous world in time. However, terrain-related issues were not completely ignored in the DIS standard. One of the most significant changes taking place as the protocols matured from SIMNET-specific to the DIS specification was the inclusion of a much more capable coordinate system. SIMNET used a flat-earth Cartesian system corresponding to the military's Universal Transverse Mercator (UTM) system and to the standard computer graphics coordinate system as well. The lower left hand corner of the terrain area was the standard reference point. Those participating in the DIS standards development realized this as a severe limitation if the protocols were to be used in larger, more expansive exercises as envisioned. As a result, DIS includes a coordinate system where the origin is placed at the center of the Earth and the Earth's curvature can be represented. Today, DIS is a viable, evolving, and still very widely used set of intercommunication protocols, despite the advent of other more capable architectures. It provides an easily understood specification of wire traffic meaning and coordinate systems and is an open standard that can be changed by community consensus.

Digital terrain was an important area not seriously addressed by the DIS standard (other than the related coordinate systems effort). SIMNET had adopted a locally effective solution to the terrain representation problem, but one that also turned out to scale poorly. From its inception, throughput was a major concern for the SIMNET engineers. Graphics engines and network transmissions had to complete rapidly enough so trainees felt all the stresses of actual combat without the artificialities and distractors often accompanying latent message receipt, slow refresh rates, and similar artifacts. These concerns had direct impacts on the use of digital terrain. First, digital terrain was pre-distributed (as mentioned above), prior to the start of any exercise. This reduced the network load since terrain information was not being dynamically served and thus was not competing with simulation traffic for network resources. Second, there were actually multiple terrain databases in use during any SIMNET exercise; individual databases were tailor-made for individual system use to maximize potential throughput, computation speed and accuracy. As an example, the graphics engines had a representation of the terrain data constructed so as to speed polygon rendering and to be able to most easily present the rendered information in a form suitable for human visual system comprehension. The SAF systems had another form of the database constructed to best serve line-of-sight calculations, route planning, and other functions based on direct calculation. In general, any time a new simulation system was added to an existing federation of interacting simulations, a terrain database would have to be built for the new system, unless the new system could consume the same format data as one of the existing systems. These decisions on terrain use have fair-fight implications. Any time multiple database copies of the same information exist, the situation is ripe for information mismatch and different depictions of the same information. The SIMNET solution allowed a potentially limitless number of different copies of the same information to exist.

Creation and adoption of the DIS standard protocols did nothing to address the terrain representation problem – there was no attempt to create a standard, run-time representation for terrain, and this situation persists today. It seems highly likely the problem will exist well into the future, unless both network bandwidth and computer processing speed make great advances to the point they become virtually unlimited. There are ways to address interoperability of the terrain representation by looking at common features, attributes and relationships in the simulated world. The system solution for terrain involves recognizing all the applications (Visual, SAF, map, etc.) have competing needs for terrain representation within the simulation. As a result, one must simply accept the differing views as illustrated in Figure 3. This figure provides a simple example to highlight a system view of a single feature like a tree with all the potential attributes for all applications. (Again, note that CGF denotes computer-generated forces, referring to the computer-driven portion of SAF)

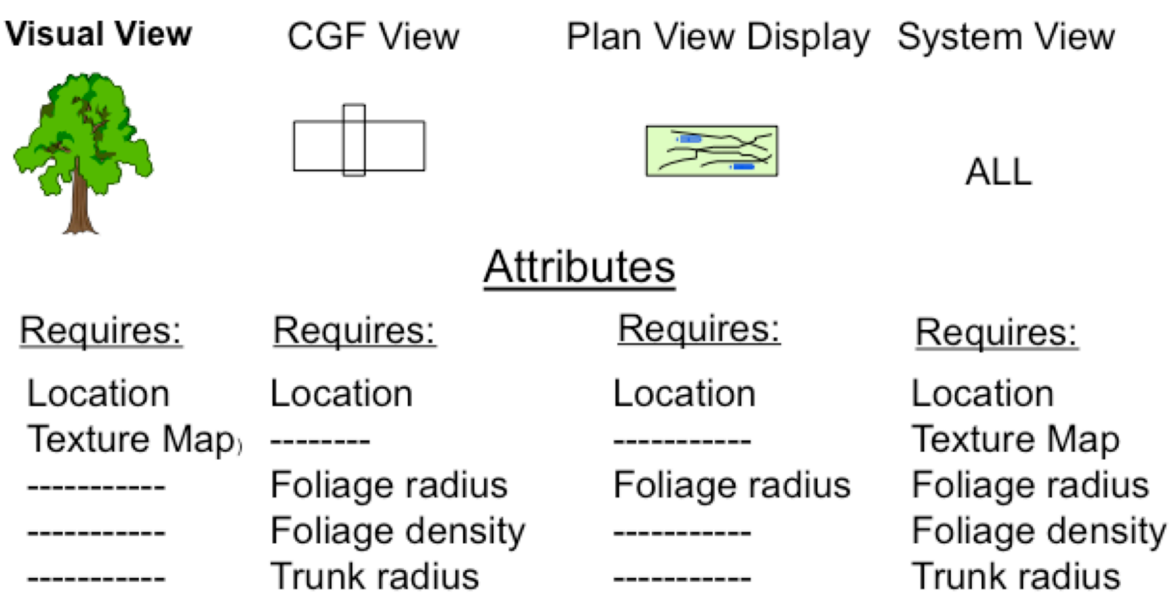

Figure 3. A Tree in its Various Forms (A Tree by Any Other Name …)

SIMNET terrain creation started with the visual representation and generated the other views using a value-adding process removing unnecessary visual data and filling in missing data required to support the other non-visual application uses in their terrain representations.

Summarizing the Lessons Learned

The SIMNET development years were remarkable in the amount of technological advances that were achieved. Experience with SIMNET implementation also demonstrated several enduring principles that will be tenants of successful simulation systems, both now and in the coming years:

- Human-computer lash ups are viable overall strategies for solving problems requiring human cognitive skills – the strategy is scalable and flexible
- Progress in automating cognitive skills and human judgment has been and will continue to proceed at a glacial pace
- Interfaces are vitally important – poor interfaces can result in system disuse while well-designed interfaces become fully transparent
- Standards are required for progress; without standards, progress can be rapid, but not scalable
- Coordinate systems are important and specifications must be suitable for the widest envisioned use
- Terrain can be a "long pole in the tent"; standardization of run-time formats is very desirable, but seems unlikely

THE DMSO PERIOD

In 1991, The Deputy Secretary of Defense began a new effort focused on modeling and simulation within the Department of Defense. The concept was to establish a DoD Modeling and Simulation (M&S) policy, facilitate coordination among the DoD modeling and simulation activities, develop and promote appropriate interoperability standards, and stimulate joint use of the associated technologies. A central part of the initiative required creation of the Defense Modeling and Simulation Office (DMSO), the precursor to the current Modeling and Simulation Coordination Office or MSCO. This Agency was to serve as the executive secretariat for the DoD Executive Council for Models and Simulations (EXCIMS) and to act as the full-time office responsible for the development and promulgation of modeling and simulation policy and standards. DMSO would act to maximize modeling and simulation efficiency and effectiveness across the joint defense enterprise. This action effectively signaled the ending of the DARPA SIMNET period and the beginning of technology transition to the DoD. The path forward for virtual Tactical Engagement Simulation (TES) was clear, as was its reliance on DIS as the single, but appropriate, modification to the SIMNET design for the systems to be fielded.

Figure 4 describes the initial DMSO technology direction based on the SIMNET program and a related DARPA program known as the Aggregate-Level Simulation Protocol (ALSP). ALSP was intended to apply SIMNET design principles to event-driven, faster than real time, constructive (primarily analytical at the time) simulation. The well-known simulation characterizations provided by General Gorman, (USA, Retired) of Virtual TES, Constructive TES and Subsistent TES (which was later renamed as Live TES) were critical organizing concepts to show commonality and convergence.

The talented and dedicated people assigned to the DMSO were responsible for many seminal achievements during this period. For the purposes at hand, this paper focuses on two areas offering potential guiding principles as the industry moves into the future. Both of these are related to standards development and promulgation. First, the DMSO was responsible for the design and implementation of the High-Level Architecture (HLA) as a more capable intercommunication architecture able to replace the DIS standard and include the capabilities demonstrated by the ALSP. The HLA was an evolution to apply an expanded architectural construct to all Virtual, Constructive and Live TES areas. Second, the DMSO initiated and sponsored development of the Synthetic Environment Data Representation and Interchange Specification (SEDRIS) as an initial effort to promote some standardization in the important area of digital terrain. These were the technical thrusts in the early days of the DMSO. There was also a policy dimension addressed later in this paper.

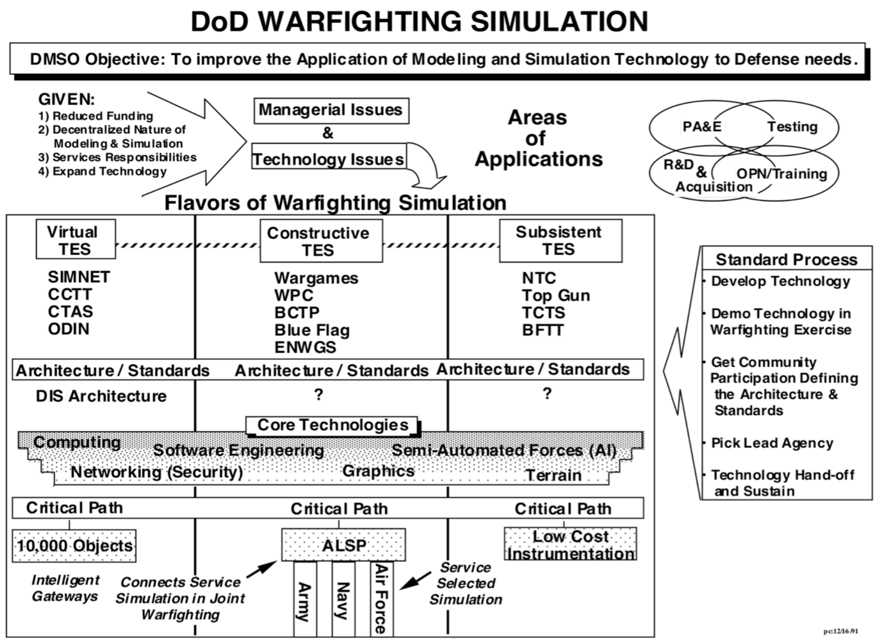

Figure 4. Initial DMSO Thought

The HLA was intended to expand the applicability of simulation to important problem domains not well served by the DIS protocols. As an example, DIS does nothing to address the time-management problem. The DIS approach was quite reasonable when the protocol was supporting virtual simulations, like SIMNET, that executed in wall-clock time. However, it was not sufficient to support analytic simulations that managed time according to islands of important events (event driven) and / or were required to execute in faster-than-real time. This is but one example fueling a perceived need to expand on the DIS capability set to develop an architecture useful for any simulation task. It was also important for the new HLA to be recognized as the single DoD intercommunication architecture standard to improve interoperability across the joint simulation community.

In the end, HLA evolved into a very capable intercommunication architecture, becoming an international resource under the IEEE 1516 series of standards that is widely used, not only within the DoD, but also by a host of other nations as well. The HLA is a considerable success that could have been even more successful. The HLA construct, including the interface specification, object model template (OMT), run-time infrastructure (RTI), federation object model (FOM) and simulation object model (SOM) are powerful, but fail to reach their fullest potential because their development was not coupled with policy (discussed later in the paper). However, there are two main lessons to be drawn from the HLA experience. First, the level and completeness of the standard specification is vitally important; the specification has to address all areas impacting interoperability. Second, the scope of standard implementation must be tailored to the needs of the intended user communities.

The HLA provided a specification standardized at the interface level. Previously, DIS had specified the actual message format and content to be passed between simulations, to create a “wire-level” standard (the content “on the wire” between communicating simulations was specified in the standard). The HLA approach left the “wire-level” content open, so industry could make independent decisions appropriate for their implementation and, hopefully, maximize efficiency for network load. The end result of this strategy was that two vendor’s implementations of the HLA (interface) standard would not necessarily interoperate with each other due to different format and content of message traffic “on the wire” connecting them. Even today, gateways to translate message traffic are required to connect two different vendor implementations of the HLA standard. So, the first important lesson is that when interoperability is the goal and specifications of standards is the primary method to achieve the goal, the standard must address all levels of interplay influencing interoperability. The government needs a reference RTI implementation (GOTS) and an on the wire standard in order to realize the full benefits of HLA.

A second lesson to be drawn from the HLA experience is not unlike another lesson the DoD has experienced in the recent past. The ADA programming language was sponsored and developed by the DoD so it could be used for any programming task (high-level applications, real-time-embedded code, and anything in between). Further, it was designed to include modern programming concepts intended to improve programmer productivity and decrease software maintenance costs. ADA failed impressively at this task! Not only did it fail to become the only programming language used for all DoD applications, it is now very difficult to find any DoD application implemented in the ADA language. This resulted from the nature of ADA itself. It includes a wide variety of features and constructs designed to reduce software development and maintenance cost, but each of these "bells and whistles" comes with a price. That price became too great a burden for most application development efforts. The situation with HLA is not nearly as extreme, but it is cut from the same cloth.

Today, HLA is widely used. However, DIS is also widely used, despite HLA having been "mandated" as the single DoD architectural choice some years ago (later rescinded). HLA has never been able to fully replace DIS. The reason is the wide variance in cost to use the two specifications. DIS is relatively simple to learn, easy to implement, and free to acquire. HLA is large and expansive, more difficult to learn, and must be purchased from a private vendor. When DIS provides the capabilities necessary for some simulation use, it is by far a lower-cost option. The lesson here is that the standard must be appropriate for its intended context of use. HLA might have avoided some of the attendant problems if the specification allowed lightweight "HLA subset" implementations and a GOTS reference implementation was provided on an enduring basis. However, "HLA subset implementations" have been specifically prohibited, so HLA will always be more complex than DIS and thus be more unattractive for less ambitious simulation applications. HLA has proven to be successful, but its level of success was limited by some of the early design and standardization decisions.

The SEDRIS effort was also a key achievement during this period. The SEDRIS goal was to address the terrain representation issue and to solve the problem of location (coordinate systems). Again, the focus was on the creation of standards to improve interoperability and decrease cost. SEDRIS was also significant because it represented the first comprehensive attempt to make improvements in the digital terrain reuse problem. As above, the essence of the dilemma is that simulations have to represent the same terrain data in multiple formats to support different needs within one application and between applications. This greatly increases the cost of creating a simulation customized to represent a particular place. Often, multiple simulation systems interact in a single exercise, multiplying the problem yet again, since each system would usually need their own representation of the environment. Rarely were single terrain databases of a specific location suitable for sharing between systems; each would need a unique representation in a specific format tailored to system calculations. SEDRIS attacked this problem by devising a system able to represent any type of environmental data and providing interfaces to translate into and out of the representation. Thus it became possible to share data between systems, using SEDRIS as an intermediate form.

A key to the degree of success SEDRIS achieved was the problem decomposition the program employed. SEDRIS resulted in the adoption of three separate ISO / IEC standards: 1) a Data Representation Model (DRM); 2) a Spatial Representation Model (SRM); and 3) the Environmental Data Coding Specification (EDCS). The DRM provided "containers" to store and provide data. The SRM provided very fast, efficient, and accurate algorithms to convert data coordinates between many coordinate systems. The EDCS provided a dictionary-like specification and codes able to unambiguously identify data. The three standards could be used independently or cooperatively. In fact, the SRM and EDCS are successful in their own right, have arguably been the greatest success stories from the SEDRIS effort, and are still in use today, apart from any SEDRIS effort.

While there was a degree of success for the SRM and EDCS components, SEDRIS as a whole has not been widely adopted as a mechanism to reuse environmental data within the DoD. The reasons for this are closely related to some of the failings of the HLA explained above. First, SEDRIS was designed and constructed to represent any kind of environmental data; terrain, bathymetry, atmospheric, space, oceanographic, and so on. Like HLA (and ADA), powerful mechanisms of this nature tend to come with added complexity and cost of use. In the SEDRIS case, it was perceived, valid or not, that the process of getting data into and out of the SEDRIS form was far too difficult and costly and a program could effectively pursue the data (re) creation problem instead. Part of this perception could also be traced to missing standards from the SEDRIS ensemble. Neither a specification about data content nor data quality was ever made part of the program. A program could go to the expense of extracting data from a SEDRIS representation only to find the data did not really meet their needs due to quality of content shortfalls.

The Rapid Data Generation (RDG) program is a current DoD effort to reuse several forms of data, including order of battle (OOB) and digital terrain data as examples. The RDG initial approach was to rely on de-facto industry standard formats (such as shape files, DTED, geotiff, and OpenFlight) to promote exchange of terrain data. Participants in the RDG program agreed to a process calling for translation of their corrected, improved, and correlated run-time format data into these standard formats for sharing among the RDG participants. The advantage of this approach is that the exchange mechanisms are all simple, standard formats that all data producing and consuming programs must be working with to be effective. Some degree of information loss is involved when translating from system run-time data into these simplified formats, but the loss is acceptable to the participants. This solution is clearly not as elegant or comprehensive as the SEDRIS approach. It is pragmatic, in that it is very low cost and even though the capabilities are reduced, those present are meeting the need at hand. (In some areas, this is not unlike a comparison between DIS and HLA.)

Related Department of Defense Policy

Developing the DoD policy was a most challenging task since there were cultural as well as technical issues confounding the process. The DoD is filled with well-established organizations, many having entrenched beliefs derived from their own history and experience with simulation use. Many organizations were sometimes more interested in talking about the past and defending the way they did things than in thinking about potential improvements for the future, both applicable within their organization and extendable to others as well. There were some that wanted a major change in DoD M&S policy on the representation of systems and capability. The initial draft DoD M&S policy in early DoD 5000.59 stated:

"Each DoD Component shall be responsible for representation of its own forces and capabilities in M&S applications, and will provide these representations to other DoD Components for joint and common use."

It was later changed and published as:

"Each DoD Component shall be the final authority for validating and accrediting representations of its own forces and capabilities in joint and common use M&S. Each Component shall be responsive to the joint and common use M&S. Each Component shall be responsive to the other Components to ensure that its forces and capabilities are appropriately represented in the development of joint and common use M&S."

There are important distinctions between the two policy statements. The original draft policy clearly placed the requirement on each DoD Component to be responsible to build representation of its own forces and provide them to others. Conversely, the revised (and current) policy does not make the Component responsible for building and providing its representation, but only validating a representation of its forces. Experience has shown validation, especially after the fact, will neither provide high-quality representations nor eliminate duplication of effort. The responsibility for representation of system and capabilities is still not resolved today.

The rationale for the first policy statement above was that the organization best suited to represent a system or capability in simulation was the organization acquiring the system or capability. This would reinforce the use of simulation as an integral part of development and test as well as the means to transition the simulation for training. The rationale for the second policy was the responsible organization would be the final accreditation authority and there could be too many demands in differing levels of representation since "one size" simulation would not meet all needs. Today, it appears clear that we do not have effective M&S policy and the duplication of representation costs more than is reasonable to bear. One of the major, fundamental goals of the HLA was that the creation of simulation object models (SOM) and in the long run standard SOMs for system and capabilities in varying levels of detail would emerge. This is the enterprise-level, lower-cost alternative to duplication.

Summarizing the Lessons Learned

The DMSO provided many advances in simulation. Some of their efforts, while still providing measurable value and increase in capability, were less successful than originally envisioned. The shortfalls could be described as failures to adhere to principles for standards development:

- A standard must fully address all component parts of the problem to be solved, either by separable pieces of the standard or as a single unified standard – the former is preferable
- Standards should be as simple as practical and limited by the scope of the problem to be solved – over specification can also have ill effects, particularly when additional specifications cannot be separated from the whole
- Just as with interfaces, standards can be more effective when they decrease user burden by building on familiar tools and interfaces
- Practical policy is essential to fix responsibility for representation and to ensure effectiveness and efficiency while establishing congruence with technical advances

THE CCTT PERIOD

I was fortunate to be selected as the first Program Manager (PM) for the Combined Arms Tactical Trainer (CATT). The Close-Combat Tactical Trainer (CCTT) was the first CATT component to be developed, starting in 1992. CCTT was tasked to build and successfully field 11 battalion-level task force sites for the Army worldwide. Each site had enough manned simulators and SAF to support battalion-level task force exercises. This goal was achieved and CCTT currently supports the Army and has been continually expanded and upgraded over time. CATT was the intended technology transfer target for the SIMNET program and it benefitted from many of the lessons emerging from earlier experiences with SIMNET, DIS, HLA, and SEDRIS. CCTT built on most of the successes of DARPA's SIMNET program, including use of the DIS protocols. CCTT was the first large-scale program of record to implement DIS standards. In fact, the CCTT program helped to drive further development of the DIS standards and is still vitally interested in further DIS development today. Standards will flourish only when they are associated with viable programs using them.

The most important lessons taken from SIMNET and applied to CCTT were to: 1) get the user involved early and; 2) plan and execute the program to show incremental progress. The CCTT program was provided on-site subject matter experts (SME) from the Armor and Infantry domains. These soldiers represented the user community and functioned as domain training experts to assist the developers. Also, CCTT depended on a spiral development approach (implement, review, revise, test) to show incremental development program progress.

One unfortunate and regrettable lesson from the initial CCTT development period was the selection of ADA as the programming language. The DARPA SIMNET program was written primarily written in C language, but the DoD policy for programs of record at the time mandated ADA as the only acceptable software implementation language. C was selected in DARPA SIMNET program because it was commonly available and taught widely in all most colleges. The people graduating from college with computer skills typically had experience with the C language. ADA was not widely taught at the college level. An early analysis of alternatives study was influenced by the prime contractor recommendation that ADA be used to implement CCTT. Ultimately, this proved to be the wrong decision and ADA was replaced in the CCTT program. Despite the policy mandate, evidence that ADA was not a viable long-term solution abounds today and there is no longer an ADA mandate. This is another example of a case in which a flawed policy had a major impact on cost and long-term schedules.

The selection of the ADA programming language also applied to implementation of the CCTT SAF, development of which was to be based on the SIMNET SAF. One major limitation of SIMNET SAF was the explicit representation of orders and instructions and this limitation was addressed in part within the CCTT SAF structural framework. However, it became impossible to set up a workable framework for extensive collaboration with DARPA on joint development of a single SAF, given the different programming languages and schedules. The chart in Figure 5 shows the evolution of SAF over time. The OneSAF testbed (OTB) led into the OneSAF program of record, producing the capability fielded today. The separate CCTT SAF has been replaced recently with OneSAF and CCTT sites have upgraded to OneSAF. CCTT SAF did make a number of key improvement with the representation of orders and instructions and an explicit method of defining SAF behaviors was developed using combat instructions sets (CIS). These development concepts flowed into the OneSAF program, but it took many years longer than needed.

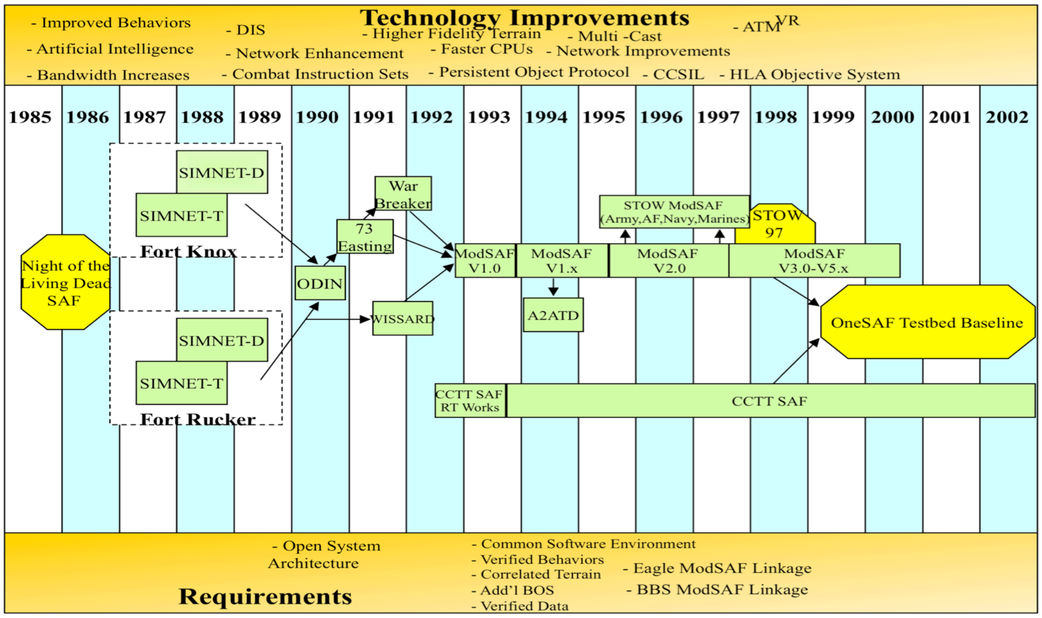

Figure 5. The Evolution of Semi-Automated Forces

The CCTT program had to deal with the terrain representation. Few seemed to comprehend the notion of different applications requiring different views of the same terrain. A fine example of this occurred during the CCTT testing. (This example was the reason for the creation of Figure 2 above.) The example occurred during the final integration events with the full systems leading to final system testing, but using a new terrain database. The testing encompassed all the components included manned simulators, SAF representation and plan view with exercise control. One of the CCTT requirements included tethering SAF entities to manned simulators. In this test scenario, the platoon leader in a manned simulator would lead his platoon on a road march and the rest of his platoon would be represented by SAF entities, following behind him on the road march. The platoon leader moving down the road came to the intersection and made a right hand turn and continued down the road. The SAF entities came to the intersection and moved off the road and stopped for a short time. After a short pause, the SAF got back on the road, increased their speed to catch up and followed the platoon leader in the manned simulator. It took months to find and fix the problem. Why didn't the SAF just follow immediately? Eventually, the engineers detected a very small gap (not visible to the human eye) in the line segments connecting the roads in the database supporting SAF mobility (routing). SAF routing required exactly connected line segments. The road line segments did not connect but had a short (.0003 meter) gap. The SAF re-planned to correct their behavior when they encountered the road network gap. They got off the road, organized a hasty fighting position with all-around coverage of observations and fields of fire. Once they re-planned their new route and identified the correct road to follow, they got back on the road and followed the platoon leader. This real example reinforced the terrain problem. Events like these coupled with the previous DMSO experience on coordination a common terrain and the clear understanding of distributed simulation technology requiring the pre-distribution of a common terrain with common features but varying attributes based on the terrain reasoning to be performed by using applications, led to the creation of the SEDRIS program. The intent was to use a large program to help drive and address complex technical issues that need to be resolved as part of the overall terrain problem.

CCTT highlighted some of the genius of the SEDRIS program. Terrain representation, the sharable and unambiguous identity of included features, and the precise representation of location (the three pillars of the SEDRIS program) have always been integral considerations during CCTT development.

Considerable progress has been made on common terrain with the Army's Synthetic Environment Core (SE CORE) program. This program is designed to take multiple source data and produce common terrain for distributed live, virtual and constructive exercises. The effort focused on establishing a fully-defined, repeatable process derived from clear specifications to produce simulation run-time formats of terrain. The simulation run-time formats are the collection of terrain features, attributes and relationships required by a specific application for a given terrain. These differing formats include the visual system image showing the 3-D virtual world, a SAF view, a map, and others. Again, each of the applications participating in a distributed simulation exercise needs their own format of the terrain, and this data must be pre-distributed (as discussed earlier). The application's run-time format organizes the terrain data in a specific way so it provides near-optimal support for the application's intended purpose. As an example, visual system databases usually organize pixels and polygons from near to far. Run-time formats will continue to be required until computation resources become an insignificant technical and resource consideration. Such is not the case today.

Figure 6 provides the architectural view of the SE CORE terrain creation process, moving from left to right with the source data as the starting point. Source data creation is not part of the SE CORE program but is provided by a number of government and commercial GIS data providers. The SE CORE process takes the provided source data and: 1) extracts the features and attributes; 2) orders and aligns them with the Master Database Population; 3) creates a Master Database, 4) processes the Run-time Database Production and, 5) produces a run-time format of a given train area for a specific simulation run-time format. The run-time database of a specific application is the end product and each simulation requires one or more unique run-time format databases. Twenty-one run-time formats are shown in Figure 6. The actual number has increased to over 30 required today.

The enterprise-level business model for distributed interoperable simulation exercises terrain databases supporting a number of applications is based on a simple cost equation. Let C represent the cost a single run-time format. C is composed of the cost of extracting and preparing the source features and attribute data (A) added to the cost of preparing and processing the terrain to create a specific run-time format (B). The simple equation is $C = A + B$. For creating any given terrain run-time format, (A) is about 60% of C and B is about 40% of C. If N is the total number of run-time formats necessary to support an enterprise, and each run-time format requires a complete C (little reuse of any previous A or B components), then what value of N makes sense at the enterprise? Again, SE CORE is now using 30 run-time format databases. Clearly, N should be a small number. This is the underpinning of the business model.

In general, much of the CCTT program can be counted as a success. It endures today as the primary virtual collective trainer for Army echelons at battalion and below. CCTT created an improved version of SAF that ushered in today's OneSAF system. It provided the original impetus functioning today as the SE CORE program. In fact, there was only one significant area where CCTT development provided a lesson of "what not to do" - choosing ADA as the system implementation language. In fairness, when CCTT development was initiated, ADA was a mandated standard for such tasks. However, the language proved to be unsuitable for continued use in systems development for CCTT and some parts of it were replaced.

Summarizing the Lessons Learned

- A standard needs to be aligned with a viable program to take hold and evolve to provide real-world utility
- Technology transfer works best when both people and ideas are transferred
- Flawed policy mandates live a long life and can be more damaging than technical errors we spend so much effort to avoid
- Terrain, terrain, terrain …

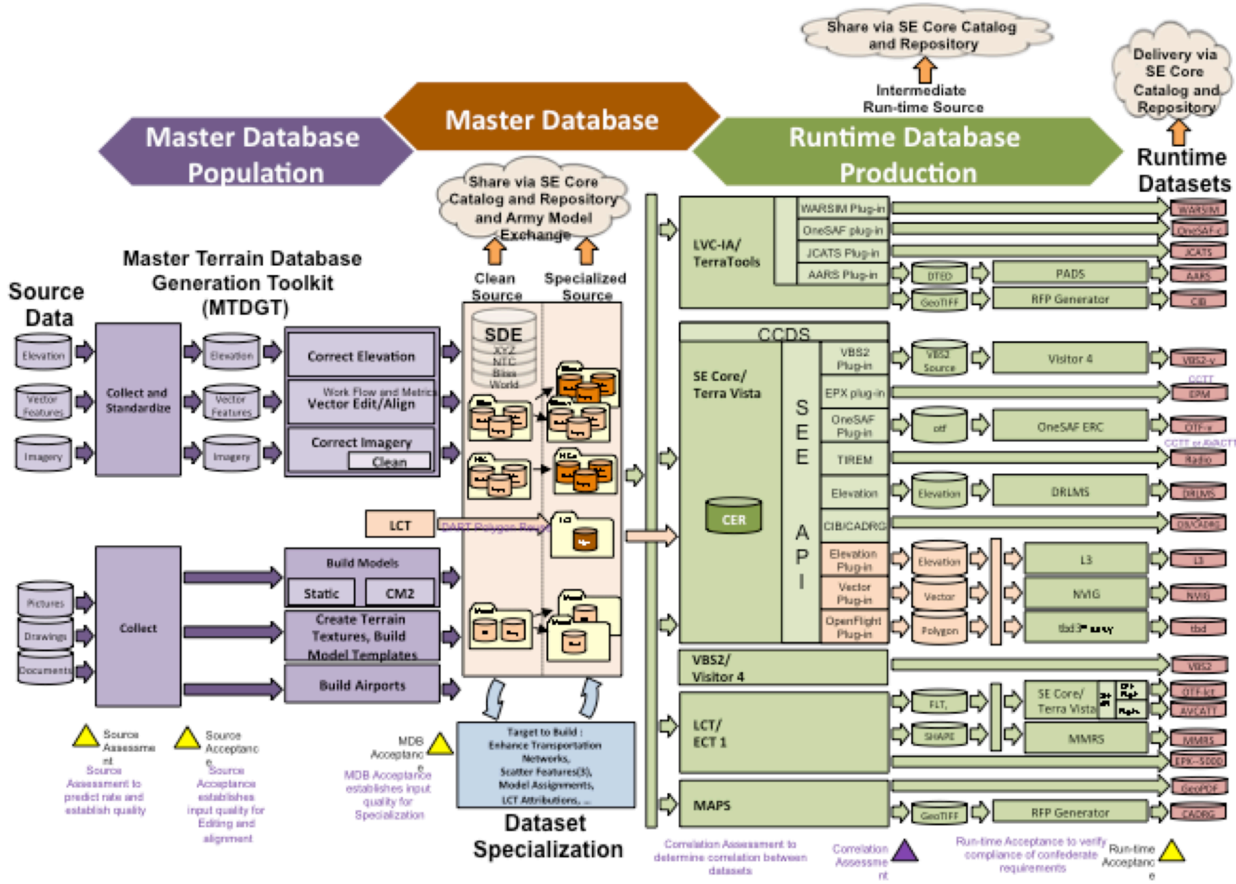

Figure 6: The SE CORE Terrain Production Process

SUMMARY AND CONCLUSIONS

The period prior to the advent of SIMNET offered several fundamental lessons. Proficiency for military units is multi-faceted, not only along echelons but also by mission task. The common unit exhibited cyclic proficiency, becoming very competent at a specific task, only to lose competency as personnel rotated and the training focus changed to another task area. Overcoming the cycle of proficiency gain and loss can best be achieved by ensuring each unit has access to continuously-available training resources.

The SIMNET period was one of remarkable achievements and advances. Key points from this time include the concept that semi-automated solutions are often cost-effective, achievable and appropriate solution strategies. This is an area where "the better is often the enemy of the good." While increasing the level of automation and computer capability clearly deserves continued effort, creating human – computer teams and allowing each to contribute from their unique strengths is a viable strategy to maintain the pace of progress. In addition, the SIMNET experience shows three important areas where effort must be increased: 1) standards are vital; 2) interfaces should be derived from or use operational systems; and 3) digital terrain is enabling, but can be limiting at the same time.

Lessons from the SIMNET period were reinforced during the DMSO years. In particular, standards need to be at once flexible, encompassing, and as simple as possible. Standards must conform to user needs. Further, policy is a key factor in all of these areas. Policy is necessary to support and drive both standards development and technological advance.

Cumulatively, all of these experiences point to the need for a continuously-available training resource, fully supported by standards and policy. Further, this training resource must be adaptable to user needs, allowing user choices for method of access (using their own equipment), time, and place. These characteristics will not only support evolution into invaluable training resources, but support mission execution and the entire system life cycle as well.

Looking Ahead

Each of the previous sections has concluded with a short summary of lessons learned during the period described. In each case, the Summarization of Lessons Learned section has been provided to identify guiding principles as the modeling and simulation industry moves into the years ahead. Those individual statements need not summarized again. Instead, we should look at those statements as a "collection" pointing towards a necessary capability if we are to enjoy continued success in this industry.

1. As stated by earlier I/ITSEC fellows, the DoD truly needs to establish and maintain a network accessible virtual world for education, training, planning, rehearsal and operations. Moreover, this network virtual world must be flexible, changing on demand to meet needs of its participants. Those needs could include locations, scale, dynamic time periods (past, present, or future), and dynamic adversaries and equipment.
2. This virtual world will necessarily be constructed from fully correlated data producing only "fair fight" results.
3. The Department of Defense needs to rethink and adjust their M&S policies to meet their long term objectives and reduce cost.
4. The interface to reach this virtual world will be dynamic. It could be reached from constructive computer-driven forces, through virtual world human interfaces, as used by CCTT trainees, or through the C2 systems used at multiple echelons of command. The integration and convergence of M&S and C2 systems will require that C2 system establish the capability to characterize and understand time, past, present and future. C2 systems will also have to be able to separate simulated data from real data at a given instance of time.
5. The virtual worlds would be equally useful to support any tasks included in the complete spectrum of defense activities. This includes multi-echelon training, planning, and mission rehearsal as well as systems initial design, test, and acquisition. In short, simulations will become transparent parts of C2 systems and normal acquisition processes.

This enviable capability will never come to fruition, and if it could, would never be sustained, without equal and unifying policy to guide the technologies as they are developed and matured across the entire Department. Such policy is woefully lacking today, and the remarkable progress the industry has made to date is a testament to the talented and dedicated people involved, but not due to a leadership failing to shepherd the successes through management guidance. This must change in the near term to continue with our rapid pace of progress.

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