SpaceFOM: An Interoperability Standard for Space Systems Simulations

Presenter: Edwin Z. {Zack} Crues, Ph.D.

Authors: Edwin Z. Crues, Dan Dexter (NASA)
Björn Möller (Pitch Technologies)
Alberto Falcone, Alfredo Garro (University of Calabria)

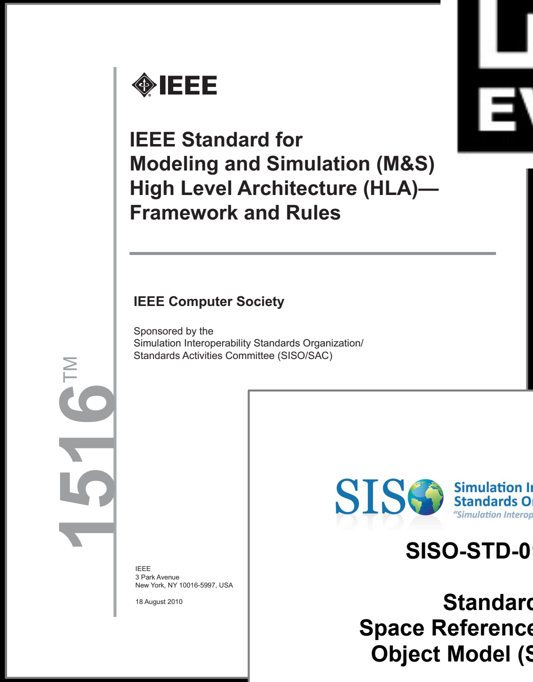
7 March 2022
Presentation to the IEEE 2022 Aerospace Conference, Big Sky, MT

Overview

- Introduction
- The Need for SpaceFOM
- SpaceFOM Basics
- SpaceFOM In Use
- Future Work
- Conclusions
- Questions

Introduction

- The Simulation Interoperability Standards Organization (SISO) Space Reference Federation Object Model (SpaceFOM) is an HLA-based simulation interoperability standard focused on the specific needs of space systems.
- IEEE 1516-2010 - High Level Architecture (HLA):
  - Originally developed by the US DoD;
  - Current version is IEEE 1516-2010, also known as HLA Evolved;
  - Long history with massively distributed simulations used for war games;
  - Only covers the core interoperability requirements.
- SISO-STD-018-2020 - Space Reference Federation Object Model (SpaceFOM):
  - A standard focused on the the needs of space systems simulations;
  - Published in January 2020 (relatively new);
  - Provides additional standards specification needed for a priori interoperability;
  - An extension of the HLA (IEEE 1516-2010).


IEEE

IEEE Standard for
Modeling and Simulation (M&S)
High Level Architecture (HLA)—
Framework and Rules

IEEE Computer Society

Sponsored by the
Simulation Interoperability Standards Organization/
Standards Activities Committee (SISO/SAC)

1516™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

18 August 2010


SISO Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

SISO-STD-018-2020

Standard for
Space Reference Federation
Object Model (SpaceFOM)

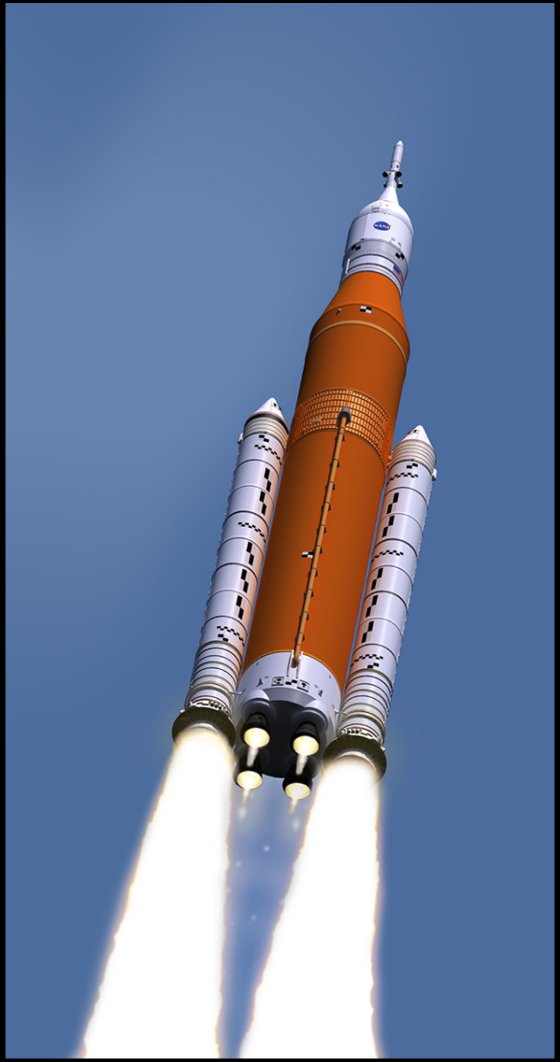
Version 1.0

25 October 2019

Prepared by
The SpaceFOM Product
Development Group (PDG)

The Need for SpaceFOM

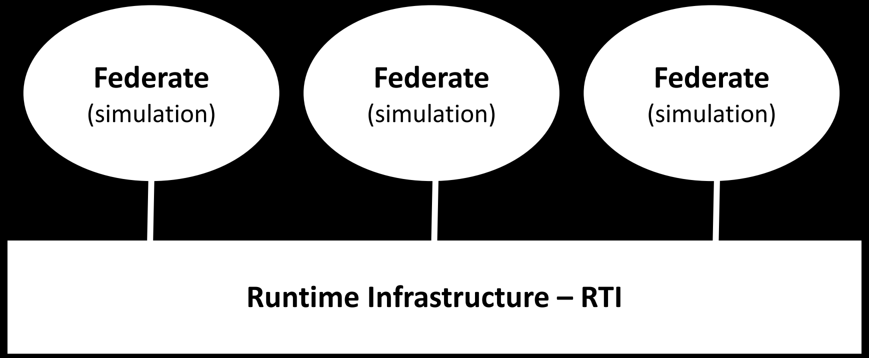
- Spaceflight is difficult, dangerous and expensive; human spaceflight even more so.
- In order to mitigate some of the danger and expense, professionals in the space domain have relied, and continue to rely, on computer simulation.
- Simulation is used at every level including concept, design, analysis, production, testing, training and ultimately flight.
- Distributed simulation provides a base technology for segmenting these complex space systems into smaller, and usually simpler, component systems or subsystems.



The Need for SpaceFOM: Continued

- Integrating simulations is costly
  - Need to minimize the integration effort for new and reused systems.
- Open standards like HLA offer a more efficient way to combine and reuse systems and tools in new configurations:
  - They also offer a neutral ground that is easier to accept for many participants than proprietary interfaces;
  - Open standard can also capture best-practices and help communicate them to new developers.
- HLA is not enough to ensure interoperability, a FOM is also needed; thus, the SpaceFOM.
- The SpaceFOM makes collaboration politically, contractually and technically easier.

SpaceFOM Basics: Fundamentals



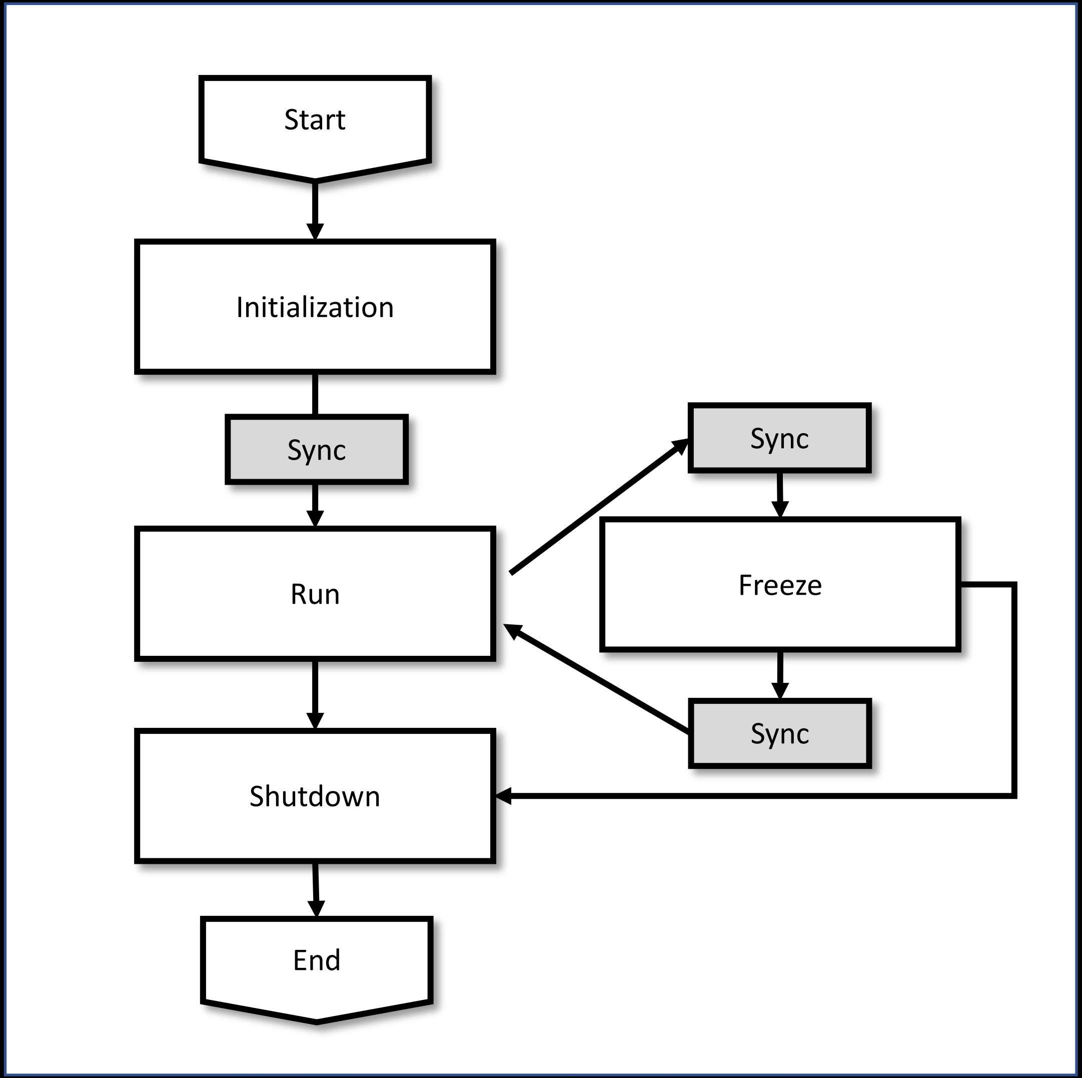
- Based on HLA
- Each simulation is called a federate
- Federates connect to a Runtime Infrastructure that provides services
- Together they form a Federation
- Data is exchanged based on a Federation Object Model (FOM)
- A session is called a Federation Execution

SpaceFOM Basics: Extension to HLA

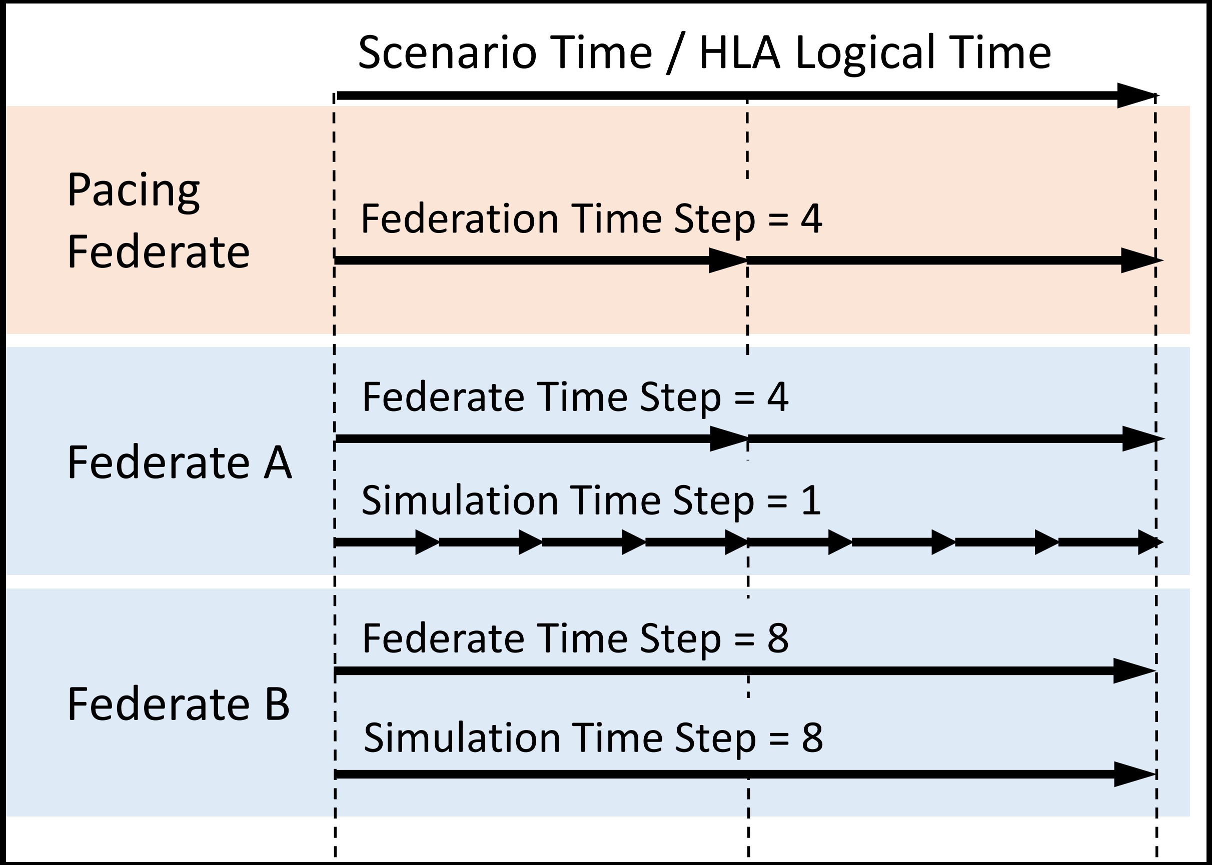
- Existing FOMs did not provide adequate support for space systems simulations.
- The SpaceFOM was developed to provide the additional specifications necessary for space-based scenarios:
  - Roles and responsibilities;
  - Common data types;
  - Timelines and time standards;
  - Time-stepped focused time management;
  - Reference frames and references frame trees;
  - Reference frame naming convention;
  - Common base for space systems objects: entities and interfaces;
  - Well defined execution control structure;
  - Rules for assessing SpaceFOM compliance;
  - Base set of FOM modules.
- In addition, the SpaceFOM itself is designed to be extended.

SpaceFOM Basics: Rules, Roles, and Execution Control

- Rules:
  - 103 Compliance Rules
  - Additional guidelines
- Federate Roles:
  - Master
  - Pacing
  - Root Reference Frame Publisher
- Execution Control:
  - A well-defined executive cycle
  - Gated to control potential deadlocks
  - Supports multi-phase initialization
  - Supports controlled mode sequencing



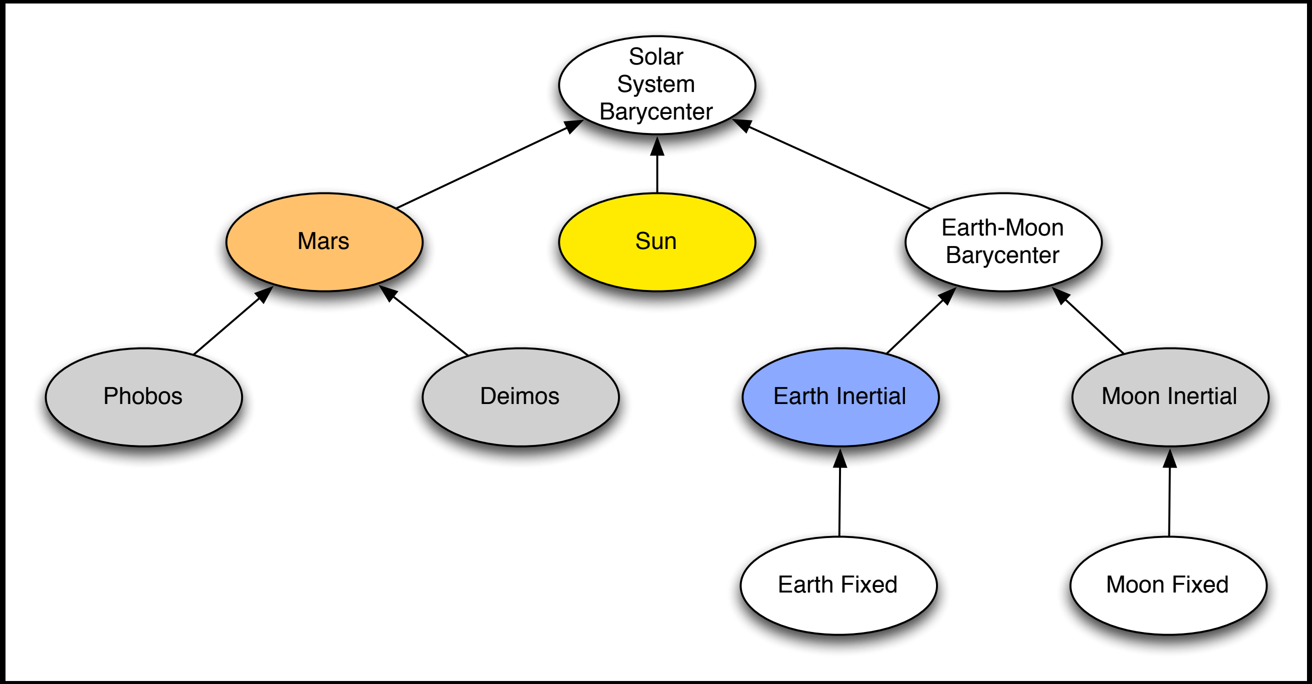
SpaceFOM Basics: Time Standard and Time Lines



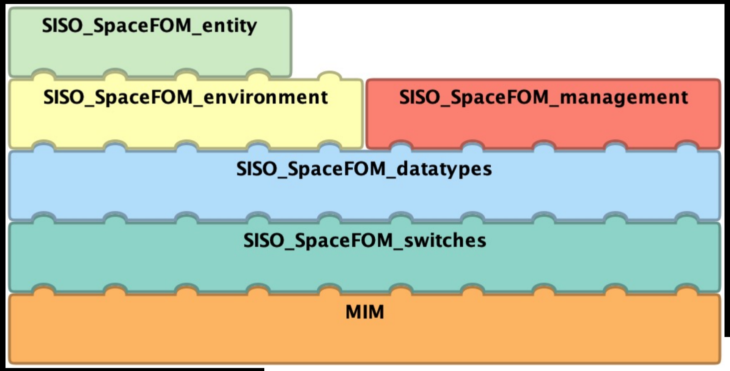
- Defines the Terrestrial Time (TT) standard as the basis for time across the federation execution.
- Defines conversions between other time standards.
- Defines 6 related time lines to support execution control:
  - Physical Time;
  - Computer Clock Time;
  - Simulation Elapsed Time;
  - Simulation Scenario Time;
  - HLA Logical Time;
  - Federation Scenario Time.
- Supports different simulation time steps.
- Support non-realtime and realtime execution.
- Support Central Timing Equipment (CTE).

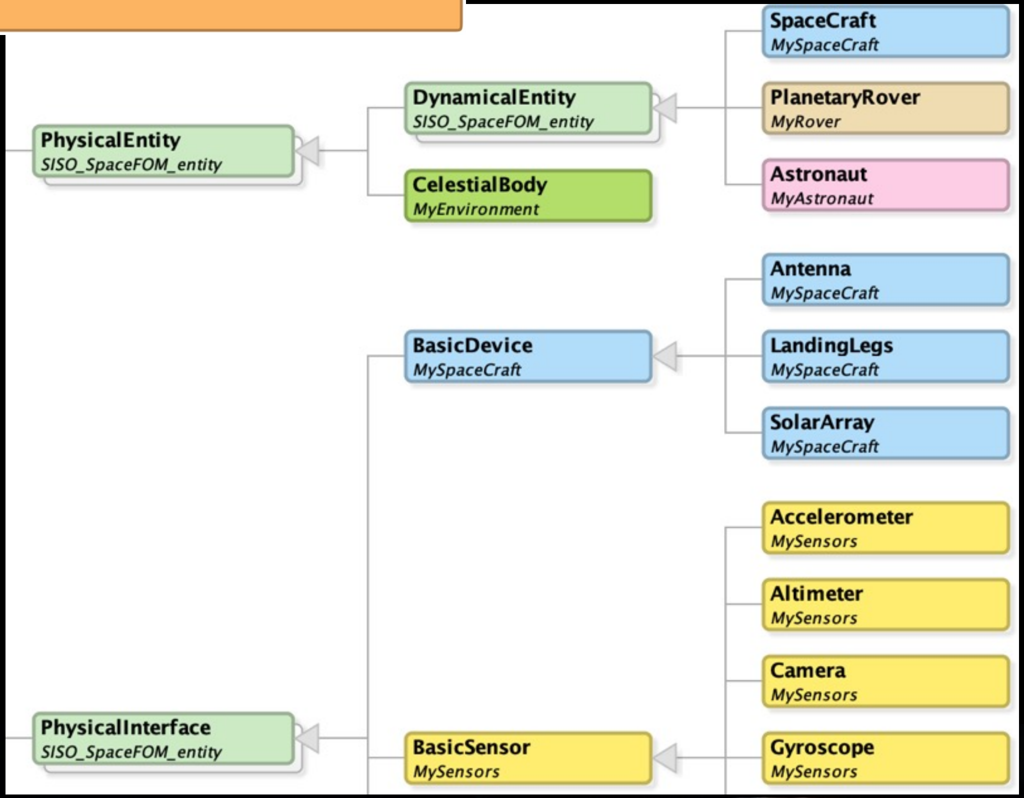
SpaceFOM Basics: Reference Frames and Trees

- Defines a reference frame tree.
- Supports the computation of a state in one frame with respect to any other frame in the tree.
- Is defined based on the needs of the specific federation execution.
- Proposes a standardized naming convention for reference frames.



SpaceFOM Basics: Objects and Extension

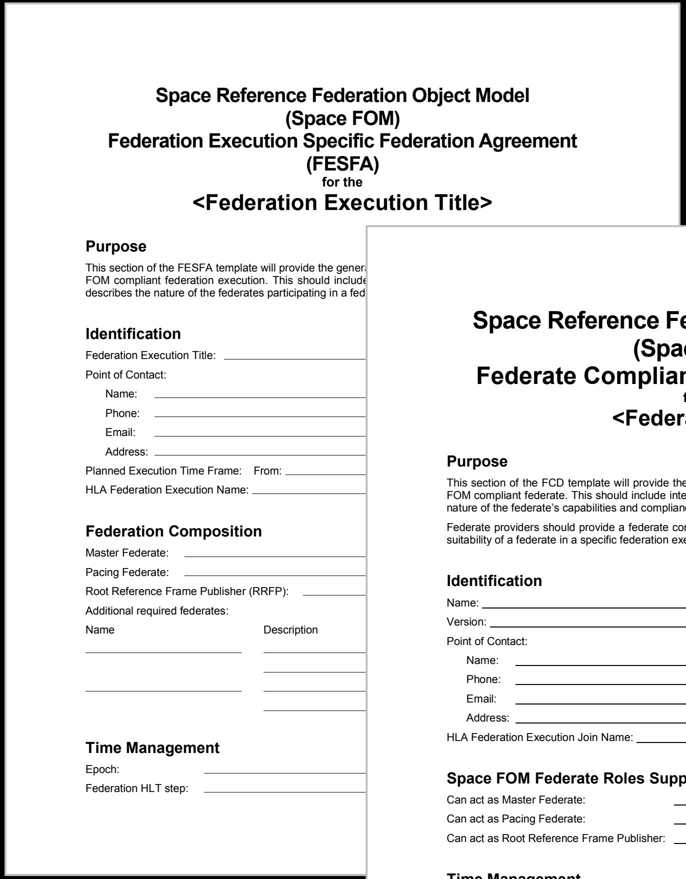




- Builds off HLA base objects.
- Provides a small set of common object types tailored to space system needs:
  - Physical Entity;
  - Dynamical Entity;
  - Physical Interface.
- Other space systems can extend from these.
- Provides a set of common unit definitions for object attributes.

SpaceFOM Basics: Documentation

- SpaceFOM describes two documents to aid interoperability and compliance:
- Federation Execution Specific Federation Agreement (FESFA)
  - Represents a Federation-wide agreement between participating Federates.
  - Pertains to a specific common set of Federation Executions.
  - Provides the general purpose and description of a specific SpaceFOM-compliant federation execution.
- Federate Compliance Document (FCD)
  - Describes the capabilities of a specific Federate.
  - Describes which roles it can play in a SpaceFOM-compliant Federation Execution.
  - Provides the general purpose and description of a specific SpaceFOM-compliant federate.



Space Reference Federation Object Model
(Space FOM)
Federation Execution Specific Federation Agreement
(FESFA)
for the
<Federation Execution Title>

Purpose

This section of the FESFA template will provide the gener
FOM compliant federation execution. This should include
describes the nature of the federates participating in a fed

Identification

Federation Execution Title:
Point of Contact:
Name:
Phone:
Email:
Address:
Planned Execution Time Frame: From:
HLA Federation Execution Name:

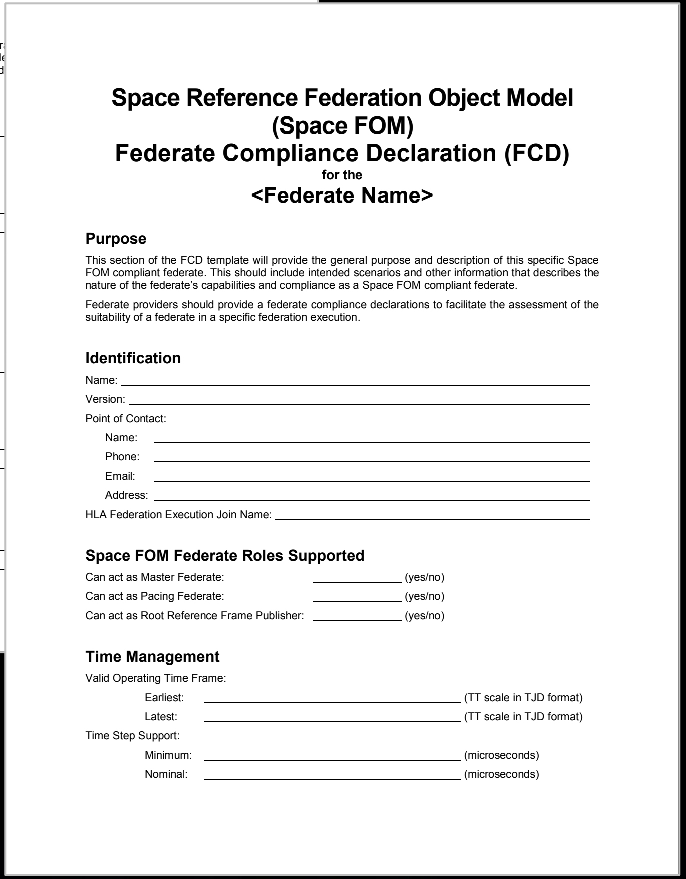
Federation Composition

Master Federate:
Pacing Federate:
Root Reference Frame Publisher (RRFP):
Additional required federates:

Name	Description

Time Management

Epoch:
Federation HLT step:



Space Reference Federation Object Model
(Space FOM)
Federate Compliance Declaration (FCD)
for the
<Federate Name>

Purpose

This section of the FCD template will provide the general purpose and description of this specific Space FOM compliant federate. This should include intended scenarios and other information that describes the nature of the federate's capabilities and compliance as a Space FOM compliant federate.

Federate providers should provide a federate compliance declarations to facilitate the assessment of the suitability of a federate in a specific federation execution.

Identification

Name:
Version:
Point of Contact:
Name:
Phone:
Email:
Address:
HLA Federation Execution Join Name:

Space FOM Federate Roles Supported

Can act as Master Federate: ____ (yes/no)
Can act as Pacing Federate: ____ (yes/no)
Can act as Root Reference Frame Publisher: ____ (yes/no)

Time Management

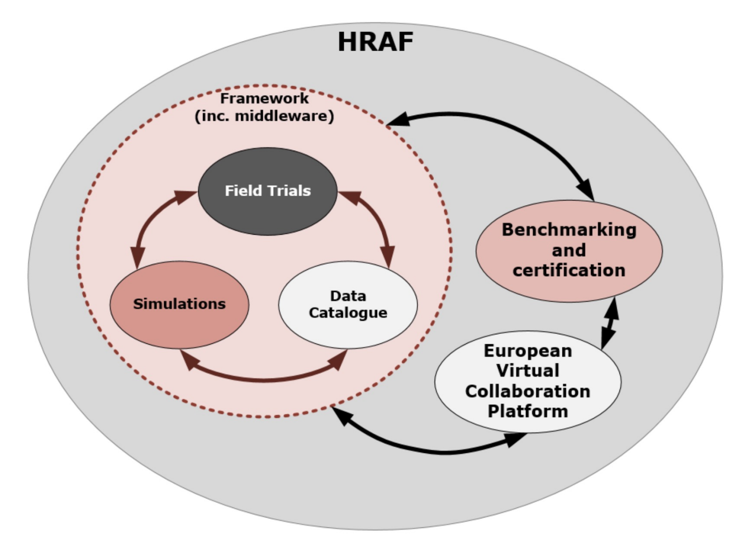
Valid Operating Time Frame:
Earliest: ____ (TT scale in TJD format)
Latest: ____ (TT scale in TJD format)
Time Step Support:
Minimum: ____ (microseconds)
Nominal: ____ (microseconds)

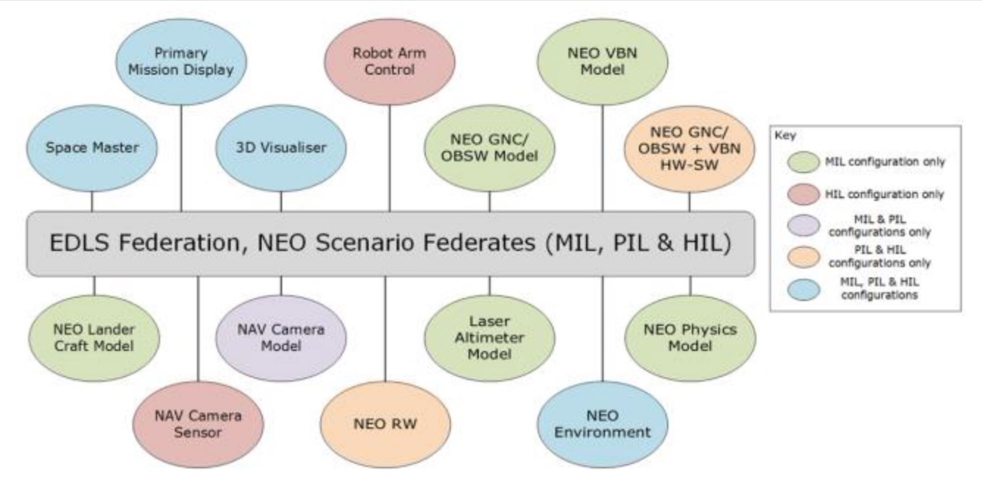
SpaceFOM in Use: SEE

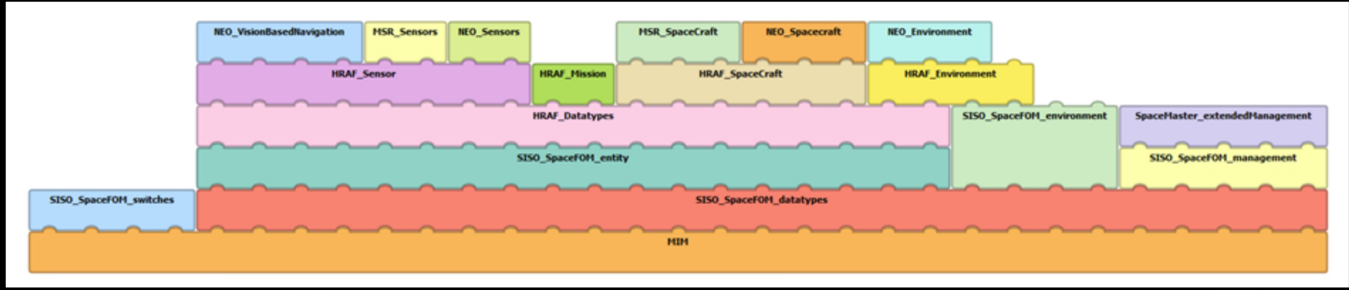
- Simulation Exploration Experience (SEE)
  - Yearly student simulation coopetition started in 2011;
  - Sponsored by SISO, NASA, Pitch, Univ. of Calabria, and others;
  - Focused on distributed simulation in the space domain;
  - Currently modeling an established lunar settlement.
- International student teams
  - Each team provides one or more federates;
  - Composed of university undergraduate and graduate students;
  - Typically have the oversight of a supervising professor;
  - Learn HLA/SpaceFOM and develop a federate in 3-4 months;
  - In 2022 there are 8 teams from 6 different countries.
- Accelerated development schedule
  - Teams form in the Fall;
  - SEE Technical meetings start in January;
  - SEE Federation Execution event in late April or early May.
- SEE was an important early incubator for the SpaceFOM
  - Provides a pre-defined interoperability implementation;
  - Simplifies the development for the teams.

SpaceFOM in Use: ESA – HRAF3

- Harwell Robotics and Autonomy Facility (HRAF):
  - Funded by the European Space Agency (ESA);
  - Supports integrated verification and validation of autonomy systems and associated technologies.
- Develop and maintain simulation and modeling capabilities:
  - Works across multiple network connected labs;
  - Uses HLA and SpaceFOM for interoperability;
  - Mixed software and hardware in the loop.
- Looking at multiple missions:
  - Mars Sample Return;
  - Precision landing on a Near Earth Object.





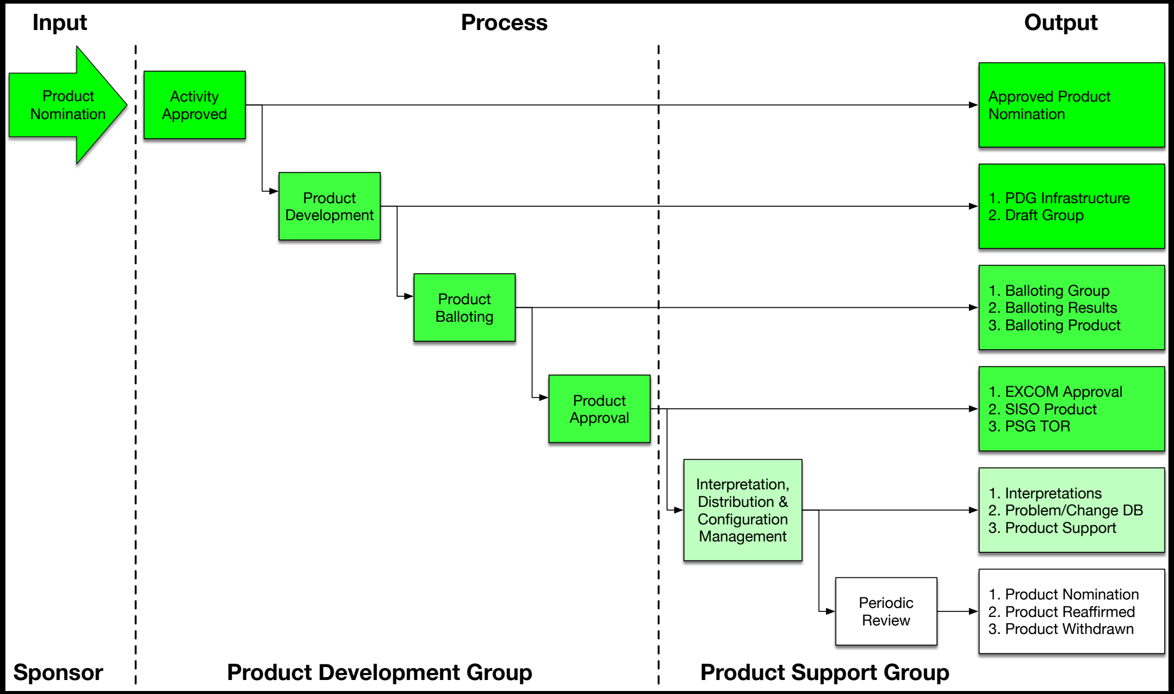


SpaceFOM in Use: NASA - NExSyS and Artemis

- NASA Exploration Systems Simulations (NExSyS):
  - Simulation and modeling team at NASA's Johnson Space Center;
  - Develop, maintain, and use a collection of open-source space systems simulation tools:
    - Trick Simulation Development Environment
      - https://github.com/nasa/trick;
    - TrickHLA
      - HLA/SpaceFOM simulation interoperability interface package for Trick-based simulations.
      - https://github.com/nasa/trickhla/
  - Develops and deploys space systems simulations for human space exploration.
- Artemis Program:
  - NASA program to return humans to the Moon;
  - A multielement architecture;
  - Multinational and commercial participation.
- Building an Artemis Base Camp simulation:
  - Multi-federate simulation;
  - Commercial and international federates;
  - HLA and SpaceFOM based.

Future Work

- SISO has a defined product development process:
  - Balloted Product Development and Support Process (BPDSP).
- The SpaceFOM Product Development Group (PDG) developed the original standard published in January 2020.
- The SpaceFOM Product Support Group (PSG) has replaced the PDG to support the standard and plan for future development:
  - The PSG is collecting input and planning for SpaceFOM V2;
  - Consider joining the effort.
- SpaceFOM is gaining visibility and is being more widely adopted in the aerospace community.



BPDSP Process Flow Chart

Conclusions

- Space exploration is a collaborative activity.
- Human space exploration missions are complex:
  - Operate in a difficult and dangerous environment;
  - Systems are designed to the very edge of our technical capabilities;
  - Multiple partners create additional organizational challenges.
- Space exploration agencies have traditionally relied on simulation:
  - Throughout the development lifecycle: concept, design, analysis, test, training, and flight;
  - Artemis missions represent a new level of collaboration and complexity;
  - One approach to managing simulation complexity is separate/distribute element simulations.
- Distributed simulation can help to manage system simulation complexity:
  - This requires a commonly adopted simulation interoperability implementation;
  - HLA provides for a base interoperability infrastructure, but more is needed;
  - Space systems have additional general simulation requirements.
- SpaceFOM provides the additional definitions needed for distributed space systems simulation:
  - Rules, Roles, Responsibilities, Base FOMs, Execution Control, Definition Documents, etc.;
  - SpaceFOM is an internationally developed simulation interoperability standard;
  - SpaceFOM is developed and supported by SISO, an international standards organization;
  - SpaceFOM is being adopted by several well-known space exploration organizations.

Questions?

NASA

SISO
Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

PITCH

UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI INGEGNERIA INFORMATICA, MODELLISTICA, ELETTRONICA E SISTEMISTICA
DIPARTIMENTO DI ECCELLENZA 2018 - 2022
MIUR
DIMES

NASA

SISO
Simulation Interoperability Standards Organization
"Simulation Interoperability & Reuse through Standards"

Pitch

UNIVERSITÀ DELLA CALABRIA
DIPARTIMENTO DI **INGEGNERIA INFORMATICA, MODELLISTICA, ELETTRONICA E SISTEMISTICA**

DIPARTIMENTO DI **ECCELLENZA**
2018 - 2022

MIUR

DIMES