Simulation Interoperability Standards Organization

"Simulation Interoperability & Reuse through Standards"

Workshop theme for 2017: "Simulation – Enabling Real-World Innovation"

Design and Principles Enabling the Space Reference FOM

2017-SIW-038

Björn Möller, Pitch, Sweden
Edwin Z. Crues, NASA, USA
Dan Dexter, NASA, USA
Alfredo Garro, University of Calabria, Italy
Michael Madden, NASA, USA
Anton Skuratovskiy, RusBITech, Russia

Background and Status

- **Previous papers present why distributed simulation is important to the Space domain**
  - SISO paper 16F-SIW-017 “A First Look at the Upcoming SISO Space Reference FOM” and two ACM/IEEE DS-RT papers
- **HLA federations for the Space domain have been developed for almost twenty years**
  - There are plenty of experiences to collect and reuse
- **Two years ago the SISO Space Reference FOM PDG kicked off**
- **The first complete draft is now available**
- **Next step: review and testing**

Federate Roles and Types of Design Patterns

- **This paper presents important design patterns used in the Space FOM**
  - Essential versions. Read the draft standard for details
- **Three key federate roles are used:**
  - The Master role
  - The Pacer role
  - The Root Reference Frame Publisher role
- **Three types of patterns are covered in this paper:**
  - Execution Control design patterns
  - Time Management design patterns
  - Spatial design patterns

Execution Control Design Patterns

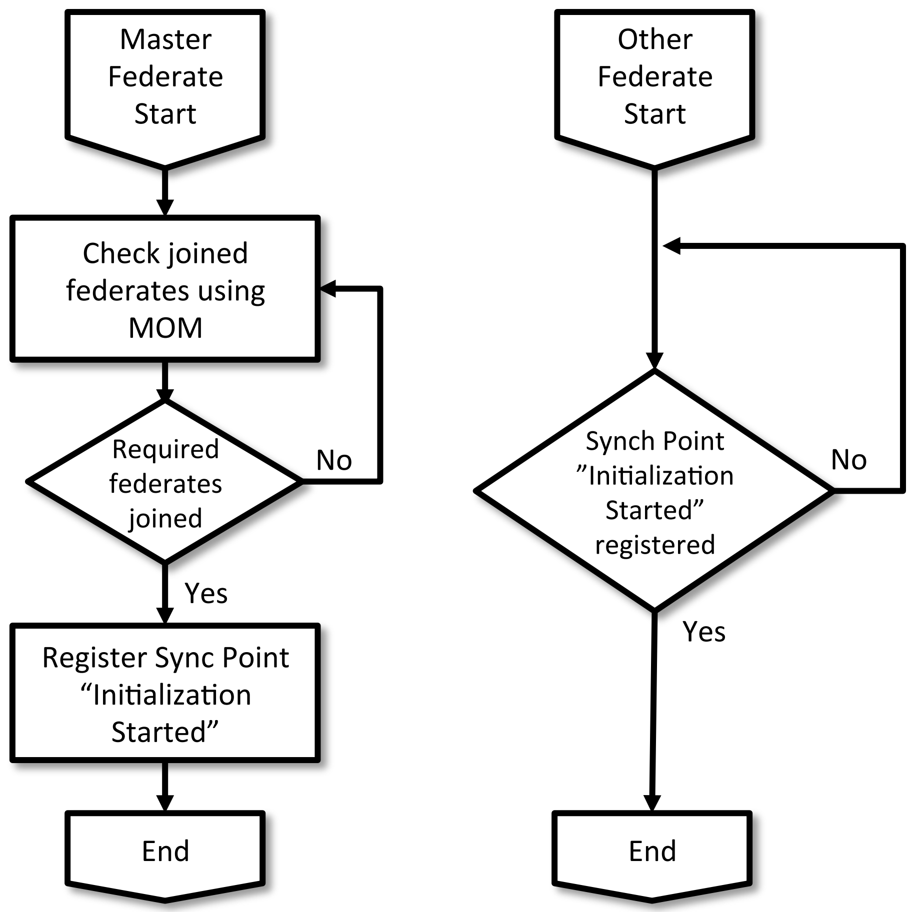
- **These patterns are mainly used to allow the Master to manage the flow of execution**
- **The patterns are:**
  - Removal of orphaned federation execution *
  - Centralized checking of required federates
  - Detection if a federate is a late joiner
  - Global configuration data in singleton instance
  - Synchronized multi-phase initialization
  - Central execution control with transition requests

*) Not presented here – read the paper

Centralized checking of required federates

- **A certain set of federates need to be present before the simulation can start.**
  - This may be for technical reasons, or to be able to perform a meaningful simulation.
- **The Master knows which federates are required and performs the check**
- **Each individual federate may not know if it is required or not**

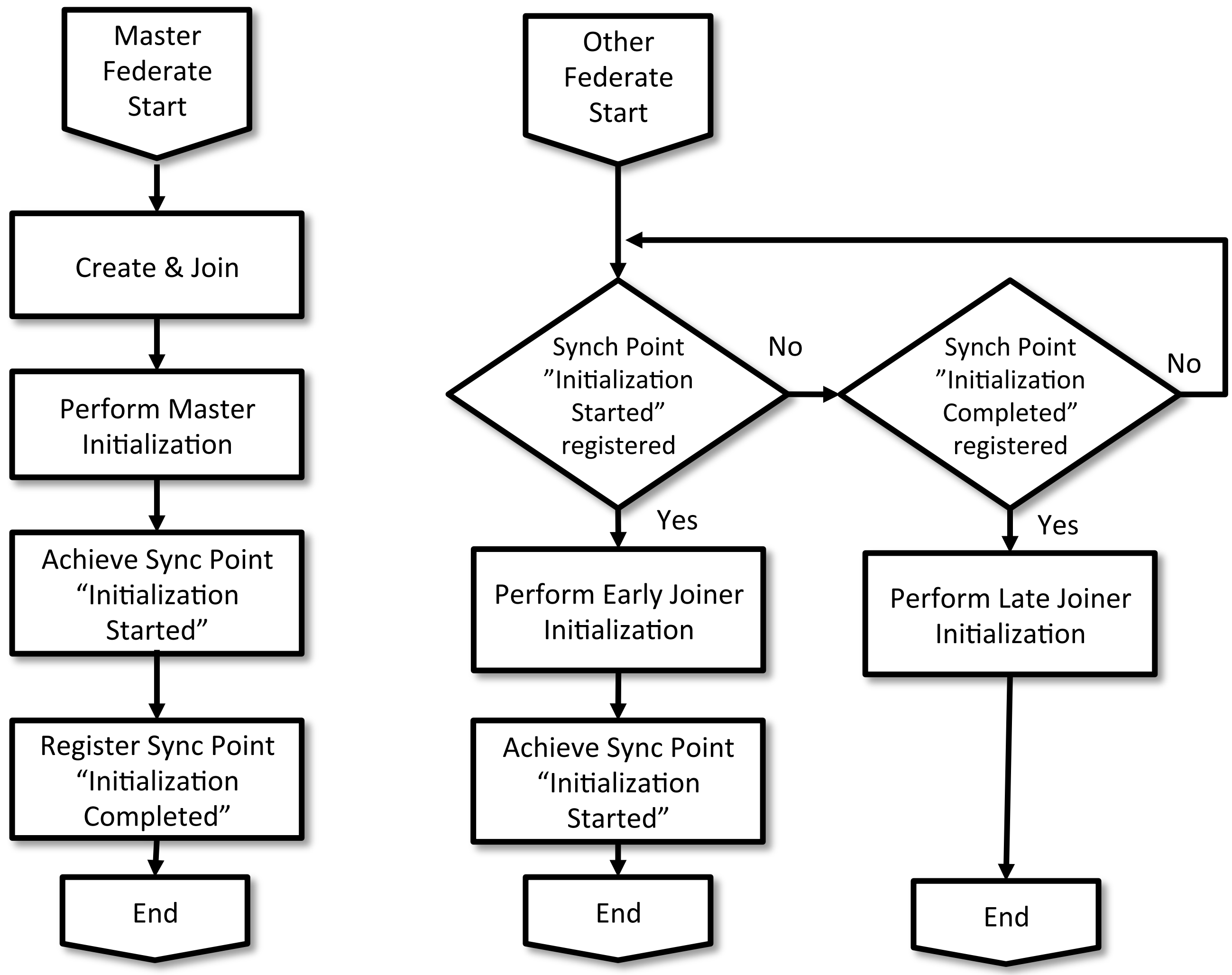
Centralized checking of required federates



Detection if a federate is a late joiner

- **This pattern applies to a federate that may execute as either an early joiner or a late joiner. Late joiner means that the initialization has already been completed.**
  - In case it joins a federation early, it needs to complete certain initialization steps, potentially in coordination with other federates.
  - In case it joins late, different steps may need to be performed.
- **This pattern extends upon the previous pattern.**

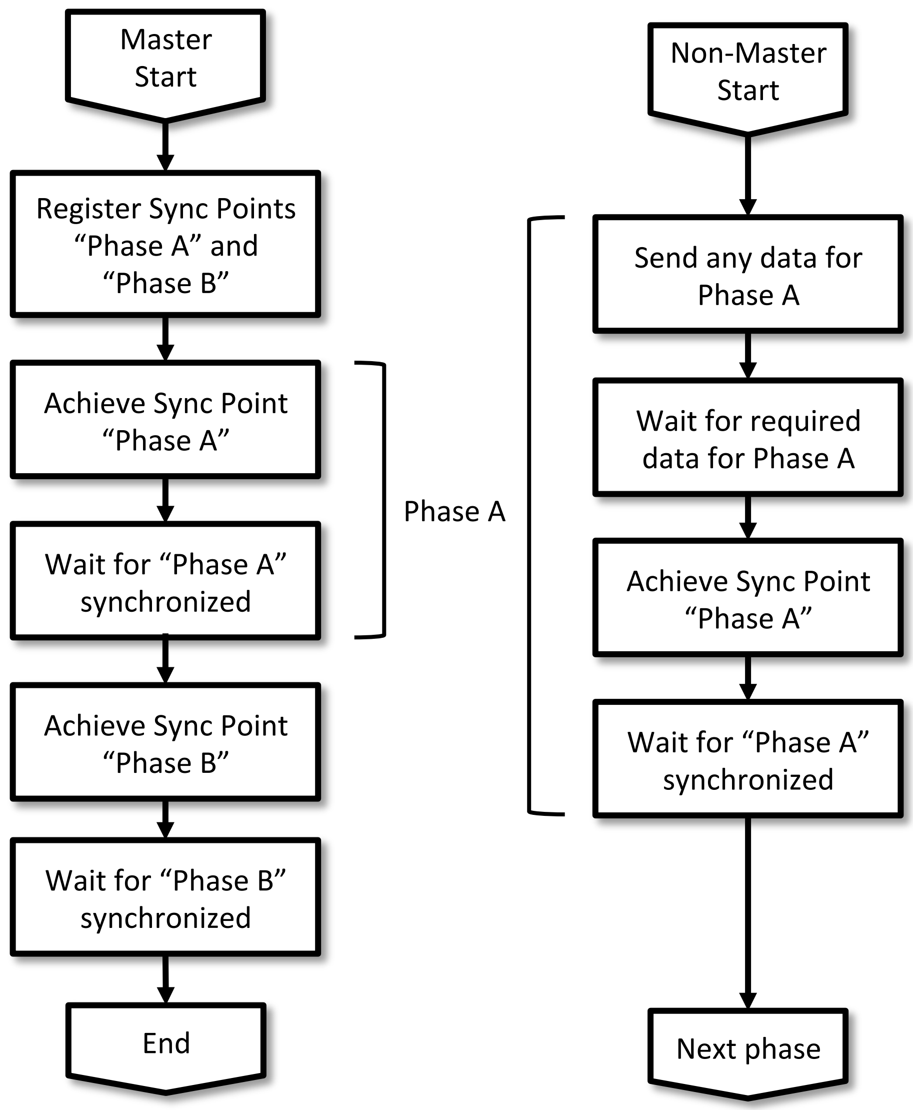
Detection if a federate is a late joiner



Synchronized multi-phase initialization

- **Before starting the main execution, federates need to exchange initial data. Some of the data cannot be calculated before some other data has been provided by some other federate.**
- **To be able to control and verify that all data has been provided, the federation needs to go through a specified set of initialization phases.**
  - In this example "Phase A" and "Phase B"
  - Practical example: initialize a multi-stage rocket

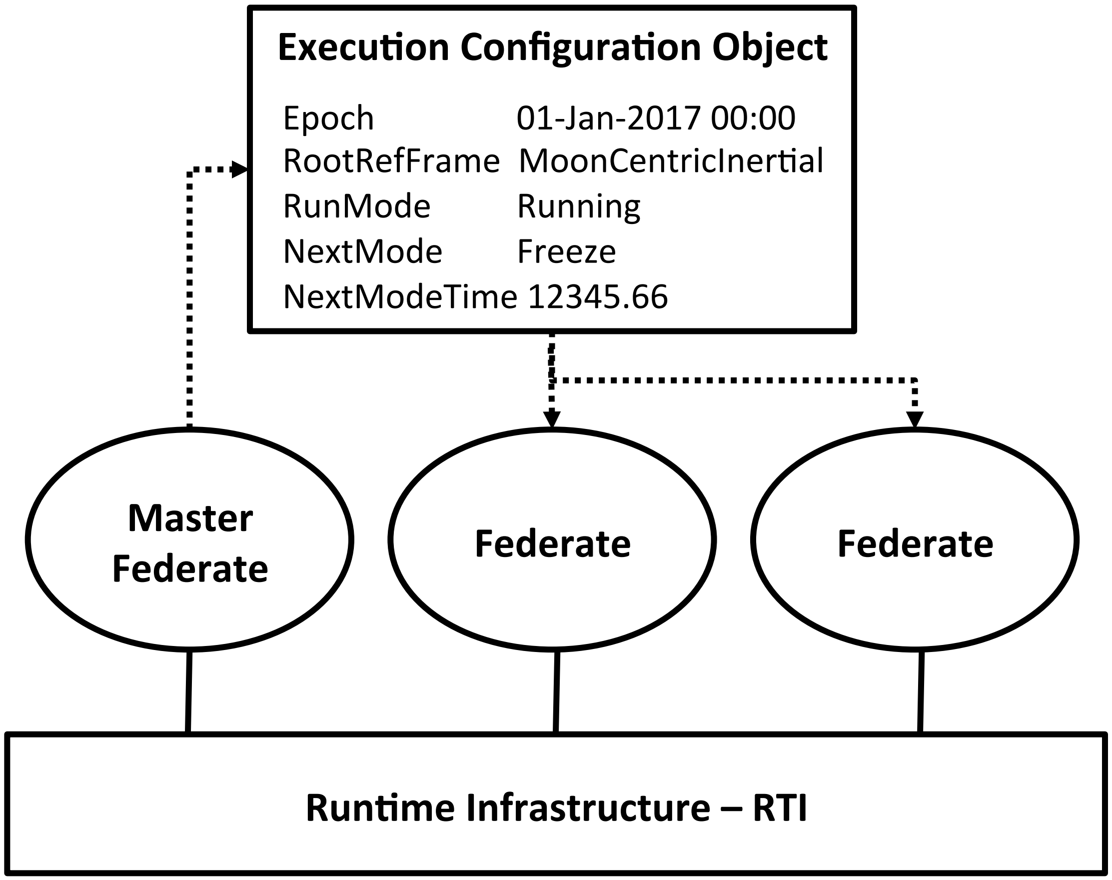
Synchronized multi-phase initialization



Global configuration data in singleton instance

- **A federation needs to share a number of global properties**
  - Storing static data in configuration files for each federate introduces a risk of mismatching data.
- **Sample static data:**
  - Epoch (start time)
  - References to important object instances
- **Sample dynamic data:**
  - Execution state
- **In this case the Master is responsible for sharing the data**

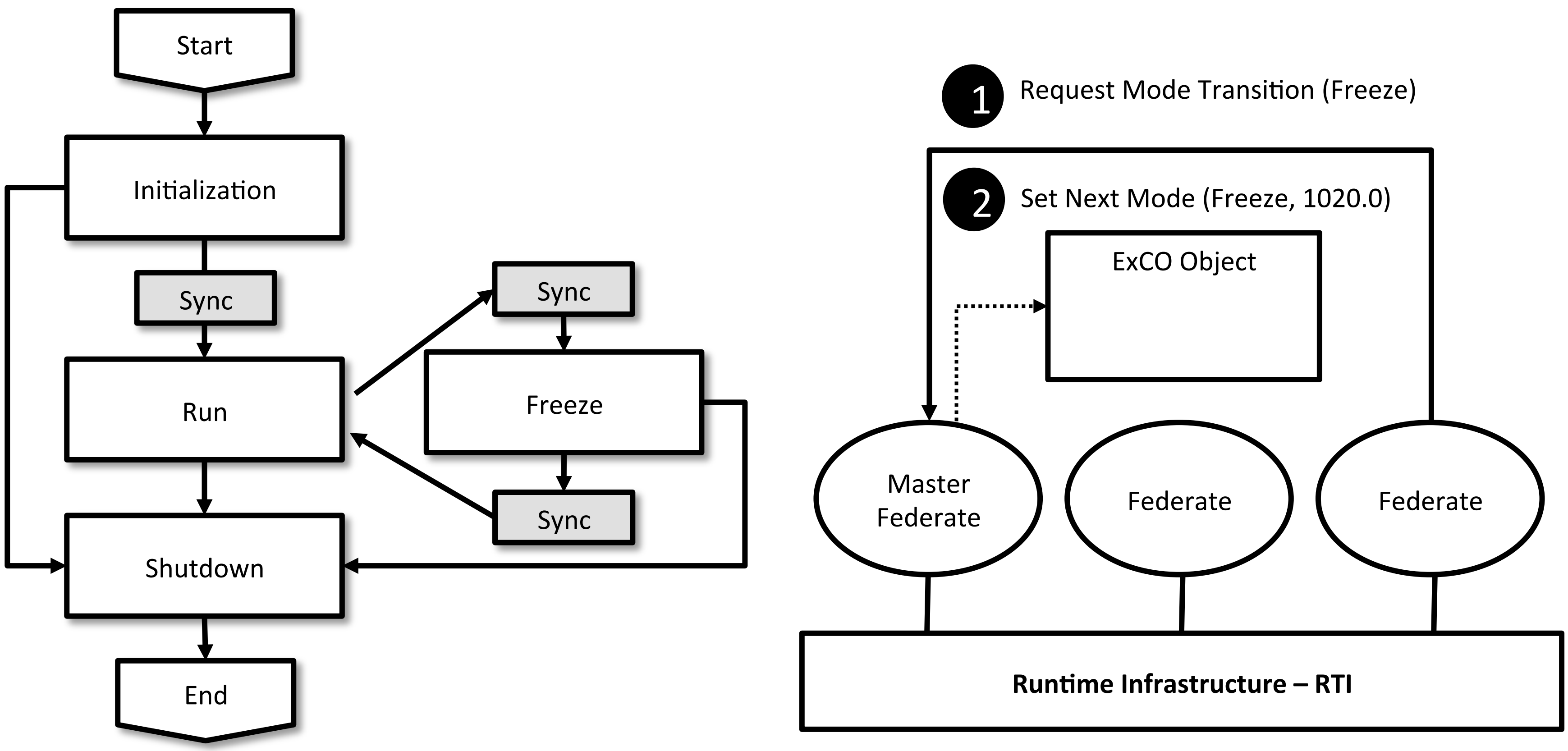
Global configuration data in singleton instance



Central execution control with transition requests

- Federates need to transition between initializing mode, running mode, freeze mode and shutdown in a controlled manner.
- Any federate may need to request a mode transition.
- Since federates may use different time steps, or may need some time to transition, the transition may not happen immediately.
- Late joining federates must perform a required transition, even if the transition was requested before a federate joined.

Central execution control with transition requests



No sync for Shutdown!

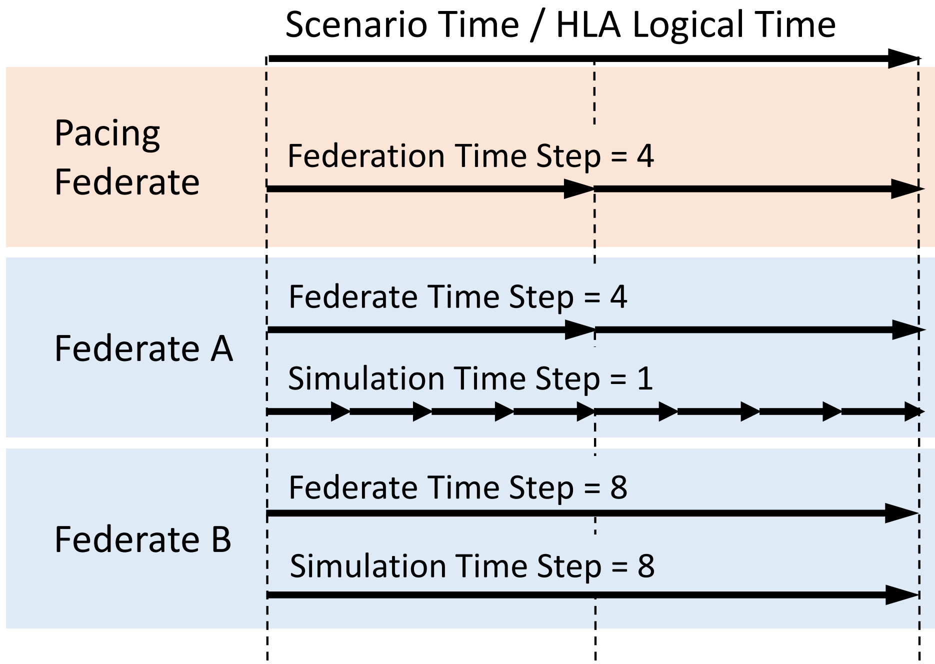
Time Management Design Patterns

- **These patterns coordinate the advance of time, exchange of time stamped data and synchronization with physical time**
  - Physical time or "real world time" in the Space Reference FOM is based on the classical Newtonian concept of absolute time, which is a simplification compared to the relativistic space-time concept.
- **Closely related to the execution control patterns**
- **The patterns are:**
  - Constant but potentially different federate time steps
  - Mix of paced scenario time and physical time

Constant but potentially different federate time steps

- A number of federates that use time-stepped simulation need to execute together in a federation.
- The time-steps are constant but may be different between federates.
- Internally, each federate has a native time step for the physics model
- The federation needs to have well-defined points in time when the federation wide state is complete and consistent, for example for check-pointing, snap-shooting or freeze of the federation.

Constant but potentially different federate time steps



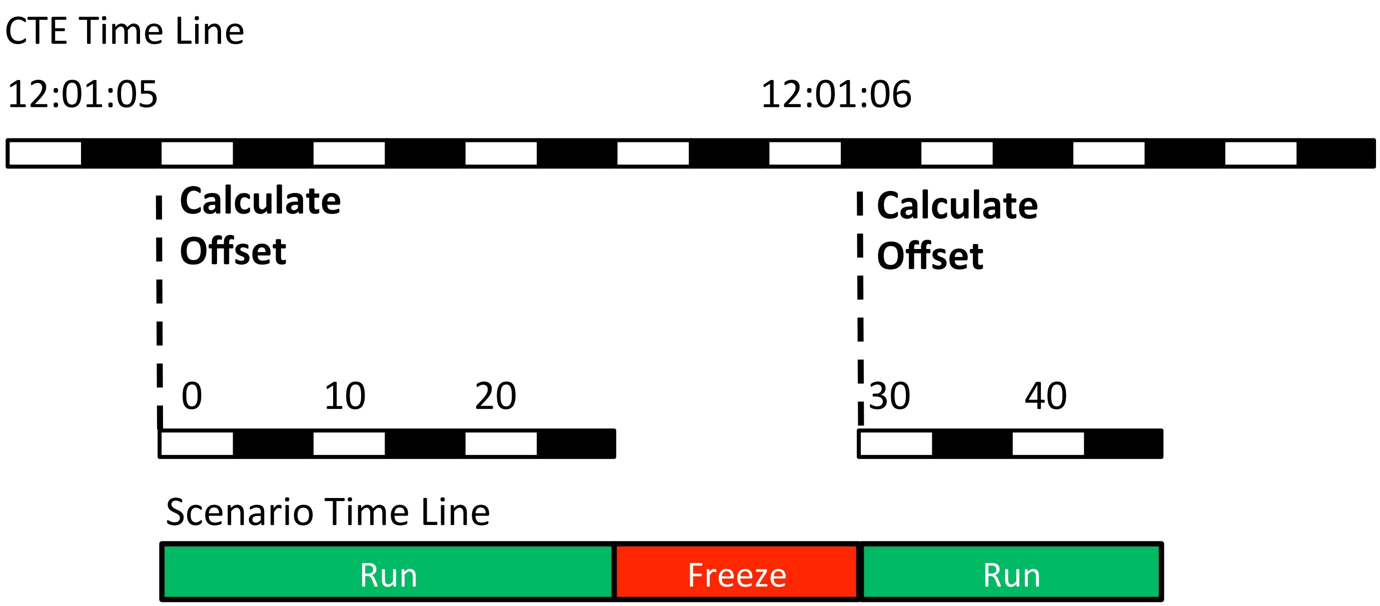
- **Federation Time Step = Pacing time step**
- **Federate Time Step = Time step used for time advance by a federate.**
  - Shall be n * Federation Time Step where n>= 1
  - Shall be n * Simulation Time Step where n>= 1
- **Simulation Time Step = native time step of internal physics model of a federate.**
- **Freeze may occur at Common Time Boundaries**

Mix of paced scenario time and physical time

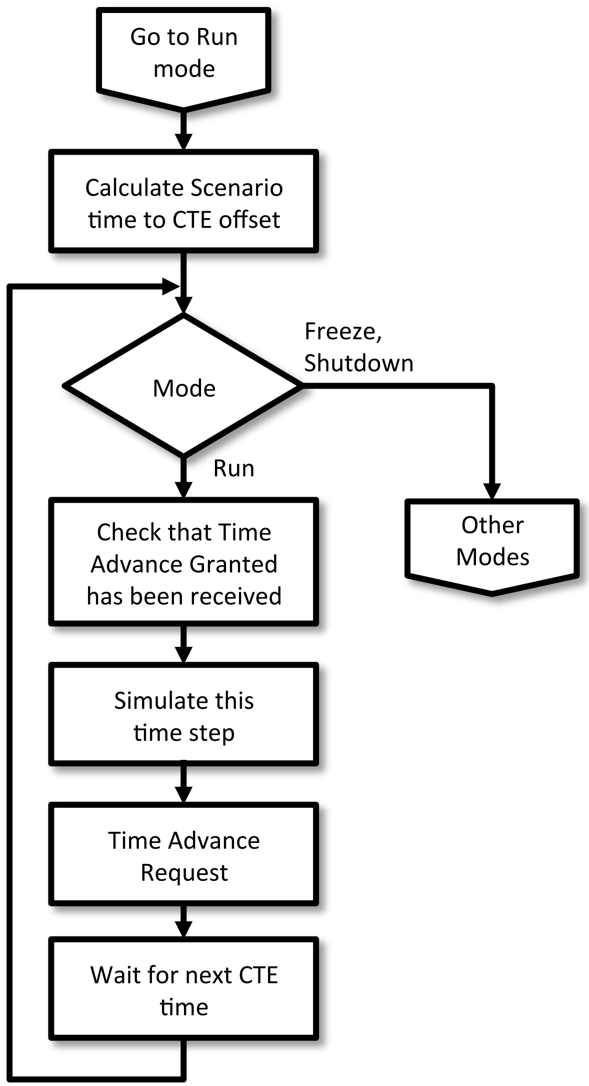
- An HLA federation can accommodate both simulations running in soft real-time and simulators that use central timing equipment (CTE) (e.g., a GPS timing board) for hard real-time synchronization.
- The HLA federation is capable of going to freeze, and later resume.
- The simulations that synchronize using the CTE, must also be able to handle these mode transitions.

Mix of paced scenario time and physical time

- **The HLA Logical time line and the CTE physical time line are connected during Run mode**
  - An offset is calculated when entering Run mode
- **When entering Freeze mode they are disconnected**



Synchronizing CTE and Logical Time



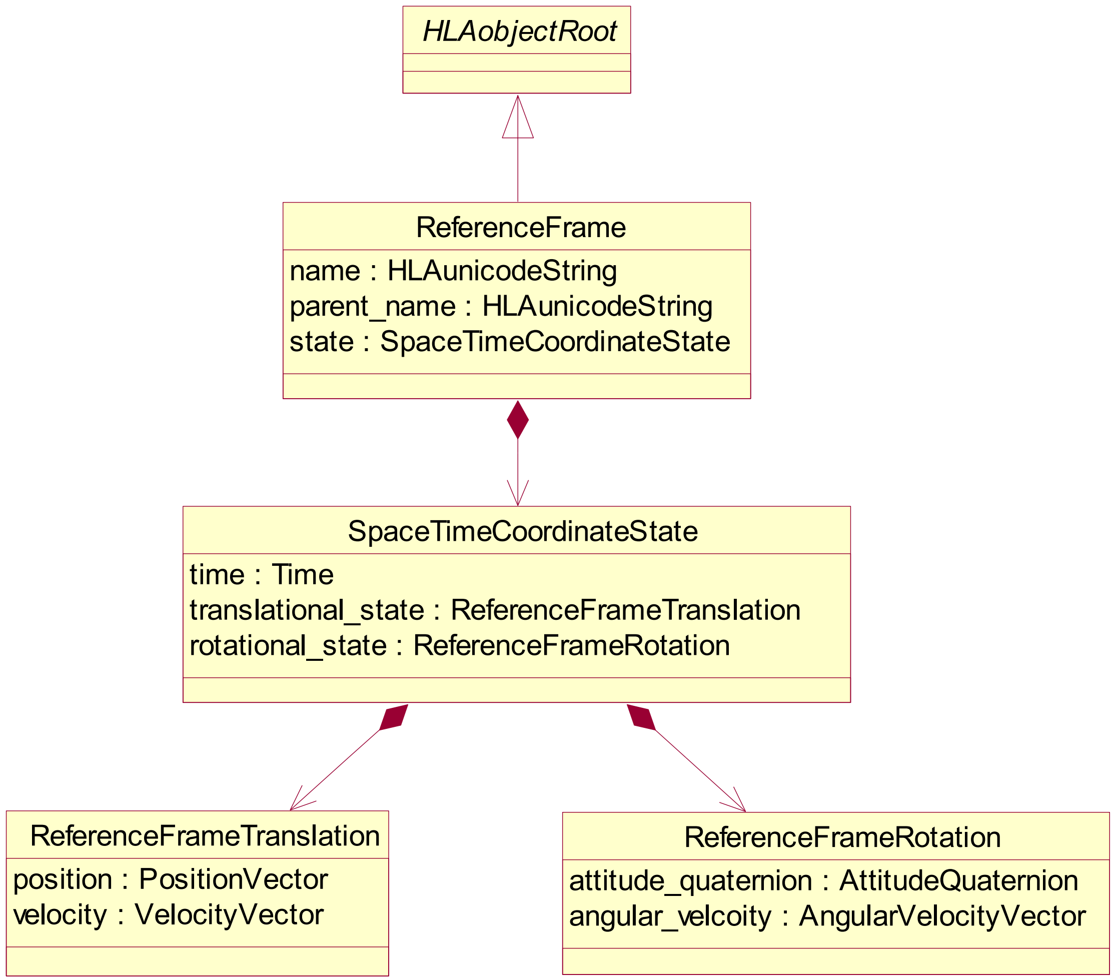
Spatial Design Patterns

- **Space simulations may include assets that operate on or about celestial bodies other than the Earth.**
  - There is no common reference frame of convenience for all space simulations.
- **When modeling operations that span multiple celestial bodies, each federate may prefer to operate an asset in a local reference frame but the federation must relate those reference frames to each other**
- **The patterns are:**
  - Reference Frames explicitly specified using object instances
  - Replaceable and Extendable Tree of Reference Frames

Reference Frames explicitly specified using object instances

- **It is conceptually and computationally inconvenient to perform all calculations using the same coordinate system.**
  - Considering the vastness of Space, attempting to use a single coordinate system would introduce unacceptable mathematical rounding errors.
- **The solution is to create one object instance of the Reference Frame class for each reference frame that is required.**
- **Each Reference Frame is identified using a name.**
- **Positions, for examples for a space vehicle, are given in relation to a named reference frame.**

Reference Frames explicitly specified using object instances

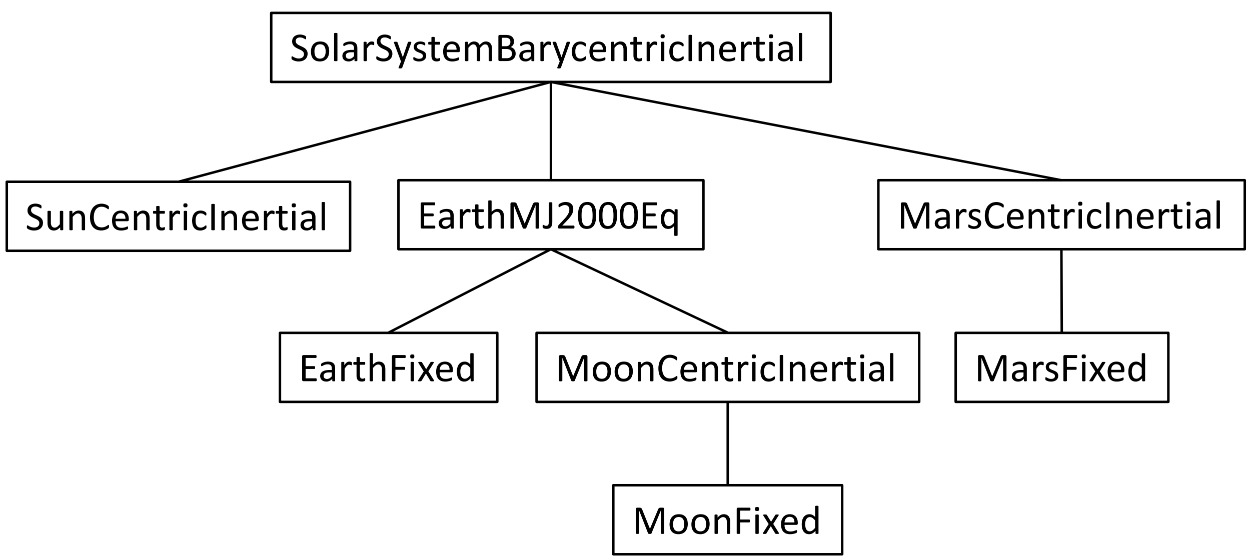


Replaceable and Extendable Tree of Reference Frames

- Need to translate coordinates between several different reference frames in order to determine spatial relationships between entities using different coordinate systems.
- Need to be able to switch between different reference frames during execution, for most convenient computations.
- Need to be able to use different sets of reference frames for different scenarios.
- Need to extend common and standardized reference frames with custom reference frames.

Replaceable and Extendable Tree of Reference Frames

- Structure the reference frames into one single directed acyclic graph (i.e. a tree).
- Each reference frame specifies its translational and rotational states with respect to the parent reference frame, except for the root.



Comparison with RPR FOM

- **Space FOM**
  - Reliable data exchange
  - Causality and repeatability
  - Well-managed set of federates
  - Coordinated execution with initialization, execution, freeze and shutdown
  - Hard real-time, soft real-time, scaled real-time or as-fast-as-possible
  - Multiple reference frames, standardized or custom
  - Few, generic object classes
- **RPR FOM**
  - Best effort data exchange
  - Not repeatable
  - Ad-hoc set of federates
  - Coordinated freeze/run
  - Soft real-time
  - Earth-centric and entity-centric coordinates
  - Wide range of specialized object classes
  - Wide range of enumerations for entity types, etc
  - DIS compatibility

Conclusion

- The focus of the first version of the SISO Space Reference FOM is execution control, time management, coordinate systems, well-known reference frames, and physical entities
- A number of design patterns and principles for this have been presented
- They are based on many man-years of practical federation development in the Space domain
- They are also suitable for reuse in other domains
- We have a continued interest in exchanging ideas with other simulation domains through SISO

SISO

Simulation Interoperability Standards Organization

"Simulation Interoperability & Reuse through Standards"

QUESTIONS