Realism in Modeling and Simulation with Implications for Virtual Reality, Augmented Reality, and Immersive Environments

Jeffrey Wallace, Sara Kambouris
Infinite Dimensions Integration, Inc.
West Plains, Missouri
jeff@id-inc.us, sara@id-inc.us

ABSTRACT

Improved realism in modeling and simulation (M&S) efforts is increasingly viewed as a necessity or requirement across a wide spectrum of Department of Defense (DoD) projects. However, the definition of M&S realism differs considerably across the community of practice.

The goal is to clarify the requirements for realism; to elucidate the meaning of realism as it pertains to different communities; and to frame key concepts in the representation of reality. In general, M&S efforts support several functional areas, including: training, mission rehearsal, test, evaluation, experimentation, acquisition, analysis, and planning.

Consider training, analysis, and acquisition as examples. The goal for M&S training is to cost-effectively challenge the skills of the trainee at the tactical, operational, and strategic levels. Skills should be challenged without risking injury to people, or damaging equipment. Training should encompass the full range of peacetime and wartime activities the trainee would engage in. M&S must provide realistic portrayals of the world to support that goal. Likewise, M&S analysis aims to provide a powerful set of tools to systematically evaluate and optimize alternative force structures against a range of foes, who may utilize potentially different tactics. The goal for M&S acquisition is to safely, cost-effectively and iteratively design virtual prototypes to assess the viability of future systems prior to production.

Increased realism supports and improves the functional areas listed above. In order to provide identification with, and understanding of realism, perspectives from each functional area will be discussed in addition to the role of modeling paradigms and implementation concepts.

ABOUT THE AUTHORS

Jeffrey Wallace, Ph.D., Co-Founder, CEO/CTO of Infinite Dimensions Integration (IDI) and has over 30 years' experience in high performance computing, interoperability, machine learning, unmanned systems, and predictive analytics, modeling and simulation. Dr. Wallace has served in a variety of leading positions in academia, government and industry. Dr. Wallace solved the computational electromagnetics that led to the modern generation of circuit design. He has led numerous teams on leadership visible projects with compressed timeframes. The most visible project was helping prove the central thesis of the Joint Strike Fighter (F-35) program award using the JEE's unique publish/subscribe API and architecture in a demanding real-time environment. Of particular interest, several projects involved advanced analytics and machine learning for Navy Medicine, semantic computing for the Joint Forces Command J7, and cloud computing for the Joint Chiefs of Staff J7. He was the chief architect or senior systems engineer for the DoD's five most complex software systems and led the development of a 5th generation, multi-purpose computer language, IMPORT, for complex system development and artificial intelligence. Dr. Wallace has written over 40 technical papers, and edited six books listed in the Library of Congress. He served as the general, or program, chair for numerous International conferences in unmanned systems, artificial intelligence, modeling and simulation (M&S), and high performance computing. He served as the VP for Membership for the Society for Modeling and Simulation International, Board of Directors, and chaired the 50th Anniversary conference. He was a plank owner in the Modeling and Simulation Professional Certification Commission, and led the team that created the Certified M&S Professional examination. He chaired the Emerging Concepts and Innovative Technologies subcommittee for the 2008 Interservice/Industry Training, Simulation and Education

Conference, the 2010 Unmanned Systems Interoperability Conference, and sponsored the 2017 Air Force FACE TIM, Dayton, Ohio.

Sara Kambouris, Ph.D., Co-Founder, COO, operating from the Missouri headquarters, IDI facilitates solutions, including but not limited to, software and hardware development, as well as, intricate sensors and systems integration issues across the entire Department of Defense (DoD), but specifically the Office of Secretary of Defense (OSD), the Joint Chiefs of Staff, along with the Air Force, Army, and Navy. IDI technology allows all software, hardware, systems of systems, systems of sensors to interoperate with any other systems or organizations rapidly, efficiently, and cost effectively. IDI specializes in next generation real-time collaborative systems and physics-based modeling and simulation.

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INTRODUCTION

Improved realism in modeling and simulation (M&S) efforts is increasingly viewed as a necessity or requirement across a wide spectrum of Department of Defense (DoD) projects. However, the definition of M&S realism differs considerably across the community of practice. The goal is to clarify the requirements for realism; to elucidate the meaning of realism as it pertains to different communities and to frame key concepts in the representation of reality. In general, M&S efforts support several functional areas, including: training, mission rehearsal, test, evaluation, experimentation, acquisition, analysis, and planning.

The primary goal for M&S training is to cost-effectively challenge the skills of the trainee at the tactical, operational, and strategic levels with different levels of realism. Augmented reality (AR) is a live direct or indirect view of a physical, real-world environment whose elements are supplemented by computer-generated sensory input (e.g. sound, video). Augmentation occurs in real time and in semantic context with environmental elements. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally manipulatable. In AR, information about the environment and its objects is overlaid on the real world. This information can be virtual or real, e.g. seeing other real sensed or measured information. Augmented reality brings out the components of the digital world into a person's perceived real world. By contrast, virtual reality (VR) replaces the real world with a simulated one. M&S must provide realistic portrayals of the world to support an organization's training goals. M&S supports realism adding to the effectiveness of the simulation.

Training skills should be challenged without risking injury to people, or damaging equipment, while encompassing the full range of peacetime and wartime activities a trainee would need to succeed. M&S analysis aims to provide a powerful set of tools to systematically evaluate and optimize alternative force structures against a range of foes, who may utilize potentially different tactics. Safely, cost-effectively and iteratively designing virtual prototypes to assess the viability of future systems prior to production will help meet that M&S acquisition goal. Increased realism supports and improves the functional areas listed for AR and VR. In order to provide identification with, and understanding of realism, perspectives from each M&S functional area will be discussed, in addition to discussing the role of modeling paradigms and implementation concepts. First, several common-sense questions regarding realism are posed for training systems:

- How do we measure the realism of a model or simulation?
- What is the relationship between realism, verification, validation, and accreditation (VV&A)?
- How do we describe differences in realism across various models or simulations?
- What underlying M&S development capabilities are needed to support the implementation of realistic simulated entities?
- What type of computational infrastructure is required to realistically portray a large scenario in a M&S supported activity?
    - Is it visual?
    - Is it related to M&S resolution and fidelity?
    - Is it the physical motions and characteristics of simulated entities (e.g., kinetic aspects)?
    - Is it cognitive behaviors (e.g., non-kinetic)?
    - Are terms like kinetic, non-kinetic, visual, and non-visual sufficient?
- Does the representation of the environment fit in terms of a kinetic/non-kinetic taxonomy that currently appears in M&S vocabulary?

The environment affects kinetic and non-kinetic phenomena. For example, weather affects sensors and vehicle mobility, yet the same conditions also affect human behavior at the human-in-the-loop grain of analysis. Therefore, it is important to consider how the environment is represented. The question arises whether to represent individual environment phenomena, or rather to represent correlated, consistent phenomenology. Unfortunately, there is no unified or widely accepted understanding for representing, or implementing, the interaction of entities and different phenomenologies. The DoD has invested extensively into military M&S efforts, but the M&S community has not been able to answer the above questions definitively. This makes objective assessment of M&S efforts extremely difficult as realism is often defined differently from one project to the next.

Furthermore, extensive funding has been invested in the study of interoperability, but the foundational modeling issues are often overlooked. Consequently, interoperability has not been maximized for training, because the foundations of each component are fundamentally sub-optimal. An effort is needed to identify and understand the "building blocks" required for successful entity and phenomenology interaction underlying realism. In conjunction with the theoretical understanding, the implementation characteristics of the building blocks must be explored and codified as well. The implementation must be able scale to permit millions of independent entities to execute in real-time to support DoD training efforts.

Subsequently, a key question must then be raised: how can coding be simplified to permit implementation of numerous, extremely complex entities, phenomenologies, and systems? Consider the representation of human behavior and the act of driving where at times, we behave according to known rules – we stop when the light is red and accelerate when it turns green. We recognize external stimuli and events around us – a ball rolls into the street and we slam on the brakes or swerve to avoid it. We also strategize – what is the best way to navigate around a traffic jam? In order to effectively model behaviors, an infrastructure is needed with ability to accept rule-based implementations of decision making and behavior. The infrastructure must also have ability to execute many different model types that represent different aspects of behavior simultaneously.

The ability to integrate any technique representing any aspect of behavior is needed. For example, consider neural networks to recognize phenomena from a collection of data, or the ability to implement strategic planning activities - e.g., utilizing techniques such as genetic algorithms (GA) or evolutionary programming (EP). Humans consistently strategize and make "optimal" decisions based on certain metrics such as traveling to a destination in the least amount of time. A warfighter will strategize, and choose a course of action to minimize casualties. GA can be utilized to model these types of mental activities. The computational methods must be flexible enough to operate synchronously (serial execution) or asynchronously (simultaneous execution). Other examples will be discussed later to describe the above concepts more fully in our representative M&S training example of the Quarterback Trainer.

ROLE OF REALISM

Again, consider the role of realism from the perspective of the training community, in which the purpose is to provide training and educational materials for the warfighter. The training should be strikingly close to actual combat situations the warfighter would experience. For this reason, phenomenologies such as visual depictions, and the ability to move in the environment must be correct. It is also necessary to obtain realism from a cognitive simulation point of view. The system should behave in accordance with the behavior of the entities in the relevant battlespace. The interactions would then be cognitively and culturally plausible. If the training is not cognitively plausible, it may be ineffective, and will ultimately be a disservice to the warfighters protecting our country.

A related difficulty involves provision of real world battlefield conditions, with responsive training and rehearsal. Warfighters report the battlefield is dynamic and changes day in/day out. However, training and implementation of new battle tactics lag; and the warfighters do not obtain the right training quickly enough. Software must be readily updated, or interoperated with new software and systems in order to provide correct, expedient, and efficient training. Many systems are unable to fully benefit from the astounding visual resolution and fidelity, because the cognitive plausibility of the threats is not implemented. The paradox can be likened to a big budget movie with amazing special effects but minimal plot. Training suffers when the trainee does not see realistic information, and/or when systems do not respond realistically.

Renewed effort is being made to fine tune the representation of individual pieces of the system based upon the challenges of our existing training systems (e.g., fighting an enemy who uses unconventional tactics, an enemy who hides among civilians and may not be identified as a male soldier in uniform, lacking cultural awareness, understanding, and/or sensitivity to local peoples in war-torn areas). Fine tuning individual pieces of the training system may lead to major integration issues forcing system components to be compromised in the very areas extensive effort had previously been placed. A plausible solution might involve integrating the skeletal framework of system components, and developing an effective overall system in concert. However, then problems of scalability may arise due to inability to apply modern computing resources and techniques.

The current generation of integration and interoperability techniques and technologies has focused around a network of workstation-type infrastructure which does not address all the new and needed requirements to train our warfighters. System components frequently run in serial rather than parallel and the inter-processor communication primitives have high latency as well as relatively low throughput. This makes a full integration of phenomenology models limited in creating a realistic whole capable of effectively mentally engaging the trainee. Another problem arises when different phenomenology representations and implementations are combined. Often, a certain type of phenomena is represented in multiple M&S components, but is not represented consistently across all the components. This leads to the "fair fight" problem currently recognized by the interoperability community, with no clear understanding of how to mitigate the shortcoming. For example, the representation of various atmospheric effects impacts the representation of sensors, which impacts the ability of weapons to target and destroy entities in the battlespace. Simplistic atmospheric models should lead to "better" sensor and weapons performance, but may ultimately produce unrealistic and skewed results that don't correlate with true performance in the field.

The unmanned autonomous systems (UAS) and robotics communities face problems with sensor modeling as well as challenges with communications systems and mobility models related to the underlying environment representations. For example, a UAS may perform well in a simulated environment, but when real-world conditions are encountered disrupting its communication (or GPS) signals, erratic or unplanned behavior may result. In this way, problems of realism are not restricted to the recognized need to address non-kinetic effects, but are also present in the kinetic domain. The problems will persist until a comprehensive understanding of the interplay between representation infrastructure, computational infrastructure, and underlying system architecture are addressed.

PERSPECTIVES ON REALISM

Training

The requirements in realism for training vary widely depending on the task being trained. For instance, pilot training requires realistic graphics and behaviors of synthetic entities to be represented in an accurate and credible way. Training staff commanders may require less visual presentation than pilot training, excepting sensor visualization of unmanned and robotics systems, and may rely more on the ability to populate the information displays. Underlying phenomena need to be represented in a way that does not require as much fine scale physical detail (such as pitch, roll, and yaw of an entity). Rather, we rely on the ability to represent underlying cognitive, or decision making, behaviors of the simulated entities (and gross physical motion) to respond realistically for the trainee. The input, as sensed by the trainee and the subsequent response of the system, needs to be plausible – it needs to look like a real system in a real-world environment. Otherwise, negative training can occur and the trainee suffers – this must be avoided. Negative training refers to practicing procedures in a manner inconsistent with how an action would be performed in combat, which results in developing bad habits; this occurs most when the trainee receives simulated data that does not reflect how the real-world system operates. At the other extreme, some training systems require high fidelity of visual and physical realism meaning representation of military equipment and human beings in a variety of capacities. Some systems are flight simulators and "first person shooter" games that are used to teach culture, customs, and protocol – these are particularly dependent on accurate real world replications. What is difficult is ascertaining the correct level of fidelity for each component of training that is necessary in order to replicate the real world in ways that matter to the brain of the trainee. What are the statistically important stimulants to that decision process? We have observed that drawing photorealistic images is important up to a certain point, but if the system does not behave "correctly", or move "normally" within the training environment, the brain rejects the training. Sometimes photorealism is required for fidelity. Oftentimes what matters most to the brain is the real world characteristic motion and behavior of a system being replicated to stimulate the decision-making process – information realism is critical for effective, efficient training. Traditionally, this has been the Achilles' heel of M&S

training systems. A training system is only as good as the quality of the data and information going in and coming out of it.

Experimentation

Requirements for realism in experimentation are similar to training because as warfare transitions to the asymmetric nature of threats, accurate portrayal of new systems is increasingly significant. The ability to virtually predict the outcome of new military systems plays a critical role in making better investment decisions in a budget-constrained future (e.g., prior to full-scale production, or prediction of change outcomes in tactics, techniques, and procedures (TTP) before employment in real-world scenarios). The need to improve outcome prediction has led to the realization that we must improve our ability to model human behavior, groups, and organizations - hence, the term "non-kinetic" modeling. There is increasing need to understand how to better represent the highly-connected nature of non-kinetic phenomena, and the role of stochastic and deterministic models and modeling constructs.

Test and Evaluation (T&E)

Realism pertaining to T&E is similar to training and experimentation. T&E focus has been on representation of physical phenomena, and interaction with system-under-test (SUT). Physical phenomena representation, with increased detail in real-time, drives the state-of-the-art. Due to the advent of net-centric warfare (NCW), the need exists to represent different types of phenomena accurately. NCW also requires representation of diverse systems, and system interactions, over various networks. Requirements include:

- Creation of complex, realistic, and scalable networks of component inter-relationships
- Distribution of autonomous controls and monitors
- Implementation of complex webs of cause and effect
- Dynamic alteration of the component execution structure
- Adaptation and evolution of the system

Acquisition

In general, the use of M&S in acquisition relates to the design and engineering of military systems and processes employing new systems. The ability to accurately predict the physical behavior of new systems and their components is required. The military "system of systems" philosophy requires replicating reality, like NCW. Networks of complex assemblies of components must be replicated accurately.

Analysis

M&S used in military analysis is different than the previous domains. The goal is to accurately predict aggregate behavior and data, requiring different mathematical approaches, versus replication of detailed physical characteristics and behaviors. The language of probability and statistics tends to dominate modeling in this domain and in terms of realism, this has very different implications. Accurate prediction and representation of asymmetric threats, or irregular warfare, is a primary challenge to the abstract, or aggregate, type of M&S. The challenge is shared by all the disciplines, but particularly by analysis and planning. The threats are low-probability events with impact inversely proportional to the size of the organization that commits the event. For example, the impact of improvised explosive devices (IEDs) and other terrorist activities, have a large impact, and are committed by a relatively small number of people. Cognitive modeling of Political, Military, Economic, Social, Infrastructure, and Information (PMESII) effects is another example.

Planning

The challenges facing the planning community are similar to analysis, where traditionally, abstract and aggregate M&S techniques have been used. The nature of modern world threats is difficult to represent and predict in this computational paradigm. With initiation of adaptive planning, there is greater need to predict military outcomes over shorter time spans. Representations for adaptive planning require increased detail across kinetic and non-kinetic phenomena.

OBSTACLES TO GREATER REALISM

Achieving realism requires complex and simplistic phenomenology representation methods and techniques. The ability to relate models, and the influences between one another, is a key limitation. Representing cause and effect networks between models, with all of the interrelationships, in a manner that can scale, remains an important objective. For example, representing the human nervous system (how activation and information sweep through the body or the intricacy of an accurate cognitive model that provides real behavior prediction capabilities) presents extreme challenges. Significant need exists to easily represent a wide variety of asynchronous behavior for many independent activities. Also, the independent, yet connectedness of the real world is difficult to represent in current approaches to computer languages and programming. Some techniques do provide a few of the required capabilities, but there are no techniques that scale to millions of independent, interacting entities.

Another feature needed to realistically represent phenomena involves representing sequences of associated activity, or behavior. Some systems have methods to support this capability, but scalability and ease of programming remain a challenge. The need to easily start and stop an action, based on the dynamically-changing conditions, is a related challenge. One of the most difficult requirements to develop realistic, complex models involves representing a network of activities triggered by changes in the physical world, or the logical world (e.g., cognitive events). Furthermore, the need exists to trigger a large number of processes based on a single changing activity. While not usually considered a phenomenology representation primitive, it is necessary to treat it as such in order to represent control of physical and non-physical systems. In this way for a model, multiple disparate sources of control inputs and/or dynamically generated inputs, in the case of non-physical systems, can be efficiently implemented. Flexibility provides value in the context of Live-Virtual-Constructive environments, including the ability to implement external and internal sources of control. The topic of non-kinetic modeling and the need to improve it, has received much attention in the industry. The need remains to identify cognitive phenomena and accurately represent cognitive events. The next section discusses methods in which this type of representation can occur, and uses analogies in nature describe the methods.

Finally, no discussion on the topic of obstacles to realism would be complete without mentioning scalability. Scalability refers to the ability to represent and execute large numbers of active physical and non-physical processes simultaneously in real time. At the present time, the execution of millions of processes in real-time is beyond most systems. This is a function of software algorithm design and the interplay with complier construction, processor design and capabilities, the network capabilities, as well as memory and storage. In general, these relationships are not universally well understood in a variety of DoD M&S development endeavors and operational systems.

COMPLEX SYSTEM REPRESENTATION PRIMITIVES AND REALISM

Complex system representation (CSR) (Wallace, and Hannibal, 2005), (Wallace, and Hannibal, 2006) employs a set of primitives that provide a powerful tool used not only in the development of highly complex systems and applications, but also in the development of realistic models and simulations. There have been a few cases of application development and integration software products which contain ***some elements*** of the CSR approach. However, no products currently exist that offer the full spectrum of representation primitives that allow functional, causal, and temporal synchronization and execution characteristics, as found in the framework employed on the Joint Strike Fighter Shared Synthetic Environment project (Wallace, and Hannibal, 2005), (Wallace, and Hannibal, 2006).

This discussion utilizes several biological examples to highlight aspects of representing reality that have been historically difficult to solve in a scalable, yet easily comprehensible framework. This section outlines a set of representation primitives that enable improvements in representational realism. These examples have wide explanatory value since the human body is more complex than any mechanical system built to date. The following sections describe various complex system representation paradigms and the biological analogs which motivate them:

- Asynchronous and synchronous *internal* characteristics or mechanisms
- Asynchronous and synchronous *external* characteristics or mechanisms
- Irregular time-scale *internal* characteristics or mechanisms
- Irregular time-scale *external* characteristics or mechanisms

The human heart is used as an example to illustrate CSR principles: a synchronized sequence of activities that occur naturally each time the heart beats (without thinking about it). The heart operates asynchronously from the rest of the body; but within the heart itself, a tightly synchronized set of activities occurs. The ideal system development methodology should permit this type of system development, implementation, and operation.

Threads and processes ((Microsoft Inc., 2005), Parallel Virtual Machine 2005), POSIX Threads Programming 2005) are commonly used to instantiate such implementation paradigms. However, numerous problems exist, including: ***Scalability*** – threads and processes rely on saving and restoring large amounts of memory or storage, which breaks down when millions of active threads and processes are required in both serial and parallel fashions. ***Performance*** – when underlying activity or processes are fairly simple, the overhead of memory storage and retrieval may limit utility. ***Implementation complexity*** – implementation syntax is typically arcane and complex usage is beyond the reach of all but the most talented programmers. ***Portability*** – most thread and process packages are not portable. ***Eliminating*** the use of stack frames is central to resolving the difficulties. Typically, large amounts of data needed to restore the computational context. The framework should provide a method to minimize the data required to restore the process state once it has been suspended. Some mechanism is needed to indicate which variables must be saved and restored. In this way, a large amount of memory can be saved; and the execution performance of processes can be drastically improved.

This same situation occurs in many militarily significant situations – from the representation of complex kinetic phenomena to non-kinetics. The ability to have millions of active processes that can be synchronous or asynchronous, with the ability to be suspended and resumed, would be quite valuable in simulating cognition or social phenomena. Any method on an object should be able to become a ***process***. A process can be represented as an event that passes time by suspending execution and resuming (maybe several times) before exiting (sometimes called "persistent events") due to persistence over time. In this manner, a unified execution environment could be developed. Processes should support at least two ways of passing time. The framework for realism, ideally, should provide at least three types of primitives in order to provide the ability to represent and implement complex functional, causal, and temporal synchronization between components. The framework should support this primitive, providing an implementation of processes as objects.

Irregular Time-scale Behavior As an example of irregular time-scale behavior, consider the example of a heart attack. A heart attack is the death of heart muscle, from the sudden blockage of a coronary artery by a blood clot, or heart malfunction. Hence, a heart attack represents an internal occurrence that has no pre-established time scale. A military example would be equipment that fails, or some other unpredictable event that is a deviation from nominal behavior. In order to represent such functionality, events are commonly used. In a realistic model of the heart, the heart attack event would trigger a wide variety of other activities. This requires a representation scheme that allows an event to trigger not only other events but a wide variety of asynchronous or synchronous processes. Ideally, the framework should support events as both methods on objects and as objects themselves. In this way both internal and external phenomena with irregular time-scales can be effectively modeled. These phenomena do not require any persistent state; and as such, does not call for the computational overhead of the process model techniques. ***Internal Events* –** events as methods on objects provide a mechanism for interaction and external integration, without exposing encapsulated internal data. In this paradigm, an object should not directly schedule an event for a class contained by another object, to avoid internal exposure and violation of object-oriented encapsulation principles. ***External Events* –** an example of an external event, following along with the heart example, would be defibrillation. This is a process in which an electronic device gives an electric shock to the heart. Shock helps reestablish normal contraction rhythms in a heart with dangerous arrhythmia or cardiac arrest. In this case the representation of the phenomena is as an external event (defibrillation) on an object (the heart). An example in the military domain would be commander behavior – the commander is monitoring plan execution and situational awareness. An order is given to a subordinate that alters the behavior of the overall system. Another obvious example would be a missile targeting an aircraft, and the subsequent response of the pilot.

Behavior Activation Mechanisms

The concept of event handlers provides polymorphism in event scheduling. Event handlers are methods on any object, and do not require inheritance. Two macros define interfaces and implementations separately. Event handlers can be directed or undirected towards a specific System Object. A subscription mechanism determines which System Objects receive undirected events when they are scheduled.

Interactions Between Individual Models, Components, or Systems

The construct of interactions provides a mechanism to represent and implement both data transfer and functional activation between models, components, or systems. They also provide polymorphism in event scheduling and processing, and are active, interoperable, and synchronous. Data can be transferred in sets of parameters, which is a container class used to store values of known types, and pass parameters in interaction handlers. They can contain values of type integer, float, double, string, and buffer (a byte array of arbitrary length) and are accessed through keys of type integer or string. This provides a general and scalable method for conceptualizing and implementing complex relationships between different aspects of the system, and flexibility in changing one part of the system without breaking the overall functioning of the overall system.

IMPLEMENTATION EXAMPLES

In the Code Examples, the problem of synchronizing the actions of components in the system is addressed. Not only must messages and a variety of disparate data be broadcast and received, activity and actions between the components must frequently be addressed to truly solve integration and interoperability problems. The implementation of this in a virtual simulation trainer is the example for this effort – the Quarterback Trainer and Evaluation System (QTES). Evaluating correctly and optimizing the training and readiness of professional and collegiate football athletes is dependent on replicating full-speed, high-performance, game-like and practice environments. A mistake picking the wrong quarterback in the draft or free agency is an eight to nine-digit financial error,

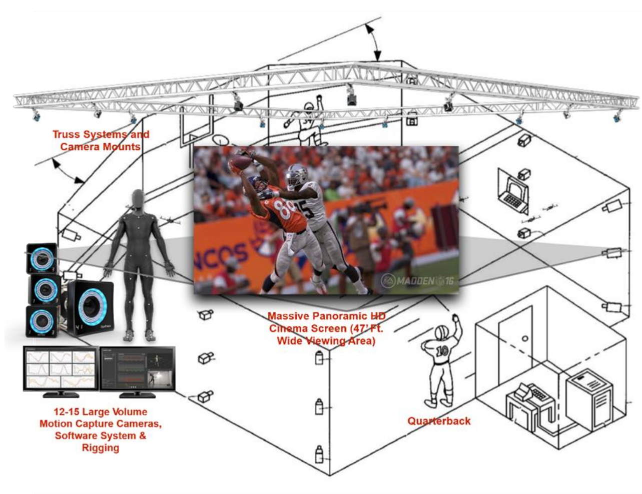


Figure 1. Virtual Reality Quarterback Training and Evaluation System

and can set a franchise back years (e.g. Detroit, Cleveland, Miami). There are many current examples where teams have recently made these costly mistakes. There are no current solutions in the market allowing for full-scale, real-time, dynamic game-like speed and performance levels on demand that generate the stress reactions of real life. One of the questions that must then be asked is "What are the Components of a VR QTES?": a high fidelity virtual human Quarterback (QB) modeling, virtual human editing and simulation, stereoscopic visualization framework, 3D cinema, high performance simulation engine, and next-generation material modeling.

The QB must be real and interact with surrounded and immersed in virtual reality (VR). Everything happens at real-time speed where a real QB, training in scene, throws a real football and interacts with his environment. The thrown ball hits a net while the virtual football continues in game atmosphere. The realistic simulation includes scene changes as the play executes. Virtual players represent the same attributes as the real players (offense and defense) and there is a roadmap that escalates to full 11-on-11 football. Why is this problem so difficult?

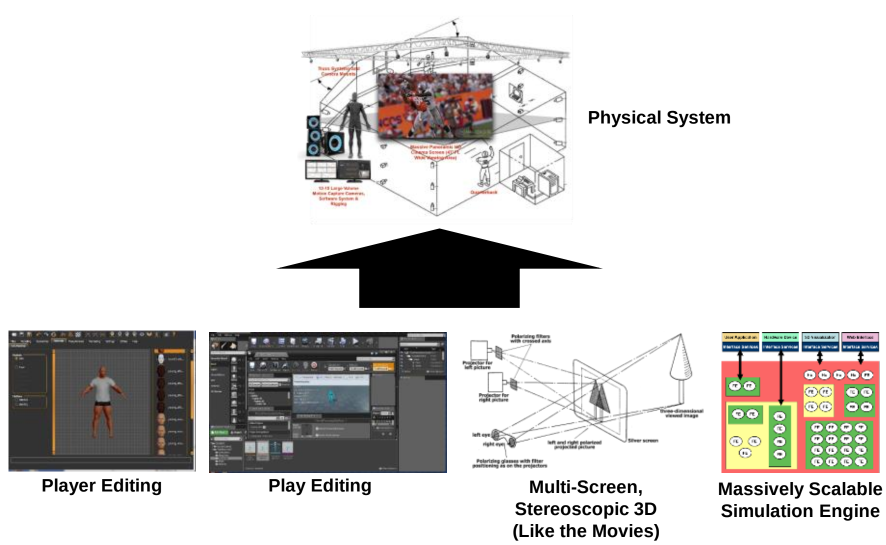
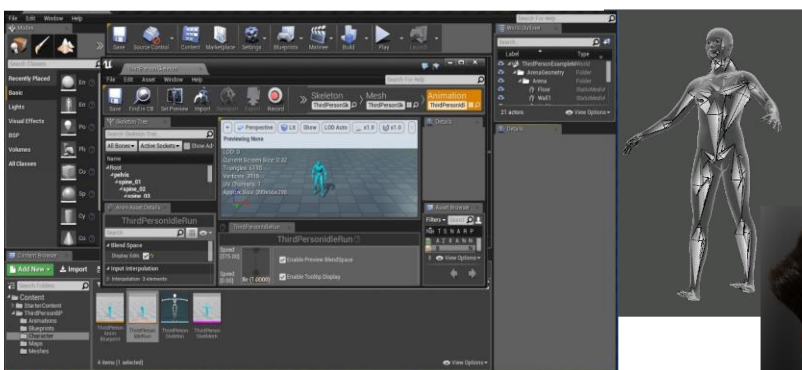


Figure 2. Components of the Virtual Reality Quarterback Training and Evaluation System

Training in VR versus the real world requires realism and it is only possible with a specialized real-time, distributed computing engine. (Wallace and Kambouris, 2012) Realism requires extreme mathematical complexity which must be computed accurately and in real time. In order to succeed, it is necessary that the simulation reacts to a real QB. Using this method, there are no precomputed scenes like movies or games, the QB can and should be able to go anywhere and the VR players follow in response to the QB's movement. This training system is quasi-competitive and uses VR headsets, and because the trainer is real-time, there is no system lag which then reduces simulator sickness. Often VR headsets provide no frame of reference or sense of placement on the field and have limited interactivity – these all lead to a lack of realism thereby greatly affecting training systems, by not engaging the QB decision-making process.

What does a realistic trainer look like? It has a full-scale immersive VR system, Player Editing for physical appearance and individual characteristics, such as speed, strength, and football skills. Play Editing institutes the notion of a virtual playbook as well as a Coach/Auto-Coach Supervision, and Post Session Analytics. Using a QTES it is possible to nearly eliminate all practice injuries and allow coaches/owners to more accurately and realistically evaluate QB talent before they invest team funds. Furthermore, a QB can virtually practice against next week's team as often as necessary to focus on strengthening and honing his skills. The QTES supports four progressive modules of increasing complexity allowing the QB to focus on areas of improvement: **Receiver Coordination and Timing (RCT) Module** - with the simulator running only the receiver routes, the quarterback will be able to practice throwing to each receiver in the pattern. **Full Receiver Sets (FRS) Module** - the full complement of receivers are present to run pass play patterns. **Receivers Against Defenders (RAD) Module** - linebackers and defensive backs and standard, simple defensive packages are provided to go against the full receiver sets. The quarterback runs the play with all coverages and fronts such as Cover 2, Cover 3, 3-4 and 4-3 sets. **Full 11-on-11 Module** - the full 11-on-11 action is simulated and the 12 standard blitz packages used by NFL teams will be added to the defense sets and then individually altered to simulate the plays run by specific opponents.



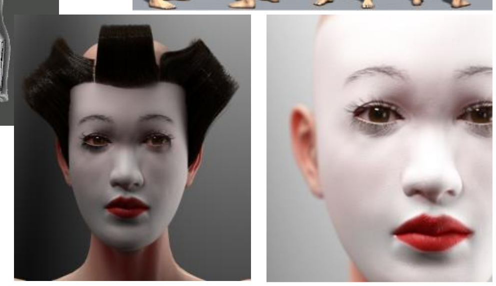


Figure 3. Play Editing and Physics-Based Human Modeling

By designing the complete system down to parts list the entire system infrastructure for the real-time, distributed computing engine facilitates ease of external input streaming for the QB and Ball, as well as the external output streaming for three-dimensional (3D) integration and data. The trainer uses high fidelity human motion models, football motion graphics detailing, while integrating the VR hardware. Using the Player Editor and Play Editor, a realistic real-time, interactive 3D stereoscopic scene can be generated comprised of: a virtual football stadium and football player clothing, football equipment and uniform using our physics-based materials framework, football play details and motion paths by Playbook Play, multi-screen, 3D stereoscopic, interactive VR scene generation (like the movies, but better), real-time computation of big data scale mathematical complexity, external real-time data I/O integration with compute streams (motion capture of QB), and accuracy of all phenomenology models.

High fidelity virtual human modeling requires the integration of every type of algorithm known: visual representation, movement, and behavior. Virtual human editing and simulation allows for the use to edit and customize humans. This simplifies data entry for the wide array parameter or data sets and enables a preview mode so that less time is wasted in scenario setup. One of the challenging parts of stereoscopic scene generation is that the system must generate two or more images simultaneously and update them in real-time.

SUMMARY

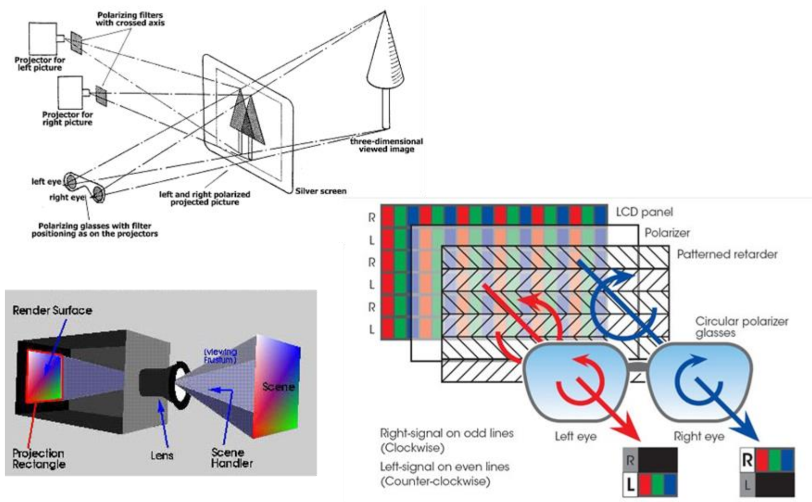


Figure 4. Stereoscopic Scene Generation

This paper highlights the major problems of realism in M&S development and systems integration. Scalable solutions to complex, real-world problems are still elusive, as is seen in the lack of realistic non-kinetic models and simulations. As such, the time is ripe to begin cross-disciplinary discussions to define what realism means in the DoD context, and to identify potential solutions by using a QTES. Not surprisingly, the concept and meaning of the phrase "realism in M&S" is purpose-specific. There are, however, some common themes. The ability to represent complex webs of synchronized cause and effect is central to the implementation of realistic M&S systems. Representing many simultaneously evolving phenomena that are interrelated is part of this capability, and critical to implementing realistic non-kinetic and complex kinetic phenomena. Components required to build a VR Training and Evaluation System are high fidelity virtual human modelling, virtual human editing and simulation, complex systems representation, stereoscopic 3D visualization framework, high performance simulation engine, and next-generation material modelling.

Another key feature for solving M&S training is to be able to stop one activity based on some arbitrary web of logic, and start another in response to changing conditions. Not the least, scalability must be achieved while providing all these capabilities. This means the ability to support 10^6 or larger entities or distinct phenomena – to which there are few known solutions. Robust solutions are the gold standard, because they do not fail with perturbations to the information transacted. A robust solution is easy to maintain when systems are modified or upgraded, and straightforward to alter when new information is required, or additional constituent systems are added. Unless the problems of realism in complex phenomena and systems representation are studied and addressed, the value of M&S investments will underperform and consequently M&S investments will be devalued. Increasingly complex architecture theories, and computer software infrastructure fads, all require developers and resource sponsors to re-implement basic behaviour. As such, solutions to the hard problems are elusive. Trainees, in turn, do not receive the effective training and tools to improve their performance. The QTES is a way of bringing increased realism to the QB decision-making process.

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