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Interoperable Simulation for Space Logistics & Operations for a Moon Base

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Abstract

Diffusion of cheap yet effective computational solutions has long been contributing to dissemination of simulation in myriad fields; indeed, nowadays it is possible to address nearly every problem by means of Modelling and Simulation (M&S) which now holds a soaring interest within many industrial fields. However, from a technical point of view, interoperability between these models often remains insufficient to achieve Systems of Systems (SoS). In fact, while it is possible to regulate data formats and units of measurements used in SoS, there are still connectivity and compatibility issues that are not completely covered by developers operating in this field. In this paper we propose an interoperability gateway developed to address this issue as well as a case study in which the solution in tested.

Keywords: Logistics, Simulation, Interoperability, Space Operations, Simulation Exploratory Experience

1. Introduction

Nowadays modeling and simulation is extensively used in multiple fields to solve complex problems, starting from logistics and seaports to pandemics and space exploration (Law & McComas, 1987; Bruzzone et al., 2013). Regarding the latter, Artemis space mission is one of most recent examples that holds such a high level of complexity (Smith et al., 2020). It aims at bringing humans back to the Moon by involving different space agencies, institutions as well as private contractors. In particular, the program is expected to include several phases distributed throughout several years and characterized by increasing difficulty. Among others, it includes a launching system that comprise a support infrastructure, a spacecraft, a gateway station, lunar landers and vehicles, and astronauts, which effectively make the project a System of Systems (Bruzzone et al., 2015; NASA, 2020). Thus, it is obvious that the program is quite challenging not only in terms of execution of the Lunar mission, but also concerning planning, preparation, and coordination. Furthermore, if we considered the dissimilar and independent nature of stakeholders it becomes evident the vital role played by simulation-based solutions when facing program planning, defining systems and subsystems along with their interactions, and assessing potential risks and pitfalls.

Nevertheless, simulation of missions of such kind is very sophisticated and tricky. Moreover, even if stakeholders have already working models of their particular systems, data exchange, integration, and interoperation among them still remain problematic. There are cases on space exploration from the past where perfectly functioning systems failed and got lost because of their improper integration; for instance, Mars Climate Orbiter was lost due to wrong thrust functioning caused by a mismatching of units of measurement among the control system and thrusters so correction of trajectory was performed using wrong values (NASA, 1999).

Obviously, similar errors could be prompted not only by distinct units (degrees vs radians, kg vs pounds) but also by dissimilarities between reference frames (e.g. left or right-handed coordinate systems), naming conventions and special codes, improper data (de)codification, and discrepancies in data transmission protocols and number representation. In order to prevent such situations from occurring during simulations, it is fundamental to guarantee that all stakeholders have been provided a clear and exhaustive set of requirements of data formats.

Another major issue is related to models' synchronization. While real time simulations are quite easy to manage from this point of view, capability to advance time faster or slower than normal becomes much more problematic. These situations could take place in difference cases such as when one of the models executes a computationally heavy procedure so that it must slowdown (e.g., CFD simulation of a rocket engine); or the convenience to advance time faster to avoid excessively long idle gaps (e.g., a rover that remains still on the surface). Finally, regarding interactions among models, these must be standardized in a way that all stakeholders have clear picture of the situation.In the light of the aforesaid, we recognize the urgent necessity to employ a standardized approach for adequate handling of the simulation. In the case of the present case, we deem High Level Architecture (HLA) as the most suitable approach. HLA is interoperability standard developed by SISO (Falcone et al., 2014, 2016, 2017) that defines a set of standard procedures, mechanisms and formats related to data exchange between simulators within the same federation. Cooperations among multiple Universities and Partners have been carried out along the last decade (Bruzzone et al., 2014; Taylor et al., 2013, 2014)Among others, it addresses registration of participants, entities and their parameters, time management and pacing, updates of values, controls over execution, interactions and other aspects that are crucial for the interoperability. However, despite being the standard conceptually clear and complete, most advanced Run-Time Infrastructures (RTI) still hold some pitfalls that may turn implementation of its key components tough. We refer to the very limited support of programming languages, which makes most of existing models, simulators, and applications incompatible at least in a direct fashion with RTIs.

2. Space Mission Logistics

One of the most critical aspects related to space missions is proper logistics. This kind of activities foresees execution of tasks in areas in which any error in preparation and planning could lead to excessive costs or even cause entire mission to fail. This is of vital importance in scenarios where is not possible to replenish lacking resources; but also, if we think of long-standing missions which are expected to be sustainable for prolonged periods, as it becomes necessary to carry out bidirectional exchange of materials. In the present case, although the Moon Base could rely on external supplies, it could also produce valuable resources to be sent to the Earth.

3. Space Mission Simulation

Since the complex problem to be faced here revolves around the management of SoS, we deem M&S as advantageous over other kinds of methodologies (Bruzzone et al., 2018). By means of simulation models, we are allowed to perform preliminary checks of planning, evaluate integration of systems belonging to distinct stakeholders, provide opportunity to test procedures and perform risk assessment together with development of emergency plans.

In addition, the fact that models themselves are devised by different stakeholders, right interoperability between models becomes hard. To this end we propose a solution that faces compatibility issues.

4. Interoperability Gateway

To tackle compatibility issues, we developed an interoperability gateway capable of handling connections to the RTI and exposing WebSocket interface to enable connection with external applications. As illustrated in Figure 1 , the gateway allows applications to perform all activities which are usually done within the federation but devoid of direct integration with it. The data exchange is facilitated by JSON (JavaScript Object Notation) format for messages. In addition, the gateway allows interoperability among models developed not just by us but with those ones of other participants as well as with several federates responsible for publishing reference frame objects, pacing and external data exchange (HLA2MPC).

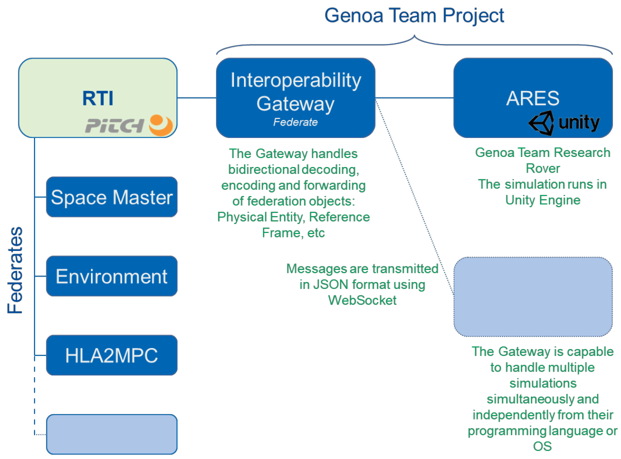

Figure 1. Interoperability gateway architecture.

```
17:19:24: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:24: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:24: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:24: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
17:19:25: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:25: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:25: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:25: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
17:19:26: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:26: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:26: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:26: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
17:19:27: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:27: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:27: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:27: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
17:19:28: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:28: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:28: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:28: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
17:19:29: WebSocket: received message: {
 "entity_name": "ARES_Rover",
17:19:29: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_1",
17:19:29: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_2",
17:19:29: WebSocket: received message: {
 "entity_name": "ARES_Rover_arm_3",
```

HLA Settings
Localhost: 127.0.0.1:8989

WS Clients

Filter messages
HLA
☐ status ☐ error ☐ debug
WebSocket
☐ status ☐ error ☑ debug
FIGA
☐ status ☐ error ☐ debug

☑ Clean old messages
☑ Debug log
☑ Follow last message

Figure 2. Gateway GUI with several controllers to manage connection.

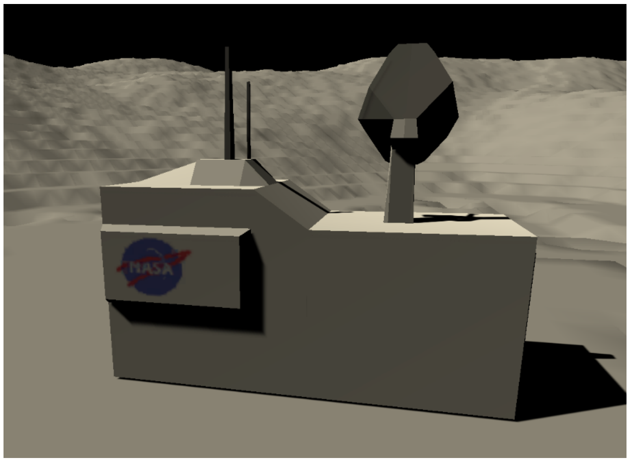

Figure 3. Lunar base 3D model on the lunar surface.

Turning to the functioning, at start the gateway registers itself in the federation as a normal federate. Then, as soon as clients are requesting to join the federation execution, gateway establishes connection to it and executes registration of single entities held by clients. Consequently, update of attributes, related decoding and encoding of messages, time management and other activities are performed.

The application has a GUI (Graphic User Interface) which enables choosing target federation address, checking connected clients and keeping track of events (Figure 2). It also includes a function to filter only the messages of interest, as shown on the next figure. The interface provides mostly textual output to user since it was considered as sufficient for system management and configuration as well as for troubleshooting.

5. Case Study

Stress testing of the solution was done within the scope of SEE (Simulation Exploration Experience) initiative, organized by NASA Kennedy Space Center and Johnson Space Center is on going from an original idea of Priscilla Elfrey dating back over a decade (Elfrey 2008; Bruzzone et al., 2014; 2016). The idea of this experience, originally called Smackdown (; Elfrey & Zacharewicz, 2011) was supporting the concept to create a solid base to diffuse up-to-date knowledge of M&S in the Universities and among companies (Ören & Waite, 2007, 2010).

The project encompasses participation of different teams from universities and research centers all around the world, which collaborate to the creation of simulations about the lunar base camp, including rovers, space station and spaceships, landing and launch systems etc.

Certainly, this type of missions involves utilization of numerous assets and support systems (Longo et al., 2016). Therefore, the framework becomes a very suitable environment for testing our solution.

As a matter of fact, the SEE initiative specifies the reference document for the published data format, namely the SpaceFOM, which includes most of the parameters typically exchanged by participants, such as name and status, position, parent reference frame, orientation, and accelerations. (Möller et al., 2017). While current version of the gateway was mainly tested by means of the noticed FOM, the software architecture allows fast and easy adoption of alternative FOMs.

In this sense, we tested the proposed solution with Pitch RTI. However, the software architecture foresees also easy integration with similar RTI solutions, such as VT Mak and/or Portico.

In order to test the system, we developed a collection of 3D models with Blender aimed at representing a part of the mission, that is, vehicles and the Lunar base, as shown illustrated in Figure 3 and Figure 4.

In the case of the vehicle, we developed a rover called 4RES or ARES (Rigorous & Resilient Robotic Research & Exploration System) equipped with a robotic arm manipulator (Figure 4).

Regarding the simulator, we developed it in Unity3D game engine by means of object-oriented programming (OOP) in C#. The existing incompatibility between Unity3D code and RTI supported languages would normally make it difficult to integrate in HLA federation.

However, the utilization of the gateway allowed seamless interoperability with other federation models. Furthermore, all parameters of the rover were properly encoded and shared among federates, while the simulation environment in Untiy3D received all data shared from them.

Figure 4. ARES Rover 3D model on the lunar surface.

6. Conclusions

Within the context of interoperable simulations, existing technical limitations may cause significant negative impact on applications involved. Actually, nowadays standards such as HLA are barely used outside military and academic domains. Given this, the authors proposed an interoperability gateway devoted to dealing with this issue. The presented solution was tested in the scope of SEE 2021 initiative and demonstrated to be capable of handling data exchange with multiple participants. It also properly addresses decoding and encoding of numerous attributes of tens of published entities. In the light of the tests performed, the proposed solution results very promising.

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