2.1 Interoperability Standards for Medical Simulation Systems

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Abstract. The Modeling and Simulation Community successfully developed and applied interoperability standards like the Distributed Interactive Simulation (DIS) protocol (IEEE 1278) and the High Level Architecture (HLA) (IEEE 1516). These standards were applied for world-wide distributed simulation events for several years. However, this paper shows that some of the assumptions and constraints underlying the philosophy of these current standards are not valid for Medical Simulation Systems. The paper describes the standards, the philosophy, and the limits for medical applications and recommends necessary extensions of the standards to support medical simulation.

1.0 INTRODUCTION

"War is the father of all things!" This statement made by the Greek philosopher Heraclites (520 BC – 460 BC) can be interpreted to be true for the rise of modeling and simulation (M&S). Although M&S has many application domains, from aerospace to Z particle simulation in physics, only the military defense domain applies a broad variety of M&S application in global federations. For example, air defense tanks in Germany provide air protection to mechanized infantry troops in Korea against aircrafts actually flying over Texas. In this case, however, all participants are brought together in a virtual battle sphere, not in a real battlefield. In this virtual battle sphere they interact with each other like they would in real systems in a real battlefield.

Two international simulation interoperability standards were developed by the M&S community to support such world-wide simulation endeavors, the IEEE 1278 standard family defining the *Distributed Interactive Simulation* (DIS) protocol, and the IEEE 1516 standard family defining the M&S *High Level Architecture* (HLA). There are other solutions that seek to improve interoperability, like the *Training and Testing Enabling Architecture* (TENA).

These developments have been applied with some success by the military. It is therefore worthwhile to look at their applicability in support of medical simulation systems. The objective of this paper is to show that this is not possible without ensuring that very strict and rigorous constraints are fulfilled, namely, to ensure that there is one common view of the problem. This is easier said than done as a common view requires that conceptualizations are shared by all models and simulations.

To prove this point, section 2 presents a short overview of the main characteristics of current simulation interoperability standards is provided. Section 3 shows the limits of their applicability in medical simulation. We show that an "additional dimension" is required that is not yet captured in current standardization efforts. Finally, the paper concludes that although many good ideas can be readily transferred from the military domain to the medical, additional research efforts are needed to ensure that simulation standards support valid federated compositions from valid simulations.

2.0 SIMULATION INTEROPERBILITY STANDARDS

This section will summarize the main ideas underlying the two IEEE simulation interoperability standards: DIS and HLA. It also describes the main ideas of TENA and summarizes some of the current LVC approaches.

Initiated in 1983 by the Defense Advanced Research Projects Agency (DARPA), the SIMulator NETworking (SIMNET) project was the first effort exploiting the new developments in computer communications and network technology for simulation. The project emphasized tactical team performance by bringing together armor, mechanized infantry, helicopters, artillery, communications, and logistics. All these simulation systems shared a common battle space. Entities did move, shoot, look, and also communicated. The interactions of these entities focused on physical aspects. Although the systems differed in resolution and details, they shared both a common understanding of the problems to be solved and the worldview underlying the battle space [1]. SIMNET is the common ancestor of DIS, HLA, TENA, and LVC efforts.

2.1 IEEE1278 – DIS

SIMNET was generally perceived to be a success. Tactical teams could now train together, fighting "shoulder to shoulder" in a virtual battlefield. Industry took this idea and turn it into a standard to support distributed interactive simulation. This standard is based on the idea that each system represents one or several individual entities that act based on common rules – the Newtonian laws of physics – in a common battle space. Interactions between these entities could be identified, categorized and standardized.

As a result, individual simulators representing weapon systems on this common virtual battlefield have a well defined set of actions and interactions: tanks could move, observe, shot at each other, exchange radio communication, etc. Individual activities led to status changes that were communicated via status reports. Interactions were communicated via messages. If two tanks engaged in a duel, the order of activities and the data to be exchanged between these entities were well defined.

Therefore, the set of information exchange specifications could be well defined. This resulted in standards for these messages, which led to the IEEE1278 Distributed Interactive Simulation (DIS) standard [2]. The Protocol Data Units (PDUs) captured (syntactically and semantically) all possible actions and interactions based on the idea that individual simulators represent individual weapon platforms.

The continuous success of DIS was based on a simple concept: individual entities following the laws of physics while exchanging messages. Messages, in this case, represent interactions.

2.2 IEEE 1516 – HLA

DIS, however, has a limitation: it is hard to apply to aggregated simulations or to simulation paradigms other than event driven simulation. The HLA interoperability standard [3] was developed to maximize the flexibility for all kind of M&S application domains and to support different M&S paradigms.

In HLA, ten rules guide information exchange between simulation systems (called federates) and a common infrastructure and network (called Runtime Infrastructure -RTI-). The resulting system is called a federation.

The information exchange requirements within a federation are captured in the Federation Object Model (FOM). The FOM defines all persistent objects and their attributes and transient objects and their parameters that can be exchanged between participating simulations. While persistent objects have to be created and updated in the participating simulation systems during runtime, transient objects are created in case of need and only used once.

Because of synchronization challenges, six service groups ensures that need information – but only that information that is needed – is delivered at the right time to the right simulation system. The six service groups are federation management, declaration management, object management, data distribution management, time management, and ownership management.

The purpose of *Federation Management* is to determine the federation. Federates join and leave the federation using the functions defined in this group. *Declaration Management* is identifies which federate can publish and/or subscribe to which information exchange elements. This defines the type of information that can be shared. *Object Management* manages the instances of shareable objects that actually are shared in the federation. Sending and receiving and updating belong into this group. *Data Distribution Management* ensures the efficiency of information exchange. By adding additional filters this group ensures that only data of interest are broadcasted. *Time Management* synchronizes the federates and *Ownership Management* enables the transfer of responsibility for instances or attributes between federates.

HLA significantly increased the flexibility of simulation federation definitions. Instead of being limited to predefined information exchange groups, the developer can specify the objects and interactions and can even support different time model philosophies. It neither assumes the level of resolution – HLA supports component level simulation, platform level simulation, and all levels of aggregation – nor does HLA assume the partition of the battle space into tactical unit or the phasing of a supported operation.

However, the underlying philosophy remained the same: all simulators are based on the same worldview of focusing on technical-physical aspects.

2.3 TENA and LVC

The Test- and Training Enabling Architecture (TENA) [4] is another successful solution predominately used on the test ranges for Test- and Evaluation (T&E). TENA sets up up a framework enabling the reuse of components and the integration of independently developed systems into a federation. However, the philosophy and design differs. TENA supports the integration of HLA and DIS based systems, but is neither HLA- nor DIS-based. TENA is not standardized by an international standardization organization, but is a de facto standard in the domain of T&E.

Following the TENA philosophy, interoperability requires a common architecture (which is TENA), the ability to meaningfully communicate, which requires a common language (TENA Object Model), and a common communication mechanism (TENA Middleware and Logical Range Data Archive). It also requires a common context (in the form of a common understanding of the environment), a common understanding of time (provided by TENA Middleware), and a common technical process (provided by TENA processes). Similarly, practical reuse and composability require the above, plus well-defined interfaces and functionality (provided in the form of tools and repositories), and a place to store reusable components (repository). TENA provides all these capabilities.

The central TENA object model is a real object model with semantically well-defined objects. As these are real object-oriented object, each object is not only defined by its data, but also by its potential behavior (in the form of methods that can be executed by the objects). This approach combines DIS and HLA ideas: the middleware provides functionality comparable to the RTI of HLA, and the TENA objects are as well defined as the DIS PDU. Ambiguities are therefore minimized – but for the price to have to use objects of TENA. If new effects or objects are needed, an extension of TENA is required before it can be handled.

Generalizing the ideas coped with so far, the recent developments for Live-Virtual-Constructive (LVC) federations emerged. Live simulation uses real people and real systems in a simulated operation. Virtual simulation uses real people and simulated systems in a simulated operation. Constructive simulation use simulated people and simulated systems in a simulated operation. As such, LVC tries to establish a framework that helps to federate live systems, such as tanks and airplane, with simulators, such as tank and flight simulators, with simulation systems. The resulting architecture shall not have the limits of current domain or paradigm specific solutions. A recent study [5] did not come up with technical solutions, but at least with a common vision and recommended first steps to prepare for such a solution.

In summary, the interoperability standards developed predominantly by the military and related solutions were successfully applied. They enable nation- and world-wide simulation federations and increase the decision quality significantly. It is therefore a worthwhile effort to check their applicability in other domains as well.

3.0 LIMITS FOR MEDICAL SIMULATION

How can medical simulation benefit from the success stories of military simulation? Is it possible to simply adapt IEEE1278 or IEEE1516 to the needs of this new user community? In particular IEEE1516 – the High Level Architecture – was successfully applied in other domains, such as transportation or even supporting NASA simulation efforts.

In the following section, we will look at the underlying philosophy of the approaches discussed in section 2 and their challenges.

3.1 Philosophy of Current Simulation Interoperability

As discussed in more detail in [6] and as mentioned on the sideline in section 2, the underlying philosophy of current simulation interoperability is dominated by reductionist approaches based on positivism. The technical-physical world of shooting, moving, looking, and communicating of weapon systems supports such a viewpoint. For instance, a simulated weapon system has a one-to-one correspondence to a weapon systems in a real battle space and jointly correspond to one common view of reality. There exists one world and one truth, and it is possible to find this truth by observation and experimentation.

However, since the early 20th century, this view shifted with relativity, quantum physics, and other scientific insights. Science started to shake the believe of one world and one reality that can be observed and understood by reductionism. Furthermore, social sciences contributed as well to move away from the one-worldview assumption. Interpretivism holds the belief that truth is a construct of the observer. Reality is relative and cannot be separated from the individual who observes it. The majority of social and human sciences subscribe to interpretivism.

Modeling actually can be a perfect example for this philosophy. In a simulation, reality is not necessarily what is real, but what is captured in a model. Something is true when it is true in the model. This means that the implemented system can derive the truth value through computation. Two simulation systems are interoperable when they derive consistent truth values; two models are composable when they represent the same worldview. Interoperability of simulations requires composability of models, and current simulation standards do not take the model level into consideration, they exclusively focus on the implementation level [7].

3.2 Multi-Scope, Multi-Resolution, and Multi-Structure

Another aspect that is not sufficiently addressed by standards, despite of a large body of knowledge compiled by academia [8], is the challenge of multiple scopes of a model, multiple resolutions, and multiple structures.

If two model use different referent systems of their perception, we deal with a challenge of differences in scope. If two models use the same referent system, but they use different attributes with different granularity, they differ in resolution. If two model use the same attribute but compose these attributes into different entities, the use different structures. All three challenges can be observed at the same time, making dealing with these challenges hard.

3.3 Problem Situations

When applying M&S, we assume the existence of a well-defined problem for which there is a solution that needs to be found. However, in particular in soft science – and often observed in the medical domain, this is not necessarily the case. One expert sees a problem, another expert perceives that everything is normal. This does not necessarily mean that one is right and the other wrong, it may simply be that they follow different theories.

To deal with this kind of situations, the term problem situation has been coined [9]: Problem situations are problems for which there is no agreement on the nature of the problem or whether there is even a problem.

4.0 CONCLUSION

The current simulation standards IEEE1278 and IEEE1516 have been successfully applied for military systems when applied in support of technical-physical models. These models all support one worldview (Newtonian physics) and support common sponsors' needs that establish well understood problems.

If a domain does not subscribe to a reductive positivistic philosophy, the application can be problematic, as the standards do not address challenges on the modeling level. As stated in [10]: *"While modeling is the process of abstracting, theorizing, and capturing the resulting concepts and relations in a conceptual model, simulation is the process of specifying, implementing, and executing this model. Modeling resides on the abstraction level, whereas simulation resides on the implementation level. Simulation systems are model-based implementations. Whether or not it is possible to merge two simulation systems in collaborative support of user requirements not only depends on the integratability of the underlying networks and the interoperability of the simulation implementations, but also on the composability of the underlying models."*

In order to support composability of medical models and interoperability of medical simulation, the challenges have to be addressed:

- considering problem situations instead of assuming well-defined problems,
- allowing and identifying different viewpoints (interpretivism) instead of one common worldview (positivism), and
- better support of models with multiple scope, resolution, and structures.

The current simulation interoperability solutions work well for the specified special case, but are unlikely to be equally successful on the broad scale over the complete spectrum.

As stated in [6]: *"It would be naïve to apply standards that were developed for physical-technical models based on a common theory representing the positivistic worldview to integrate socio-psychological models derived from competing theories representing interpretivism and expect valid* *results."* The same is true for the medical domain.

Instead of shoehorning simulation into a federation, the alternative may be to work towards a domain of new standard efforts: the efficient and effective support of *exploratory analysis under uncertainty and disagreement*, and supporting development of strategies that are flexible, adaptive, and robust. Recommendations given in [8] and [11] towards the use of multi-simulations should be researched for medical simulation systems as an alternative to the current solutions that are too limiting and only valid in a small spectrum of the interest domain of medical simulation.

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