Standards-Based Interoperability for Autonomous System M&S and Operational Technology (OT)

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ABSTRACT.

RTI will demonstrate open standards-based interoperability between Operational Technology (OT) and Modelling & Simulation (M&S) autonomous systems. Specifically, RTI will show interoperability between applications based on the Future Airborne Capability Environment (FACETM) and Sensor Open System Architecture (SOSATM) specifications, Unity® and Epic Games® Unreal Engine® gaming engines, and applications using RTI Connext® TSS. Based on the open OMG® Data Distribution Service (DDSTM) standard, Connext TSS is the first certified conformant FACE Transport Service Segment (TSS) solution. This demonstration consists of two drone simulators, one using the Unity gaming engine and the other using the Epic Games Unreal Engine gaming engine. The drone flight simulator publishes location, video and Lidar data through a SOSA-aligned plugin using a SOSA-compliant Interaction Binding to publish data. The Lidar data is displayed using RVIZ, a ROS 2 application. Location is fed into different User Interface (UI) applications and an Ansys FACE-conformant A661 server. Interoperability of the Connext TSS product is proven between an Ansys Cockpit Display Systems (CDS), an ENSCO IData CDS, and a Presagis CDS. The goal of this demonstration is to show the utility of using the same standards-based technology used in operational autonomous systems to connect distributed next-generation M&S systems enabled with security, Quality of Service, application portability and wire-level interoperability. Achieving this unique level of interoperability provides flight simulators and CDS with the advanced M&S technology required to address the challenge of multi-vendor interoperability as well as fostering capability development of future operations.

Keywords: *Data Distribution Service, Open Architecture, Interoperability*

1. DEFINITIONS

For clarity, it is perhaps useful to begin by briefly making a generalized distinction between Information Technology and Operational Technology:

- Information Technology (IT) as used here refers to the use of computers and networking typically in the context of administrative or business operation systems.
- Operational Technology (OT) as used here refers to the use of computers and networking typically in the context of sensing, monitoring, controlling and changing based on their interaction with the cyber or physical environment. For our purposes this extends beyond industrial control uses into militarily relevant applications such as command and control, intelligence, surveillance, weapons, and so forth.

Modelling, Simulation and Training (MS&T), or alternately Modelling, Simulation, Training and Analysis (MST&A) as used here refers specifically to the *computer science* discipline across its many facets.

2. BACKGROUND

Historically, defence programs start engineering models and perform initial simulation as early as feasible in order to validate advanced research concepts and optimize engineering approaches prior to initiating expensive development of the operational system. As a rule, the earlier a mistake is caught or a desired change is captured in the development lifecycle, the easier and less expensive it is to fix the fault or implement the change.

This early modelling and simulation has taken many forms – and evolved greatly – over the years. Many early efforts involved mathematical modelling of physical systems. From there, dedicated hardware in the loop (HIL) simulation, software in the loop (SIL) simulation, and testing in laboratory conditions with specialized tools steadily progressed.

However, as software development processes began to mature, best practices demanded that earlier manual code review and unit testing processes evolve into the use of automated testing, simulators and stimulators. Then the advent of distributed systems demanded the use of network simulation and fuzzing tools to test scalability and stability. Further, as software began to dominate the development effort, and the complexity of the software grew enormously, the nature of early-stage OT M&S began to change. Programs began to recognize the need for common data representations, common data models (CDMs), data modelling languages (e.g. OMG UML and SysML), and common simulation tools. [1]

The current state of industry practice in this regard is Model Based Systems Engineering (MBSE) [2] which unifies and formalizes the art and science developed over the last 30+ years. The International Council on Systems Engineering (INCOSE) defines MBSE as “Model-based systems engineering (MBSE) is the formalized application of modelling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.” [3] These have proven useful for showing relationships among system functions, requirements, processes, developers, and users. [4]

Interestingly, this can hold true whether developing, for example, a new autonomous aerial combat system or the formal training systems to be used by its military operators, or even the software developers that are creating a simulated online game version of the real-world physical autonomous system.

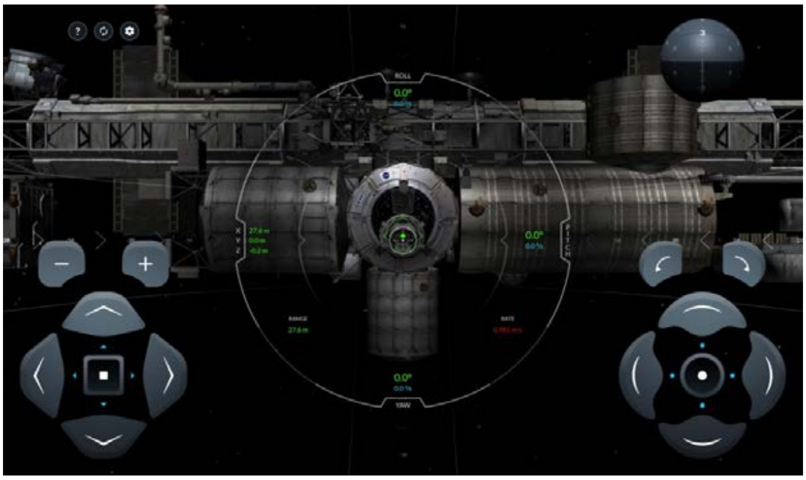

Fig. 1. Image of SpaceX Dragon 2 International Space Station (ISS) docking graphical interface in which the on-ship application, the astronaut training simulation, and the popular free online game are visually nearly identical [5]

In the current era, software dominates development and we are beginning to see this cross traditional industry roles. For example, the incorporation of the MS&T technology directly into the deployed OT, such as the use of products derived from gaming physics engine technology into the operational production user human machine interface (HMI) of automobiles. General Motors (GM), for example, announced its use of Epic Games Unreal Engine to drive the vehicle's information displays, citing its use as "an advanced real-time 3D creation tool, enabling photorealistic visualizations and lifelike animation" in its press release. [6]

Fig. 2. GMC Hummer vehicle interface using Epic Games Unreal Engine [7]

Previously, such UI would be developed in house or perhaps make use of specialized HMI or UI software frameworks. Thus, vendors who were once considered in separate specialized domains now find themselves directly competing across overlapping markets. This is the beginning of a remarkable change in the practice of software development for complex mission and safety-critical cyber-physical systems.

3. COMBINING MS&T AND OT

All this background now brings us to the main theme of this paper, namely, the seamless use of the same technology for MS&T and the OT. More specifically, we are especially concerned with the data model and data distribution mechanism for connecting MS&T and OT in complex distributed systems.

Of course, to achieve this a great many software quality attributes and practical details must be carefully considered. Some of the most essential include:

- Interoperability, at the data model, application programming interface (API), and on-the-wire protocol levels
- Quality of Service, such as reliability, priority, throughput, latency, and content filtering
- Security, often involving partitioning and isolation of domains
- Scalability, from high-performance local nodes with reliable connections, to geographical widely distributed nodes with unreliable disrupted/disadvantages, intermittent and lossy (DIL) connections
- Maintainability over the program lifecycle, often involving upgrades and patches spanning many years

In order to reliably and routinely connect MS&T and OT, the quality attributes of each must be such that acceptable performance of individual applications and the overall system is preserved. This means, for example:

- Handling the "impedance mismatch" of greatly differing data-rates/throughputs and timing/latency constraints

- Ensuring robustness in the presence of unreliable DIL network transports
- Providing isolation and resiliency of the OT to continue operating in presence of cyber threats that may emerge from the addition of the MS&T as an additional attack surface
- Logging for assessment and non-repudiation when issues arise between using multiple organizations' applications
- Providing flexibility to add or remove nodes, applications and services – ideally with automatic discovery mechanisms such that they can be enter or leave in any order and at any time without causing disruptions to the overall system

4. TECHNOLOGY DEMONSTRATION CONFIGURATION

For our technology demonstration, RTI research focused on multi-vendor interoperability between MS&T and OT. Specifically, we focused on a representative set of MS&T and OT products used in airborne autonomous systems. Our demonstration achieves interoperability between FACE-compliant and SOSA-compliant applications, Unity and Epic Games® Unreal Engine gaming engines, and avionics applications using RTI Connext TSS. Connext TSS is based on the open OMG Data Distribution Service (DDS) standard and was developed by RTI as the first certified conformant Future Airborne Capability Environment (FACE) Transport Service Segment (TSS) solution.

Our demonstration consists of two drone simulators: one using the Unity gaming engine, and the other using the Epic Unreal Engine gaming engine. These drone flight simulators publish location, video and lidar data compliant with SOSA Interaction Binding rules via a SOSA-aligned plugin.

The lidar data is displayed using RVIZ, a ROS 2 application. Location is fed into different UI applications and an Ansys FACE-conformant A661 server. The demonstration also highlights how Connext TSS can interoperate seamlessly with Ansys Cockpit Display Systems (CDS), ENSCO IData CDS, and Presagis CDS.

In summary, the overall demonstration shows interoperability between the technologies listed in Table 1.

Table 1. Technologies Used in Interoperability Demonstration

Item	Technology
1	Unity gaming engine with Microsoft AirSim drone simulator
2	Epic Unreal Engine gaming engine with Microsoft AirSim drone simulator
3	Video data via SOSA Interaction Binding
4	Lidar data via SOSA Interaction Binding
5	Lidar data displayed using RVIZ, a ROS 2 application
6	Connext TSS drone location data to Ansys A661 server
7	Connext TSS driving simultaneous interoperability between Ansys CDS, ENSCO IData CDS, and Presagis CDS

Figure 3 below shows a graphical depiction of how these technologies are interconnected. The key enablers used are the Connext Databus along with the Connext Gateway and Connext TSS.

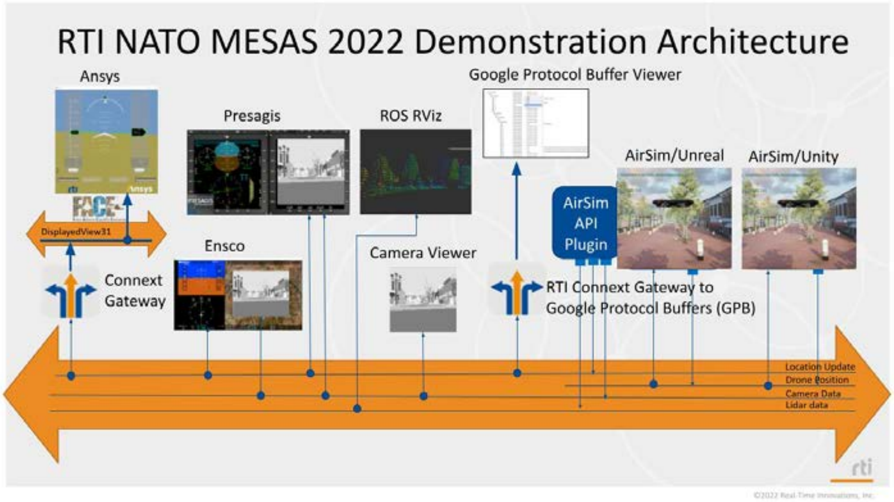

Fig. 3. Diagram of technology demonstration showing interoperability between autonomous avionics applications via Data Distribution Service (DDS) databus

5. USE OF DDS AND AS KEY ENABLING TECHNOLOGY

As many have noted [8], military MS&T technology is now largely following the innovations of commercial industry, rather than leading them. Additionally, the trend over the last two decades has been to require adoption of open standards and open architecture principles in the acquisition of defence systems. In principle, the combination of these two facts should result in the ability to select products from multiple (even competing) vendors, reconfigure and update software applications, and enable the addition of additional participants (i.e. new monitoring, logging, analytics, user consoles, etc.) into an overall system.

To a considerable extent, this has been the case. However, challenges remain. Mostly important is the issue of interoperability at multiple levels. For example, at the application programming interface (API) level there must be standardization for portability and, at the protocol level, there must be standardization for on-the-wire seamless communications. There is also still the issue of incorporation of legacy systems that predate the adoption of data-centric open standards. Ultimately, in some instances, there is no alternative but to use of adapters, bridges, gateways, and related technologies.

5.1 OMG DDS Overview

To address these concerns, RTI provides the Connext product suite used in the technology demonstration. RTI Connext is a set of developer tools, a software library that is compiled into an application, and additional runtime services designed to provide distributed communications services needed within the overall MS&T and/or OT system. Connext DDS is compliant with the OMG DDS standard. The standard ensures that all competing products that are compliant will be interoperable at the wire level and API level. This means that applications built by different teams using various compliant vendor products will all interoperate with little effort.

Further, DDS is *data centric* – meaning data is treated as a first-class citizen. Most other communications solutions are *message centric* and send their data over the network as encoded bits (opaque payloads) that the network cannot understand. All the knowledge about encoding and decoding the data rests with the applications themselves. This forces every application to implement numerous features to support reliability, security and interoperability.

In contrast, *data centric* means that developers naturally define open data models that describe the structure of the data that will move between applications. This allows DDS to automatically handle encoding, security, optimized/reliable delivery, and more. DDS offers a path to *open architecture*.

RTI Connext DDS is a *loosely-coupled*, and *fully decentralized* communications framework. This makes it possible to scale systems quickly, without recompiling or shutting the systems down. Instead of creating brittle, point-to-point network dependencies, DDS communicates over the concept of *topics*. Applications simply declare what kind of data (topics) they are interested in, and DDS delivers it. This eliminates the brittleness of requiring applications to identify specific endpoints that they need to talk to – DDS handles all of this, so developers can focus on application code and not on how to send data over the network. DDS runs reliably over LAN and WAN.

DDS provides fine-grained read/write access control to the data. While encrypting all communications is generally useful, when a system only wants to restrict subsets of the data this approach will not work. For example, when *some* users should not see classified data, this can be very difficult or even impossible to implement. Because DDS is data centric, it knows what is in each packet, and it can therefore be configured to apply encryption at the topic level. Using DDS fine-grained access control, it guarantees that only authorized applications receive this data – enabling highly customizable multi-level secure communications. This could be thought of as *software-defined security*. Security is discussed in greater detail in the next section.

Finally, because DDS is loosely coupled and it uses the concept of topics to communicate, it supports *location-independent processing.* Cloud-based simulators need solutions need to integrate both local and remote compute + storage resources. Connext provides this capability.

5.2 OMG DDS Security

In DDS, security is implemented above the transport layer. This is one of the key enablers to provide a software-defined multi-level security (MLS) capability. It also means that any Connext DDS transport can be used securely, including UDP, TCP and shared memory. Support for UDP multicast (both reliable and best effort) enables very efficient data distribution to multiple authenticated subscribers to the same data.

The OMG DDS Security Specification is comprehensive. It provides support for authentication, authorization, access control, confidentiality, integrity, and non-repudiation for all the data sent over DDS. Moreover, it provides a security auditing capability to evaluate the overall communication state. It is designed to handle scalable deployment scenarios, specifically the one-to-many distribution of encrypted information while maintaining real-time quality-of-service.

OMG DDS Security provides fine-grained access control over the messages and sub-messages that include both data and meta-data. This is the second key enabler for a software-defined MLS capability. Using this in conjunction with other features of DDS, it provides agile encrypted routing of classified data at the data packet level.

6. FUTURE WORK

RTI plans to evolve the technology demonstration with a number of enhancements, including additional simulation frameworks, data visualization applications, human machine interface (HMI) tools, and more network transports. We may also add more quantitative performance displays to go along with the core functional interoperability demonstration. Connext makes adding additional components straightforward. Interested parties may contact RTI at research@rti.com if interested in having an in-house demonstration at their facility, participating in further research, or adding additional technologies to the demonstration.

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